Two Northeastern DOTs Consider Green Infrastructure Techniques for Coastal Highway Resilience:

A Joint Study with Divergent Outcomes

Credit: Maine DOT

Credit: New Hampshire DOT

August 2018

This report documents a pilot project sponsored by the Federal Highway Administration (FHWA), the Maine Department of Transportation, and the New Hampshire Department of Transportation to assess the potential for green infrastructure techniques to protect sections of Route 209 in Phippsburg, ME and Route 1B in Portsmouth, NH. It is one of five pilot projects FHWA sponsored to assess the potential for natural infrastructure to protect coastal roads and bridges. More information can be found at: https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/index.cfm

FHWA-HEP-18-088

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HEP-18-088	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Two Northeastern DOTs Consider Green Infrastructure Techniques for Coastal Highway Resilience: A Joint Study with Divergent Outcomes		5. Report Date August 2018 6. Performing Organization Code:
7. Author(s) • Judy Gates, Director, Environmental Office; Maine Department of Transportation; 16 State House Station; Augusta, Maine 04333 • Timothy Mallette, Hydraulics Engineer, Bureau of Highway Design, New Hampshire Department of Transportation; PO Box 483, 7 Hazen Drive; Concord, NH 03302-0483 • Samuel B. Merrill, Ph.D, Senior Practice Leader and Alexander Gray, Adaptation Specialist; GEI Consultants, Inc.; 5 Milk Street, Portland, ME 04101 • Dr. Tom Ballestero; University of New Hampshire		8. Performing Organization Report No.
9. Performing Organization Name and Address Maine Department of Transportation 16 State House Station Augusta, Maine 04333		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Highway Administration 1200 New Jersey Avenue, SE Washington, DC 20590		13. Type of Report and Period Pilot final report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Maine and New Hampshire Departments of Transportation studied the potential for green infrastructure techniques to protect Route 209 in Phippsburg, ME and Route 1B in Portsmouth, NH from coastal flooding. Maine results show it is possible to extend the time before a conventional gray infrastructure solution (sheet pile wall or riprap) becomes necessary to protect Route 209, ranging from an expected 19 years in the no-action scenario to 83 years in the most aggressive gray infrastructure scenario. On ecological grounds, results suggest the most favorable alternative would be seaweed management and staked snow fencing to hold sand in place, plus a coir log or root wad crib structure at the toe of the front dune of the beach adjacent to Route 209, plus plantings above and below the current erosional scarp and sand behind the coir log wall or root wad crib structure. In New Hampshire, results show that intermediate-low levels of sea level rise may cause the existing causeway to be inundated only once in 2060 and twice in 2065. However, if sea level rise follows an intermediate-high trajectory, the causeway may be inundated 188 times in 2060 and 338 times in 2065. The team evaluated ecological benefits of elevating Route 1B (such as enhancing biodiversity, carbon sequestration, and transitional habitat through the addition of fringing salt marsh), along with alternatives of restoring habitat in the vicinity.

17. Key Words green infrastructure, sea level rise, resilience		18. Distribution Statement No restrictions.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 47	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

Figures

Tables

Appendices

Executive Summary

In 2016, the Maine Department of Transportation (MaineDOT) received funding from the Federal Highway Administration to conduct a joint exploration between MaineDOT and New Hampshire DOT (NH DOT) to explore the applicability of green infrastructure techniques to enhance coastal highway resiliency. Coastal changes along Maine and New Hampshire seaboards increasingly affect state highway infrastructure serving discrete local populations as well as seasonal visitors. Coastal sites sit adjacent to some of the rarest and most fragile types of habitats with documented contributions to their state's natural landscape. Both Maine and NH DOTs are committed to understanding threats to coastal infrastructure posed by climate factors. Contributing to this understanding, this report details project meetings, interviews, data collection and analysis methods, results, and implications for both states.

Each state selected a study site experiencing chronic effects of coastal processes impacting highway safety and/or access now and into the future. The Maine site sits directly adjacent to Route 209 and Hunnewell Beach in the town of Phippsburg near Popham Beach (Figures 1 and 2). The shoreward portion of Hunnewell Beach ends in an erosional scarp, while the beach itself is a mapped frontal sand dune also mapped as significant wildlife habitat. The road along this stretch of highway is complicated by its position between this seaward frontal sand dune and a landward critically imperiled (S2) marine pitch pine ecosystem, a rare and underrepresented natural community. These characteristics make this site extremely environmentally sensitive and highly regulated in addition to having underlying geology not conducive to construction activities (e.g. sand and ledge). As with the Maine site, the location selected by NH DOT presents significant constructability and natural resource challenges (Figures 1 and 2). The Route 1B causeway from Portsmouth to New Castle experiences regular flood events that are only expected to increase in frequency; the causeway itself is the only structure above sea level between islands. Subtidal substrates on either side of the causeway are soft marine sediments, with fragile fringing salt marsh along the upper tidal extents. Riprap runs along the sides of the causeway.

Key questions in Maine included whether green infrastructure techniques adjacent to a vulnerable road at Route 209, including crib walls and plantings on the beach, could help extend the life of the road given a changing coastline due to sea level rise and storm surge, and if so, would it be cost efficient in terms of extending the number years of future use of the road and feasible in terms of state and federal regulatory constructs. Key questions in New Hampshire included the degree to which the elevation of a causeway on Route 1B would substantially increase expected years of access across the causeway, taking into consideration prospective construction of salt marsh and eelgrass habitat adjacent to the causeway, and the ecological benefits that might accrue from such action. Site specific applications of green, green-gray, and gray treatments designed for the two sites included

native plantings only, keyed heavy riprap only and combinations of plantings, nourishment and structures to combat erosive action at the sites.

Figure 1. Maine and New Hampshire Study Sites.

Erosional scarp at Route 209 shoulder
Phippsburg, ME; September 19, 2016
Credit: Maine DOT

US Route 1B Causeway
New Castle, NH; May 4, 2011
Credit: New Hampshire DOT

The two DOTs developed cost inputs and erosion rate estimates, which the project team then revised and expanded. Advisory and Technical Teams (Table 1) determined that two types of benefits would be evaluated for each design alternative: 1) years of preserved access across the road or causeway and 2) the degree to which ecological benefits would be created or preserved. The project team conducted a benefit-cost comparison for each site-specific alternative that considered not only initial installation cost, but also the need to reconstruct several of the alternatives as sea levels increase.

Maine results show it is possible to extend the time before a conventional gray infrastructure solution (sheet pile wall or riprap) becomes necessary to protect Route 209, ranging from an expected 19 years in the no-action scenario to 83 years in the most aggressive gray infrastructure scenario. On ecological grounds, results suggest the most favorable alternative would be seaweed management and staked snow fencing to hold sand in place, plus a coir log or root wad crib structure at the toe of the front dune of the beach adjacent to Route 209, plus plantings above and below the current erosional scarp and sand behind the coir log wall or root wad crib structure. Costs of the alternatives ranged from $0.5 million to $12.3 million, and from $173 - $282 thousand when viewed as dollars per additional year of access preserved. On financial grounds, alternatives to select are strongly influenced by the length of time MaineDOT wants to delay using a gray infrastructure approach. State and federal regulations governing activities in frontal sand dunes posed the greatest challenge to implementing any stabilization at this site. Even with predictable enhancement of habitat values, any of the action alternatives that include excavation, hardening, and/or installing green structures are not permittable.

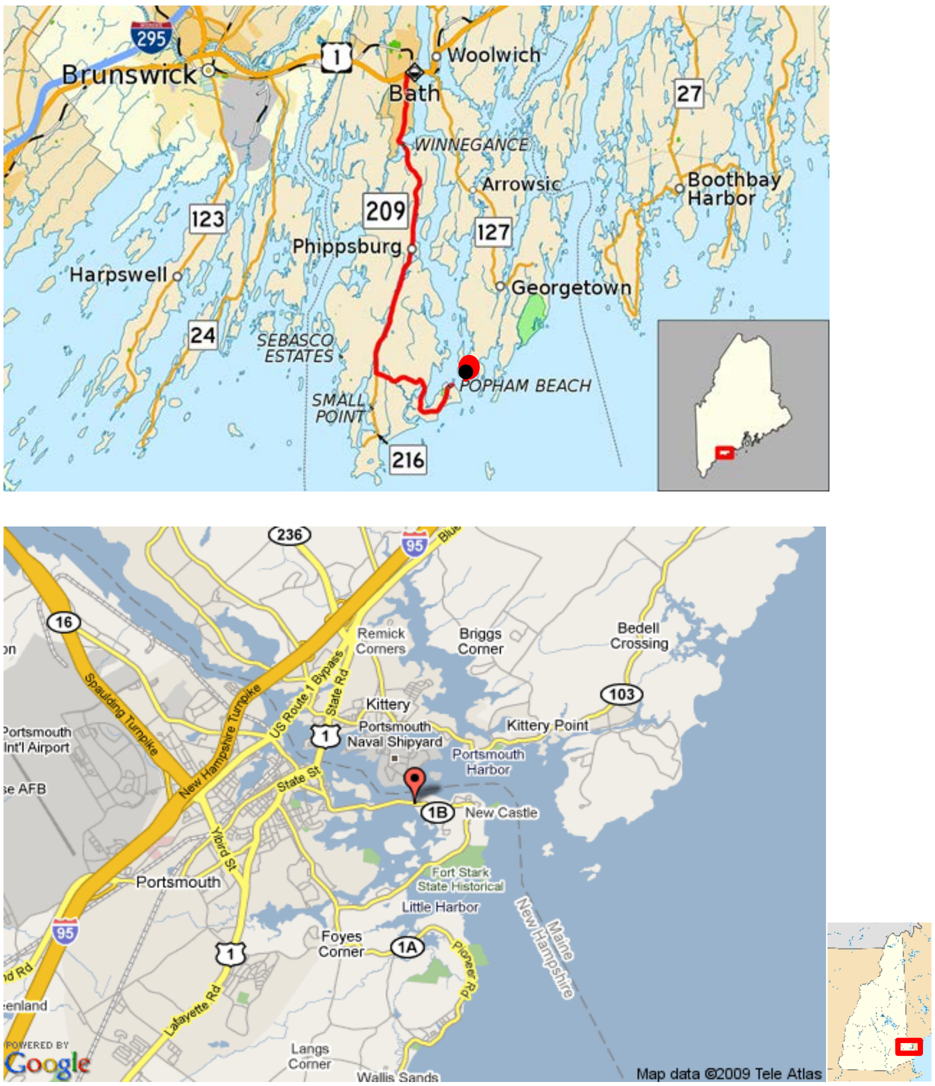
In New Hampshire, results show that intermediate-low levels of sea level rise may cause the existing causeway to be inundated only once in 2060 and twice in 2065. However, if sea level rise follows an intermediate-high trajectory, the causeway may be inundated 188 times in 2060 and 338 times in 2065. Ecological benefits of the elevation alternatives (such as enhancing biodiversity, carbon sequestration, and transitional habitat through the addition of fringing salt marsh), along with alternatives of restoring habitat in the causeway vicinity and constructing a bridge, were also evaluated. The presence of residential development directly adjacent to both the highway and tidal waters complicates analysis of this site, as does redundant access to the south end of New Castle. The New Hampshire legislature has opted to consider this area's road system holistically as part of a larger effort. Therefore, advantages and disadvantages of each alternative proposed in this report are discussed, but no recommendations are made. Instead, the alternative infrastructure solutions for the Route 1B causeway are expected to be considered through a more detailed assessment by State officials in the next several years.

1. Background

Maine has invested substantial effort in investigation of current and future impacts of sea level rise and storm surge on natural and built landscapes. Multiple interrelated studies focused on potential marsh migration and its implications for land conservation choices, anticipated changes to coastal state parklands, impacts to coastal communities, and adaptation of both inland and coastal state transportation infrastructure (GEI Consultants 2015, MaineDOT 2016, Merrill and Gates 2016, Merrill et al. 2017). In the current project, MaineDOT is using the highly-studied ecosystem near Popham Beach in Phippsburg to assess feasibility of green or green-gray infrastructure techniques to stabilize threatened areas of Route 209 from erosion, storms, and sea level rise (Figures 1 and 2). State Route 209 provides the sole access to this peninsula owned and maintained by MaineDOT, and serves year-round residents and visitors, a seasonal influx of summer tourists to Popham Beach State Park, and the historic sites of Fort Popham and Popham Colony. East of the park entrance Route 209 is experiencing active coastal erosion from storm events. Modeling of this area shows that continued erosion will result in the loss of the road section within several decades if stabilization measures are not taken. By comparing feasibility and effectiveness of candidate adaptation designs, this effort helps MaineDOT standardize the decision process as part of its environmental risk matrix currently being automated across state transportation projects. MaineDOT is also using this project to evaluate whether a similar step-wise approach for green infrastructure is transferable to a broad suite of coastal ecosystems.

New Hampshire has been similarly active in identifying vulnerabilities to sea level rise and storm surge and developing strategies and recommendations for improving resilience to coastal infrastructure as it is constructed, rehabilitated, or replaced. The NH DOT evaluated the impact of these vulnerabilities in its 2014 report *Potential Impact of Climate Change on Transportation Infrastructure – Assessment of Vulnerability and Recommendation of Adaptive Strategies.* Among other things, this report calls for NH DOT to incorporate climate change in transportation design and use appropriate techniques to protect vulnerable bridges and roadways, including living shoreline and low impact development. Further, the state has established a legislative Commission (RSA 483E) that has recommended incorporating specific scenarios for future sea level rise, storm surge and extreme precipitation in infrastructure design based on risk tolerance. Among the roadways most at risk are sections of Route 1B (New Castle Avenue), a causeway connecting Portsmouth to the Town of New Castle (Figures 1 and 2). The NH DOT and the NH State 10-Year Transportation Plan have programmed a feasibility study for this roadway to investigate and evaluate alternatives to improve resilience particularly to sea level rise. The causeway traverses a sensitive salt marsh fringe identified as “highest ranked habitat” by NH Fish & Game. Conventional means of increasing elevation by adding fill and increasing side slopes results in natural resource impacts that are unpalatable to regulatory and resource agencies, limiting alternatives to those with fewer impacts to the adjacent coastal wetland. Alternatives developed through this study identify several lower-impact, adaptive alternatives, primarily steepening shoulder riprap to avoid additional coastal wetland impacts. This study lends itself to a more thorough evaluation of the benefits of green infrastructure either alone as an alternative to gray stabilization methods, or in combination with increased gray infrastructure supporting additional road elevation. As with Maine's Route 209, a standardized evaluation process applied here would be broadly useful on other assets with similar vulnerabilities.

Figure 2. Geographic locations of Phippsburg, Maine and New Castle, New Hampshire.



Credit: Tele Atlas

2. Methods

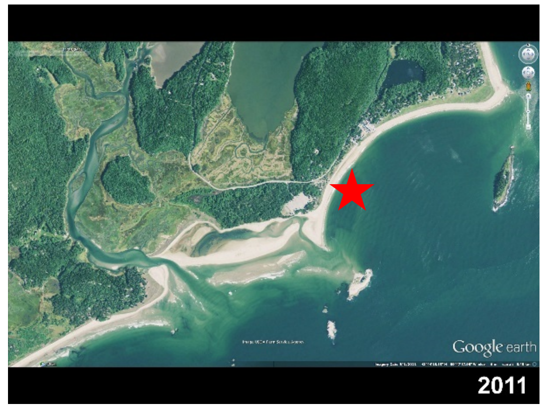
Federal Highway Administration (FHWA) provided funding for this project in 2016. MaineDOT served as the administrative lead; both DOTs contributed state funds as match for FHWA funds. GRANIT provided GIS support in New Hampshire.

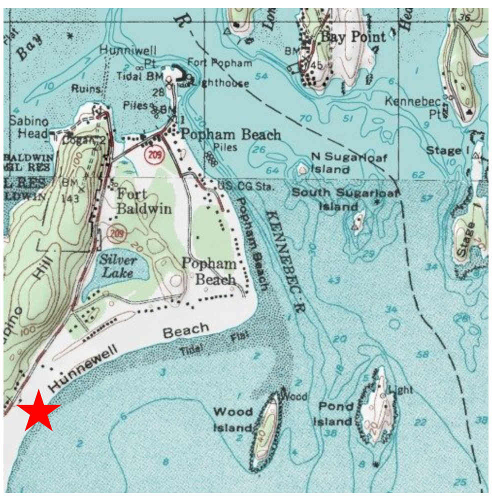
MaineDOT hosted meetings in Maine and New Hampshire involving numerous organizations and agencies which self-identified as either providing technical or advisory input. All participants collaboratively identified principles that would be used to guide development of candidate designs. Technical teams in each state then worked together to develop design principles that might: 1) provide greater resiliency to the combined threats of sea level rise and storm surge for the transportation infrastructure at each site, and 2) simultaneously provide protection or enhancement of significant natural features and other ecosystem benefits at each site. Identified goals mirrored those articulated in FHWA's request for proposals, of which the overarching consideration was whether green or green-gray infrastructure could potentially enhance coastal highway resilience to projected sea level rise to the extent of traditional gray approaches as well as to identify benefits and costs resulting from considered alternatives. Advisory participants' role involved concept development and final document review, while Technical Team members engaged in guiding design components, evaluating outcomes, and developing conclusions. Dr. Ballestero of UNH provided more detailed design and specific components based on their input.

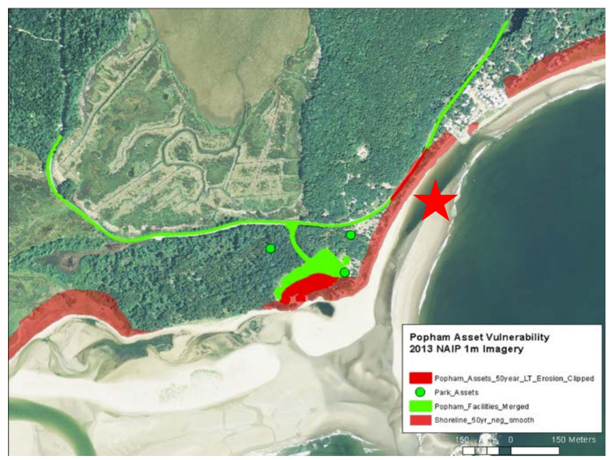
Project managers in both Maine and New Hampshire wanted to characterize the degree to which ecological benefits might be impacted, protected or created under each design alternative in consideration, versus taking no action. During project team meetings, however, the team recognized that ecosystem benefit results of this type would likely be imprecise and possibly misleading if pursued as a technical modeling effort. Therefore, in addition to evaluating cost and number of years that access would be preserved, project managers decided to evaluate each design alternative in more qualitative terms, relying on the local perspective and expertise of ecologists on each team. The contractor conducted phone and email interviews with team members in both states to address each design alternative under consideration. Commonly referenced categories of ecosystem services discussed included significant wildlife and plant habitat, water quality benefits (e.g., filtration), habitat connectivity, carbon storage, and directly human-related benefits such as contributions to recreation opportunities, aesthetics, land values, and vehicular access to destinations on either end of the roadways.

Conceptual drawings of design alternatives are provided in this report. Maine and NH DOTs developed cost inputs and erosion rate estimates, which were revised and expanded in collaboration with Dr. Ballestero and his team and provided in this report and. Teams in each state determined that two types of benefits would be evaluated for each design alternative: 1) years of preserved access across the road or causeway and 2) the degree to which ecological benefits would be created or preserved.

Figure 3. Maine site photos – Hunnewell Beach, Phippsburg, Maine





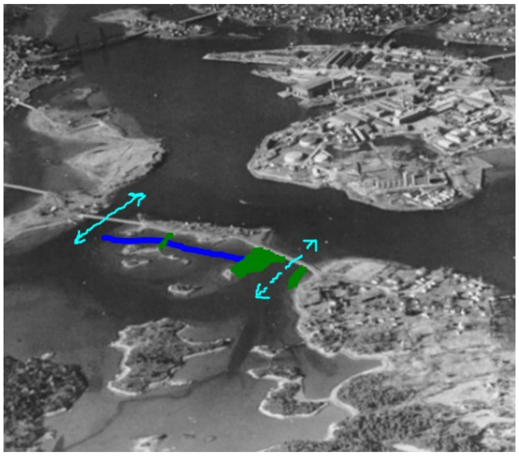


Credits (clockwise from top left): Maine DOT; Map©2018Google; Maine Geological Survey; Maine Geological Survey

Figure 4. New Hampshire site photos – Route 1B Causeway, New Castle, New Hampshire

Credit: New Hampshire DOT

Credit: New Hampshire DOT



Credit: New Hampshire DOT

Credit: New Hampshire Geological Survey

Table 1. Members of Advisory and Technical Groups assisting with pilot.

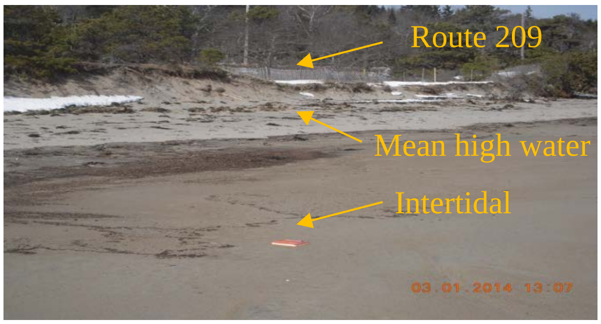
Entity	Participant	Area of interest	Technical	Advisory
GEI Consultants	Alex Gray	Climate and Coastal Hazards	X	
TNC	Alex Mas	Resource Conservation		X
NHDOT	Ann Scholz	Materials & Research	X	
UNH	Cameron Wake	Climate Impact		X
FHWA-Maine	Cassie Chase	Environmental Engineering		X
MaineDOT	Charlie Hebson	Chief Hydrologist	X	
Rockingham Planning Commission	Cliff Sinnott	Planning		X
Rockingham Planning Commission	David Walker	Planning		X
FHWA-NH	Jamie Sikora	Environmental		X
TNC	Jeremy Bell	Aquatic Habitat Restoration		X
MaineDOT	Judy Gates	Policy development	X	X
Maine Coastal Program	Kathleen Leyden	Coastal Resources		X
NHDOT	Kevin Russell	Engineering	X	
NH Coastal Program	Kirsten Howard	Coastal Resiliency	X	
Maine Natural Areas Program	Kristen Puryear	Ecology	X	
FHWA-NH	Leigh Levine	Planning and Development		X
Blue Sky Planning	Liz Hertz	Facilitation; Resiliency	X	X
Maine DEP	Nathan P Robbins	Climate Change		X
Maine Geological Survey	Peter Slovinsky	Coastal processes	X	
MaineDOT	Tim Cusick	Superintendent of Operations	X	
GEI Consultants	Sam Merrill	Climate and Coastal Hazards	X	
NHDOT	Tim Mallette	Hydraulics engineering	X	X
UNH	Tom Ballestero	Hydrologist	X	
TNC	Tamara Pinard	Resource Conservation		X
FHWA	William Van Peters	Resource Center		X

3. Maine

3.1 Design Alternatives

Design alternatives developed for this study were evaluated based on both their ecological and non-ecological benefits and costs to implement and maintain their function. Alternatives ranged in complexity, lifespan, impact area, cost, and ability to slow the current erosion rate. These included:

- Alternative 1 – Do nothing.



