A Study of Bluff Bank Erosion for Bustins Island, Freeport, ME

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CONTENTS

INTRODUCTION

Bustins Island is an unbridged island located in eastern Casco Bay with a length of 0.8 miles and maximum width of 0.35 miles. It is an incorporated self-governing village within the Town of Freeport. While agriculture and fishing have been historically important land uses, the island community today consists of 115 residential cottages operated seasonally (see Appendix A, Figure A1 for location map). Much of the shoreline is owned in common by the island's elected governing body, the Bustins Island Village Corporation.

Bustins Island does not contain any significant surface water bodies. Storm drainage primarily occurs as sheet flow that becomes shallow or is concentrated in channels along the road or in perennial streams. Bustins Island's streams form multiple watersheds that have been delineated for the purposes of this analysis, with a primary focus on the surface drainage affecting significant shoreline erosion on the southeast shore of the Island.

The Island has considerable elevation rise above Casco Bay – more than 60 feet in the center – allowing downslope or positive drainage from the island's center to the shoreline. In various locations along the shoreline, the upland is located more than ten feet above the tidal-influenced elevation and is considered a shoreline wall or bluff. Property lots have been laid out such that drainage passes through the lots and has been diverted around individual cottages.

Protection of surface water as a resource has been a high priority for islanders for a number of years, as is discussed in the "Bustins Island Comprehensive Plan 2011-2020", approved in August 2014. The primary focus to date has been on protecting drinking water quality. The Comprehensive Plan discusses several water supply and hydrogeologic assessments of groundwater supply and quality protection completed in 1991 and 2004. According to the assessments, although water demand is seasonal and the aquifer has time to recover, upland water supply is limited by the storage area or small footprint of the island.

As will be discussed later in this report, surface water runoff has been identified as potentially significant cause of bluff erosion on Bustins island by CCSWCD staff. Methods for reducing erosive effects of surface water runoff will also accomplish previously identified goals to increase recharge of aquifers supplying drinking water. By increasing recharge of aquifers, issues such as saltwater intrusion and seasonal depletion can be avoided.

SUMMARY OF FINDINGS

- Several bluff sites of Bustins Island are in a state of accelerated bank erosion based on bluff bank erosion ratings.

- The adverse consequences of accelerated bluff erosion on Bustins Island has resulted in increased sediment yields and changes in bluff stability and associated shoreline types. These instabilities and shifts in bluff type not only produce higher sediment transport but can degrade the physical and biological function of the bluff.

- Culverts and stormwater infrastructure are contributing to some of the instability, mainly due to changes made to the manner in which rainfall historically infiltrated the watershed versus the way in which stormwater discharges through the landscape today. Essentially, natural sheet flow and infiltration of the runoff has been replaced by erosive channelized flow. The general eastward flowing runoff has been altered enough to create concentrated flow parallel with the road, which is further concentrated by ditches and turn-outs, resulting in gullied depressions draining the numerous subcatchments and carrying surface soils with it.

- Bluff analysis revealed that several of the extreme and very high bank erosion rates are producing aggradation downslope of the failures, with debris piles that are a sign of active bluff migration from vertical instability that develops in the bluffs effort to dissipate wave energy. The results can be seen as indentations into the bluff face, taking the form of avulsions (crescent shaped indentations sloping toward sea level), caves (where water carves material under the bluff face creating an overhang), and notches (vertically oriented indentations).

- The stabilization technique most often used in Casco Bay and elsewhere to reduce slope steepness is the installation of a hardened surface at the toe. However, in the study site cases on Bustins Island a living shoreline and/or soft stabilization approach could be utilized.

- With effort from landowners, a reduction in the amount and intensity of stormwater runoff could:
  - decrease bank erosion rates;
  - reduce downstream impacts associated with increased sediment supply;
  - help aquatic and terrestrial habitats; and
  - protect land loss from avulsion.

PROJECT PURPOSE AND SCOPE

This report is one of five case studies included in a larger shoreline assessment project, namely the NOAA funded "Building Resiliency Along Maine's Bluff Coastline" project. The project has two primary goals:

- To understand the landscape processes such as wind, runoff from upland areas, tidal effects, wave effects, and other factors affecting shoreline erosion along the Casco Bay shoreline; and
- To plan for various best-management practices for bluff stabilization with emphasis on innovative "living shoreline" stabilization designs. Living shoreline designs mimic the natural environment to protect coastal areas from erosion in contrast to "hard" armoring with concrete, stone, or similar materials. See Appendix A, Figure A1 for the locations of the Case Studies.

The principal intended outcome of these studies is to determine how bluff erosion stability can be modulated by a living shoreline approach. Living shorelines include various stabilization techniques that replicate natural systems (biomimicry) based on the rate at which natural geomorphic processes or sediment deposition should be occurring versus expedited rates resulting from human modification.

