Building Resiliency Along Maine's Bluff Coast

Award No. NA14NOS4190047

Final Report

December 21, 2017

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Objectives and Outcomes

Goal 1: Better Access to Data to Plan for Storms and Sea Level Rise

New data sets and methods of bluff geomorphology and hazard assessment were developed with collaborative studies by U. Maine, MGS, and CCSWCD. Site studies were narrowed down to ten Casco Bay locations facilitated refinement of methods for evaluating, monitoring, and quantifying erosion (Figure 1). Case studies were used for independent field testing of decision support tools developed by CCSWCD. Through a tiered decision-tree approach developed by CCSWCD, a path of evaluating hazards and stabilization alternatives was established. The decision process uses data from case-study sites for examples. Some of the needed information for new sites is now available from the MGS web site and further enhancements and data release are planned.

The MGS Earth Resource Information Program (ERIP) developed online mapping hazard portal enhanced with multiple storm hazards including static storm surge and sea-level rise scenarios. The portal also provides hurricane inundation (National Hurricane Center SLOSH) from Category 1 through 4 hurricanes. These data can be combined with high-resolution lidar data that shows coastal geomorphology of bluffs and adjacent lowlands subject to storm erosion. The portal also includes the 2015 Highest Annual Tide line supported by a database of water levels for regulatory or engineering design use.

A second MGS mapping portal can import additional data sets for local and regional analysis. These data can include NOAA EVI map data, historical aerial photographs, state water quality classification, wildlife habitat boundaries, and shellfish resource areas that all aid in pre-permit site planning and shoreline stabilization alternatives analysis.

The Cumberland County Soil and Water Conservation District developed bluff assessment tools and flow charts to facilitate erosion hazard analysis and considerations for regulatory permitting (Appendix A).

Several iterations and testing resulted in a Technical Manual, a Shoreline Management Assessment Decision Tree, and an Instability Rating Form that are all used together for evaluating coastal bluffs. The manual introduces the concepts as well as sources of information to enable a user to categorize and classify bluffs. Through a decision-tree process, users are led to determine information needs, gather information, and consider alternatives for shoreline stabilization. The decision tree can also be used in analysis and regulatory review of permits.

The CCSWCD compiled information on plants from the extensive Natural Resources Conservation Service database and created a *Coastal Planting Guide* specific to Maine bluffs. The guide is arranged for use at different geomorphic positions on a coastal bluff and considers sun exposure, hydrology, and canopy in recommending proper selection of species to help reduce erosion and over steepening of coastal bluffs. The CCSWCD investigated multiple sites in Casco Bay and created three final case studies, each with different sub-sites, hydrologic features, sediment types, and fetch exposure. These case studies provide examples of how to use the Technical Manual and supporting assessment tools to evaluate bluff hazards and to identify potential shoreline stabilization approaches.

Transferrable Structure from Motion (SfM) modelling and work-flow methods were created by U. Maine partners. Due to the hyper local spatial aspects of these measurements, they were not fully integrated into a regional GIS-based model. However, U. Maine demonstrated the applicability of drone imagery for expanding data capture to regional spatial scales. This new approach has value in site-evaluations to determine rates of land loss and sediment release to the intertidal zone. Based on lessons learned from the U. Maine work, MGS built the in-house capacity to collect, analyze, and archive additional SfM data for quantifying bluff erosion rates. In the future, MGS will be able to incorporate SfM data into a coastal database with public access. This will allow the data to be used for future change analysis or for sediment budgets needed for policy development or permit reviews.

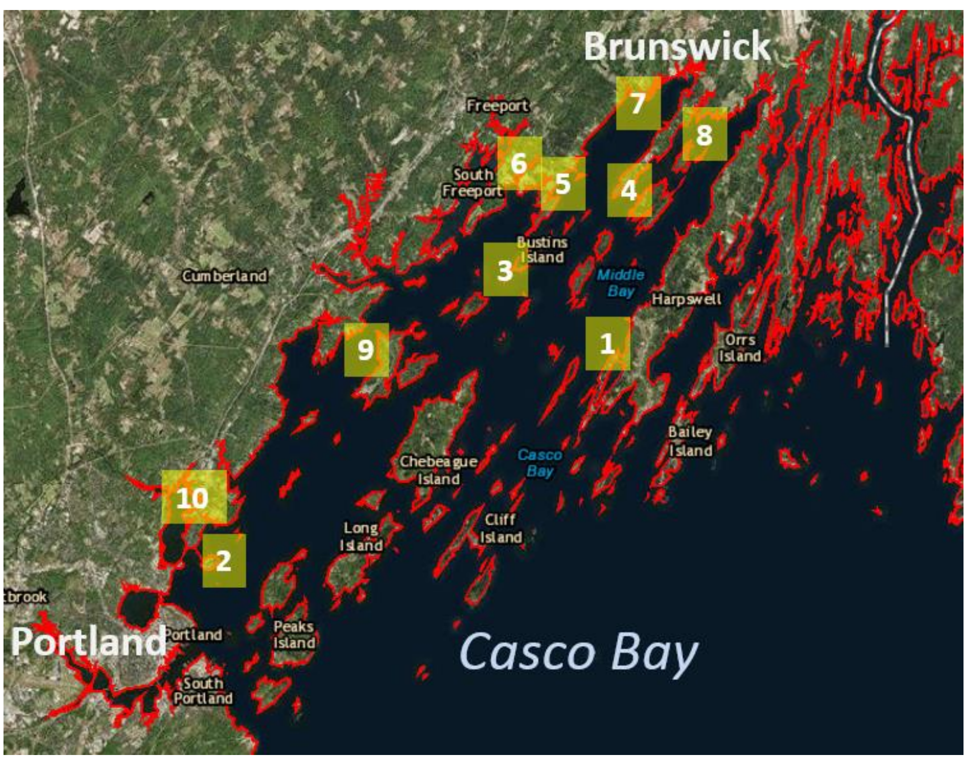


Figure 1. Areas investigated and discussed in this report: Mitchell Field (1), Mackworth Island (2), Bustins Island (3), Mitchell Field (4), Little Flying Point (5), Little River (6), Bunganuc Bluff (7), Miller Point (8), Cousins Island (9), and Tidewater Farm (10).