Existing conditions, Hunnewell Beach, Phippsburg, ME; April 2017
Credit: Maine DOT

- Alternative 2 – Seaweed management and a staked snow fence at the lower dune.

Seaweed management with staked snow fence. Credit: Maine DOT

- Alternative 3 – Coir log or root wad wall roughly 5 feet seaward of the current erosional scarp, plantings and seeding, as well as seaweed management and a staked snow fence at the lower dune.

Root wad seawall (Photo credit: BioEngineering Associates)

- Alternative 4 – Same as Alternative 3 except the coir log or root wad wall is placed closer to the water, at the toe of the frontal dune.
- Alternative 4a – Same as Alternative 4 except there is also a beach nourishment component, adding sand landward of the coir log or root wad wall to effectively move the erosional scarp closer to the water.
- Alternative 5 – Sheet pile wall driven to ledge at an estimated depth of between 10-20 feet at the edge of the road shoulder. The action would only be triggered when the erosional scarp reaches within15 feet from the road measured horizontally from mean high water.
- Alternative 6 – “S” design riprap slope beginning at the edge of the road shoulder. The action would only be triggered when the erosional scarp reaches within15 feet from the road measured horizontally from mean high water.

While Alternatives 5 and 6 would be considered solely gray infrastructure, they represent a ‘typical’ stabilization response; in this setting, either could be implemented at the end of a green infrastructure alternative so that the entire solution is reasonably considered green-gray rather than completely gray, which would provide few ecological benefits. Table 2 below presents the design alternatives and their individual components. Design alternative (referred to as “alternatives” on plans) drawings are included as Appendix A.

Table 2. Matrix of Maine design alternatives and components.

Design Component Alternative	Seaweed management and staked snow fence at lower dune	Coir log/ root wad wall ~5 feet seaward of erosional scarp	Coir log/ root wad wall at toe of front dune	Plantings and seeding	Sand addition landward of short wall	Sheet pile driven to refusal at edge of road shoulder	"S" design riprap slope beginning at edge of road shoulder
Alternative 1	No action						
Alternative 2	X						
Alternative 3	X	X		X			
Alternative 4	X		X	X			
Alternative 4A	X		X	X	X		
Alternative 5	X					X	
Alternative 6	X						X

3.2 Cost vs. Access

The Maine technical team decided to use the erosion rate at the beach along Route 209 to calculate the number of years of access across the road. This estimate, a "no action" scenario, was then used as a reference to which each design alternative would be compared, based on the team's experience with similar coastal projects using green infrastructure techniques. The current distance from the road to the Mean Higher High Water line is 45 feet. The historic erosion rate since the 1950s in this area has been 3 feet/year (verbal communication, Maine Geological Survey), but the rate jumped to 15 feet and 12 feet in each of the last 2 years. These jumps could have been from larger than normal storm surge events. The entire Popham Beach complex experiences drastic shifts in sand distribution influenced by a complicated interaction between Kennebec River drainage sediments, a very large offshore sand deposit, the outlet of the Morse River, coastal storms and the underlying geology of this part of Maine. Because erosion rates through the next several decades cannot be reliably anticipated, the technical team selected the historic rate of 3 feet/year for this study.

While estimating years of access from one end of the road or causeway to the other was an important design criterion, the larger goal of this project was to weigh green and green-gray solutions to compare how well they provide ecological benefits that may be lost or never realized if purely gray solutions were selected. Thus, years of access reflects the number of years a solution can provide ecological benefits prior to a gray solution becoming necessary.

The alternatives in Table 3 below are fewer than in Table 2, including only those that have a green component (i.e., the sheet pile wall and riprap are excluded). Alternative 1, the "no action" alternative, has an unchanged erosion rate. At this erosion rate (3.0 feet per year) and a beach width of 58 feet, the road would likely require reinforcing using a hardened gray solution due to erosion in roughly 19 years.

Table 3. Benefits from green solutions in terms of reduced erosion rates and number of years before gray solutions are needed to protect the road.

BENEFIT			
Alternative	**Reduction in Erosion Rate from No Action**	**Erosion Rate (Feet/Year)**	**Years Before Gray Solution Needed**
Alternative 1	0%	3.0	19.3
Alternative 2	10%	2.7	21.5
Alternative 3	50%	1.5	38.7
Alternative 4	50%	1.5	38.7
Alternative 4a	50%	1.5	83.3

The seaweed management and snow fence proposed in Alternative 2 is estimated to reduce erosion by 10%, producing an erosion rate of 2.7 feet per year. Given that the beach width is not changing with this solution (the erosional scarp is not moved forward as in Alternative 4A), it is expected to be 21 years before a gray solution is needed to maintain the road's integrity.

Alternatives 3 and 4 both decrease the "no action" erosion rate by 50%, but similarly they do not increase the effective beach width. The road in both alternatives would last 38 years before a gray solution is needed to maintain access to the other side.

Alternative 4a resembles Alternative 4 except that it includes a form of beach nourishment that would move the effective erosional scarp towards the water in the near term, so despite Alternative 4a having the same erosion rate (1.5 feet per year) as Alternatives 3 and 4, the rate is applied to 125 feet of beach rather than 58 feet. Thus, projections are roughly 83 years before a gray solution is needed to maintain the road's integrity.

Table 4 shows costs for the green and green-gray design alternatives; Alternative 1 has no associated costs and is not shown. Appendix B contains sub-item costs. Annualized costs represent the cost of each item spread over the years before replacement. For example, the annualized cost for plantings in Alternative 4 would be $8,159 per year for 30 years. Using annualized costs helps model the uncertainty of lifespans, which are in part related to impacts from strong storms and may happen either before or after a structure's designed lifespan. Annualizing the lifespan thus removes the certainty that a storm will come every 5 years (and, for example, destroy a snow fence), and allows those costs to be modeled on a yearly and less extreme basis. To account for inflation, annualized costs were multiplied by 3% each year until a gray solution would be needed to protect the road – based on the erosion rates of each alternative (Table 4) – and then summed. For example, the cost of snow fences over the course of Alternative 3 totals $412,999. All items within each alternative were summed for a total cost of each alternative.

Table 4. Costs for design alternatives (no costs associated with Alternative 1)

COST						
		Lifespan	Item Cost	Annualized Cost	Cost (Using 3% Interest Rate for Annualized Costs) Before Gray Solution Needed	Dollars Per Additional Years of Access Before Gray Solution Needed
Alternative 2	Snow Fence	5	$28,588	$5,718	$174,594	$87,297
	Seaweed Management	5	$56,250	$11,250	$343,539	$171,769
				TOTAL	**$518,133**	**$259,066**
Alternative 3	Snow Fence	5	$28,588	$5,718	$412,999	$21,737
	Seaweed Management	5	$56,250	$11,250	$812,635	$42,770
	Construction Erosion Control	15	$18,750	$1,250	$90,293	$4,752
	Coir logs/root wads (near scarp)	15	$479,851	$31,990	$2,310,779	$121,620
	Planting	15	$244,761	$16,317	$1,178,676	$62,036
	Seeding	15	$116,373	$7,758	$560,405	$29,495
				TOTAL	**$5,365,788**	**$282,410**
Alternative 4	Snow Fence	5	$28,588	$5,718	$412,999	$21,737
	Seaweed Management	5	$56,250	$11,250	$812,635	$42,770
	Construction Erosion Control	30	$18,750	$625	$45,146	$2,376
	Coir logs/root wads (near dune)	30	$479,851	$15,995	$1,155,390	$60,810
	Planting	30	$244,761	$8,159	$589,338	$31,018
	Seeding	30	$116,373	$3,879	$280,203	$14,748
				TOTAL	**$3,295,711**	**$173,458**
Alternative 4a	Snow Fence	5	$22,870	$4,574	$1,673,538	$26,149
	Seaweed Management	5	$45,000	$9,000	$3,292,925	$51,452
	Construction Erosion Control	40	$18,750	$469	$171,507	$2,680
	Coir logs/root wads (near dune)	40	$383,881	$9,597	$3,511,365	$54,865
	Planting	40	$244,761	$6,119	$2,238,834	$34,982
	Seeding	40	$116,373	$2,909	$1,064,461	$16,632
	Beach nourishment	NA	$311,204	NA	$311,204	$4,863
				TOTAL	**$12,263,833**	**$191,622**

The most expensive alternative to build and maintain is Alternative 4a. This is partly a result of the number of years the beach is intact (64 years) compared to no action, requiring that green infrastructure components be replaced over a longer period. For example, the snow fence is replaced every 5 years over the 83-year lifespan of the beach in that alternative. In other words, extending the life of the beach increases costs of routine maintenance and replacements. The last column shows cost per year based on additional years of access the alternatives provide beyond the 19 years in the no action scenario. For example, the total cost for Alternative 2 is $518,133 but in terms of cost per additional years of access, Alternative 2 costs $259,066 per year because Alternative 2 only provides two additional years before needing a gray solution when compared to no action.

3.3 Ecological Benefits and Other Considerations

In addition to its characterization as a frontal sand dune subject to strict state (38 MRSA § 480, Maine Chapter 355) and federal (Clean Water Act) regulations, the beach area on the Maine site is mapped by the Maine Department of Inland Fisheries and Wildlife (IFW) as "Tidal Waterfowl and Wading Bird Habitat" and "Shorebird Roosting and Feeding Habitat", collectively regulated as Significant Wildlife Habitat (Maine Chapter 335). The area supports large numbers of migrating shorebirds (sandpipers and plovers), which use the saltmarsh and mudflats on Atkins Bay as well as the lagoon, sand spit, and beach at Popham. From telemetry studies conducted by IFW, we know that these birds regularly fly between these areas with each tide change, so there is considerable interconnectedness of habitat functions at a larger spatial scale than just the stretch of beach along Route 209. Also, the beach area and adjacent section of Route 209 are close enough that vehicle-struck sandpipers are occasionally found on the road, having been using the saltmarsh pannes near the road. Landward of the beach lies the rare coastal pitch pine complex, with its sensitive plant community components. GEI interviewed four members of the Maine technical team with ecological backgrounds for their input about benefits of each design alternative.

***Alternative 1* –** Do nothing.

If no action is taken, the beach area would continue to exist for a period, estimated in this study to be 19 years based on long-term shoreline change rates. During this time, an estimated 15 feet of habitat would exist between the scarp line and the road. Ecological benefits of the system would continue to include the natural buffer that dunes and beaches provide to the upland, existence of a rare and underrepresented natural community and habitat type in the state (pitch pine dune woodland), persistence of seed sources and native vegetative cover, root systems providing sand stabilization, and habitat connectivity from one end of the pine woodlands to the other and along the beach itself. Similarly, the Federally threatened and State Endangered Piping Plover, and State Endangered Least Tern, would be expected to continue to build nests on adjacent Popham Beach and may forage along the beach and sand dunes in this stretch along Route 209. Current benefits also include recreation, aesthetics, and contributing to local land values.

A majority of ecological benefits would be lost when the beach is eroded to within 15 feet of the road. However, the rate of loss would be different for each benefit and may not follow the same trend as the erosion rate. For example, recreation benefits may persist for most of the 19 years or potentially longer, until a threshold where beach visitors decide the beach is too small even at low tide, whereas benefits from habitat connectivity may decline more linearly, in closer relation to the rate of erosion. Land values may also exhibit a threshold after the 19-year period. That is, if the road becomes less usable through repeated flooding events when the beach is mostly or entirely eroded and eventually not usable because repeated repairs and reconstruction are no longer pursued, there would likely be large impacts on land values, especially for the 150 – 200 parcels to which the road segment is the only current connection.

***Alternative 2* –** Seaweed management and staked snow fence at lower dune.

Seaweed management and staked snow fence at the lower dune occur in all action-oriented design alternatives evaluated. These standard best management practices are usually undertaken in concert with larger activities; however, here they are evaluated here as a stand-alone alternative because of low cost and estimated potential to slow the erosion rate by 5-15% on their own. This benefit results from the structures capturing small amounts of sand and providing modest temporary stability to the toe of the existing sand dune and upper beach area. Although the structures may be wiped out by a storm in any given year, they can be put back in place after each loss at relatively low cost. By prolonging the existence of the upper beach, sand dune, and pitch pine dune woodland, the actions represent protection of these ecological assets. In extending the time before the road itself would be degraded, land values and other benefits would also be extended over the same time.

Negative aspects of this alternative include that visibility of the fencing may detract from aesthetics, and degradation of the fence during storm events may introduce materials into the ocean, possibly causing entanglement concerns for marine species (Note: this should only cause minor concerns because current Department of Environmental Protection regulations require fencing materials to be biodegradable). Similarly, although regulations specify that fencing should not restrict plover movements, it is unknown whether fencing would be a physical barrier restricting plovers' foraging activity on the site.

***Alternative 3* –** Coir log wall or root wad crib structure placed 5 feet seaward of the erosional scarp, plus plantings above the erosional scarp.

This action would further slow the erosion processes that would otherwise remove the ecological benefits described in Alternative 1. Also, coir log walls or root wad crib structure would introduce ecological benefits because they are vegetative and will support biological communities as long as they persist. Installation occurs by wrapping the coir matting around the face of the coir log and around sandy material, then staking it to the ground to hold the pillow in place. Additional sand deposition occurs behind log wall or root wad crib structures, allowing more root growth and proliferation of microorganisms and invertebrates. This sand accumulation would not contribute significantly to water filtration because it is too porous, but some filtration may occur if finer material accumulates in or on the structures. Plantings above the erosional scarp provide vegetative structure and additional stability, likely extending longevity of the beach and the ecological benefits it provides.

***Alternative 4* –** Coir log wall or root wad crib structure placed at the toe of the front dune, plus plantings above the erosional scarp and behind the coir log wall or root wad crib structure.

The results of this alternative mirror those of Alternative 3 except that the structure would be installed at the toe of the front dune instead of the seaward edge of the erosional scarp (as shown in Appendix B). This effectively moves the scarp seaward by the distance from the scarp to the toe of the front dune. Benefits arise because the erosion becomes a threat to the road when the scarp reaches 15 feet from the road, so this action would immediately add decades to the longevity of the beach (assuming a constant rate of erosion) and provide the ecological benefits in Alternatives 1 and 3 for this longer period.

***Alternative 4A* –** Coir log wall or root wad crib structure at toe of front dune, plus plantings above and below the erosional scarp *and sand behind coir log wall or root wad crib structure*.

Backfilling beach compatible sediment behind the wall or root wad crib structure creates a new elevation for the beach surface as shown in Appendix B this alternative. Note that 1) the introduced structure would not act as a wall to retain the new sand; the new sand would simply fill in an area currently scraped by tidal action; and 2) regulatory constraints may require use of "new" material rather than collecting it from the existing beach or offshore sand deposit. The slopes on this new grade would then be planted with native shrubs and grasses (those species already present at site) from the structure up to the edge of the strip of pitch pine dune woodland habitat. This creation of a new dune or scrub/shrub slope typically results in numerous ecological benefits, including increased dune habitat connectivity, an increase in the site's ability to slow water moving toward the ocean, and increased carbon storage, thus assisting with soil stabilization. Because the habitat would no longer be beach, there may be a decrease in recreational value for potential swimmers, but visitors may instead come for birdwatching or other activities. In any event, this design alternative would significantly extend the time before erosion reaches 15 feet from the road, triggering a gray infrastructure alternative.

***Alternative 5* –** Sheet pile driven to refusal at edge of road shoulder.

Sheet pile walls are a conventional gray infrastructure technique that on their own would incorporate no ecological benefits for the site such as habitat, recreation, or aesthetic benefits. Upon installation, which does not need to occur until the current erosional scarp reaches 15 feet from the road, one could expect a modest decrease in some ecological benefits from site disturbance and because the wall could interfere with normal root expansion of the pitch pine dune woodlands. However, once implemented, the wall would substantially increase the benefit of longer term vehicular access.

***Alternative 6* –** "S"-design riprap slope beginning at edge of road shoulder.

Riprap is a conventional gray infrastructure technique incorporating no green or living shoreline elements and providing few ecological benefits by cutting off any potential natural movement of sand, dune structure, or vegetative cover. The slope could not be immediately constructed, because the existing beach would need to be excavated, whereas the objective for the site is to preserve and/or enhance ecological benefits of existing habitat for as long as possible. Also, use of riprap is also not currently permitted in the dune system, so this regulatory constraint poses a significant barrier to installation. Should it be implemented, riprap would substantially increase the benefit of longer term vehicular access. Ecological benefits would be minimal to non-existent, limited to any colonization of interstitial spaces between riprap.

3.4 Implications

There is challenge and opportunity in deciding among the alternatives evaluated for the beach at Route 209. The challenge is in understanding how urgent the erosion situation is; if the situation is not urgent, it is difficult to justify the expense of immediate action. The opportunity is not only in saving money in construction and preserving vehicle access, but also in protecting and/or enhancing ecological benefits in the natural communities adjacent to the road. Balancing the challenges and opportunities is particularly difficult, not only because the elements being compared between design alternatives have different units of measure (some with dollar signs and some without), but also because of uncertain determinations of value across the decision-making structures of MaineDOT.

Conventionally, the time when a transportation agency might act at a site like Route 209 is when it is recognized that if no action is taken, the road itself may be semi-permanently inundated or lost, limiting resident access via the road. However, it became clear through conversations among both technical and advisory group members that natural resource agencies and advocates would prefer that action occur when enhancement or protection of habitat values is most advantageous. The question of urgency thus becomes important: "if we don't do anything, this significant habitat won't be here anymore – but when is it urgent?" Is there a threshold year before which it would be best to use simpler, less expensive, and more ecological design alternatives, and after which it only makes sense to use more conventional gray infrastructure designs? In the absence of a transportation need, is it the responsibility of a DOT to address imminent habitat loss? A key factor in determining whether there is a threshold, and if so, what that might be, is understanding the ecological benefits of the current system in the first place. Then and in combination with evaluations of cost per years of access preserved with each alternative, an optimal design may become apparent and can be timed appropriately.

Participants exhibited strong interest in maintaining existing ecological benefits to the extent possible. For example, in designing the alternatives evaluated for Route 209, the Maine Technical Team discarded several candidate designs, such as log wall construction at the shoulder and heavy riprap prior to inundation, because of extensive disruption of existing habitat. Given limited access to the Fort Popham community, maintaining vehicle access via Route 209 must remain a strong interest, thereby retaining gray alternatives into the future. A complete relocation of the road along this stretch of highway is complicated by its position between a seaward frontal sand dune and a landward critically imperiled (S2) pitch pine dune woodlands. These ecosystems are not only rare, but are characterized by soils not conducive to siting infrastructure. Abandoning Route 209 eastward of Popham Beach eliminates costs associated with maintaining resilience, but decisively eliminates automobile access to the Popham Colony and Fort Popham, stranding the community of year-round as well as seasonal residents and visitors.

3.5 Next Steps

Regarding ecological benefits, the set of observations collected during the interviews led to an overall favoring of Alternative 4A, using seaweed management and snow fence plus a coir log or root wad crib structure at the toe of the front dune and plantings on top of the beach, followed by installation of a sheet pile wall when the scarp reaches 15 feet from the road. Timing on this installation is unknown and would need to be determined through experience – that is, it could come at any time with one extreme storm event or not come for over 100 years. Responsive and adaptive management will therefore be required through continual monitoring of the site and observation of when significant ecological benefits are being lost. This would allow those benefits to be preserved for as long as possible.

However, these ecological observations need to be considered alongside the cost-per-year-of-access-preserved evaluations above to understand overall implications of these results. The financial results above suggest that if just the access benefit of an alternative (the length of time before a gray solution is needed to protect the road) is the most important metric, then Alternative 4a is the best since it will last about 83 years (or 64 years beyond doing nothing). If the cost of an alternative is the most important metric then Alternative 1 ("no action") is the best – or perhaps Alternative 2 because it is the least expensive alternative besides doing nothing, but at least it slows down erosion. But because it only extends the time until a gray solution is triggered by two years, it may not be preferable. Or, if the most important metric is dollars per year of additional access before needing a gray solution, Alternative 4 is best. But then, one could argue that Alternative 4a is less than $20,000 per year more expensive than Alternative 4, and because the road would be protected for an additional 45 years beyond the years of access that Alternative 4 would provide, it might be worth spending just $20,000 more per year to preserve the road that much longer and provide ecological benefits during this period. The challenge, of course is that Alternative 4a is by far the most expensive overall and perhaps MaineDOT would not choose to allocate $12.3 million to this site over the life of the project.

These observations outline how the costs and non-ecological benefits of access could be assessed, but they do not necessarily point towards a clear decision without more information about agency priorities. Despite significant enthusiasm from state and federal resource agencies and non-profit environmental advocacy organizations, permitting a green infrastructure project at the Popham Hunnewell Beach site poses insurmountable challenges under today's regulatory constructs. In initial conversations between MaineDOT and Maine's DEP, the latter expressed a decidedly negative response to permitting any of the action alternatives. This reaction softened slightly upon considering "green infrastructure" as a subset of "living shorelines", an approach already under discussion between DEP and advocacy organizations. At this time, regulatory barriers bar any actions posed as part of this study and, as a result, MaineDOT has no immediate plans to pursue a green infrastructure solution along its coastal highways.

3.6 Useful Information

For purposes of this exercise, the question of which alternative to select for this site can be evaluated for feasibility using a budget-based approach, first identifying agency interest in funding green infrastructure projects in general and the level of funding that might be available. Next, which projects could be funded with available funds? More importantly, are they worth funding? Here the second question is more difficult. For example, if the State only has $520,000 available for this type of initiative, Alternative 2 is the only project that could be funded – however, the agency should also consider that, given that Alternative 2 only provides two additional years of access, those funds might beneficially be allocated elsewhere in Maine (perhaps where another road, bridge, or culvert has a lifespan that would be increased by 10 or more years versus the two extra years provided in Alternative 2). Similarly, if the State were to be able to allocate $12.3 million to Alternative 4a, is it worth it given the ecological benefits that would accrue and the longer period until a gray infrastructure solution is triggered? Or should the State instead spend $3.3 million to fund Alternative 4, and use the remaining funds to provide benefits of another green infrastructure project elsewhere in Maine? This holistic approach assumes that the State has several other exploratory green infrastructure efforts on which to base such decisions. While it may make decision-making more complex, it could provide a method for assessing a possible infrastructure project within a portfolio of similar opportunities. Compared to site-specific evaluations, this may be a useful application of benefit-cost analysis for green infrastructure innovations and provide flexibility for ongoing budget management.