The intended audience for this case study report is Bustins Island property owners, the Town of Freeport, Project Partners (DACF, Maine Geological Survey, University of Maine), and any other parties interested in shoreline stabilization in the region. The intent is to highlight the risks and benefits of any site-specific restoration actions so that project decisions will be informed. An overall goal for this project is to encourage voluntary participation by the village's governing body and other landowners to achieve shoreline restoration and stabilization, thus minimizing erosion and bluff deterioration.

Implementing a stabilization plan would improve natural shoreline habitat conditions, slow down accelerated erosion processes along the shoreline, and reducing the effects of upland runoff. This case study report does not include subsurface exploration beyond readily observable exposed bluff face nor instrumented survey beyond the use of a hand-held GPS unit used to locate features discussed.

METHODOLOGY

Extensive research in streambank mechanics and streambank stability analysis has been published by Simon and Thorne, (1996), Rosgen (1993), and Thorne (1999). This case study report seeks to apply advances in the science of streambank stability to improve the understanding of bluff erosion mechanics on Bustins Island. The principal outcome of these study site assessments is to determine how bluff erosion stability can be modulated by a living shoreline approach.

At the Bustins Island study area, the significance of surface erosion processes contributing sediment to the total annual sediment transport was assessed for nine bluff study sites on the island. During the week of October 7, 2016, bank erosion surveys were performed by using a "Bluff Decision Tree" approach to narrow the number of parameters considered for each erosion study site assessment (see Appendix D, Figure D1 for the assessment flow chart used for the decision tree approach.)

The instability assessment rating involved an inventory of bank erosion along the bluff reach in the study area. The ratings range is as follows: Good (1), Fair (2), Poor (3). The ratings were applied to three areas of the bluff: Upper Bank; Lower Bank; and Toe. The numeric rating levels (1-3) were ranked while in the field and associated with four descriptive criteria (Appendix D, Figure D2). The study also included two upland focus areas where runoff effects are producing erosion at several of the bluff study sites.

GEOLOGY AND SEA LEVEL HISTORY

The coastal Islands of Casco Bay are considered part of the Coastal Lowlands draining the northern boundary of the Town of Freeport. The geology of the Coastal Lowlands is highly varied, consisting of sandy beaches, salt marshes, tidal creeks, and small bays bordered by high cliffs (Appendix A, Figure A4).

Most of the Casco Bay region is at or just above sea level. Changes in sea level over time have had a marked impact on the region and provide insight into planning for future sea level changes. Today, Maine's near-shore areas today consist of drowned forest lands and river valleys. The tops of hills that were weighed down by glaciers during the Ice Age, then sunken as the glaciers melted, appear now as more than 400 islands in Casco Bay. The deeper channels in the Bay were once river and stream valleys. Figure 1 provides recent sea-level change from tide gauges.

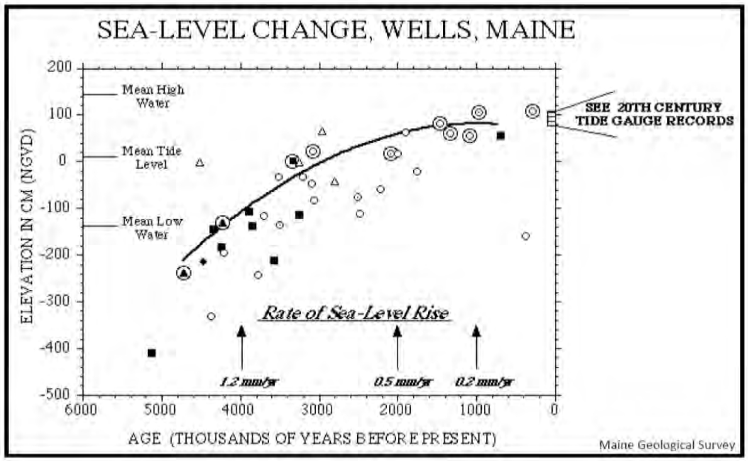

FIGURE 1: RECENT SEA LEVEL CHANGE AT PORTLAND, ME. THE MEAN SEA LEVEL RISE IS 0. 07 INCHES/YEAR. IMAGE SOURCE: NOAA.

According to a 2006 Maine Geological Survey, "the State of Maine is planning for a two-foot rise in sea level over the next 100-year in response to documented and predicted rises in sea level for the global oceans and the Gulf of Maine. An estimated two-foot rise in sea level will have dramatic impacts along Maine's coastlines in terms of sensitive geographic areas including beaches and dunes, wetlands, and nearshore habitats." Figure 2 shows Maine's history of sea-level changes from radiocarbon dating from preserved peats.