Goal 2: State and Local Officials Improve Non-Regulatory Approaches

The second goal of this project was to engage coastal communities in the ways to improve coastal management of natural resources and processes while protecting property from hazards. Throughout this effort, groundwork was established for a better scientific understanding of natural processes including the "bluff cycle" of land loss, sedimentation on the upper intertidal zone, and gradual erosional release of sediment to local salt marshes and mud flats. Until now, this concept has been invisible except to the geological community.

Education and outreach through this project has greatly expanded the understanding of state and local officials with much more significant knowledge and acceptance of the value of erosion to maintaining coastal ecosystems now and into the future. Coordination among the Department of Marine Resources (DMR), Department of Inland Fisheries and Wildlife (IF&W), and Department of Environmental Protection (DEP) has reached a new level of understanding of the benefits of nature-based approaches to erosion management and to the preservation of coastal environments that support commercial activities such as clamming and worming. Furthermore, it is now widely understood that terrestrial land loss helps intertidal environments keep pace with sea level rise and that the past practice of stopping all sediment transfer has implications for wave attenuation, intertidal erosion, salt marsh degradation, and commercial harvesting.

During this project, the DEP has developed a heightened interest in living shorelines as an approach to shoreline stabilization. Through MGS engagement during this process, and when significant permits were under consideration, the DEP has modified the traditional permitting under the State's Natural Resources Protection Act (NRPA) in a few cases to allow consideration of the "mud budget" and salt marsh creation at the toe of eroding bluffs. Prior to these examples (see Permitting Innovations below and Appendix B) permit applicants avoided stabilization work in the upper intertidal zone and below the Highest Annual Tide because of a general state prohibition that also required payment of an in-lieu fee for filling a coastal wetland. The DEP now remains open to considering intertidal portions of projects for shoreline stabilization and may waive the in-lieu fee in some circumstances where there are net environmental benefits.

Town of Brunswick: The team worked to expand the knowledge on coastal bluff processes and hazards with planners, the shellfish warden, the conservation commission. Starting in April 2015, MGS was active with the DEP permit processes for two major projects with resource agency engagement, primarily represented by team members. Active regulatory reform started during this project and following a Shoreland Zoning moratorium. The town found regulatory deficiencies in their Municipal Shoreland Zoning Ordinance and amended them to be consistent with the DEP Ch. 1000 standards (Brunswick, 2017). In addition, the Town of Brunswick now requires Code Enforcement Officer review if development results in filling and earthmoving of volumes that exceed 10 cubic yards (Brunswick, 2017). This approach parallels Ch. 1000's Stream Protection District or Resource Protection District. Regulatory revisions made by the Town of Brunswick will provide examples for other municipalities to consider.

Town of Harpswell: The project team engaged a civic committee charged with oversight for management of municipal park with extensive eroding bluffs. The park, Mitchell Field, provided examples of tree roots and driftwood increasing bluff-toe stability. MGS and CCSWCD did groundwater and surface water analysis. MGS evaluated shore-fast ice and seeps from bluff-face springs. Field work led to MGS considering beach nourishment with coarse sediment as a natural approach to reducing bluff-toe erosion (see the Lubec example in Appendix B). The DACF Municipal Planning Assistance Program announced a NOAA-funded Coastal Communities Grant opportunity that included a component on building resiliency with living shorelines. The Town of Harpswell budget and town meeting cycle precluded submitting a timely proposal for Mitchell Field but may consider a proposal in a subsequent year.

DACF Bureau of Parks and Lands: The project team attempted engagement of supervisors and park managers to address erosion threatening public trails and safety at Mackworth Island in Falmouth. The park property was used as a case study area. MGS located field examples of tree roots, dead trees, and driftwood that increased bank stability. This site provides an excellent opportunity of publicly accessible examples of how a nature-based approach would mimic natural conditions. The CCSWCD case study here will provide both guidance to the Bureau as well as opportunities for field education on living shorelines.

State engagement: Team efforts resulted in a change within the DEP on the department's approach to living shoreline applications. In the case of a Brunswick permit, DEP provided a waiver of the in-lieu fee normally required for work in the intertidal zone. This permit at Miller Point proposed recycling bluff sediment to create a bluff-toe buffer with a fringing salt marsh. The design also incorporated a significant sediment volume placed over riprap that was expected to be time-released to the intertidal zone to mitigate toe erosion and help balance the sediment budget (Appendix B). This new approach may open the possibilities for natural shoreline type restoration or habitat creation while reducing project costs through local sediment management and fee reduction. Mr. Nault evaluated impacts to marine resources and the commercial clam and worm industry adjacent to the site. Through this process, DMR remained open to modification of upper intertidal zone habitats when commercial resources were not affected and when they may possibly be enhanced or preserved with rising sea levels. Maine IF&W also participated in review of project impacts to shore birds, mammals, and bats. All agencies recognize environmental processes are dynamic and that erosion is a necessary process for maintaining intertidal ecosystems and sediment budgets as sea levels rise.

Outreach: The Municipal Planning and Assistance Program coordinated two workshops for Regional Planning Councils in 2016 and 2017. In Maine, these regional planning organizations are a trusted source for municipal planning advice and the best point of contact and assistance for communities seeking to enhance coastal resiliency. The Timeline of Presentations (below) also summarizes additional workshops and outreach to various communities, municipal officials, engineers, consultants, and citizens. The most complete products from this project culminated at a workshop *Building Coastal Resilient Bluffs* arranged by the Cumberland County Soil and Water Conservation District on September 11, 2017 at the Greater Portland Council of Governments office (Appendix C).

Project Results

Maine Geological Survey

Project Management

This project was jointly managed by the Maine Geological Survey and the Maine Coastal Program. MGS worked with all project partners and independently to advance multiple aspects of this grant.

MGS worked through the Bluff and Landslide Checklist of the *Coastal Property Owner's Guide* for improvement in ways useful for site characterization and suitability for decisions related to living shoreline applications. This information was shared with U. Maine and CCSWCD partners to shape field studies and bluff assessment methods. The Assessment Rating Form developed by CCSWCD is a derivative of the checklist. Modeling design by U. Maine included factors from the checklist (Appendix D).