A final consideration that may influence these decisions is about value that MaineDOT will place on public perception of actions it might take. In some cases management alternative itself can be valued in terms of maintaining or enhancing relationships with local governments or stakeholders, even if other, more infrastructure-related outcomes from the action are not as substantial as had been intended. In a peer-reviewed example, Kelley (2013) attempted to stabilize actively eroding dunes at Popham Beach where inlet-associated erosion had threatened park infrastructure (a bathhouse). Because it was clear that the inlet channel causing the erosion would eventually change course, the state opted to erect a temporary seawall with fallen trees at the site. Effectiveness of the technique was questionable because, over time, retreat of the dunes behind the trees was similar to that at either end of the "wall". Kelley (2013) notes that installing the structure did reassure the public that "something was being done," which itself was thought to be a beneficial result for the agency, especially as a mechanism to "retain calmness in a difficult situation". Whether installation of the green infrastructure alternatives detailed in this report would provide similar reassurance is difficult to quantify or compare between alternatives. Given the uncertain gain in resilience at this site, the value of public perception at this site might be in deciding whether to implement any action at all given costs, regulatory hurdles, and ephemeral transportation and ecological benefits.

These considerations should be integrated when making decisions about management action at Route 209. To do this well, it may be helpful to recollect the stated purpose of the initial Federal Highway grant: the project aimed to "improve the resilience of coastal roads, bridges, and highways through implementation of ecosystem-based, green infrastructure approaches." However, as the preceding discussion demonstrates, decisions MaineDOT needs to make are as much about "buying time" as they are about "improving resilience." That is, questions to address at Route 209 may be less about habitat preservation or other natural resources-based elements of concern, and more about the degree to which the agency values 1) access across that stretch of road, over time; 2) social benefits of recreation and aesthetics potentially provided by each alternative, over time; and 3) public perception of agency responsiveness.

4. New Hampshire

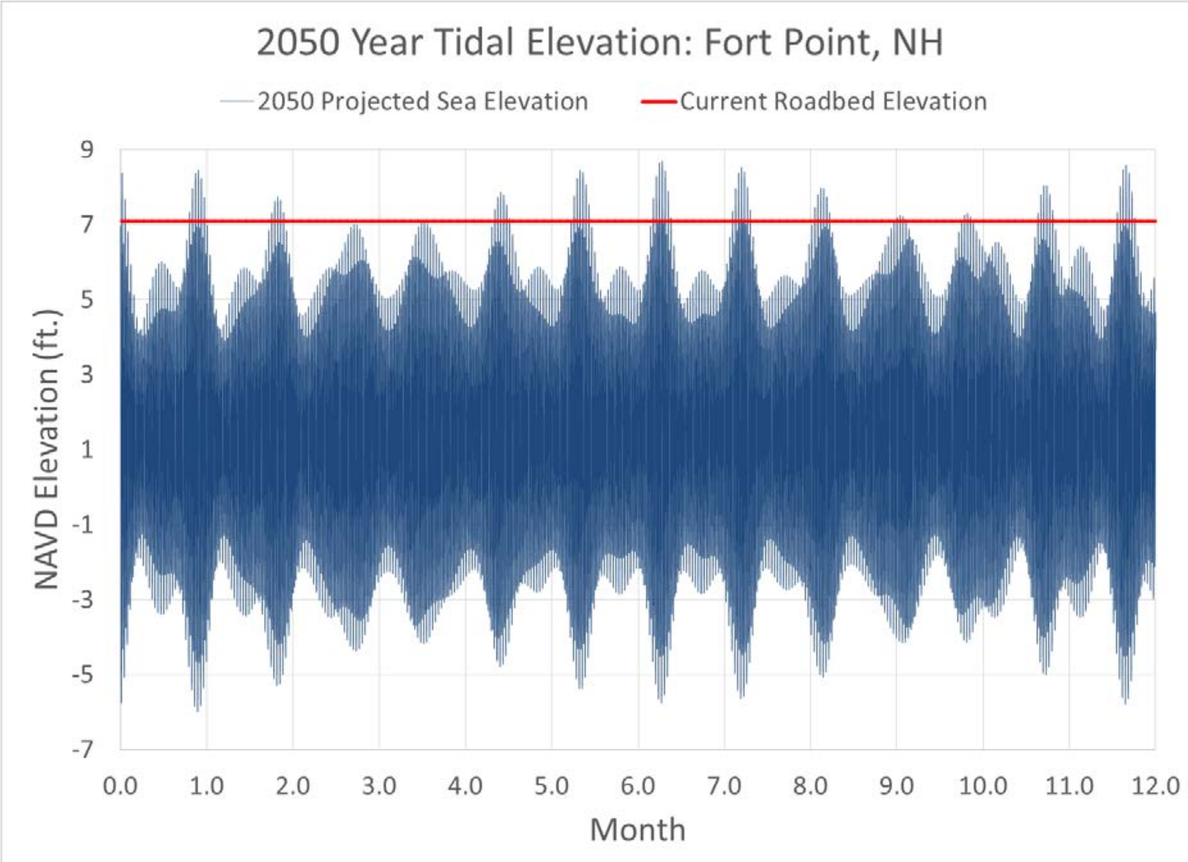
4.1 Design Alternatives

The five alternatives evaluated for the area surrounding the causeway were no action, restore fringing marsh adjacent to the causeway, elevate, elevate and restore fringing marsh, and construct a bridge. Areas where restoration activities would occur and conceptual designs are included as part of Appendix C. Component activities include excavation for sea grass in two areas south of the causeway and using this material to build out salt marsh habitat to 40 feet from the top of the existing bank, also along the south of the causeway. Excavated areas would be seeded with sea grass. Constructing the salt marsh involves moving existing riprap along the causeway's south edge to become armor for the new edge 40 feet farther south. Conceptual designs provided for two slopes of this salt marsh (Appendix C) adequately represent the 'restore' design for the purpose of comparing to the other designs. Current elevation of the causeway surface is 7.1 feet NAVD 88; the elevate scenarios considered elevating the road (and marsh?) by an additional 2 feet (9.1 feet NAVD88). Except as discussed below under "Ecological Benefits and Other Considerations," the Technical Team determined that bridge construction entailed too many uncertainties for detailed comparison with the other alternatives.

4.2 Cost vs. Access

The Technical Team observed that access across the causeway would only be substantially different between the elevation alternatives and the non-elevation alternatives, with restoration not likely to substantially influence access during the period of evaluation. Similarly, years of access preserved by each design alternative are not likely to be a function of erosion because, unlike in the Maine context, there is little erosion at the NH site that is likely to compromise the causeway. Rather, vehicular access across the causeway will be most directly influenced by frequency of overtopping. Work by the University of New Hampshire (2014) and the Fort Point tide gauge project inundation frequency as occurring 58 times during the year 2050 (tides higher than the red line in Figure 5). Although this information informs our study, it does not describe gradual changes in inundation frequency over time or patterns beyond 2050.

Figure 5. Year 2050 projected tidal inundation, current causeway elevation (Figueroa et al., 2014).



Although storm surge events overtop the causeway, especially at high tide, to be conservative the pattern of overtopping frequency was produced by evaluating only the increasing frequency of overtopping during high tide events. Inundation by storm surges of different sizes adds to the inundation estimates provided here. Harmonic analysis of Fort Point, NH tide frequencies produced "violin plots" that reflect event counts on the x-axis and intensity of the event on the y-axis (tidal elevation in this case). These violin plots show the probable distribution of data at different sea levels; so long skinny violins represent long ranges with low frequencies, while short and wide violins represent short ranges with high frequencies. Generally, violin plots are more informative because they show every potential exceedance of current sea level elevations versus using only mean or median values.

Figure 6 shows tidal harmonics for the Fort Point tide station using 5-year intervals changing over time as base sea levels rise. The blue violins represent observed water levels recorded at 20-minute time intervals during 2005, 2010 and 2015. NOAA's Intermediate Low (green violins) and Intermediate High (red violins) sea level rise estimates were added to observed water levels from 2016 (the most recent complete dataset) to calculate water levels every 5 years from 2020 to 2065. The solid black line represents the current causeway elevation (7.1 feet NAVD88) and the dashed black line represents the elevation of the proposed causeway

(9.1 feet NAVD88). Note that neither green nor red violins cross the current causeway elevation in 2035, but both do by 2065.

Figure 6. Harmonic analysis for the Fort Point tide station in relation to causeway elevation. Credit: GEI Inc.

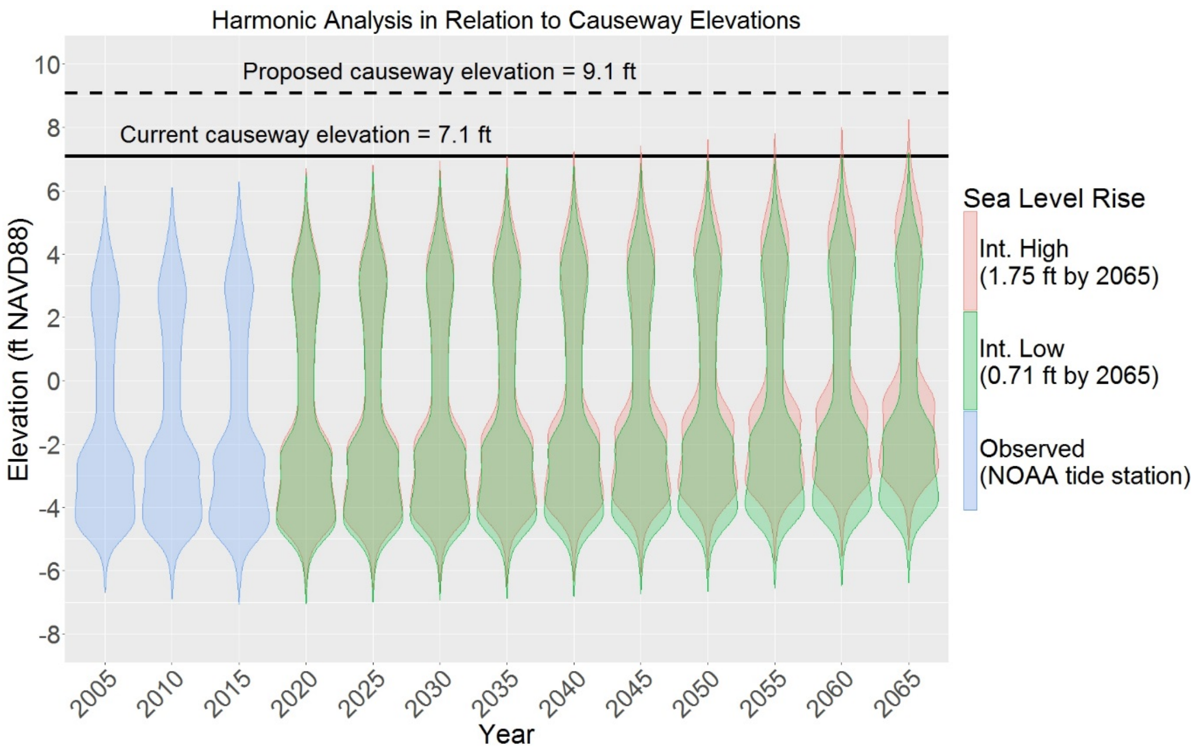
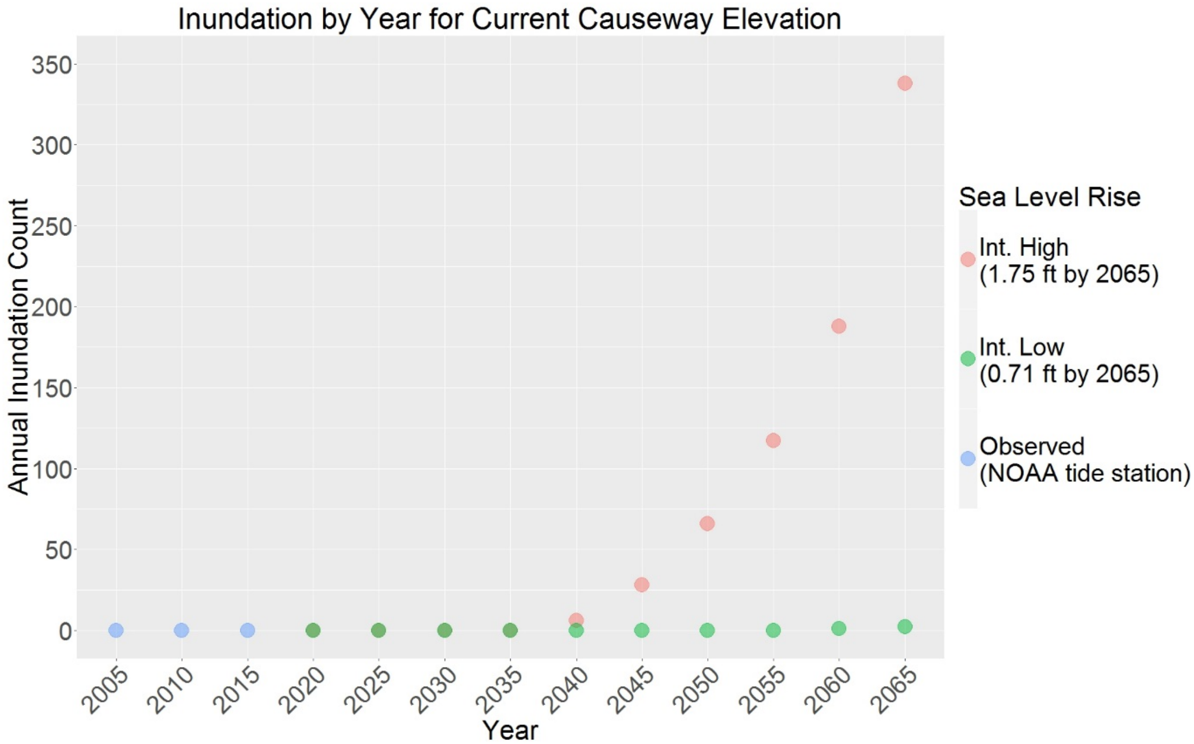


Figure 7 represents the number of times per year that water levels exceed the causeway elevation over the course of the years plotted referencing the same 20-minute time intervals used to create the violin plots in Figure 6. Like the violin plots, blue dots represent observed water levels and red and green dots represent water levels from intermediate high and intermediate low sea level rise, respectively. Intermediate sea level rise causes the causeway to be inundated only once in 2060 and twice in 2065, which is not substantially more than it would be without sea level rise. However, if sea level rise follows the intermediate high trajectory, the causeway would be inundated 188 times in 2060 and 338 times in 2065. It is important to note that many of those inundations are consecutive; recordings were taken every 20 minutes in the data set used for these extrapolations. Therefore, if we assume that water levels extending above the road would last 20 minutes (which some may not), the 338 occurrences would total roughly 113 hours of inundation in 2065.

Figure 7. Expected frequency of causeway inundated based on sea level rise projections and tidal harmonics. (Credit: GEI Inc.)



Cost estimates developed in this study (Appendix D) do not examine cost of elevating the causeway; however, this will need to be developed through subsequent study. Cost estimates in this study reference ecological restoration costs. They are provided for cases where the causeway is elevated (the first table in Appendix D, referencing drawings XS800a and XS1100a in Appendix C) and not elevated (the second table in Appendix D, referencing drawings XS800b and XS1100b in Appendix C). The difference between totals in the two cost tables in Appendix D ($1,637,266 - $1,098,428 = $538,838) represents the extra cost of elevating the causeway when restoration occurs, regardless of slope and staging of the restoration activity. This amount should be accounted for in any future causeway planning that includes the restoration activities examined in this study.

4.3 Ecological Benefits and Other Considerations

Alternative 1 – No action.

The causeway is adjacent to several intertidal and subtidal habitats, including, but not limited to, small amounts of fringing salt marsh, unconsolidated rocky shore/bedrock and beach, significant mudflats, an eelgrass bed to the North of the causeway, and some limited shellfish habitat (Figures 8 and 9). Even if no action is taken, existing ecological benefits persist at this site over the short term. Benefits include habitat for fish and other vertebrates and invertebrates including shorebird stopover habitat and foraging sites for resident fauna;

carbon storage and nutrient processing; bank stabilization; and other elements of a healthy coastal ecosystem of this type. Short-term persistence of benefits can be expected decline with habitat conversion occurs as sea level rises. Under an intermediate-high sea level rise scenario, existing fringe salt marsh areas can be expected to convert to mudflat and, if conditions allow, some salt marsh may migrate up onto higher elevations currently occupied by roadways by 2075. In addition, deeper water will likely result in loss of eel grass beds given today's water clarity. Current recreational benefits include substantial use by residents and visitors for scenic driving/motorcycling, walking, running, bicycling, and causeway fishing access; however, the narrow shoulder on the causeway limits pedestrian and cyclist use. The embayment to the south of the causeway sees active use for recreational sailing year-round. The causeway also provides limited access to rocky beach areas and the New Hampshire Fish & Game Department Goat Island saltwater fishing access car-top boat launch, which is experiencing some erosion. In this alternative, these recreational uses can be expected to persist until the causeway becomes inaccessible due to frequent inundation from sea level rise.

***Alternative 2* –** Restore.

Enhancing salt marsh habitat in the area surrounding the causeway is reasonably expected to result in some increase in ecological and social benefits over time consistent with the increased presence of salt marsh flora and associated fauna and imported topsoil/humus. Increased benefits include carbon storage, nutrient processing, fisheries and bird habitat, and bank stabilization. The restoration design includes converting of some mudflat and other unconsolidated sediment to salt marsh, resulting in a potential loss of mudflat benefits; however, given the projections showing mudflat expansion and salt marsh loss under all sea-level rise scenarios, it is recognized that protecting and enhancing salt marsh, where possible, is a priority (current salt marsh, mudflat, eelgrass, and shellfish extents are depicted in Figures 8 and 9). Depending on the sea level rise scenario and the elevation associated with the restoration design, the restored area could convert completely to mudflat by the next century. Recreation benefits may increase slightly when the restoration activities are completed due to additional birdwatching and aesthetic benefits; however, access to the site will likely decline over time as the causeway experiences increased inundation associated with sea level rise and if salt marsh takes over the causeway area.

***Alternative 3* –** Elevate.

If the causeway is elevated without restoration, recreational benefits will likely persist over the long term as access across the causeway will remain intact. In lieu of benefits, elevation will have significant ecological impacts because it will require an expanded footprint below mean high water that will likely destroy existing fringe salt marsh, mudflats, some sea grass, and negatively affect associated fauna in the expanded footprint. Construction could potentially cause additional sedimentation in the water column, causing secondary impacts to nearby flora and fauna. It is likely that salt marshes in some of these areas would eventually convert to mudflat. It is currently unknown whether any rare species exist at the site and thus, whether they would be impacted by this alternative. Overall, the extent of ecological impacts will depend on the elevation design and footprint area as well as construction timing and mitigation practices. Recreation benefits to pedestrian and cyclist use will likely increase if the causeway shoulder is expanded in the elevated design, however an expanded shoulder will further increase the project footprint, expanding its ecological impacts in the intertidal and subtidal areas. Recreational access to the site is likely to remain intact as the time until the causeway will be regularly inundated by high tide would be delayed by at least several decades. Depending on the extent of the project footprint, some mooring sites and recreational boating may be impacted to the south of the causeway.

Alternative 4 – Elevate and Restore.

If the salt marsh habitat is enhanced in the area surrounding the causeway it is reasonable to expect increased ecological and social benefits over time consistent with the increased presence of salt marsh flora and associated fauna and imported topsoil/humus. These benefits include carbon storage, nutrient processing, fisheries and bird habitat, and bank stabilization. The elevation and restoration design would convert significant mudflat and other unconsolidated sediment to salt marsh, resulting in a potential loss of mudflat benefits, but given the projections showing mudflat expansion and salt marsh loss under all sea-level rise scenarios, it is recognized that protecting and enhancing salt marsh, where possible, is a priority (current salt marsh, mudflat, eelgrass, and shellfish extents are depicted in Figs. 4 and 5. Elevation could potentially result in added sedimentation in the water column, causing secondary impacts to nearby flora and fauna. Because rare species occurrence at the site has not been noted, it's unclear whether they would be impacted by this scenario (current wildlife habitat rankings in the causeway vicinity are provided in Figure 10). Overall, the extent of ecological impacts depends on the elevation design and footprint area as well as construction timing and mitigation practices. Recreational access to the site remains until the causeway is regularly inundated by high tide would be delayed by at least several decades, resulting in increased pedestrian and cyclist use with widening of shoulders during elevation and enhanced birdwatching and aesthetic benefits resulting from the restoration. Depending on the extent of the project footprint, some mooring sites and recreational boating may be impacted south of the causeway.

Alternative 5 – Construct Bridge.

A high degree of uncertainty exists around potential bridge design impacts until detailed ecological impact studies can be completed. Predictions of hydrologic and hydraulic changes near the site and extending into the Piscataqua River and Little Harbor areas vary. Dramatic changes in currents and sediment transport-albeit to the more natural, pre-causeway system-could occur. Changes in currents resulting from a bridge have the potential to impact abutting properties. This could exacerbate shoreline erosion and impact habitats, including salt marshes, eelgrass, shellfish beds, and mudflats. These possible changes to hydrology and hydraulics and the associated impacts should be assessed through further analysis. Recreational benefits associated with use of the bridge would likely increase if an expanded shoulder is included and persist over the long term, assuming the bridge is built using the highest sea level rise scenarios that are possible within the structure's lifespan. Change and potential loss of recreational benefits associated with boating could occur due to shifting currents. This alternative would come closest to restoring natural hydrology in the area, but the site and its surroundings are highly developed. To fully understand the balance of ecological and human impacts and benefits associated with removing the causeway tidal restriction, additional analysis is required.