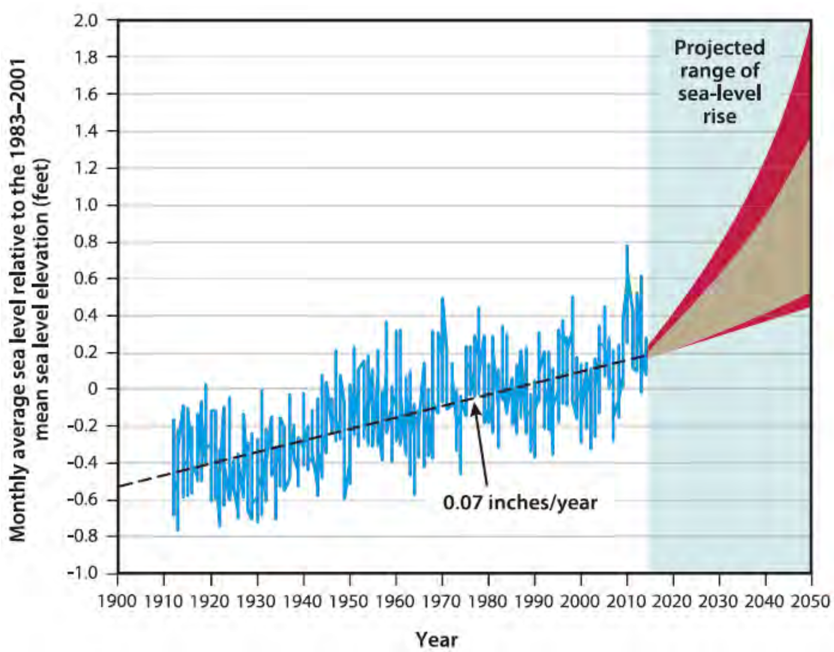

FIGURE 2: RADIOCARBON DATING USED TO CONSTRUCT SEA-LEVEL CURVE FROM PRESERVED PEATS. IMAGE SOURCE: MGS.

PROJECT LOCATION AND STUDY LOCATIONS

Bustins Island has bluff exposure around much of the island (Appendix A, Figure A2). The area for this case study report is limited to the bluff facing southeast to the seaward portion of Casco Bay. The area investigated is considered highly unstable as identified by the Maine Geologic Survey stability rating and as determined through boat-based assessment and aerial imagery.

This document describes the findings for approximately 875-feet of the Bustins Island shoreline and its associated upland drainage areas. The Bustins Island study site was broken down into eleven smaller study sites (Appendix A, Figure A3). Some of the study sites revealed effects from surface runoff in the presence of seepage in the bluff and/or erosion at the top of bluff slopes.

Study sites 9 and 10 are upland study site areas that are generating runoff affecting shoreline erosion. Significant storm runoff above the bluff is recognized as contributing to its instability. Unconsolidated soil is sloughing off the upper bank and being washed away by upland runoff and wave encroachment.

The focus of study was narrowed to nine sites along the southeast shoreline north of the Bustins public landing dock. The sites begin where noticeable changes in shoreline landform can be seen occurring as land loss just north of the public dock.

STUDY AREA WATERSHED DELINEATION

Bustins Island has a total watershed of 117-acres, of which 10.1-acres of overland flow were assessed as contributing to shoreline instability through erosion. Table 1 summarizes the upland areas assessed.

The assessment was made using LiDAR-based elevation data provided by the Maine Office of GIS. The data were processed using ArcGIS hydrologic modeling tools to generate a drainage model, showing natural drainage channels and catchments. It should be noted, the LiDAR-based drainage model does not capture flow patterns which have been modified due to land development, such as the construction of buildings and roads.

In the case of Bustins Island, overland drainage patterns have been altered, resulting in erosion. CCSWCD staff adjusted catchments generated by the model based on field observations. The adjusted subcatchments that supply runoff to study areas 1 through 11 are shown in Figure 3. Specifically:

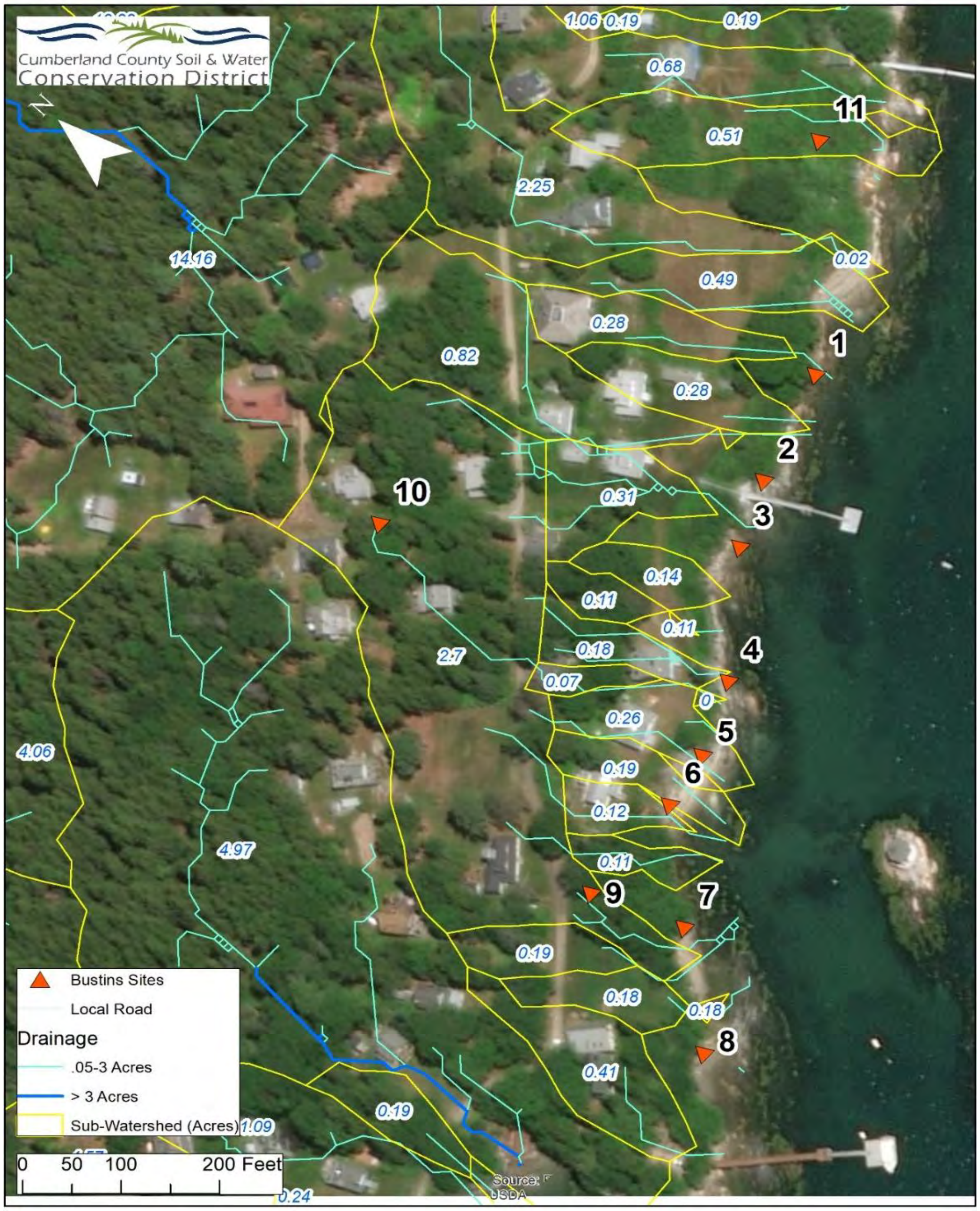

FIGURE 3. CASE STUDY LOCATION ON BUSTINS ISLAND. ASSESSMENTS OF STUDY SITES INCLUDED CONSIDERATION OF UPLAND SUBWATERSHED DRAINAGES, SHOWN WITH THIN YELLOW LINES. AREAS OF SUBWATERSHED DRAINAGES ARE SHOWN WITH BLUE ITALIC FONT. MODELED DRAINAGE PATHS ARE SHOWN IN THE BLUE LINES FOR EACH SUB-DRAINAGE.

- Changes to drainage patterns in the upland areas 9 and 10 have created concentrated flow along the roadway. This pattern change is contributing to surface drainage directed toward the top of the shoreline bank failures 7 and 8.
- Historically, shoreline areas 2 and 3 appear to have had similar erosive effects from culverts installed to redirect drainage patterns near the intersection of the roads.

TABLE 1: SUBCATCHMENT AREAS FOR ELEVEN SHORELINE STUDY SITE AREAS ASSESSED ON BUSTINS ISLAND.

Study Site – see Figure 1, Study Area map, and "Bustins Public Safety Map" in Appendix A for location	Subcatchment Area	CN	Subcatchment Length (ft)	Instability Rating Scale 3 (best) – 9 (worst)
SS 1 – Ledge area NE of "Richardson" dock	0.36	0.2	300	6.5
SS 2 – Area adjacent to "Richardson" dock	0.96	0.2	425	5
SS 3 – SW of "Richardson" dock	0.41	0.2	195	7.5
SS 4 – Downslope from Bustins Island parcel B31	0.37	0.2	200	6
SS 5 – Downslope from Bustins Island parcel B32A	0.26	0.2	175	7
SS 6 – Downslope from Bustins Island parcel B33	0.31	0.2	138	8
SS 7 – Downslope from outfall adjacent roadway ditch	2.8	0.2	400 Ditch	8
SS 8 – Downslope from library	0.23		70	7.5
SS 9 – Upland area draining to SS7	2.7		2600	N/A
SS 10 – Upland area draining to SS9 and SS7	0.33		90	N/A
SS 11 – Area next to "Kitchin" dock	1.19		390	N/A

SOILS

Soils on the south part of Bustins are typically Hollis Formation with a very rocky fine sandy loam to fine sandy loam to the northern shoreline. The unconsolidated soil is sloughing off the upper bank and being washed away by upland runoff and wave action.