MGS reviewed scientific literature on the design and installation of living shorelines in other states and papers on ecology of fringing marshes, development, and structural design relevant to Maine. MGS reviewed information on use of living shorelines in Virginia (VIMS, 2010) and the U.S. Army Corps of Engineers Natural and Nature-Based Features (USACE, 2015). An annotated bibliography with these and other references is provided in Appendix E.

In June 2016, Casco Bay study sites had reconnaissance visits and subsequently some were imaged by Mr. Slovinsky (MGS) and Rick Harbison (Greater Portland Council of Governments, GPCOG) over two days. With a boat, GPCOG drone, and a FAA license held by Mr. Harbison, they obtained oblique aerial images of eroding bluffs in Casco Bay for case studies. Sites where known erosion hot spots were and previous stabilization efforts occurred were imaged. The most famous and controversial of these is at Bunganuc Bluff (Bunganuc Landing Road; 43°51'33.06"N, 70° 0'40.78"W) in Brunswick. The Town of Brunswick, the Maine DEP, and the U.S. Army Corps of Engineers all considered permits for bluff shoreline stabilization to minimize landslide risk to a residence. Dr. Dickson reviewed and commented on this location and acted as an intermediary between regulators and the applicant's consultant as living shorelines were considered as a supplement to traditional engineering (Appendix B).

Mr. Slovinsky convened a technical working group (also in conjunction with a related NROC project) to aid in the development of a GIS-based living shoreline decision support tool for Casco Bay. The group consists of representatives from the CCSWCD, NOAA, the Town of Brunswick, The Nature Conservancy (TNC), and Casco Bay Estuary Partnership. The technical group met 3 times during the reporting period and has revised the inputs and weightings of the inputs for the tool several times.

Dr. Dickson conducted field work at Mackworth Island and Mitchell Field to evaluate groundwater seeps, intertidal geology, bluff slope geology, and wave exposure in conjunction with CCSWCD case studies. Bedrock, surficial, and shoreline geology were examined as was the HAT, inundation of the bluff from 3 and 6 feet of storm surge or sea-level rise and hurricane inundation with the SLOSH model output. Shaded relief from lidar data also provided a geomorphic context to the study site. The geological aspects of bluff analysis were tested using MGS' online Maine Geology Web Maps portal. Results were shared with CCSWCD as were background memos MGS submitted to the Maine DEP on a bluff and landside remediation effort at Bunganuc Bluff in Brunswick. This information exchange helped the District improve understanding of the framework and standards used by DEP for permitting shoreline stabilization structures.

MGS and MCP amended the contract with CCSWCD in the spring of 2017. This allowed the project to continue field investigations, measurements, and case study development through another spring and summer field season. This extension enabled Mr. Slovinsky and Mr. Barry to conduct an additional site assessment April 28, 2017 at the Brunswick Mere Point study site near Webb Field Road. The shoreline adjacent to the field experienced a landslide during the project period so immediate, post-slide evaluation was possible. This work resulted in a new case study (Appendix A).

Structure from Motion

Based on the success of Mr. Whiteman's work, MGS GIS Coordinator Whittaker and Senior Geologist Spigel did additional research into SfM and acquired the same AGISoft Photoscan software (used by U. Maine) to build in-house capacity for additional 3D models of bluff erosion and monitoring. They worked on more permanent methods of ground control points (linked to RTK-GPS Earth coordinates) for future field seasons. MGS anticipates continued bluff monitoring and investigations of slope instability following on the work by Mr. Whiteman. MGS established improved georeferencing of sites and documented the process and metadata development to guide others and provide records in a GIS database. A precise geospatial framework for model data in both tidal and terrestrial datums for the design of traditional, hybrid, or green shoreline stabilization structures will be follow-on work by MGS after this project. This Earth-coordinate data is needed to be able to add storm surge levels, FEMA floodplain elevations, ice action, and sea-level rise scenarios to future modeling efforts.

Geospatial Analysis

Early in this project, MGS made significant progress on the highest annual / astronomical tide (HAT) GIS tool that provides the highest resolution geospatial “shoreline” for the entire Maine coast. This uses the NOAA VDatum program and a Maine Office of GIS digital elevation model from lidar in ArcGIS. This tool has been further developed for sea-level rise inundation simulations in GIS and for regulatory use in permit applications.

In 2015, MGS released digital mapping tools and data sets via the web for the 2015 highest annual tide, several sea-level rise scenarios, and inundation from category 1-4 hurricanes. The web mapping application is available in the hazards section of the MGS web site. These static inundation levels may be used as inputs to the bluff modeling effort and are valuable for consultants designing shoreline stabilization.

Mr. Slovinsky and Dr. Dickson refined the MGS GIS-based mapping routine to take high-resolution lidar data and variables for landslide susceptibility (including slopes vulnerable to minor bluff erosion along the coast). These results were used for municipal outreach in the project and to identify shoreline segments that might qualify for future demonstration projects.

In 2016 MGS did preliminary work on components of the GIS model including incorporation of lidar-derived data on: (a) slope, (b) aspect – geographic orientation, (c) curvature, (d) slope geomorphology, (e) intertidal or shoreline geology, and (f) surficial geology, along with (g) proximity to known slope failures, and (h) fetch. Flood elevation on the bluff embankment was also considered as a possible input from digital Flood Insurance Rate Maps (DFIRMs). DFIRMs were not specifically adopted in a GIS analysis for this project.

In 2015 MGS and NOAA’s Doug Marcy and Jamie Carter held a technical conference call and shared information on modeling methods, shared information on the U. Maine effort, and discussed applicable efforts in the Great Lakes states, Chesapeake Bay, California, Massachusetts, and others. Applicability of the NACCS data for water and wave recurrence levels was discussed. NASA and European Space Agency radar data from satellites was reviewed for accuracy and application for bluff change analysis. Other computing methods such as BMAP and SBEACH were discussed. Land cover analysis application in GIS and modeling was reviewed. Three-dimensional visualizations for education were discussed.