Figure 8. Wetland, salt marsh, and mudflat extents in the New Castle causeway vicinity. Credit: University of New Hampshire

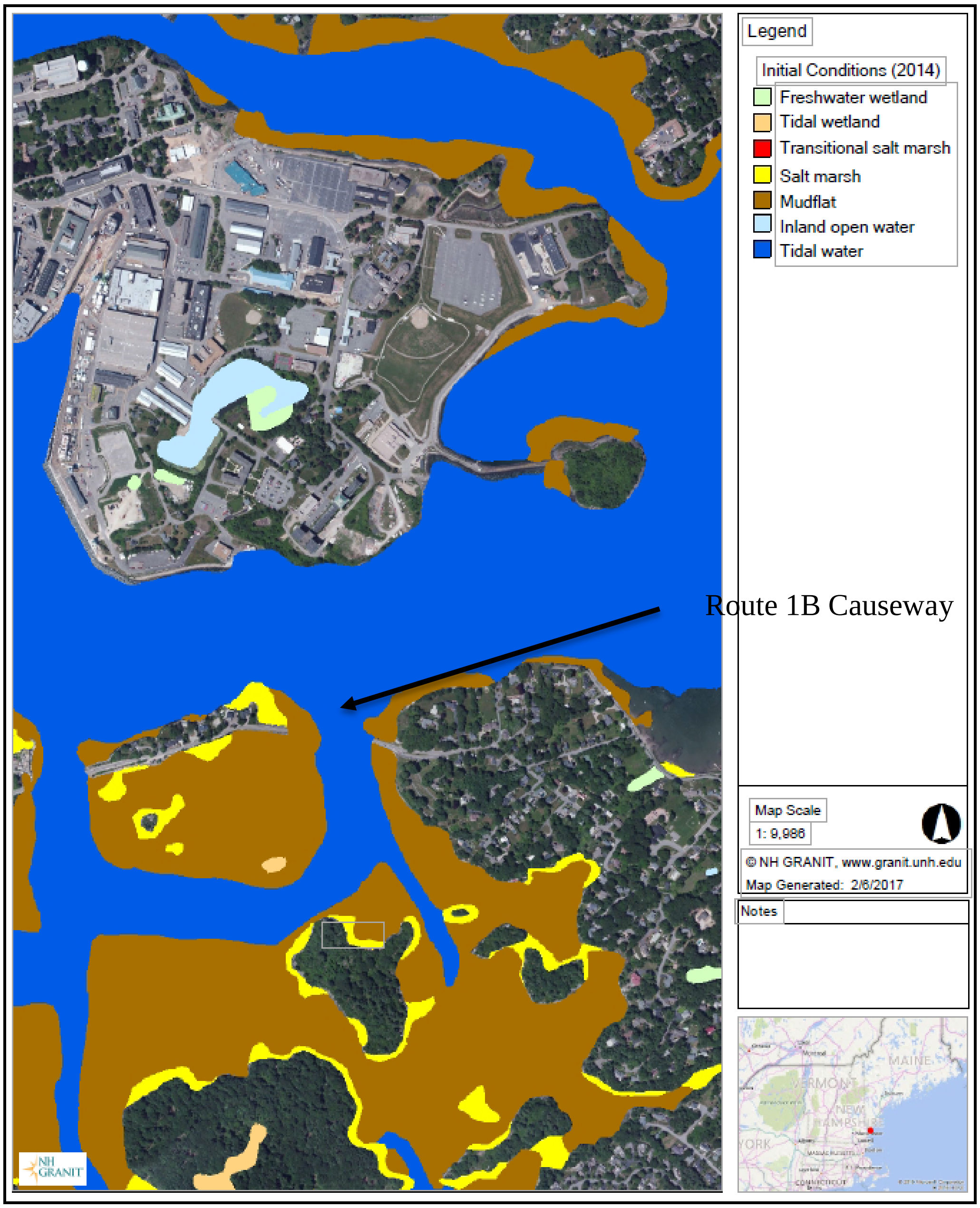


Figure 9. Shellfish and eelgrass beds in the New Castle causeway vicinity. (Credit: University of New Hampshire)

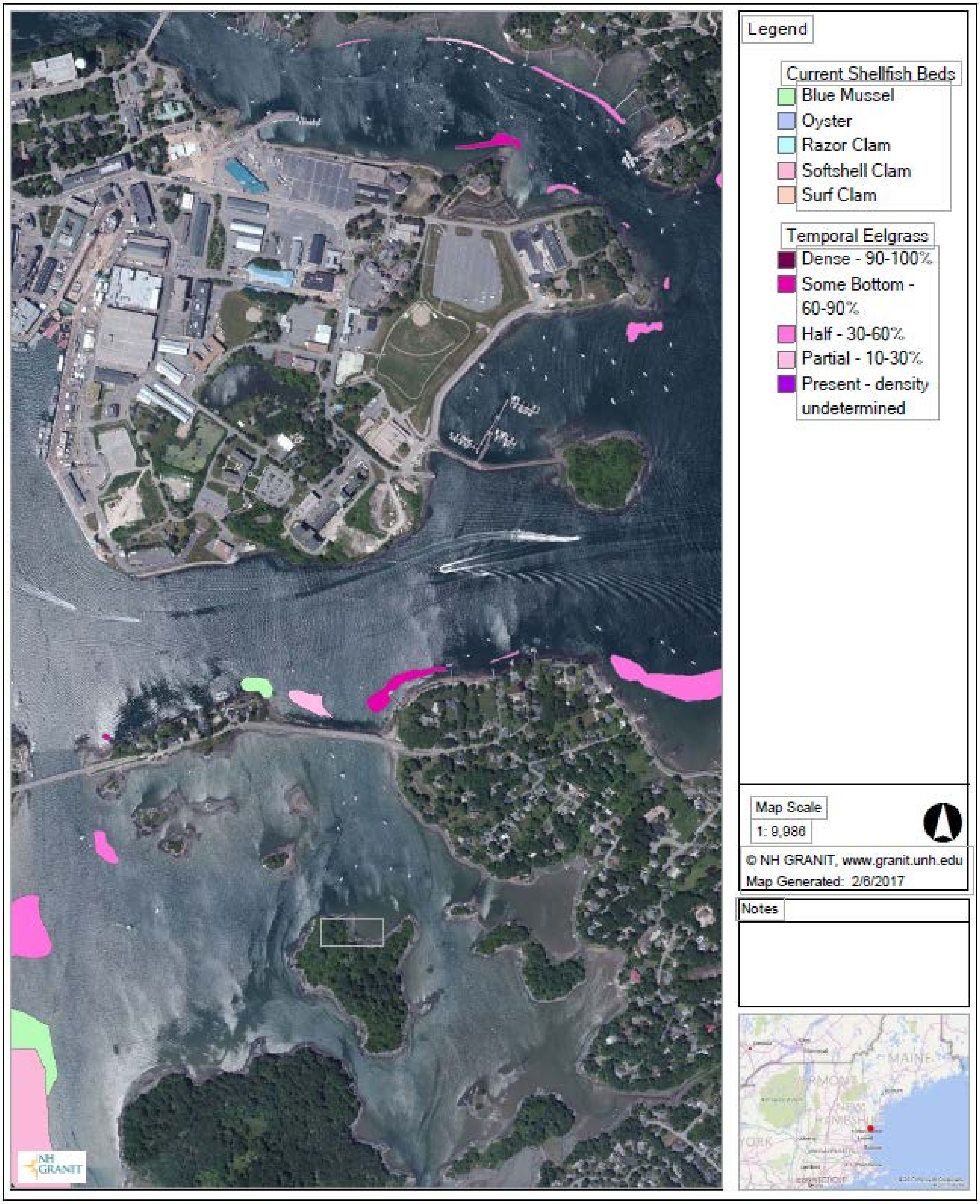
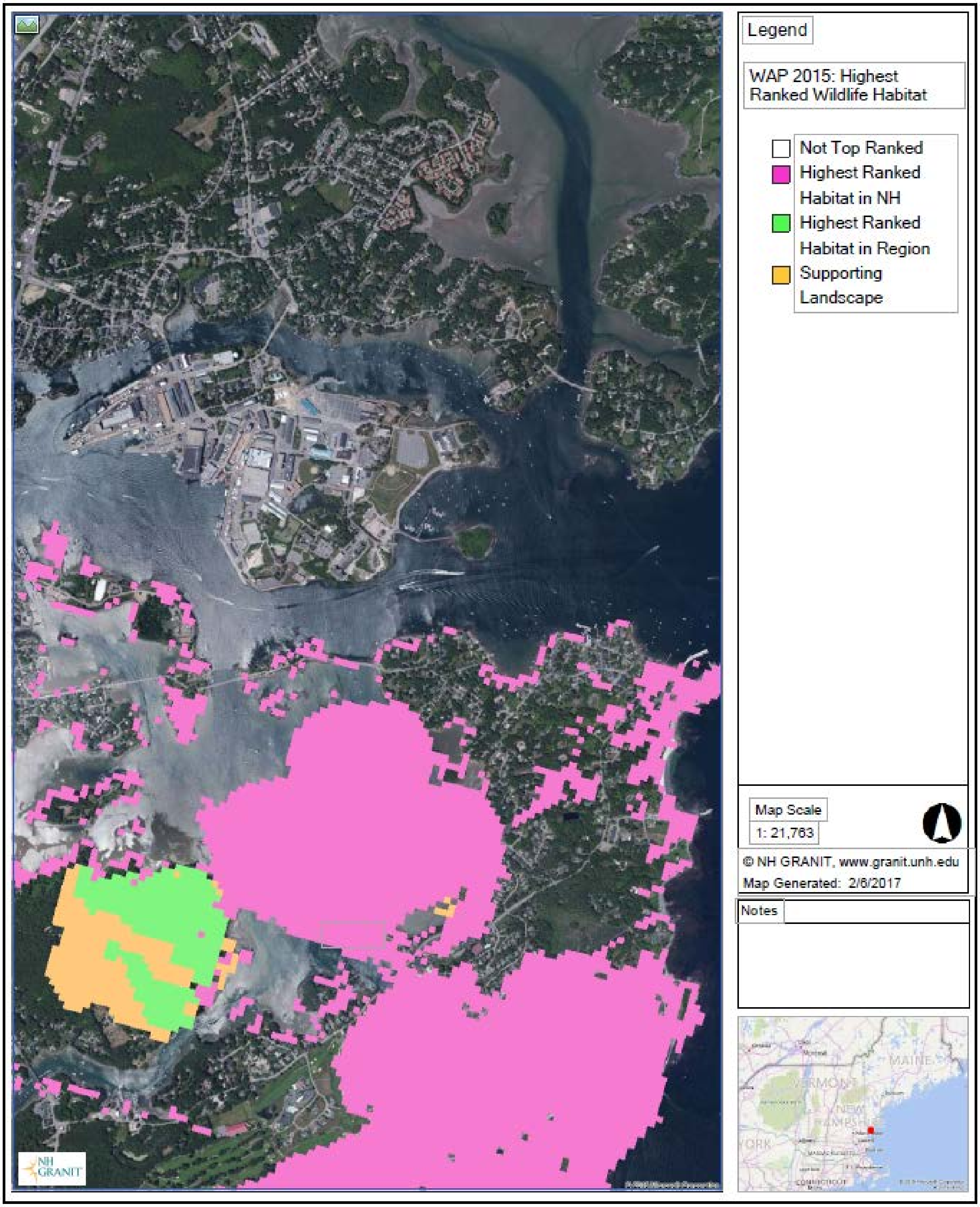


Figure 10. Wildlife habitat rankings in the New Castle causeway vicinity. Credit: University of New Hampshire



4.4 Implications

Observations in this report add to existing efforts to evaluate transportation alternatives in the Route 1B causeway area and begin to incorporate concerns about a changing climate into infrastructure upgrade decisions in coastal New Hampshire. These include work conducted by the NH DOT (NH DOT, 2014), the New Hampshire Coastal Risk and Hazards Commission (NHCRC 2016), and the University of New Hampshire in an evaluation of causeway alternatives (Figueroa et al. 2014). These documents contribute to ongoing conversations about vulnerable coastal infrastructure in New Hampshire including among the US Army Corps of Engineers, NH DOT, NH DES, NH Fish and Game, and other entities such as the City of Portsmouth and the NH Climate Adaptation Workgroup. Within the next several years the New Hampshire legislature will consider this diverse collection of inputs during a feasibility study on alternatives for the Route 1B causeway, and specific decisions will be made about how to proceed.

Two questions before the groups and individuals that will collectively select among the available design alternatives are "should we elevate the causeway?" and "should we conduct habitat restoration activities?" Prior work on several engineering alternatives available for the causeway (Figueroa et al. 2014) considered doing nothing versus raising the causeway footprint with a reinforced mechanically stabilized earth wall and construction of a bridge. The raised and reinforced alternative was found to be optimal. However, the study did not evaluate cost of each alternative in detail, access preserved through the useful life of the infrastructure, or ecological benefits that could be obtained through possible restoration activities at the site.

Results from the current study suggest that unless regular inundation (>330 times per year by 2065) is tolerable, elevation should be strongly considered. A 2-feet elevation would likely reduce inundations attributable to high tide to zero inundations per year through 2065, and would likely not need to be constructed before 2035, given the sea level rise curves used in this study. Without elevation, however, and given uncertainty in which sea level rise scenario may occur, regular access across the causeway may reasonably be expected to have at least some interruptions beginning in 2035 and increasing through 2065. The cost of maintaining uninterrupted access through 2065 is therefore reasonably stated as the cost of elevation.

4.5 Next Steps

Regarding the salt marsh restoration activities along the south side of the causeway, there is question about whether they should be pursued if the causeway is not elevated. That is, most habitat restoration initiatives undertaken in New Hampshire are efforts toward long-term preservation of habitat. Without elevation, however, ecological benefits to be gained by restoration may be time-delimited, producing only short-term benefits. Because this may render restoration less attractive as a management alternative, whether restoration is pursued may depend in part on whether elevation is pursued.

Further, to make any decisions about the causeway, additional work is needed to evaluate implications of either elevation or restoration, including evaluating the quantity of tidal flushing that would be seen under each design scenario; analysis of future surge probabilities and their possible impacts on potential designed structures and habitats; and regional comparisons to examine whether other sites in New Hampshire's portfolio of coastal transportation assets are more likely to benefit from the resources that might be allocated to any redesign contemplated for the causeway. In any event the approach used here (itemizing costs of restoration activities, estimating frequencies of inundation, and comparing ecological benefits under elevation and non-elevation scenarios) may be transferable to other sites in this portfolio.

5. Literature Cited

Figueroa, M., C. Jacques, J. Chaisson, and S. Pape (2014). "Sea level rise adaptation alternatives for New Castle causeway." Student paper submitted for Civil Engineering 788 at the University of New Hampshire, Faculty advisors Drs. Jo Daniel and Jennifer Jacobs.

GEI Consultants, Inc. (2015). "Assessing Program Risk Through Benefit-Cost Analysis for Bridge and Culvert Design." Final Report for MaineDOT and FHWA, 2015.

Kelley, J. (2013). "Popham Beach, Maine: An example of engineering activity that saved beach property without harming the beach." Geomorphology 199:171 – 178.

Maine Department of Transportation (2016). "Implementing Eco-Logical Implementation Assistance Project Update." Report to FHWA on the SHRP2 Eco-Logical project.

Merrill, S., and J. Gates (2016). "Lifecycle Design and Cumulative Benefit-Cost Analysis for Transportation Resiliency." Center for Infrastructure Protection and Homeland Security Report, December.

Merrill, S., J. Gates, and A. Gray (2017). "Integrating assets vulnerable to sea level rise and extreme weather events into ongoing structural review decisions at MaineDOT." Proceedings of the Transportation Research Board, January.

New Hampshire Coastal Risk and Hazards Commission (2016). Preparing New Hampshire for Projected Storm Surge, Sea-Level Rise and Extreme Precipitation. http://www.nhcrhc.org/wp-content/uploads/2016-CRHC-final-report.pdf

New Hampshire Department of Transportation (2014). Potential Impact of Climate Change on Transportation Infrastructure – Assessment of Vulnerability and Recommendation of Adaptive Strategies. Concord, NH, April.

6. Limitation of Liability

This report presents comparisons of conceptual design alternatives in coastal Maine and New Hampshire. Results are based on feature data from MaineDOT and NH DOT, available digital elevation models, and modeling parameters suggested by and confirmed with MaineDOT. In the event of actual storm surge events and assuming sea levels continue to rise, actual impacts to roads, causeways, beaches, and other features will vary from those presented in this report. The hypothetical inundation conditions described herein do not indicate or represent the actual integrity, condition, or safety of transportation infrastructure or natural features modeled if inundation events do occur. Results of this analysis should only be used to estimate general patterns of vulnerability under each design scenario evaluated; reuse of this report for any other purposes, in part or in whole, is at the sole risk of the user.

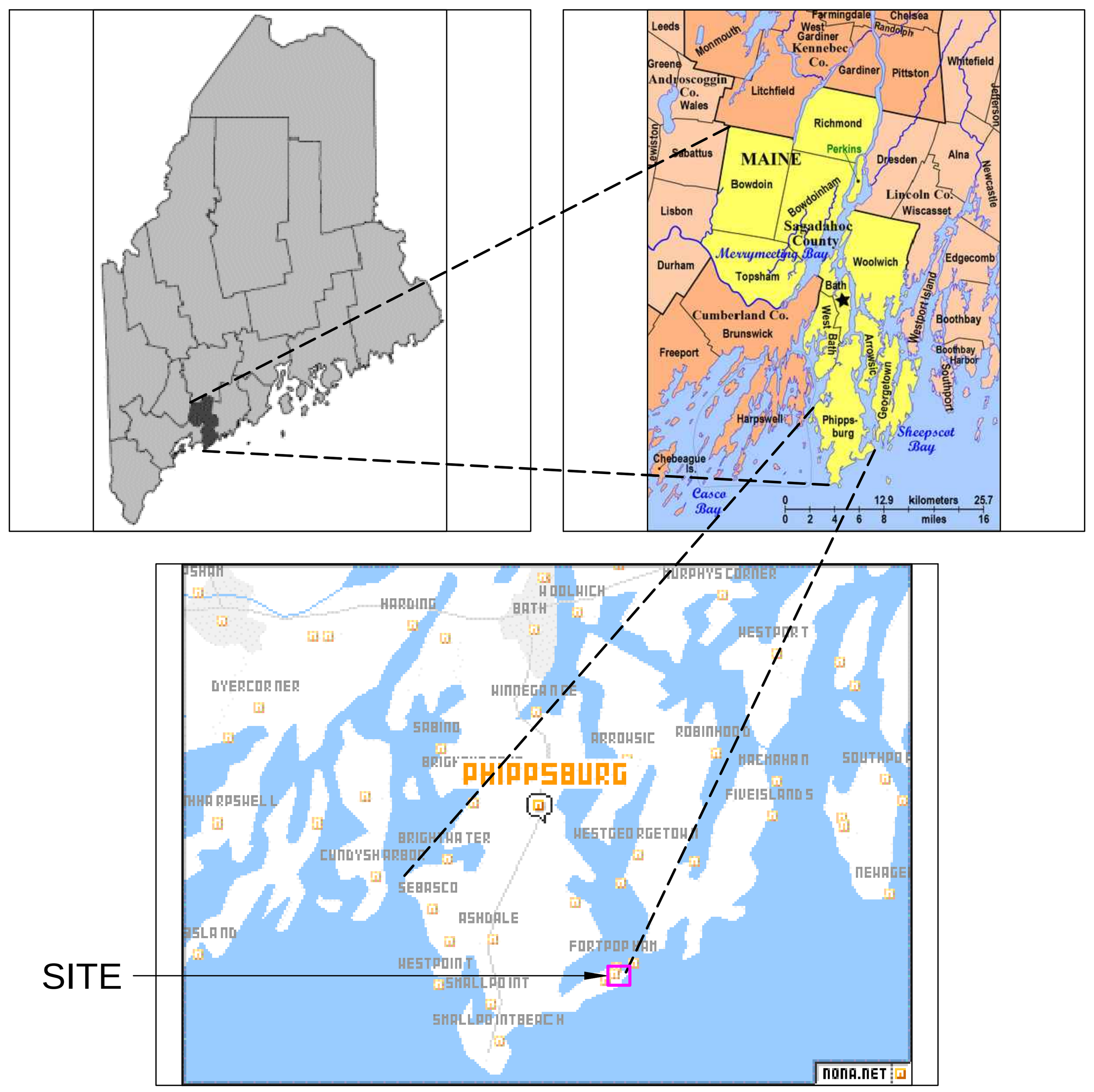
Appendix A

Area Maps and Conceptual Designs for Route 209 in Phippsburg, Maine

POPHAM BEACH SHORELINE RESTORATION

CONCEPTUAL DESIGN OPTIONS

POPHAM BEACH, PHIPPSBURG, MAINE



VICINITY MAP
NOT TO SCALE

POPHAM BEACH
BIRD'S-EYE VIEW

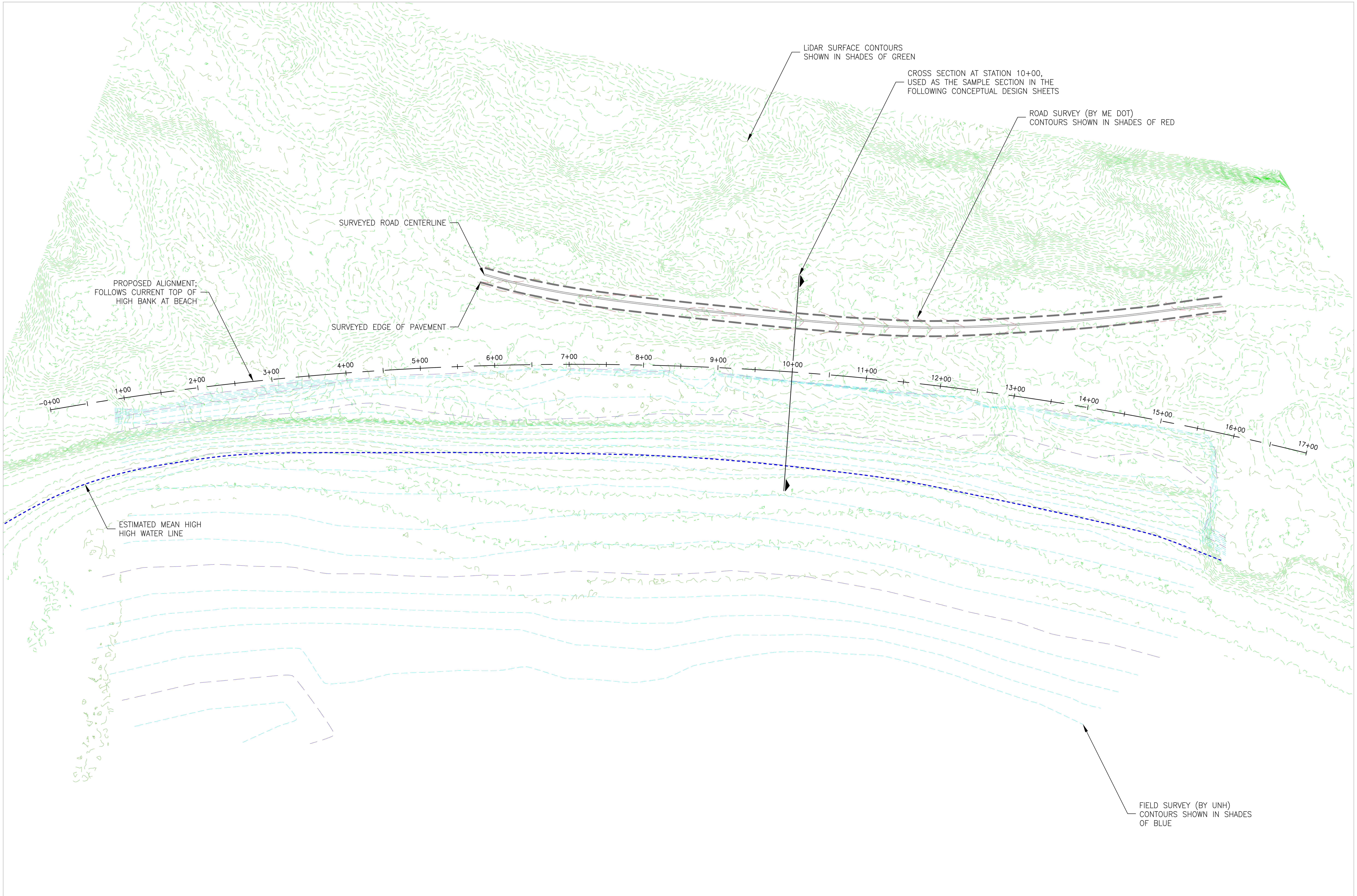
LIST OF SHEETS

NO	SHEET ID	SHEET TITLE
1.	OVIEW	SITE OVERVIEW
2.	AERIAL	SITE OVERVIEW WITH AERIAL
3.	OPT1	CONCEPTUAL OPTION 1
4.	OPT2	CONCEPTUAL OPTION 2
5.	OPT3	CONCEPTUAL OPTION 3A
6.	OPT4	CONCEPTUAL OPTION 3B
7.	OPT4A	CONCEPTUAL OPTION 4A
8.	OPT5	CONCEPTUAL OPTION 4B
9.	OPT6	CONCEPTUAL OPTION 5