The soil profile of sandy loam is generally shallow with a depth of about 14 inches to bedrock, according to the USDA soil survey. The moderately rapid permeability (2-6 inches/hour) of sandy loam allows most areas to infiltrate and quickly reach the low permeability of the bedrock. This limiting of water to infiltrate allows water to perch on top of the rock resulting in shallow groundwater and boggy areas. This is evident in the central portion of the island where water can pond in hummocky forested areas.

SLOPES

Alteration to drainage pathways for runoff generated upslope of the study areas is generally running with the sloping topography. The general eastward flowing runoff has also been altered enough to create concentrated flow parallel with the road which is further concentrated by ditches and turn-outs. Essentially, natural sheet flow and infiltration of the runoff has been replaced by erosive channelized flow.

Slopes range from 8 to 20 percent (USDA, 1974). Water infiltration capacity is moderate and runoff can be rapid because of shallowness to bedrock. The topography at the shore edge is steep with many rock outcrops. Surface drainage that is concentrated is resulting in gullied depressions. Changes in drainage patterns have occurred as drainage is redirected around cottages.

The Maine Geologic Survey (MGS) compiled stability mapping in 2012 for bluffs in Casco Bay (Appendix A, Figure A2). Zones of high instability are shown in red. At the shoreline assessment sites, MGS has determined this area to be highly unstable, which has been confirmed by data from the field.

SHORELINE CONDITIONS AND COASTAL PROCESSES

Coastal erosion is constantly changing the coastal shoreline. Erosion rates are dependent on several variables that are highly complex. These relationships include independent and dependent variables. Independent variables such as upland discharge, sediment supply, geology, soils, landforms, and climate have effects on dependent variables such as sustainable slope, vegetation density, and shoreline erosion rates. Changes in shoreline topography provides the catalyst for increased wave run-up and coastal flooding. There are various forms of shoreline erosion as shown in Figure 4. These include rill and gully erosion, groundwater seepage that often lead to shoreline slumping, or landslide movements. Wind erosion across open water is responsible for wave attack resulting in toe erosion.

The coast of Maine is primarily unconsolidated sediments located in the intertidal zone and is vulnerable to shoreline erosion (Kelly, et al. 1996). A combination of natural processes and human activity is responsible for causing shoreline change. The natural processes include waves, tidal currents, storm surges, ice scour, and upland runoff. The affects these forces have on beach and bluff shape can be seen in Figure 5.

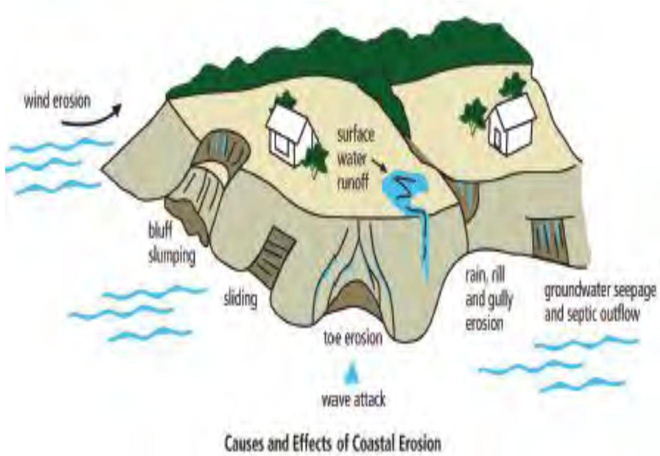

FIGURE 4. CAUSES AND EFFECTS OF COASTAL EROSION. IMAGE SOURCE: KEILLOR AND WHITE, 2003

Bustins study areas and shoreline erosion is episodic based on toe exposure to waves. Beach shape in front of the shoreline controls the sizes of the waves that reach the toe. Human activities, such as hardened coastline structures, can also have an effect on the shoreline causing increased erosion in areas adjacent armored shorelines.