MGS evaluated a method of projection of intertidal slopes inland to undercut bluff embankments and cause bluff-top recession is one approach. This slope-projection method was applied on the west coast and could be useful for simulating different sea levels and the sediment volumes that might reach the intertidal zone. This simple approach can generate a basic sediment budget may have implications and applications for design, management, and policy. Compared to other methods, slope-projection was determined to be overly simplistic for the complex coastlines of Casco Bay so this approach was not included in GIS modeling.

MGS investigated options to incorporate wave attack at the base of bluffs. Toe erosion from waves is an important factor in causing bluff instability. U. Maine numerical wave modeling exists for Casco Bay but was still a work in progress and was not immediately transferrable. Thus, MGS decided to evaluate the exposure of bluff shorelines to potential wave attack through analyzing annualized fetch. Ten years of annualized wind conditions (2006 to 2016) from a nearby NOAA buoy (NDBC 44007, located in outer Casco Bay 12 nm southeast of Portland) was used. The wind data was fed into a USGS GIS-based fetch model (Rohweder and others, 2008) to calculate annualized average fetch within Casco Bay Figure 2. After experimentation in GIS, fetch was classified into five categories: very low (<=0.5 miles), low (0.5-1.0 miles), moderate (1-3 miles), high (3-5 miles) and very high (>5 miles). Additional description of this effort is in Appendix C.

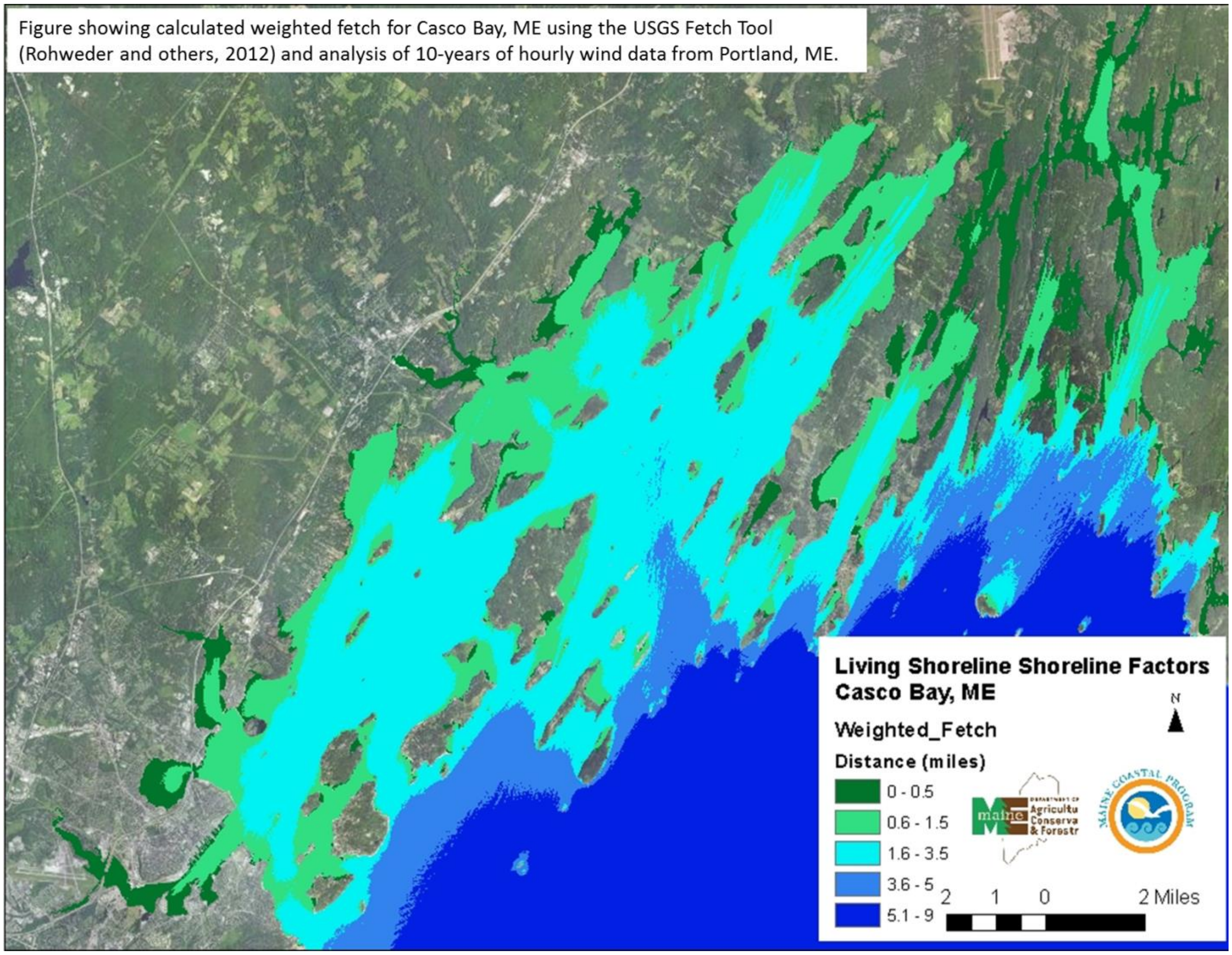


Figure 2. Analysis of fetch in Casco Bay was used as a proxy for wave energy that can erode the toe of bluffs. Figure by P. A. Slovinsky.

The extent of shoreline hardening within Casco Bay was determined using GIS analysis of issued Maine DEP permits and visual inspection of the shoreline using aerial imagery. While this effort was underway, Maine received updated Environmental Vulnerability Index (EVI) GIS data, which identified shoreline hardening as part of its analysis. Using this combined information, MGS determined that approximately 77 km (48 miles) of shoreline is hardened in Casco Bay. This layer is useful in identifying bluff areas with traditional engineering structures and those bluffs that remain in a natural condition.