NOTES

1. THESE ARE CONCEPTUAL DESIGN SHEETS AND SHOULD NOT BE USED FOR CONSTRUCTION PURPOSES.

University of New Hampshire



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 26 SEPT 2017

University of New Hampshire

NOTES:

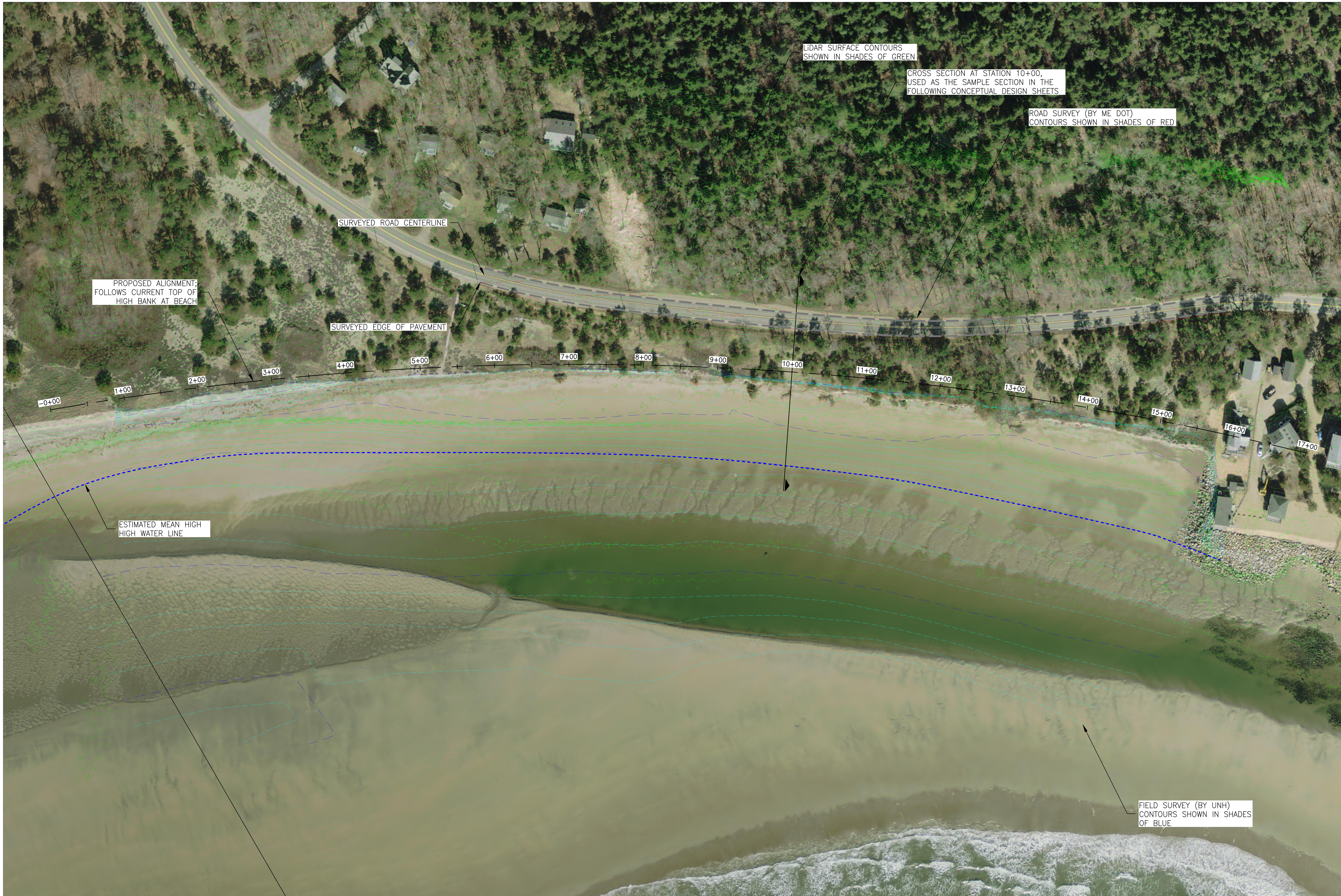
DATE:
REVISION #:

SHEET TITLE: SITE OVERVIEW
SHEET SET: CONCEPTUAL DESIGN OPTIONS
PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION
PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

N

SCALE: 1" = 60'
0 30 60 90

SHEET ID: OVIEW
SHEET NUMBER: 01 OF 09



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 26 SEPT 2017

University of New Hampshire

NOTES:

REVISION #:
DATE:

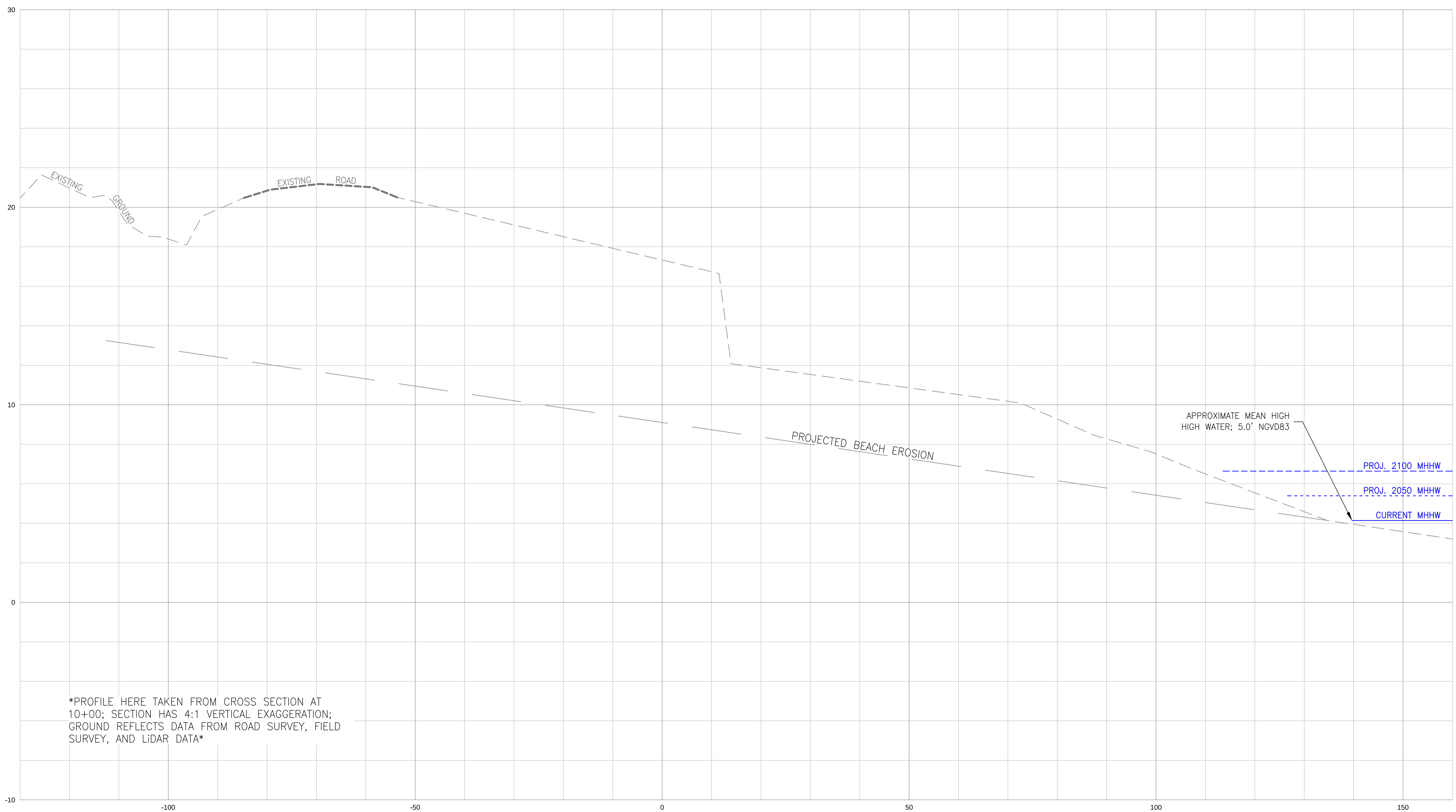
SHEET TITLE: SITE OVERVIEW WITH AERIAL
SHEET SET: CONCEPTUAL DESIGN OPTIONS
PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION
PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

N

SCALE: 1" = 60'
0 30 60 90

SHEET ID: AERIAL
SHEET NUMBER: 02 OF 09

OPTION 1:
DO NOTHING; ALLOW NATURAL FORCES TO CONTINUE TO ERODE BEACH AND DUNES.



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 26 SEPT 2017

University of New Hampshire

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL OPTION 1

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION

PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

SCALE: 1" = 10'

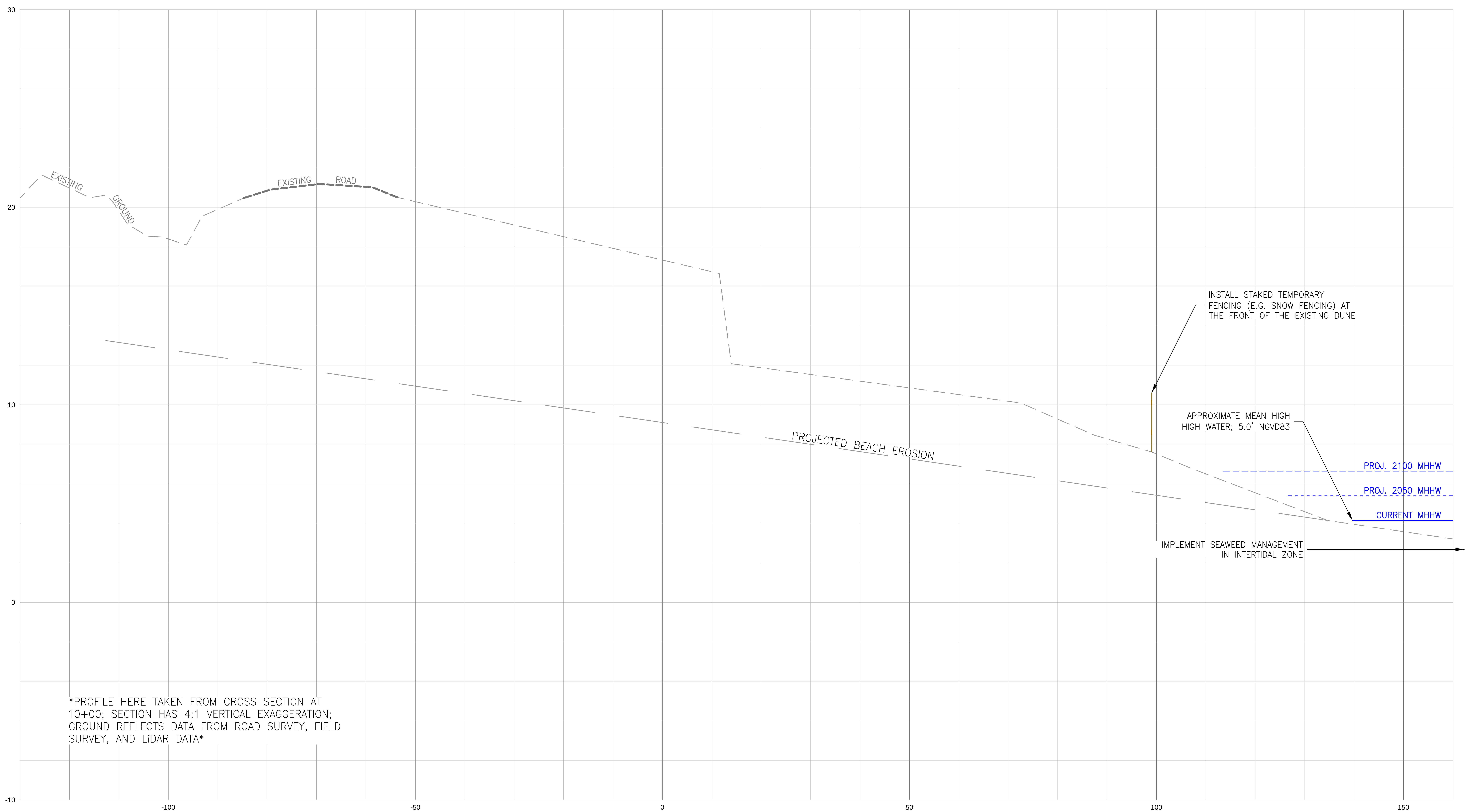
0 5 10 15

SHEET ID: OPT1

SHEET NUMBER: 03 OF 09

OPTION 2:

IMPLEMENT ONLY SEAWEED MANAGEMENT AND STAKED TEMPORARY FENCING (E.G. SNOW FENCING) AT THE FRONT OF THE EXISTING DUNE. RESERVE FURTHER INVESTMENTS UNTIL LOSS OF ROAD IS IMMINENT AND THEN IMPLEMENT STABILIZATION MEASURES SELECTED FROM OTHER OPTIONS.



PROFILE HERE TAKEN FROM CROSS SECTION AT 10+00; SECTION HAS 4:1 VERTICAL EXAGGERATION; GROUND REFLECTS DATA FROM ROAD SURVEY, FIELD SURVEY, AND LiDAR DATA

DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 26 SEPT 2017

University of New Hampshire

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL OPTION 2

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION

PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

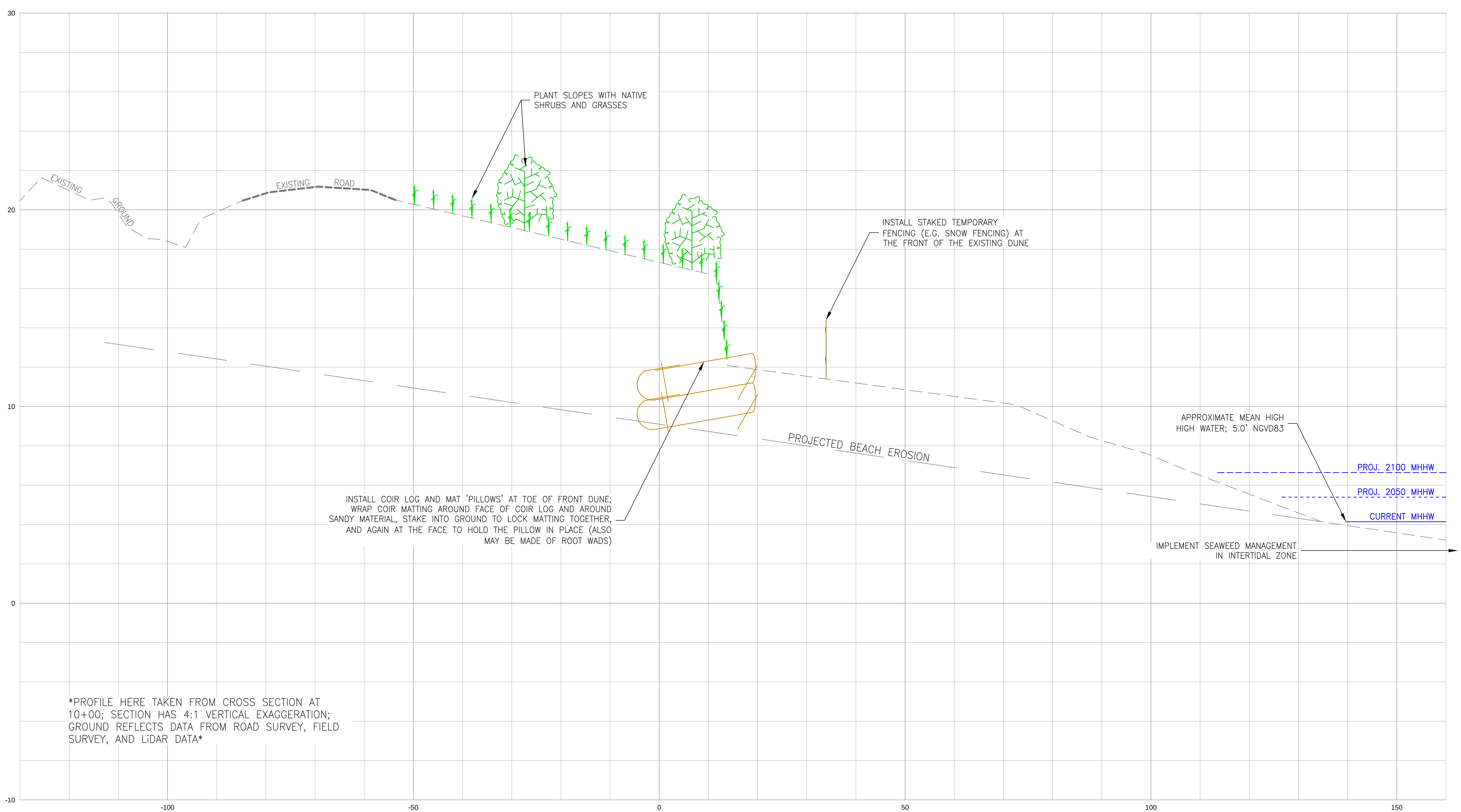
SCALE: 1" = 10'

0 5 10 15

SHEET ID: OPT2

SHEET NUMBER: 04 OF 09

OPTION 3:
IN ADDITION TO SEAWEED MANAGEMENT AND FENCING, INSTALL COIR 'PILLOWS' AT FRONT DUNE. PLANT W2ITH NATIVE SHRUBS AND BEACH GRASSES.



PROFILE HERE TAKEN FROM CROSS SECTION AT 10+00; SECTION HAS 4:1 VERTICAL EXAGGERATION; GROUND REFLECTS DATA FROM ROAD SURVEY, FIELD SURVEY, AND LiDAR DATA

DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 26 SEPT 2017

University of New Hampshire

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL OPTION 3

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION

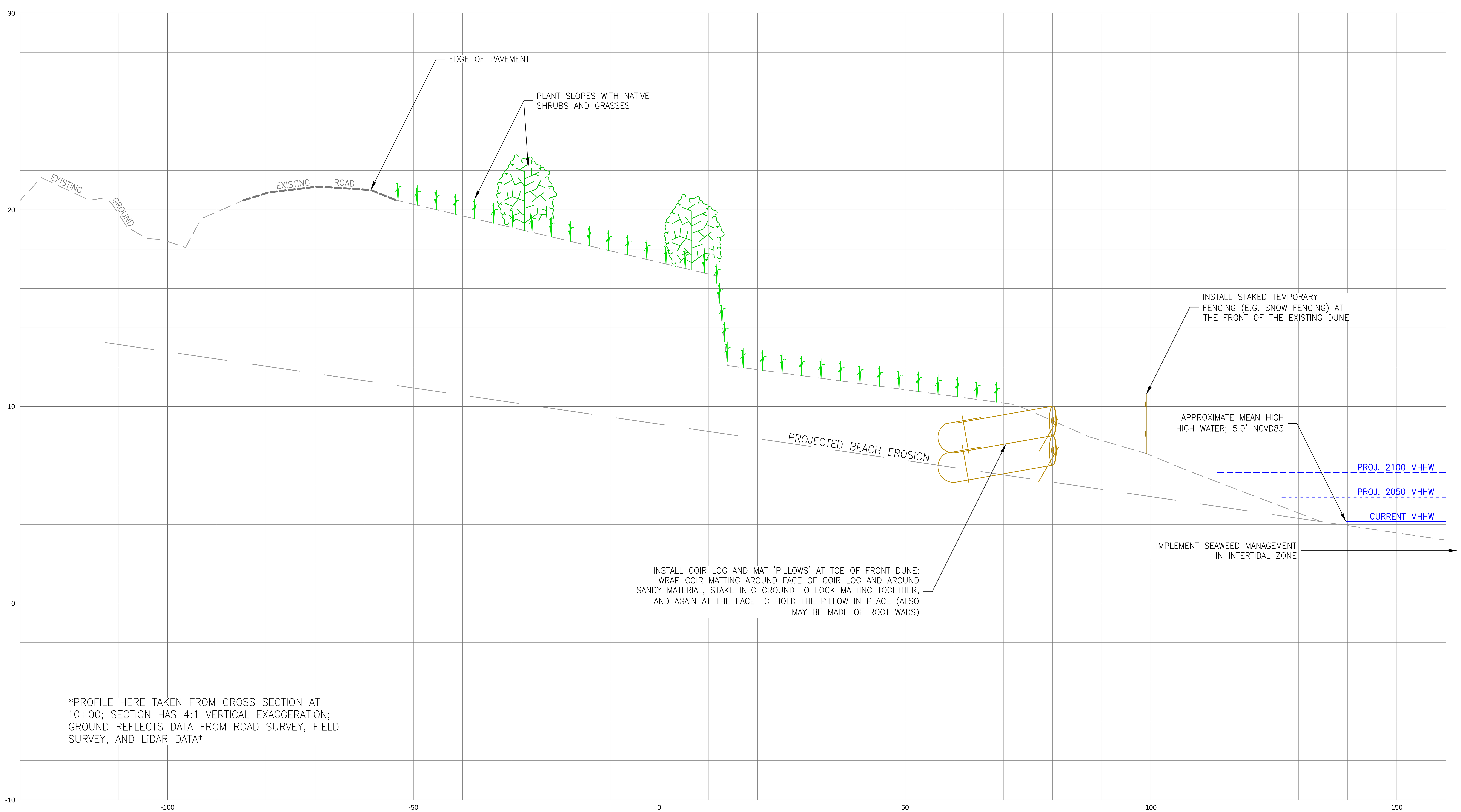
PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

SCALE: 1" = 10'
0 5 10 15

SHEET ID: OPT3

SHEET NUMBER: 05 OF 09

OPTION 4:
IN ADDITION TO SEAWEED MANAGEMENT AND FENCING, INSTALL COIR 'PILLOWS' AT FRONT OF TOE OF DUNE. PLANT WITH NATIVE SHRUBS AND BEACH GRASSES.