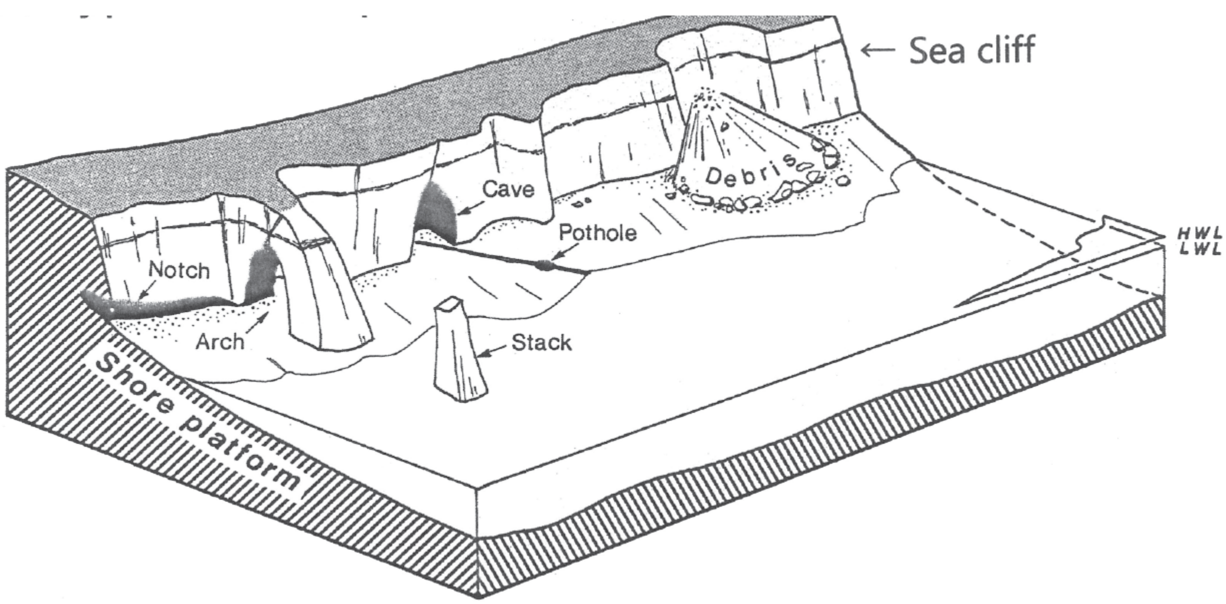

FIGURE 5: SHORE PLATFORM. IMAGE SOURCE: TSUGUO SUNAMURA, 2015

RESULTS

Bustins Island shoreline instability rating assessment resulted in nine separate surveyed bluff study site segments and their associated upland subcatchments (Table 2). Several of the bluff sites on Bustins Island are in a state of accelerated bank erosion.

Unmanaged stormwater and failing infrastructure are contributing to some of the instability due largely to the increased intensity, duration, and frequency of today's rain events.

The bluff analysis revealed that several of the extreme and very high bank erosion rates result in deposition of material downslope of the failures. Debris piles are a sign of active bluff migration from vertical instability which develop in the bluff's effort to dissipate wave energy. The results are avulsions, caves, and notches.

The study site areas ranged from approximately 49 feet to 168 feet in length. Two of the subcatchment areas (Study sites 9 & 10) are identified as having direct impact on the shoreline erosion rate at the respective bluff sites (Study sites 7 & 8). Ratings for the nine sites were as follows:

TABLE 2. STUDY SITE INSTABILITY RATING AND CONCEPTUAL TREATMENT (FOR STUDY SITE LOCATIONS REFER TO FIGURE 3).

Study Site	Upper Bank	Lower Bank	Toe Bottom Bank	Shoreline Length (ft)	Treatment Concept
1	Fair	Poor	Excellent	81	Stabilize toe and lower bank. Mitigate surf run-up.
2	Good	Good	Excellent	76	Increase buffer width.
3	Fair	Fair	Fair	70	Mitigate concentrated runoff. Increase buffer width.
4	Fair	Fair	Excellent	168	Increase buffer width.
5	Fair	Fair	Good	57	Maintain riprap. Look for erosion slipping of rock. Increase vegetation on bank & buffer width.
6	Fair	Fair/ Poor	Poor	49	Install root wads, coil wraps, and native planting.
7	Poor	Poor	Good	76	Fill in woody debris. Plant with native coastal vegetation, use coil wraps, and mitigate concentrated runoff with rain gardens.
8	Poor	Poor	Good	99	Place toe rock with woody debris. Lesson slope/establish native plants. Mitigate concentrated runoff with rain garden.
11	Excellent	Excellent	Excellent	165	Maintain vegetation

Typically, the stabilization technique used to reduce slope steepness is the installation of a hardened surface at the toe. In the study site cases on Bustins, however, a living shoreline and/or soft stabilization approach could be utilized. In addition, with effort from the Town and private landowners, management of runoff from upland locations can:

- decrease bank erosion rates;
- reduce impacts associated with erosion and increased sediment;
- help aquatic and terrestrial habitats; and
- protect against land loss due to bluff failures.

ECOLOGICAL OBJECTIVES

Bustins Island and the surrounding areas of Casco Bay provide critical habitat for a diverse array of species. These include endangered and threatened bird species and many types of aquatic lifeforms. Recent declines in shellfish populations have made protection of water quality in this area of Casco Bay an urgent concern.

Coastal bluff stabilization is one way to reduce sediment loading to Casco Bay. This can accomplish ecologically beneficial objectives within each study site bluff proposed for restoration/protection. By intercepting and dissipating the concentrated runoff of the ditches, reducing seepage from steep embankments, and providing toe stabilization with a living shoreline, it may be possible to reduce bank erosion that is the leading cause of bluff failure and land recession.

Utilizing vegetation in the shoreline bank will act as the structural support needed to stabilize open soil and enhance the building of organic material for future vegetation to grow. Another restoration objective in restored bluffs is to reduce lateral erosion on newly exposed bluffs using log vane and root wad combination structures. These structures will also serve as bluff cover and habitat for species present near the bluffs.