Mr. Slovinsky of MGS developed a GIS layer file and database of state-issued (DEP) permits along the shoreline of Casco Bay. The data were analyzed, within the limits of digital records, to determine that about 240 of 850 permits were shoreline stabilization that included about 54 km of riprap and 23 km of bulkhead construction in Casco Bay. This layer was shared with CCSWCD to narrow down field efforts and identify case study sites. This layer was used in spatial analysis overlay and is integral to the classification of bluff stability types (MGS Coastal Bluff Map series) used in permit reviews and Shoreland Zoning setbacks.

MGS considered converting existing MGS GIS landslide susceptibility Arc Macro Language scripts to ArcGIS python code. Mr. Halsted determined that there was no simple or automated translation. Rather than modify the existing landslide maps, MGS developed a new approach with weighting factors based, in part, on prior MGS modeling experience and ongoing analysis of suitability of sites for living shorelines.

MGS worked to develop a GIS-based Living Shoreline Suitability Decision-Support Tool (Figure 3). The need for such a tool became apparent based on: (1) the number of requests by municipalities and individual homeowners for information relating to shoreline stabilization and living shoreline approaches, (2) an increase in the number of permitted shoreline stabilization projects, especially for both developed and undeveloped coastal bluffs, and (3) overlap between the existing project and a regional NOAA-funded project on living shorelines in New England.

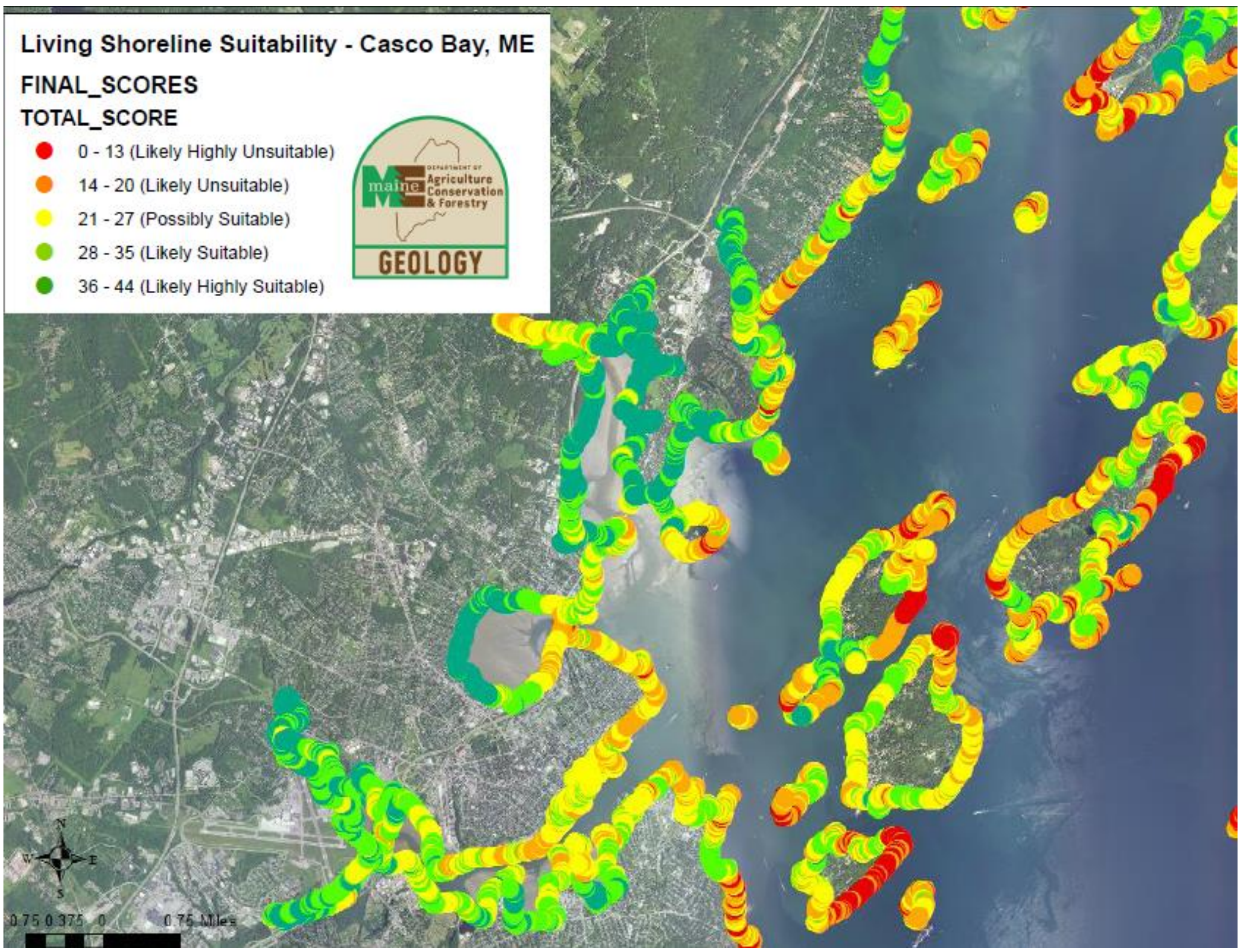


Figure 3. Multiple shoreline variables were incorporated to a single score to identify locations where living shorelines are most suitable. Figure by P. A. Slovinsky.

MGS formed a technical working group to focus on developing such a pilot tool for the Casco Bay region. The working group includes representatives from MGS, NOAA, TNC, CCSWCD, CBEP, and a municipality. The group met several times, reviewed similar support tools from other states and regions, and reviewed various factors that could be used to determine the suitability of sites for living shoreline approaches. Factors the tool includes are:

- Weighted fetch, based on a U.S. Geological Survey Fetch Tool that uses calculated wind rose percentages from 10 years of hourly wind data from Portland
- Landward and seaward Shoreline Types and Habitats, from updated NOAA Environmental Vulnerability Index mapping
- Nearshore bathymetry (depths shallower than 1 meter within 10 meters of the shoreline)
- Aspect (the direction the shoreline is facing)

- Additional parameters that can be included for further site analyses include:
  - Relief (within 50 feet of shoreline)
  - Slope (within 50 feet of shoreline)
  - Tidal Wading Bird and Waterfowl Habitat
  - Eelgrass Habitat
  - Shellfish Habitat
  - Proximity of existing structures (within 100 feet of shoreline)