PROFILE HERE TAKEN FROM CROSS SECTION AT 10+00; SECTION HAS 4:1 VERTICAL EXAGGERATION; GROUND REFLECTS DATA FROM ROAD SURVEY, FIELD SURVEY, AND LiDAR DATA

DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 26 SEPT 2017

University of New Hampshire

NOTES:

DATE:

REVISION #:

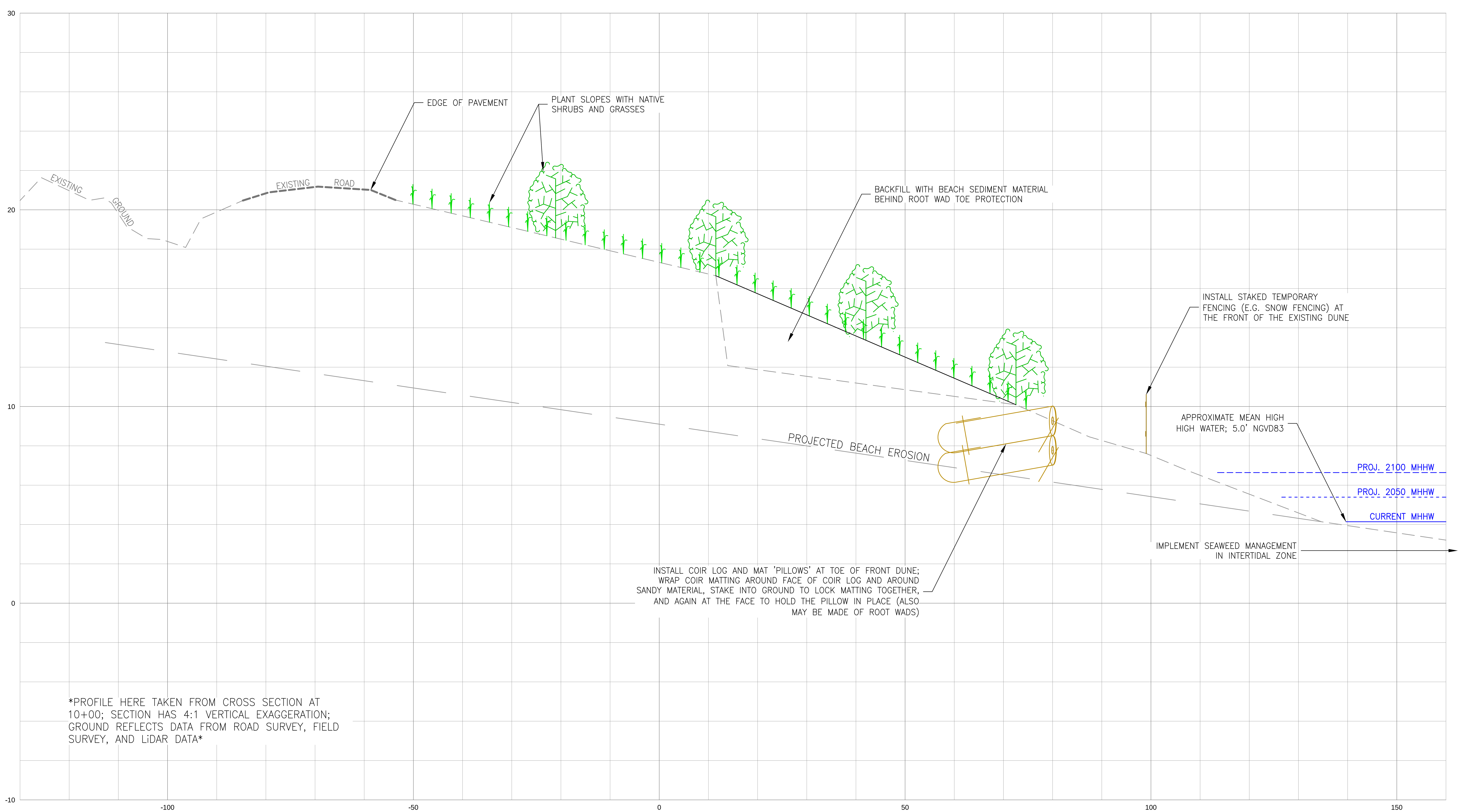
SHEET TITLE: CONCEPTUAL OPTION 4
SHEET SET: CONCEPTUAL DESIGN OPTIONS
PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION
PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

SCALE: 1" = 10'
0 5 10 15

SHEET ID: OPT4

SHEET NUMBER: 06 OF 09

OPTION 4A:
IN ADDITION TO SEAWEED MANAGEMENT AND FENCING, INSTALL COIR 'PILLOWS' AT FRONT DUNE OR CRIB WALL STRUCTURE. ADD BEACH SEDIMENT MATERIAL BEHIND PILLOWS TO TOE OF ROAD BANK; PLANT WITH NATIVE SHRUBS AND BEACH GRASSES.



PROFILE HERE TAKEN FROM CROSS SECTION AT 10+00; SECTION HAS 4:1 VERTICAL EXAGGERATION; GROUND REFLECTS DATA FROM ROAD SURVEY, FIELD SURVEY, AND LiDAR DATA

DESIGNED BY:	JCB, TPB
DRAWN BY:	JCB
CHECKED BY:	TPB
DATE:	26 SEPT 2017

University of New Hampshire

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL OPTION 4A

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION

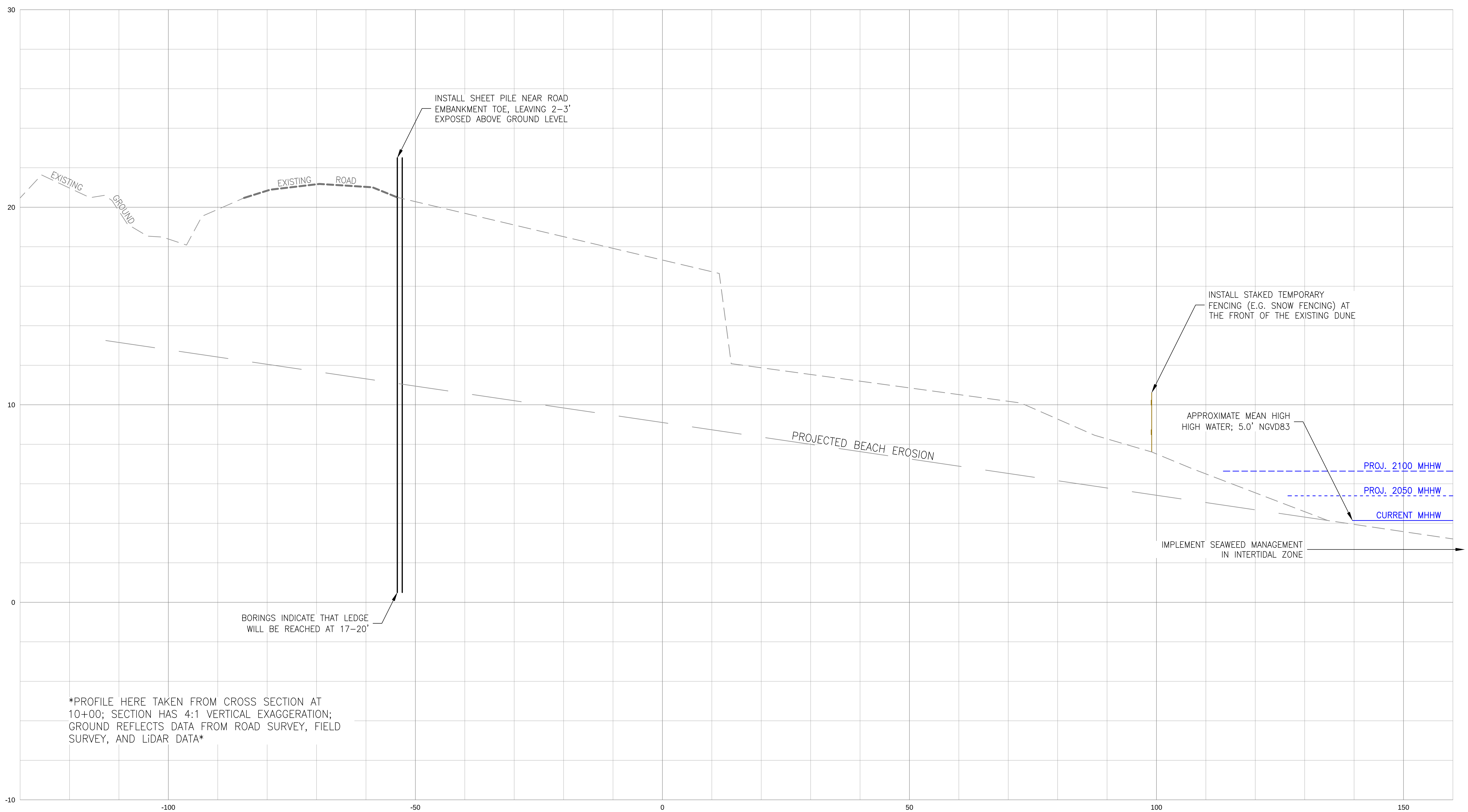
PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

SCALE: 1" = 10'
0 5 10 15

SHEET ID: OPT4A

SHEET NUMBER: 07 OF 09

OPTION 5:
UNTIL THE EROSIONAL SCARP REACHES 15' FROM THE ROAD, CONDUCT SEAWEED MANAGEMENT AND FENCING REGIME AS IN OPTION 2, THEN INSTALL STEEL SHEET PILE WALL JUST SEAWARD OF EROSIONAL SCARP AT ROAD, LEAVING APPROXIMATELY 2-3' ABOVE GROUND LEVEL. INDICATIONS FROM MAINE GEOLOGICAL SURVEY BORINGS IN ADJACENT AREAS ARE THAT LEDGE WILL BE REACHED AT 17-20'.



PROFILE HERE TAKEN FROM CROSS SECTION AT 10+00; SECTION HAS 4:1 VERTICAL EXAGGERATION; GROUND REFLECTS DATA FROM ROAD SURVEY, FIELD SURVEY, AND LiDAR DATA

DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 26 SEPT 2017

University of New Hampshire

NOTES:

DATE:

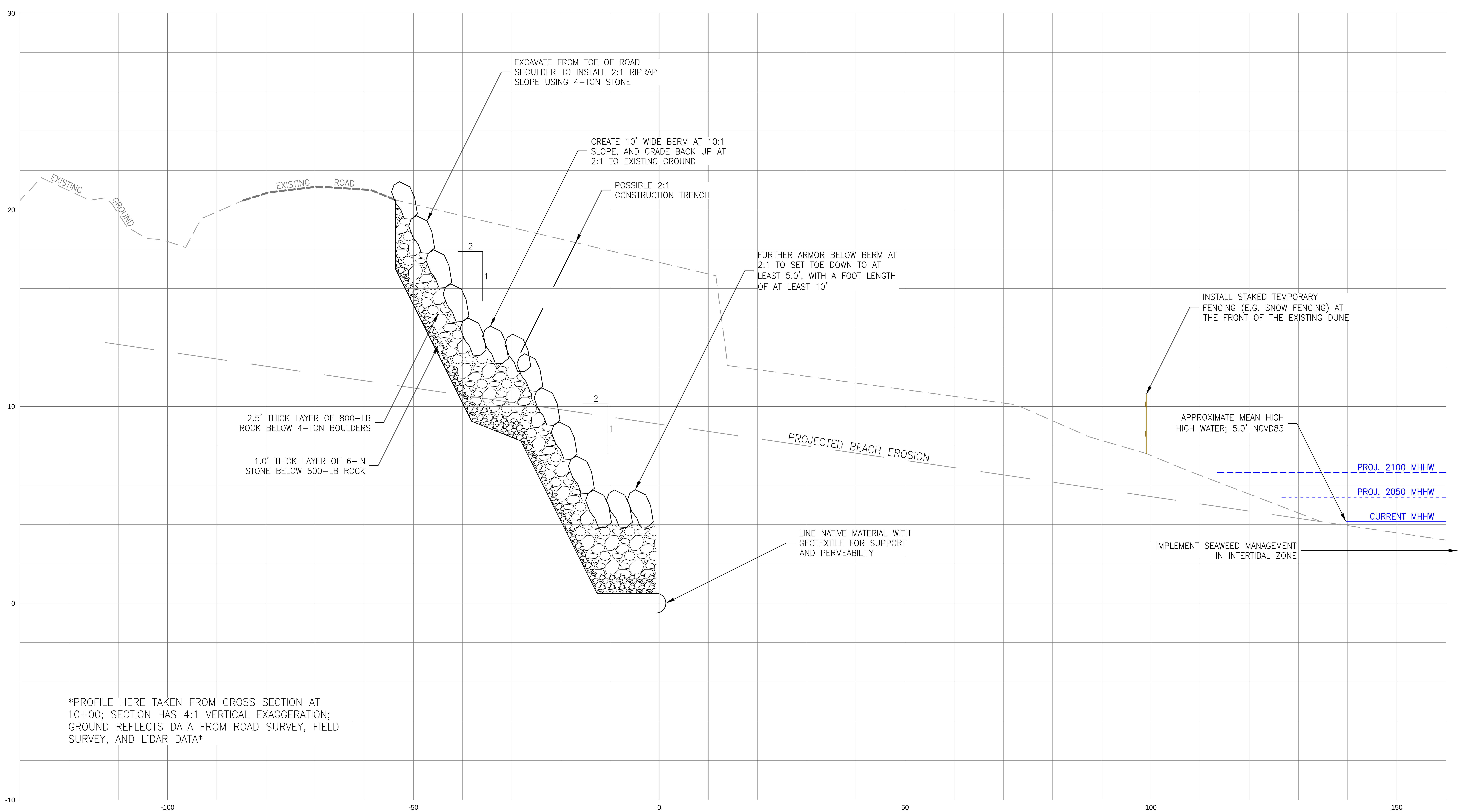
REVISION #:

SHEET TITLE: CONCEPTUAL OPTION 5
SHEET SET: CONCEPTUAL DESIGN OPTIONS
PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION
PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

SCALE: 1" = 10'
0 5 10 15

SHEET ID: OPT5
SHEET NUMBER: 07 OF 09

OPTION 6:
UNTIL THE EROSIONAL SCARP REACHES 15' FROM THE ROAD, CONDUCT SEAWEED MANAGEMENT AND FENCING REGIME AS IN OPTION 2, THEN INSTALL 'S' SLOPE JUST SEAWARD OF EROSIONAL SCARP AT ROAD; EXCAVATE FROM ROAD SHOULDER TO INSTALL 2:1 RIPRAP SLOPE USING LARGE DIAMETER STONE, CREATING A DITCH WITH A 10' WIDE FLOOR.



PROFILE HERE TAKEN FROM CROSS SECTION AT 10+00; SECTION HAS 4:1 VERTICAL EXAGGERATION; GROUND REFLECTS DATA FROM ROAD SURVEY, FIELD SURVEY, AND LiDAR DATA

DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 26 SEPT 2017

University of New Hampshire

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL OPTION 6
SHEET SET: CONCEPTUAL DESIGN OPTIONS
PROJECT NAME: POPHAM BEACH SHORELINE RESTORATION
PROJECT LOCATION: POPHAM BEACH, PHIPPSBURG, MAINE

SCALE: 1" = 10'
0 5 10 15

SHEET ID: OPT6

SHEET NUMBER: 09 OF 09

Appendix B

Conceptual Alternative Costs and Lifespans for Route 209 in Phippsburg, Maine

Item List with Unit Costs				
Item	Units	Unit Cost	Quantity	Item Cost
Mobilization	ea	$ 10,000	1	**$ 10,000**
Snow Fence	ft	$ 1.30	1,000	$ 1,300
Snow Fence Installation	$	$ 21,570	1	$ 21,570
Total Snow Fence Construction Cost	$			**$ 22,870**
Seaweed Management	ea	$ 45,000	1	**$ 45,000**
Root Wad Installation	$	$ 319,048	1	$ 319,048
15' Long, 18" Dia. Root Wads	ea	$ 75.00	402	$ 30,150
10' Long, 18" Dia. Root Wad Sill Logs	ea		0	$ -
Root Wad Cable	ft		0	$ -
Root Wad Duckbills	ea		0	$ -
Coconut Pith	cy	$ 10.00	201	$ 2,010
Root Wad Staples	ea		0	$ -
Root Wad Rebar	ea		0	$ -
Total Root Wad Construction Cost	$			**$ 351,208**
Coir Pillow Installation	$	$ 351,456	1	$ 351,456
Length of 18" Coir Log	ft	$ 10.00	1,600	$ 16,000
Length of 8' Wide Roll Coir Matting	sf	$ 1.75	8,177	$ 14,310
Coir Pillow Stakes	ea	$ 0.80	2,644	$ 2,115
Coir Pillow Rebar	ea		0	$ -
Total Coir Pillow Construction Cost	$			**$ 383,881**
Beach Sediment Fill	cy	$ 35.00	3,664	$ 128,223
Beach Sediment Installation	$	$ 120,740	1	$ 120,740
Total Sediment Fill Construction Cost	$			**$ 248,963**
Species 1 Plants	ea	$ 15.00	886	$ 13,290
Species 2 Plants	ea	$ 20.00	615	$ 12,300
Species 3 Plants	ea	$ 22.00	462	$ 10,164
Species 4 Plants	ea	$ 25.00	370	$ 9,250
Upland Planting Stakes	ea	$ 0.80	2,333	$ 1,866
Upland Planting Installation	$	$ 148,939	1	$ 148,939
Total Planting Cost	$			**$ 195,809**
Seed 1 Mix	lb	$ 20.00	1,358	$ 27,160
Seed 2 Mix	lb	$ 25.00	1,358	$ 33,950
Straw	lb	$ 3.00	308	$ 924
Mulch	lb	$ 5.00	308	$ 1,540
Seeding Efforts	$	$ 29,515	1	$ 29,515
Total Seeding Cost	$			**$ 93,089**
Sheet Pile	sf	$ 27.00	18,400	$ 496,800
Pile Driving Mobilization	ea	$ 49,000	1	$ 49,000
Traffic Control	day	$ 800	60	$ 48,000
Sheet Pile Installation	$	$ 564,384	1	$ 564,384
Total Sheet Pile Construction Cost	$			**$ 1,158,184**
Rip Rap Slope 4-ton Stone	cy	$ 40.00	5,757	$ 230,298
Rip Rap Slope 800-lb Rock	cy	$ 25.00	4,798	$ 119,947
Rip Rap Slope 6-in Stone	cy	$ 15.00	1,919	$ 28,787
Rip Rap Slope Earthwork	cy		0	$ -
Rip Rap Slope Geotextile	sf	$ 0.20	54,408	$ 10,882
Rip Rap Slope Installation	$	$ 1,225,070	1	$ 1,225,070
Total Rip Rap Slope Construction Cost	$			**$ 1,614,983**

Option Component Cost		Summary of Items by Option									
Item	Item Cost	1	2	3a	3b	4a	4b	4Aa	4Ab	5	6
Mobilization	25%		X	X	X	X	X	X	X	X	X
Marine Erosion Control	$ 15,000			X	X	X	X	X	X		
Road Erosion Control	$ 5,000									X	X
Snow Fence	$ 22,870		X	X	X	X	X	X	X	X	X
Seaweed Management	$ 45,000		X	X	X	X	X	X	X	X	X
Root Wads	$ 351,208			X			X		X		
Coir Pillows	$ 383,881				X	X		X			
Sediment Fill	$ 248,963							X	X		
Planting	$ 195,809			X	X	X	X	X	X		
Seeding	$ 93,089			X	X	X	X	X	X		
Sheet Pile	$ 1,158,184									X	
Riprap Slope	$ 1,614,983										X
TOTAL:		$ -	$ 84,838	$ 899,970	$ 940,812	$ 940,812	$ 899,970	$ 1,252,015	$ 1,211,173	$ 1,537,568	$ 2,108,567

Design Option Unit Costs		Conceptual Option									
Property	Units	1	2	3a	3b	4a	4b	4Aa	4Ab	5	6
Estimated Cost	$	$ -	$ 84,838	$ 899,970	$ 940,812	$ 940,812	$ 899,970	$ 1,252,015	$ 1,211,173	$ 1,537,568	$ 2,108,567
Overhead	%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Total Option Cost	$	$ -	$ 93,321	$ 989,967	$ 1,034,893	$ 1,034,893	$ 989,967	$ 1,377,217	$ 1,332,291	$ 1,691,324	$ 2,319,423
Linear Length	ft	800	800	800	800	800	800	800	800	800	800
Unit Length Cost	$/ft	$ -	$ 117	$ 1,237	$ 1,294	$ 1,294	$ 1,237	$ 1,722	$ 1,665	$ 2,114	$ 2,899
Design Lifespan	yrs	3	5	15	15	30	30	40	40	50	50
Annual Protection Cost	$/yr	$ -	$ 18,664	$ 65,998	$ 68,993	$ 34,496	$ 32,999	$ 34,430	$ 33,307	$ 33,826	$ 46,388