WATER QUALITY OBJECTIVE

One of the unexpected goals of upland infiltration projects for Bustins Island is the potential to improve water quality runoff from the areas assessed. The proposed upland stormwater control recommendations will increase the time it takes for runoff to reach the bottom of any subcatchment (time of concentration). This will in turn increase the probability of attaining slower flow through the subcatchment, increasing infiltration. Increasing infiltration should provide increased ground water recharge. The restoration will also improve water quality by reducing sediment inputs from surface erosion.

RESTORATION DESIGN METHODOLOGY

Design methodology for coastal bluff restoration can be done in several ways. It is often determined by the type of restoration considered and uses a stable reference as a template to restore an unstable area. This method is suggested for use on Bustins Island's study sites.

A reference bluff should be of the same bluff soil type, aspect (orientation), bank angle and fetch (proximity and compass bearing of open water) as the bluff to be restored. Geomorphic measurements from such a reference bluff are used to develop typical profiles and to calculate the dimensions of the bluff to be stabilized. Data from reference bluffs should be used to develop the final stabilization design.

Stabilization in a shoreland zone has numerous regulations that need to be followed and addressed in the permitting of stabilization projects. This report does not go into permitting details or provide permitting support. However, it is clear that some of the living shoreline approaches described here will require special permitting or status as pilot projects to allow for experimentation, documentation, and further study (For current permitting guidelines see http://www.maine.gov/dep/blwq/docstand/szpage.htm).

CONCEPTUAL DESIGNS

Living shoreline stabilization seeks to incorporate several features including upland watershed work to improve the hydrology, hydraulic and geomorphic stability, and habitat. Recommended features will be constructed of natural materials. These features include, but are not limited to, bank vegetation, toe wood, sills and vanes, and upland stormwater control utilizing vegetated gardens.

Study sites 9 and 10 are the most impacted from altered overland stormwater runoff in the upland areas. Study sites 5 through 8 are challenged by channelized runoff. Stabilization for all of these areas will include energy dissipation in the upland watershed and the use of vegetated rain gardens to detain and infiltrate water further from the bluff with the goal of reducing seepage at the bluff face.

Conceptual designs for bluff areas 6 - 8 propose the use of woody debris structures such as root wads to dissipate wave run-up energy and create beneficial placement of material at the toe.

The upper bank areas of bluffs should be considered for salt-tolerant native plants with dense root structures resilient to strong winds such as bayberry and other plants, as appropriate for local conditions. See the Coastal Planting Guide, Appendix E for more information.

To the greatest extent possible, all materials should be locally sourced to limit construction expenditures associated with hauling of material. Currently, there are numerous large trees and root wads on the island that could be utilized for bank stability.

RECOMMENDED CONCEPTS

Mean-High Tide Bench Structures: Bench structures are relatively flat topographic features constructed at the base of steep slopes to increase the distance between wave shear forces and readily erodible bank materials (Figure 6). Such benches are typically vegetated with a suite of deep rooting woody shrubs and herbaceous species adapted to surviving in saltwater conditions. Mean-high tide benches mimic the effects of a naturally occurring inundation plain and allow energy dissipation into a stable form that possesses the width and depth necessary to transport shoreline sediment load over time without aggrading or degrading. Mean-high tide benches are relatively easy to construct and may be modified to include other features, such as wood toe.

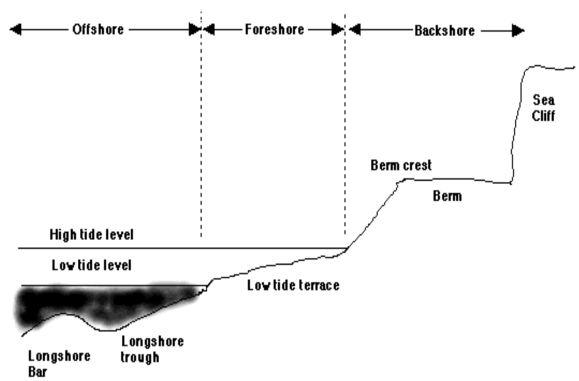

FIGURE 6: MEAN HIGH TIDE BENCH STRUCTURE. IMAGE SOURCE: HTTP://OREGONSTATE.EDU/INSTRUCT/OC103/LAB7.HTML

Wood Toe Structures: Wood toe structures are relatively inexpensive, easy to construct structures which utilize a combination of woody debris, live cuttings, fill, and sod mats (materials readily available on the island). Wood toe serves to protect vulnerable and unstable banks while also providing a roughness element to help ensure connectivity habitat remains viable (Figure 7). Wood toe structurers are recommended for study sites 6, 7, and 8. These structures will provide effective mean tide stabilization.