Historical shoreline erosion rates are not available for Maine bluffs so MGS analyzed alternatives for measuring land loss and quantifying bluff stability. MGS investigated the possible applications of radar satellite data (InSAR) for measuring bluff erosion rates. Ms. Whittaker downloaded and worked with European Space Agency (ESA Sentinel 1) Comet satellite radar data for a better understanding on how the data might be used. Ms. Whittaker reviewed literature and training for this data processing (Appendix E). With the 2015 launch of Sentinel 2, the shoreline will be resampled every 6 days. This temporal data set might be able to detect landslides of the size seen in the Mere Point case study and perhaps smaller slope failures in the future. Other researchers have done geohazard analyses with Sentinel data detected small horizontal offsets (2 cm) along active fault lines and calculate rates (cm/month) of ground subsidence. Mr. Carter inquired about its applicability and indicated there may be some merit based on work he learned of elsewhere although resolution may still limit its application to Maine bluffs. A primary advantage of radar is that data can be collected day and night and through cloud cover. It may be possible to develop alongshore statistics of slope failure that can be combined with visual imagery, surficial geology, and geomorphic classifications to better quantify risk of bluff failures. While data intensive, this approach, if determined applicable, could work nationally and probably globally for detecting and mapping shoreline land loss as well as assisting risk quantification.

Ms. Whittaker evaluated Landsat data for Casco Bay. There were only a few images spaced far apart in time that were not blocked, at least in part, by cloud cover. While not high resolution, MGS checked the data for use to identify where ice built up along the shoreline. These data were insufficient for mapping ice extent in Casco Bay. Data on ice extent for inclusion in GIS modeling was not found for this project. Further exploration into additional remote sensing sources is recommended.

University of Maine

Bluff Erosion Modeling

In this project, U. Maine built and experimented with numerical models of specific bluffs in Casco Bay. The team created digital representations of bluffs for testing of slope failure from toe erosion. This three-dimensional (3D) modeling was possible using digital images collected at field sites and combined in software (Structure from Motion, or SfM). The U. Maine team experimented with SfM images and refined the field methods for data collection. They used conventional GPS surveying techniques to "ground-truth" computer models and place them in earth coordinates to be useful with vertical datums such as mean high water. Mr. Whiteman conducted shoreline reconnaissance and regular site visits to bluffs in the Casco Bay project area to collect data and survey in GPS references for monitoring erosion (Figure 4).

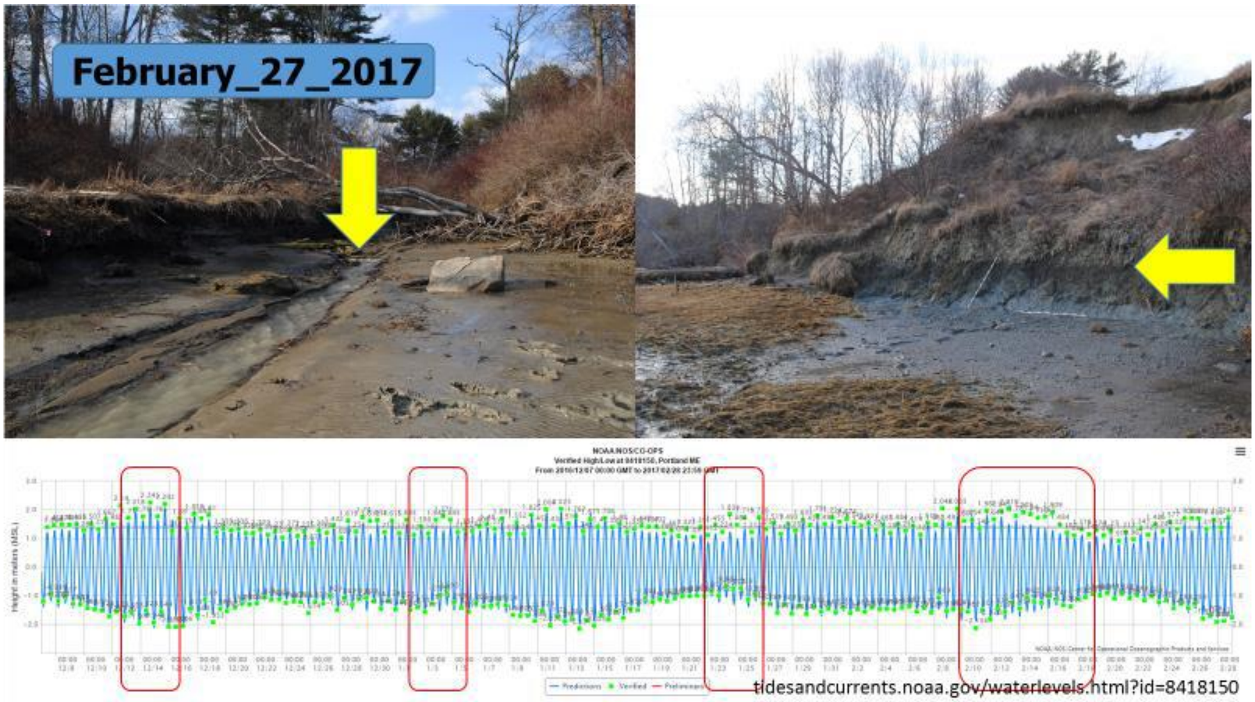


Figure 4. Active toe erosion at Little River in Freeport was documented and used in SfM modeling. For a year-to-year SfM comparison see Appendix D. Illustration by N. Whiteman.

Mr. Whiteman and Dr. Dickson worked on concepts of shore-normal bluff modeling using GIS (Appendix D). MGS and U. Maine developed annotated bibliographies (Appendix E) that were shared with the team. This reference collection has additional information on the numerical modeling used as well as examples of studies elsewhere that helped constrain the choices made in this project.