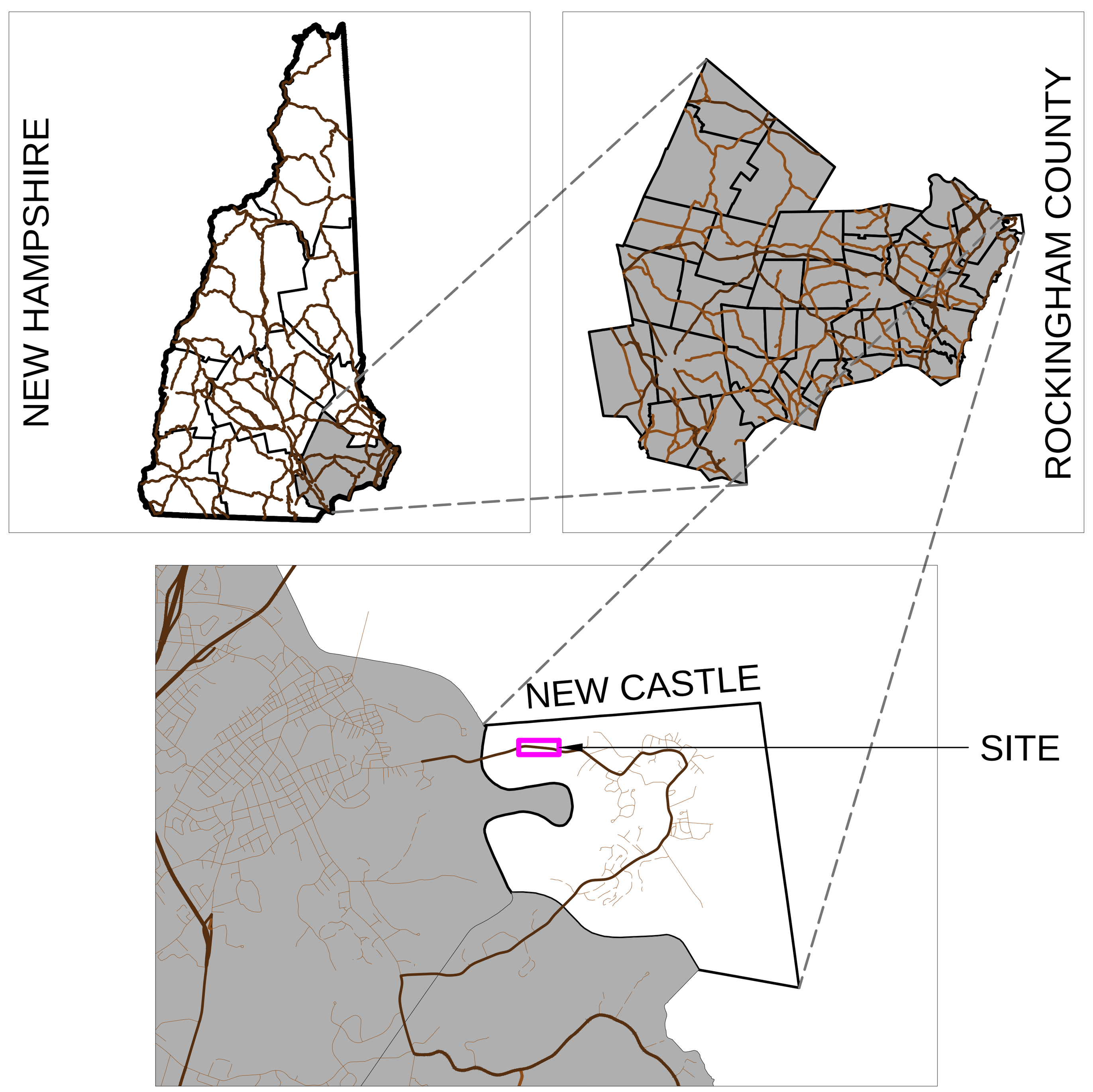
Appendix C

Area Maps and Conceptual Designs for Route 1B Causeway in New Castle, New Hampshire

ROUTE 1B COASTAL RESILIENCE PROJECT

CONCEPTUAL DESIGN OPTIONS

ROUTE 1B NEAR GOAT ISLAND, BETWEEN PORTSMOUTH AND NEW CASTLE, NEW HAMPSHIRE



VICINITY MAP
NOT TO SCALE

SITE MAP
NOT TO SCALE

LIST OF SHEETS

NO	SHEET ID	SHEET TITLE
1.	X-OVIEW	SITE OVERVIEW
2.	P-OVIEW	CONCEPTUAL SITE OVERVIEW
3.	P-AERIAL	SITE OVERVIEW WITH AERIAL
4.	XS800a	CONCEPTUAL DESIGN SECTION 8+00 a
5.	XS800b	CONCEPTUAL DESIGN SECTION 8+00 b
6.	XS1100a	CONCEPTUAL DESIGN SECTION 11+00 a
7.	XS1100b	CONCEPTUAL DESIGN SECTION 11+00 b

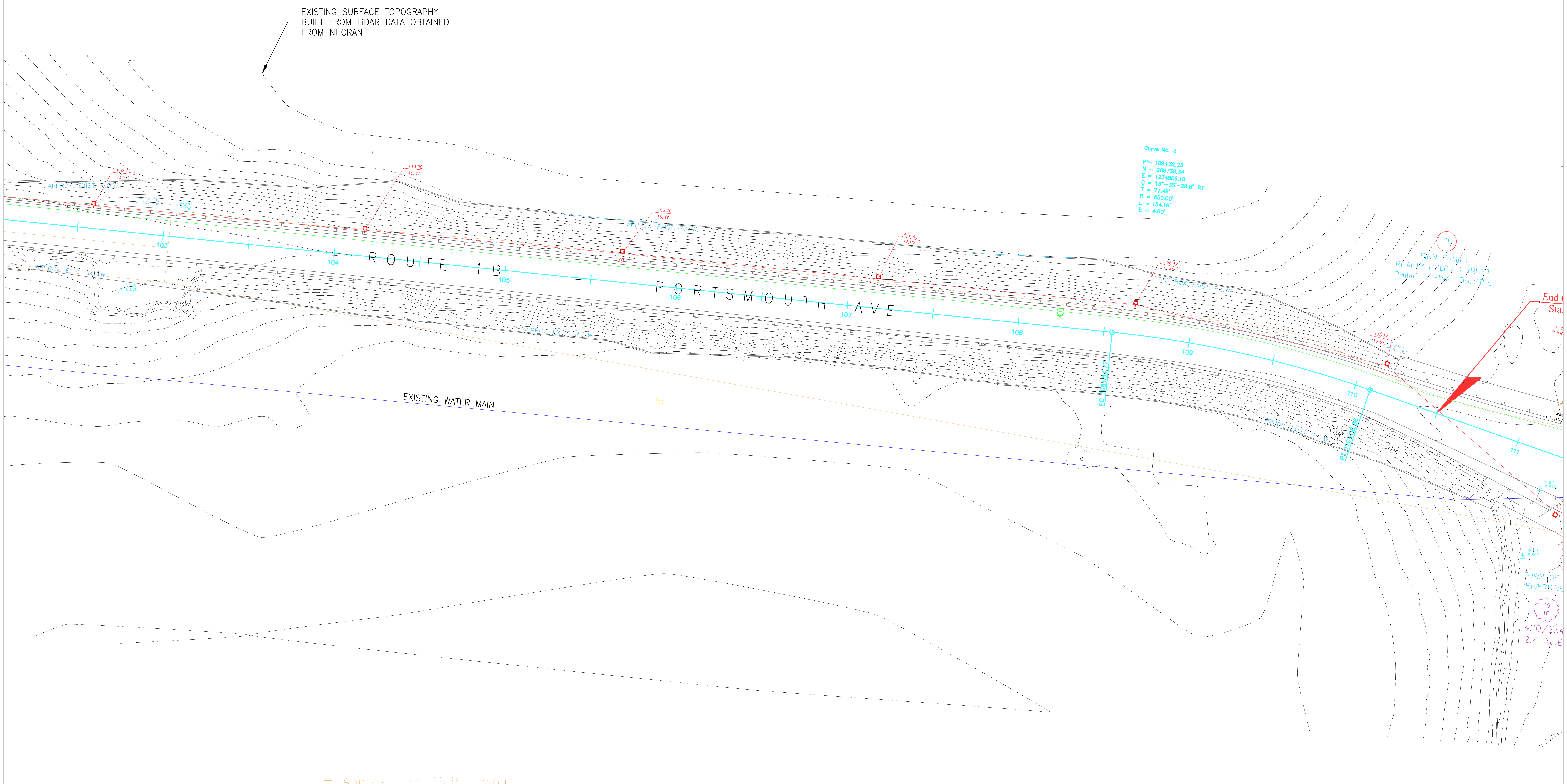
University of New Hampshire

University of New Hampshire
CHART
Coastal Habitat Restoration Team

NOTES

1. THESE ARE CONCEPTUAL DRAWINGS, AND ARE NOT TO BE USED FOR ANY OTHER PURPOSE.
2. ALL TIDAL ELEVATIONS SHOWN ARE ESTIMATED FROM NOAA STATION 8423898 - FORT POINT NH, WHICH IS LOCATED 1 MILE EAST OF THE SITE, IN NEW CASTLE AND ON THE PISCATAQUA RIVER, AND ARE REFERENCED TO THE NAVD88 DATUM.
3. THE ONLY TOPOGRAPHIC DATA AVAILABLE DURING THE DEVELOPMENT OF THESE PLANS IS 2-FOOT LiDAR CONTOUR DATA, REFERENCED TO NAVD88 AND NH83F (NEW HAMPSHIRE STATE PLANE, US FEET) DATUMS. THE CONTOURS DO NOT GO BELOW ELEVATION 0.0'.
4. PENDING A SITE SURVEY, ALL TOPOGRAPHIC DATA IS ESTIMATED FROM THE LiDAR CONTOURS, AND THE DESIGNS OPTIONS ARE SET BASED OFF THIS DATA. DESIGNS MAY BE ALTERED SLIGHTLY WHEN BETTER DATA IS OBTAINED.
5. USE OF SHEET PILES MAY BE PREFERRED OVER 3:1 SLOPE DIMENSIONS OR RESTORATION QUANTITIES WOULD REQUIRE APPROPRIATE ADJUSTMENT TO THE AREAS AS DEPICTED ON THIS PLAN.

NOTE: A SEWER LINE EXISTS IN THE CAUSEWAY, BUT IS NOT SHOWN AND SHOULD NOT BE AFFECTED BY PROJECT. ALL DATA SHOWN, OTHER THAN THE LiDAR SURFACE WAS PROVIDED BY NHDOT IN THE FORM OF MICROSTATION UNDERLAYS. THIS INFORMATION IS SHOWN FOR REFERENCE ONLY.



DESIGNED BY:	JCB, TPB
DRAWN BY:	JCB
CHECKED BY:	TPB
DATE:	10 OCT 2017

University of New Hampshire

University of New Hampshire CHART Coastal Habitat Restoration Team

NOTES:

REVISION #:	DATE:

SHEET TITLE: SITE OVERVIEW

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: ROUTE 1B COASTAL RESILIENCE PROJECT

PROJECT LOCATION: ROUTE 1B NEAR GOAT ISLAND IN NEW CASTLE, NH

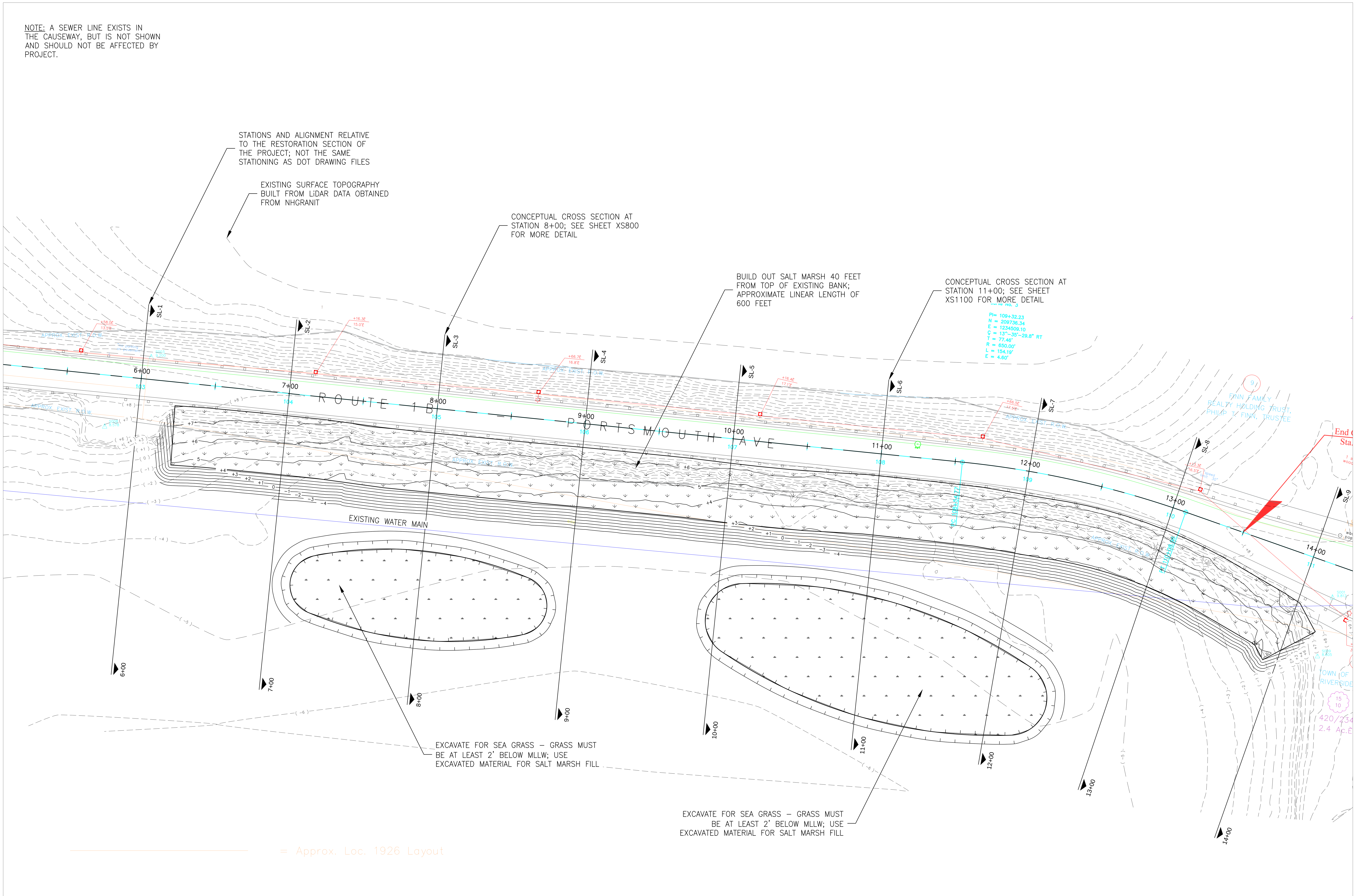
N

SCALE: 1" = 30'

0 15 30 45

SHEET ID: X-OVIEW

SHEET NUMBER: 01 OF 07



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 10 OCT 2017

University of New Hampshire

University of New Hampshire CHART Coastal Habitat Restoration Team

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL SITE OVERVIEW

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: ROUTE 1B COASTAL RESILIENCE PROJECT

PROJECT LOCATION: ROUTE 1B NEAR GOAT ISLAND IN NEW CASTLE, NH

N

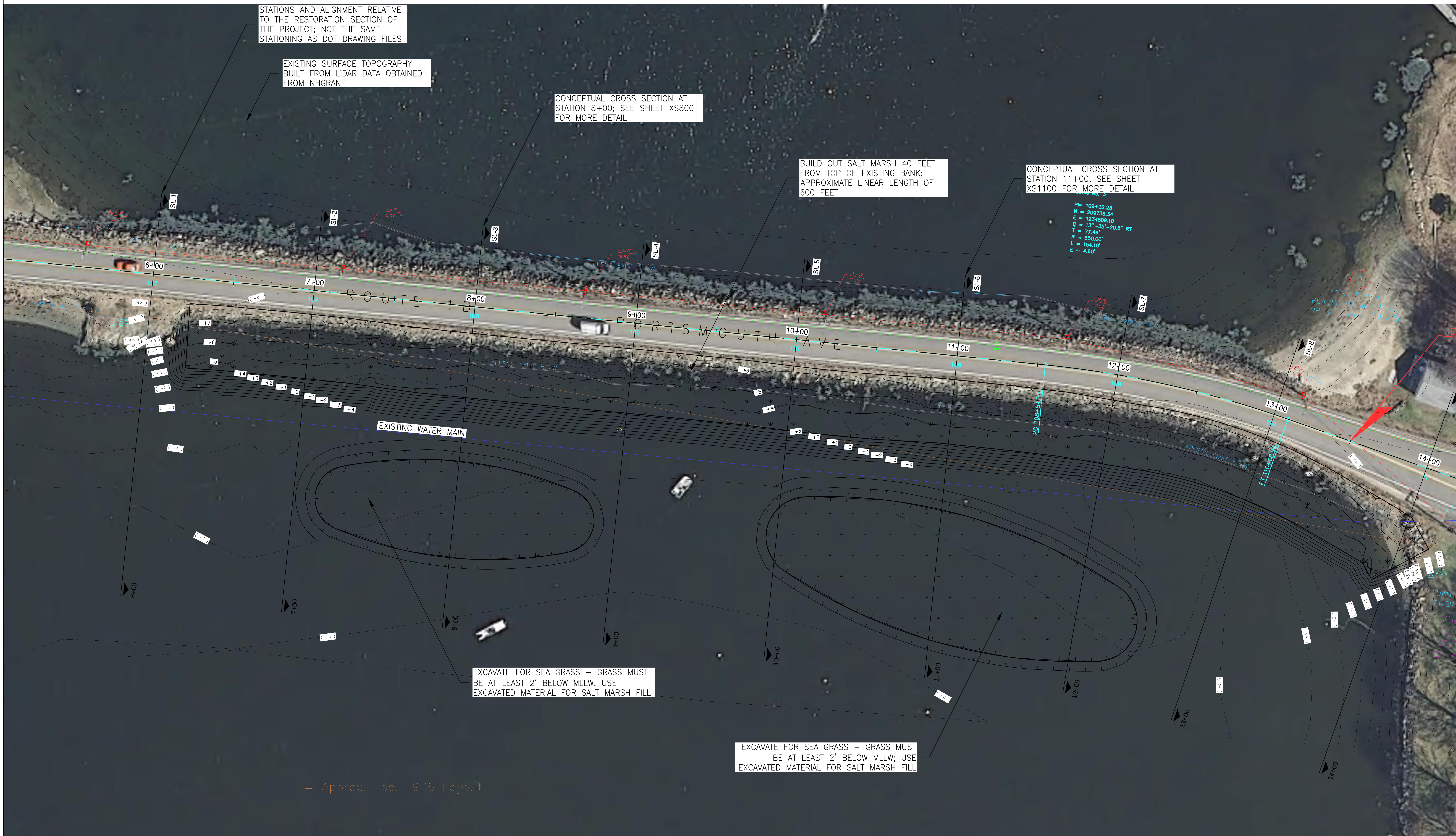
SCALE: 1" = 30'

0 15 30 45

SHEET ID: P-OVIEW

SHEET NUMBER: 02 OF 07

NOTE: A SEWER LINE EXISTS IN THE CAUSEWAY, BUT IS NOT SHOWN AND SHOULD NOT BE AFFECTED BY PROJECT.



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 10 OCT 2017

University of New Hampshire

University of New Hampshire CHART Coastal Habitat Restoration Team

NOTES:

DATE:

REVISION #:

SHEET TITLE: PROPOSED OVERVIEW WITH AERIAL

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: ROUTE 1B COASTAL RESILIENCE PROJECT

PROJECT LOCATION: ROUTE 1B NEAR GOAT ISLAND IN NEW CASTLE, NH

N

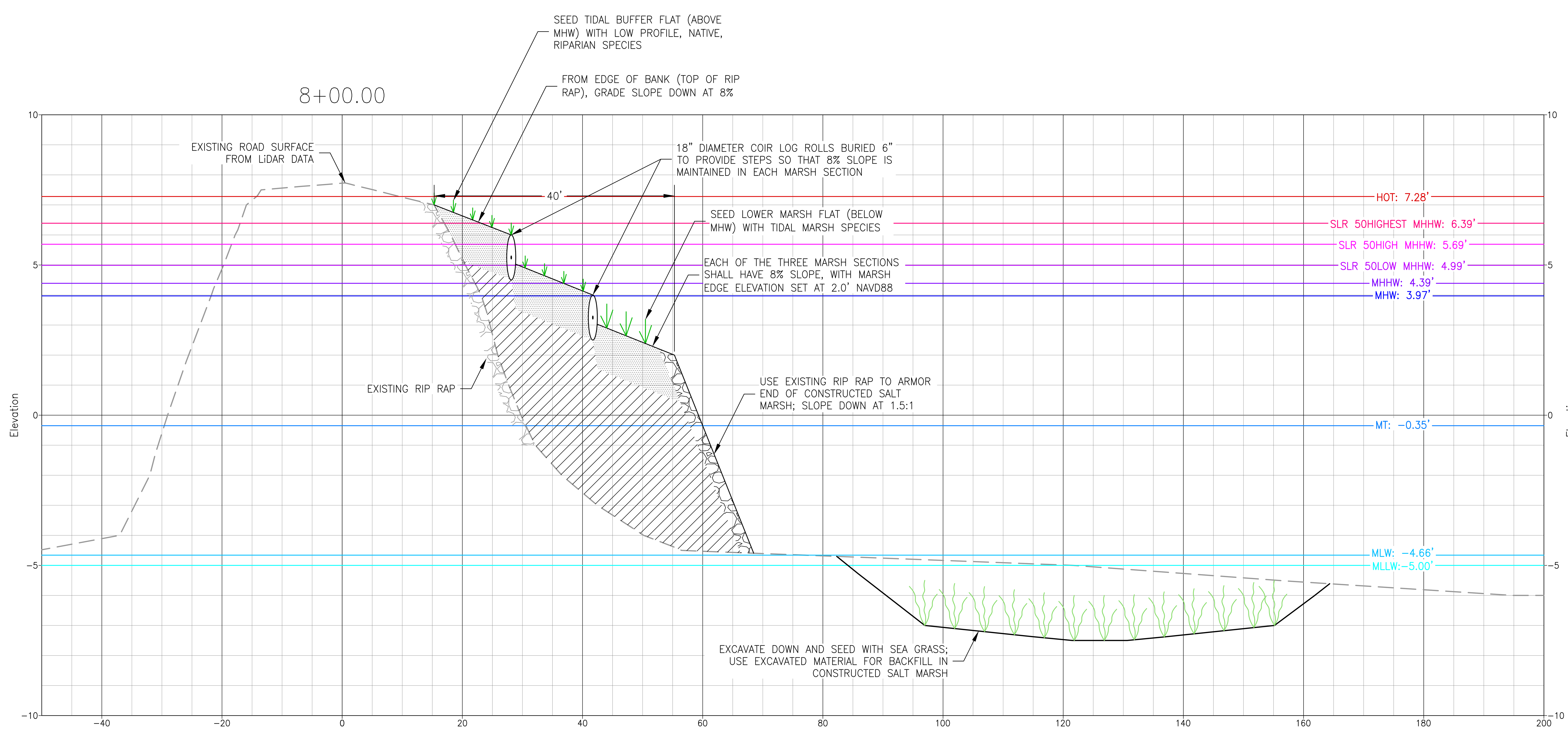
SCALE: 1" = 30'

0 15 30 45

SHEET ID: P-AERIAL

SHEET NUMBER: 03 OF 07

NOTE: FOR PLANNING PURPOSES,
MID-CENTURY SLR = 1.3', AND
END-OF-CENTURY SLR = 3.9'



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 10 OCT 2017

University of New Hampshire

University of New Hampshire CHART Coastal Habitat Restoration Team

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL DESIGN SECTION 8+00 a

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: ROUTE 1B COASTAL RESILIENCE PROJECT