FIGURE 7: WOOD TOE STRUCTURES. IMAGE SOURCE: BIOENGINEERING ASSOCIATES, HTTP://BIOENGINEERS.COM/SEASIDE/

Log/cobble step-pool structures: Log step-pool structures are log, root wad, and cobble constructed structures used "inditch" to stabilize the concentrated ditch flow where strong helical flows, high boundary stress, and high velocity gradients create high stress in the ditch (Figure 8). Log/cobble structures are designed to reduce accelerated ditch erosion instream by reducing near-bank slope, velocity, velocity gradient, ditch power, and shear stress. Log/cobble structures will be installed for the ditch line running from study site 10 to study site 9.

FIGURE 8: LOG / COBBLE STEP POOL STRUCTURES. IMAGE SOURCE RYAN ET. AL. 2014

Step-pool structures: Step-pool structures are a series of pools with sequential drops in elevation (Figure 9). These provide grade control and energy dissipation for high gradient channel sections. Scour holes created in each pool provide for sediment capture. Step pools may be constructed with rock or trees. Step-pool structures to mimic energy dissipation found in natural stream systems.

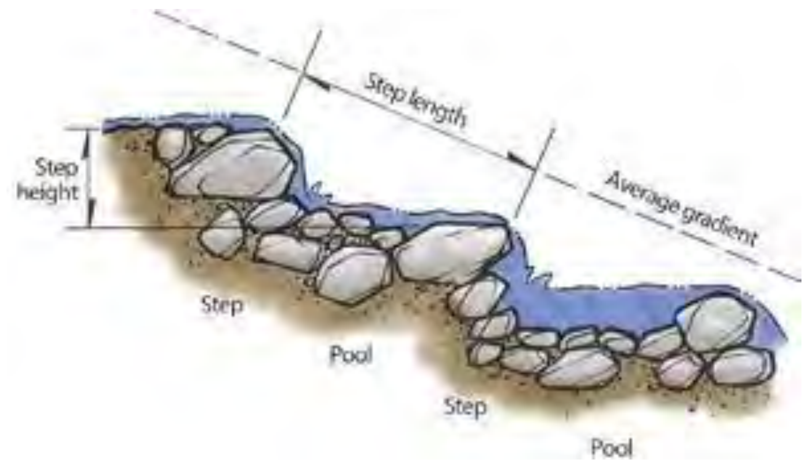

FIGURE 9: STEP POOL STRUCTURE. IMAGE SOURCE: TODD MOSES, 2010

Rain garden stormwater detention: Vegetated rain gardens can be considered on individual lots to locally capture runoff from impervious surfaces like roof lines and driveways. These are natural absorption and filtration systems that allow water to return to underground aquifers instead of running over land, becoming concentrated flow, and creating erosion. These gardens are a depression in a low area of a property that should be planted with native species that have adapted to withstand inundation from runoff water but are also drought tolerant (Figure 10). These gardens are created with organic material and compost in order to encourage an abundance of microorganisms that will help build soil structure along with plant roots which then filter water that comes into the garden. There needs to be an overflow outlet to accommodate large storm runoff. Surface area of the treatment soil shall equal 4% of the area that drains to the garden. Therefore, many small gardens are preferred over centrally collecting larger gardens.

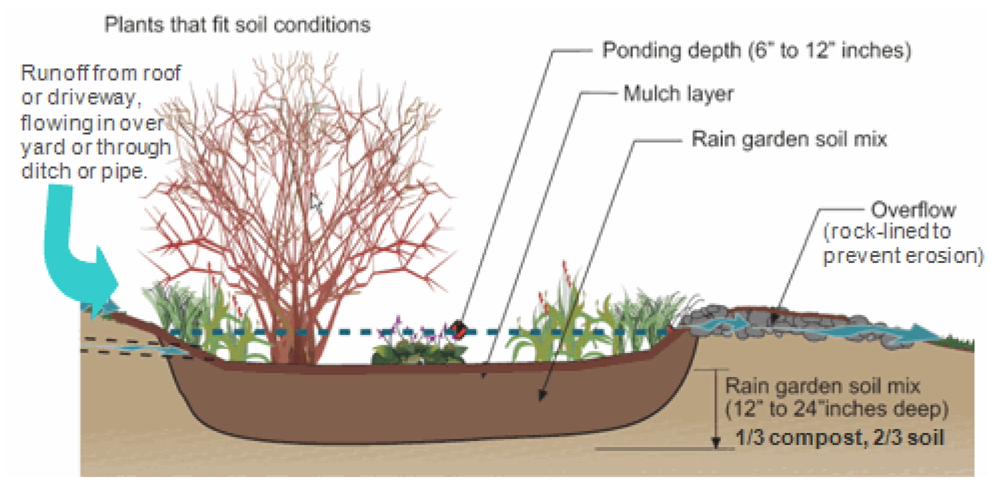

FIGURE 10: RAINGARDEN DESIGN CONCEPT. IMAGE SOURCE: SEATTLE PUBLIC UTILITIES, 2015

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