SfM topography was used in a dynamic physical model (Figure 5). The work-flow demonstrated methods to import SfM data on bluff morphology into a dynamic model. The team selected the FLAC3D quantitative model to simulate slope failures. This second model required an assumption of sediment properties, such as stress and strain, in the model's mathematical mesh to simulate land loss. The team used values from the Presumpscot Formation mud that makes up most Maine's coastal bluffs. Mr. Whiteman was also able to take changes, detected in SfM scans over repeated field visits, into the FLAC3D model to evaluate kinematics and deduce stress/strain behaviors from surface motion observations. Boundary conditions for wave-induced erosion in Casco Bay also had to be estimated for lack of site-specific data. Dr. Kelley and Mr. Whiteman worked with Professor Peter Koons at the U. Maine School of Earth and Climate Sciences. Dr. Koons contributed his modeling skills to the project.

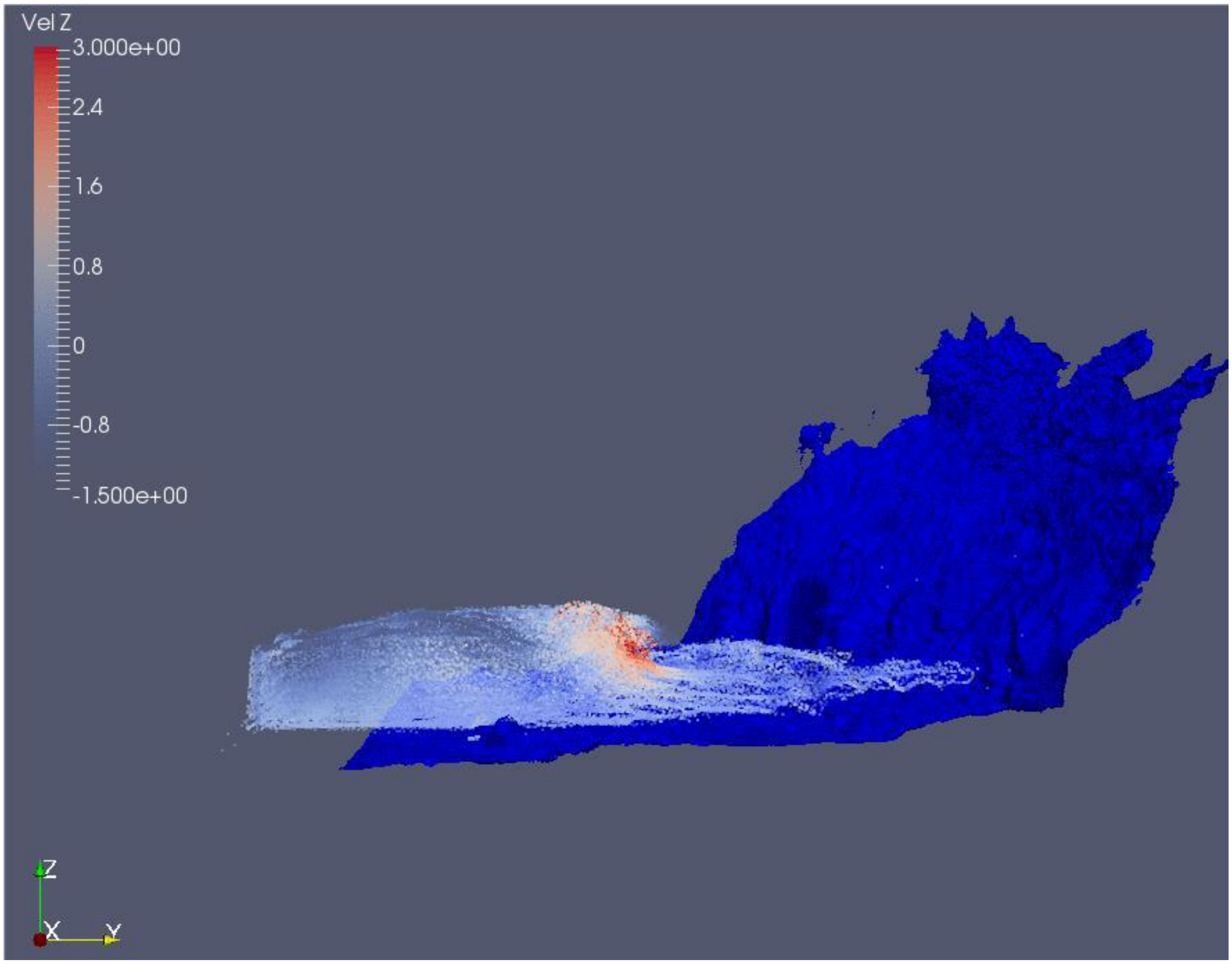


Figure 5. A 3D model of Little River used in DualSPHysics shows a breaking wave (red) with a velocity of 2-3 m/s impacting the bluff toe. Velocities are in meters per second. Graphic by N. Whiteman.

U. Maine graduate student Nick Whiteman also worked on the SCAPE+ model that was released to the public by the iCOASST project overseas. Study of the model's value for Casco Bay determined it had shortcomings. As was already known in Maine, slope failures lead to temporary toe protection from the influx of additional sediment. It seems that this model does not account for sediment accumulation at the base of a bluff over time. SCAPE+ may have more relevance to projecting future upland retreat with sea level rise than in the design or evaluation of living and hybrid shorelines.

New to the project in 2017 was Mr. Whiteman's work with an additional model based on Smooth Particle Hydrodynamics (SPH). DualSPHysics is a model that is used in civil and coastal engineering and familiar to some consultants. This program can work with SfM results and with the FLAC3D model and is superior to finite element models. This model can start with bluff conditions (SfM), then the bluff toe can be eroded with SPH, leading to slope failure with FLAC3D, thus producing a new bluff geomorphology. The newly-failed bluff can then be attacked by more waves with SPH, and so on, to simulate bluff evolution over time. Wave forces and resulting sediment erosion can be modeled this way (Figure 6; Appendix D). It is hoped that wave attenuation from shoreline engineering such as living shorelines can also be modeled. This capability should help with design criteria for shorelines such as those in the CCSWCD and U. Maine study sites. Furthermore, it may be helpful feedback to

MGS GIS fetch-modeling efforts to better understand wave characteristics that are found in sheltered areas that might or might not support living shoreline installations.