PROJECT LOCATION: ROUTE 1B NEAR GOAT ISLAND IN NEW CASTLE, NH

VERTICAL EXAGGERATION: 5V:1H

SCALE: 1" = 10'

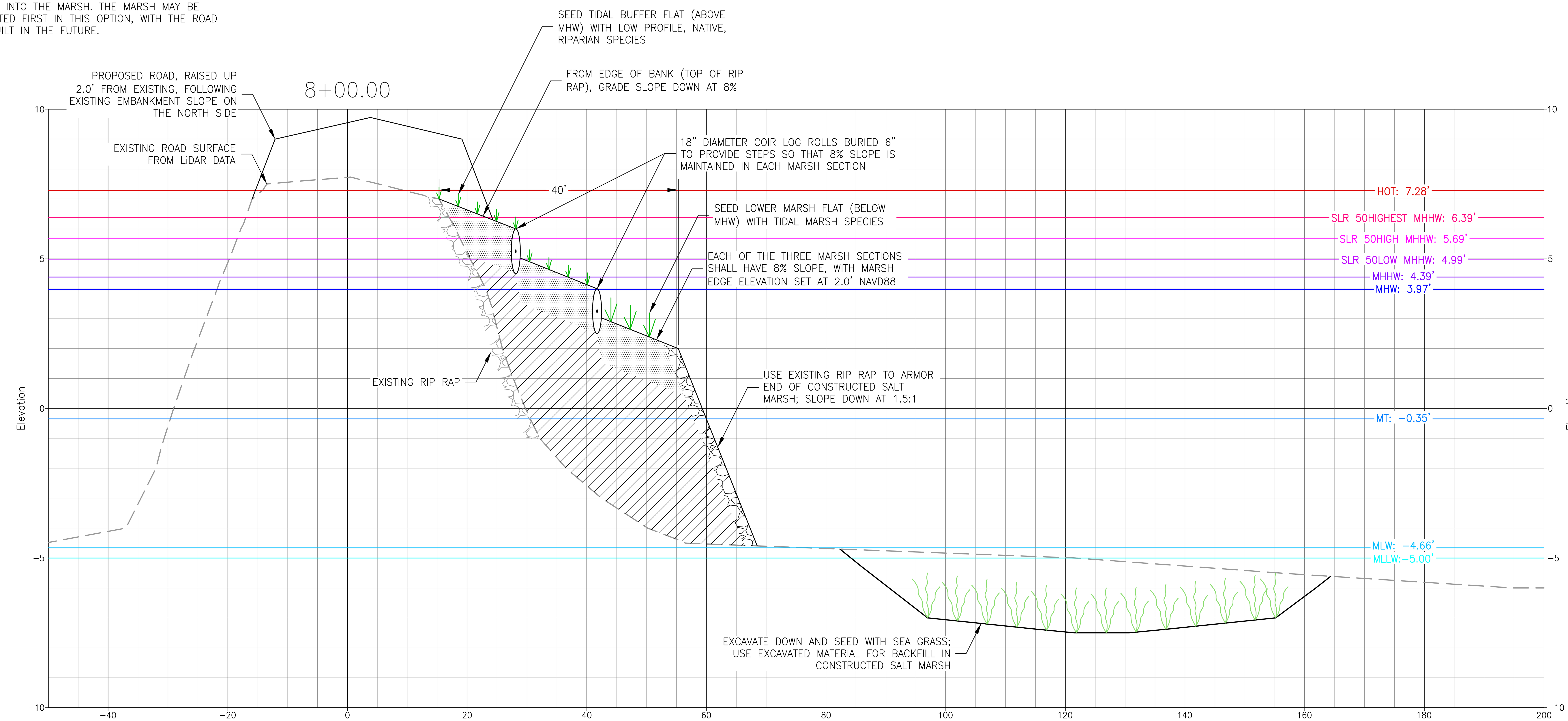
0 5 10 15

SHEET ID: XS800a

SHEET NUMBER: 04 OF 07

NOTE: FOR PLANNING PURPOSES,
MID-CENTURY SLR = 1.3', AND
END-OF-CENTURY SLR = 3.9'

NOTE: XS 8+00 b IS THE SAME AS XS 8+00 a, BUT SHOWING THE EXISTING ROAD RAISED UP 2.0', FOLLOWING THE EXISTING SLOPE OF THE EMBANKMENT TO THE NORTH SIDE OF THE ROAD, AND TYING INTO THE MARSH. THE MARSH MAY BE CONSTRUCTED FIRST IN THIS OPTION, WITH THE ROAD OPTION BUILT IN THE FUTURE.



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 10 OCT 2017

University of New Hampshire

University of New Hampshire CHART Coastal Habitat Restoration Team

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL DESIGN SECTION 8+00 b

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: ROUTE 1B COASTAL RESILIENCE PROJECT

PROJECT LOCATION: ROUTE 1B NEAR GOAT ISLAND IN NEW CASTLE, NH

VERTICAL EXAGGERATION: 5V:1H

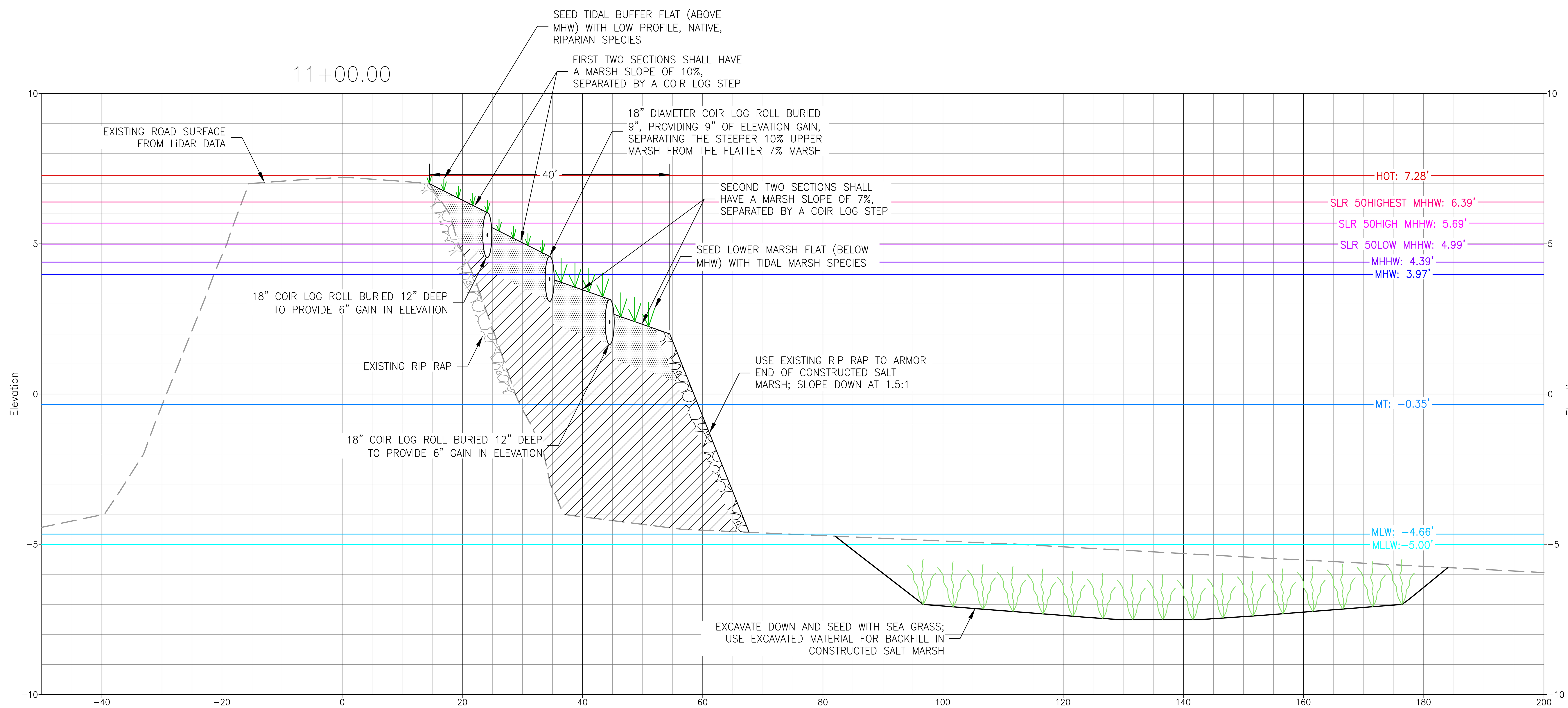
SCALE: 1" = 10'

0 5 10 15

SHEET ID: XS800b

SHEET NUMBER: 05 OF 07

NOTE: FOR PLANNING PURPOSES,
MID-CENTURY SLR = 1.3', AND
END-OF-CENTURY SLR = 3.9'



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 10 OCT 2017

University of New Hampshire

University of New Hampshire CHART Coastal Habitat Restoration Team

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL DESIGN SECTION 11+00 a

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: ROUTE 1B COASTAL RESILIENCE PROJECT

PROJECT LOCATION: ROUTE 1B NEAR GOAT ISLAND IN NEW CASTLE, NH

VERTICAL EXAGGERATION: 5V:1H

SCALE: 1" = 10'

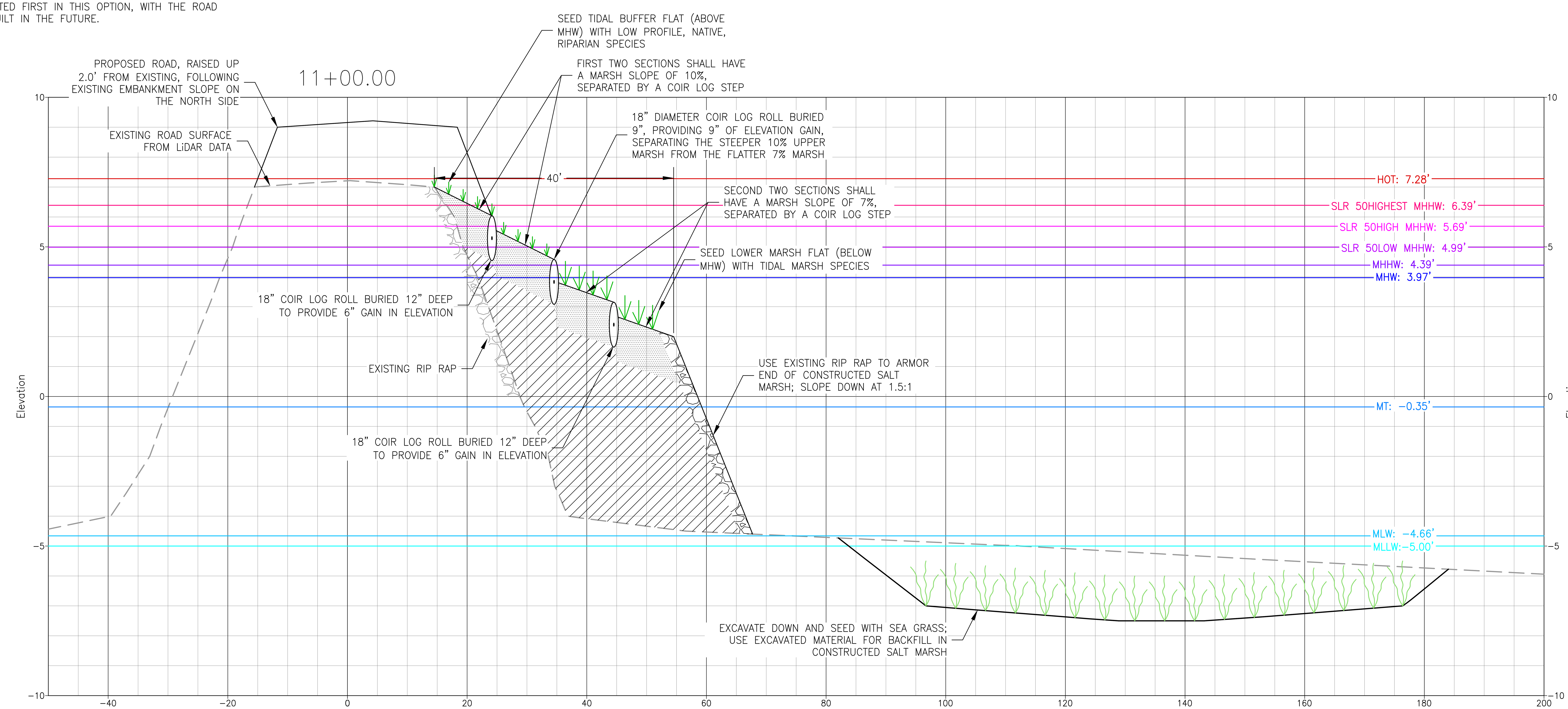
0 5 10 15

SHEET ID: XS1100a

SHEET NUMBER: 06 OF 07

NOTE: FOR PLANNING PURPOSES,
MID–CENTURY SLR = 1.3', AND
END–OF–CENTURY SLR = 3.9'

NOTE: XS 11+00 b IS THE SAME AS XS 11+00 a, BUT SHOWING THE EXISTING ROAD RAISED UP 2.0', FOLLOWING THE EXISTING SLOPE OF THE EMBANKMENT TO THE NORTH SIDE OF THE ROAD, AND TYING INTO THE MARSH. THE MARSH MAY BE CONSTRUCTED FIRST IN THIS OPTION, WITH THE ROAD OPTION BUILT IN THE FUTURE.



DESIGNED BY: JCB, TPB
DRAWN BY: JCB
CHECKED BY: TPB
DATE: 10 OCT 2017

University of New Hampshire

University of New Hampshire CHART Coastal Habitat Restoration Team

NOTES:

DATE:

REVISION #:

SHEET TITLE: CONCEPTUAL DESIGN SECTION 11+00 b

SHEET SET: CONCEPTUAL DESIGN OPTIONS

PROJECT NAME: ROUTE 1B COASTAL RESILIENCE PROJECT

PROJECT LOCATION: ROUTE 1B NEAR GOAT ISLAND IN NEW CASTLE, NH

VERTICAL EXAGGERATION: 5V:1H

SCALE: 1" = 10'

0 5 10 15

SHEET ID: XS1100b

SHEET NUMBER: 07 OF 07

Appendix D

Conceptual Alternative Costs for the Route 1B Causeway in New Castle, New Hampshire

New Castle 41226 - Preliminary Concept Estimate
Road open, not raised

Item		Unit	Quantity	Unit Price	Total
202.701	Removal of Guardrail	LF	400	2.50	$1,000
203.1	Common Excavation	CY	0	9.75	$0
203.1x	Common Excavation for marsh eelgrass	CY	2,257	13.00	$29,341
209.1 ?	Tidal Marsh Backfill	CY	6,011	28.00	$168,308
304.35	Crushed Gravel for Drives	CY	0	35.00	$0
304.4	Crushed Stone Base (Fine Gradation)	CY	0	16.00	$0
403.11	HBP, Machine Method	TON	200		$0
403.12	HBP, Hand Method	TON	75		$0
403.6	Pavement Joint Adhesive	LF	3,500	0.00	$0
417	Cold Planing Bituminous Surfaces	SY	185	0.00	$0
583.9	Reset Existing Riprap	SY	779	25.00	$19,475
585.2	Stone Fill Class B	CY	0	35.00	$0
585.25	Cobble-Gravel-Sand	CY	0	25.00	$0
585.3	Stone Fill Class C	CY	0	25.00	$0
587.1	Keyed Stone Fill	CY	779	35.00	$27,265
593.222	Geotextile, Separate, Class 2, Monofilament, Woven	SY	2,525	5.00	$12,625
606.xxx	Beam Guardrail (narrow section, no offset blocks)	LF	2,650		$0
606.1455	Terminal Unit, EAGRT (25')	U	6	0.00	$0
606.417	Portable Concrete Barrier for Traffic Control	LF	1,250	30.00	$37,500
606.9522	Temp. Impact Attenuator, Non-Redirective, Test Level 2	U	2	3,500.00	$7,000
616.171	Portable Temp Signals, Trailer Mounted	U	1	15,000.00	$15,000
618.61	Uniformed Officers with Vehicle	$	10,000	1.00	$10,000
618.7	Flaggers	HR	1,000	22.00	$22,000
619.1	Maintenance of Traffic	U	1	15,000.00	$15,000
619.253	Portable Changeable Message Sign	UWK	16	350.00	$5,600
621.21	Retroreflective Beam Guardrail Delineator (White)	EA	35	5.00	$175
621.31	Single Delineator with Post	EA	35	35.00	$1,225
645.512	Compost Sock for Marsh Steps	LF	2,000	3.50	$7,000
645.7	Storm Water Pollution and Prevention Plan	U	1	4,000.00	$4,000
645.71	Monitoring SWPPP & Erosion and Sediment Control	HR	75	90.00	$6,750
646.51	Turf Establishment w/ Mulch, Tackifiers and Loam	SY	1,425	5.00	$7,125
647.29	Imported Topsoil/Humus	cy	1,503	14.00	$21,042
650.x	Eelgrass Plantings	ea	5,924	5.00	$29,620
650.2	"Landscaping" pertaining to Eelgrass planting labor & equipment	U	1	48,580.00	
	"Landscaping" pertaining to Marsh construction labor & equipment	U	1	267,695.00	
	Subtotal Landscaping				$316,275
650.x	Upper Marsh Plantings	ea	3,976	15.00	$59,640
650.x	Upper Marsh Seeding	lb	44	20.00	$880
650.x	Upper Marsh Straw	lb	796	0.25	$199
650.x	Lower Marsh Planting	ea	7,587	5.00	$37,935
698.13	Field Office C	Mon	4	1,400.00	$5,600
699	Temporary Erosion and Sediment Control	$	3,500	1.00	$3,500
1010.15	Fuel Adjustment	$	2,000	1.00	$2,000
1010.2	Asphalt Cement Adjustment (not needed if < 1000 tons)	$	0	1.00	$0
	Sub-Total 1				$873,080
	Contingencies (10% of Sub-Total 1)				$87,308
	Sub-Total 2				$960,388
692.	Mobilization (~10% of Sub-Total 2)	U	1	35,000	$35,000
	Item Total				$995,388
	Construction Engineering (10% of Item Total)				$99,540
	Construction Estimate Total				$1,094,928
	No Additives for Non-Federal projects				$0
	Traffic Force Account				$2,500
	Utilities Force Account				$1,000
	Construction Total =				$1,098,428

New Castle 41226 - Preliminary Concept Estimate
Alternating one-way traffic during construction, raised 2 feet.

Item		Unit	Quantity	Unit Price	Total
202.701	Removal of Guardrail	LF	2,605	2.50	$6,513
203.1	Common Excavation for raising road 2 feet. & driveways	CY	5,000	9.75	$48,750
203.1x	Common Excavation for marsh eelgrass	CY	2,257	13.00	$29,341
209.1	Granular Backfill	CY	4,500	28.00	$126,000
209.x	Tidal Marsh Backfill	CY	6,011	30.00	$180,330
214	Fine grading	U	1		$30,000
304.35	Crushed Gravel for Drives	CY	50	35.00	$1,750
304.4	Crushed Stone Base (Fine Gradation)	CY	500	25.00	$12,500
403.11	HBP, Machine Method	TON	600	75.00	$45,000
403.12	HBP, Hand Method	TON	75	125.00	$9,375
403.6	Pavement Joint Adhesive	LF	3,500	0.00	$0
417	Cold Planing Bituminous Surfaces	SY	185	0.00	$0
583.9	Reset Existing Riprap	SY	779	25.00	$19,475
585.2	Stone Fill Class B	CY	0	35.00	$0
585.25	Cobble-Gravel-Sand	CY	0	25.00	$0
585.3	Stone Fill Class C	CY	0	25.00	$0
587.1	Keyed Stone Fill	CY	779	35.00	$27,265
606.417	Portable Concrete Barrier for Traffic Control	LF	1,250	30.00	$37,500
606.91	Resetting or Setting GuardRail	LF	2,605	15.00	$39,075
606.9522	Temp. Impact Attenuator, Non-Redirective, Test Level 2	U	2	3,500.00	$7,000
616.171	Portable Temp Signals, Trailer Mounted	U	1	15,000.00	$15,000
618.61	Uniformed Officers with Vehicle	$	10,000	1.00	$10,000
618.7	Flaggers	HR	1,000	22.00	$22,000
619.1	Maintenance of Traffic	U	1	45,000.00	$45,000
619.253	Portable Changeable Message Sign	UWK	16	350.00	$5,600
621.21	Retroreflective Beam Guardrail Delineator (White)	EA	35	5.00	$175
621.31	Single Delineator with Post	EA	35	35.00	$1,225
628.2	Sawed Bituminous Pavement	LF	1,975	2.00	$3,950
632.0104	Retroreflective Paint Pavement Marking, 4" Line	LF	4,650	0.50	$2,325
645.512	Compost Sock for perimeter berm	LF	2,000	3.50	$7,000
645.531	Silt Fence	LF	2,600	3.00	$7,800
645.7	Storm Water Pollution and Prevention Plan	U	1	4,000.00	$4,000
645.71	Monitoring SWPPP & Erosion and Sediment Control	HR	75	90.00	$6,750
646.51	Turf Establishment w/ Mulch, Tackifiers and Loam	SY	1,425	5.00	$7,125
647.29	Imported Topsoil/Humus	cy	1,503	14.00	$21,042
650.x	Eelgrass Plantings	ea	5,924	5.00	$29,620
650.2	"Landscaping" pertaining to Eelgrass planting labor & equipment	U		48,580.00	
	"Landscaping" pertaining to Marsh construction labor & equipment	U		267,695.00	
	Subtotal Landscaping				$316,275
650.x	Upper Marsh Plantings	ea	3,976	15.00	$59,640
650.x	Upper Marsh Seeding	lb	44	20.00	$880
650.x	Upper Marsh Straw	lb	796	0.25	$199
650.x	Lower Marsh Planting	ea	7,587	5.00	$37,935
698.13	Field Office C	Mon	4	1,400.00	$5,600
699	Temporary Erosion and Sediment Control	$	3,500	1.00	$3,500
1010.15	Fuel Adjustment	$	2,000	1.00	$2,000
1010.2	Asphalt Cement Adjustment (not needed if < 1000 tons)	$	0	1.00	$0
	Sub-Total 1				$1,234,515
	Contingencies (10% of Sub-Total 1)				$123,451
	Sub-Total 2				$1,357,966

Item		Unit	Quantity	Price	Total
692.	Mobilization (~10% of Sub-Total 2)	U	1	35,000	$35,000
	Item Total				$1,392,966
	Construction Engineering (10% of Item Total)				$139,300
	Construction Estimate Total				$1,532,266
	No Additives for Non-Federal projects				$0
	Traffic Force Account				$5,000
	Utilities Force Account (non-participating for water line, not including sewer)				$100,000
	Construction Total =				$1,637,266