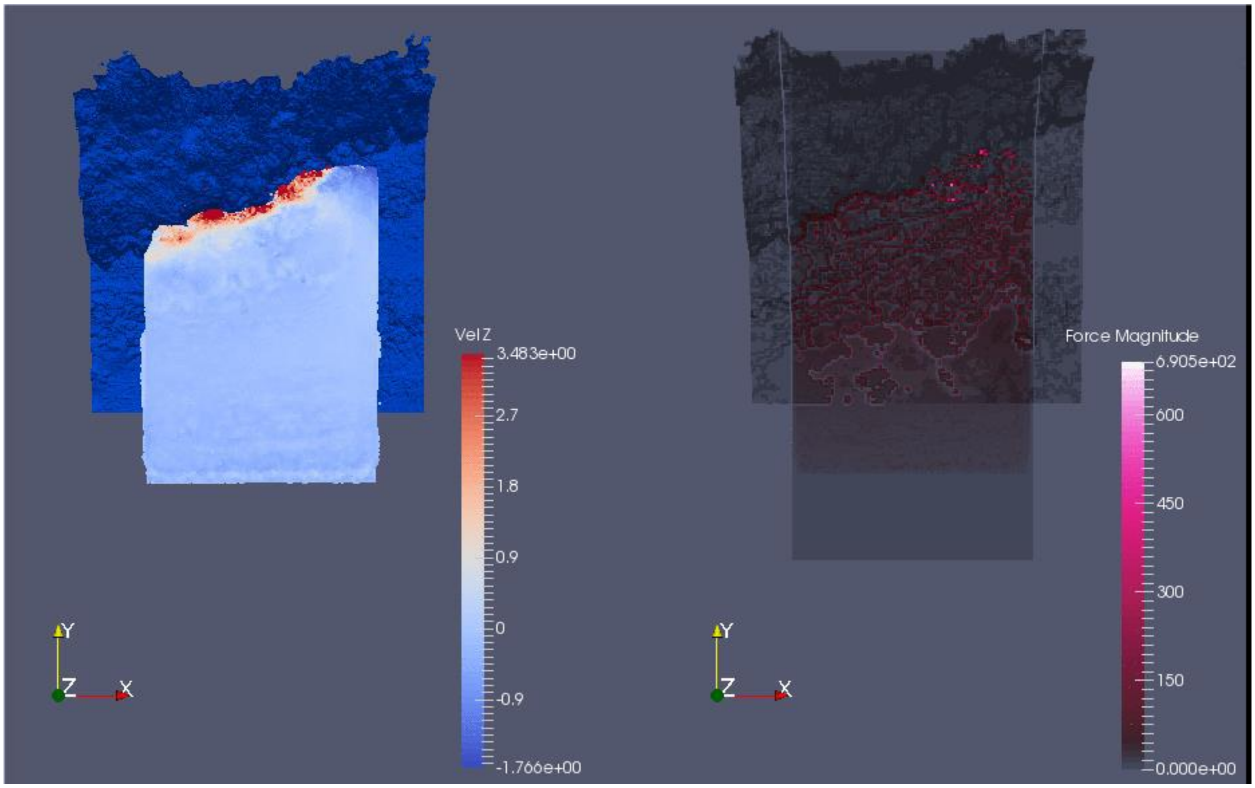


Figure 6. Left image is a view, as in Figure 5, but from above looking down at wave velocities along the bank. The right image shows mechanical forces (Newtons) on the bluff and intertidal zone for living shoreline designs. Graphic by N. Whiteman.

With data collected in the second field season, the proof-of-concept of monitoring change was shown by Mr. Whiteman. As anticipated, changes in bluff geomorphology was detected over just a single year (See Figure 2e in Appendix D). The illustration shows changes in sediment on the bluff face could be detected and quantified. The year-to-year comparison also shows movement of driftwood on the intertidal zone. This scale of monitoring will have application in tracking and quantifying the success or failure of living shorelines or hybrid engineering projects. Also significant was the detection of a tree beginning to move downward on the slope. Simple comparisons over time should help identify evolving coastal hazards in addition to local sediment budgets.

Numerical modeling work with FLAC3D demonstrated that SfM data could be imported from multiple field surveys. The U. Maine team determined that predicting failure with this finite element model would require both more repeated field observations and site-specific geotechnical properties of the buried clay. In addition, the model would benefit from groundwater data such as depth to the water table and sediment pore pressures, both of which vary seasonally and spatially along the coast. Results from these study areas will, at a minimum, constrain some parameters in the model and provide the basis for ongoing investigations.

Smooth Particle Hydrodynamics (SPH) modeling at U. Maine with DualSPHysics was shown to work well with both SfM and FLAC3D. These three software programs can manipulate bluff data, examine thresholds for slope failure, and create modified topography after toe erosion by waves.

U. Maine studies have created a process for simulating bluff erosion: Current conditions collected with photography (drone and ground) converted to a 3D topographic model (SfM) that then has terrain modified by toe erosion (SPH) that is imported for failure analysis (FLAC3D) with a resulting new 3D model for further erosion (SPH) in a loop that creates an evolving landscape over time. Modeling could also be expanded to take factors such as flooding and surface runoff into consideration. The team has not yet accomplished the loop cycle but has shown a path for iterative modeling that can be done for coastal bluffs.

In addition to quantifying the bluff erosion process through toe erosion, the U. Maine team believes the modeling can also be used to simulate living shoreline projects. Topography and physical characteristics of wave-attenuation structures can be added to the model and tested over time. This could include construction of fringing salt marshes or hybrid engineering structures such as perched tidal flats behind coir logs. The work by U. Maine thus lends itself to design analysis for comparison with natural erosion. While new and innovative, the results from U. Maine are transferrable to the coastal engineering community for use in evaluating erosion hazards and developing new shoreline stabilization approaches.

At the beginning of this project a geographic information system (GIS) model predicting bluff erosion was envisioned. Work by the U. Maine team demonstrated that, before a predictive model for Casco Bay can be created, there needed to be substantial modeling (as described in the work above) to quantify bluff evolution over time. The best path toward that goal is to continue site monitoring to collect data about changes over time and to expand to more shoreline areas, perhaps through more extensive aerial surveys. A database of evolving bluff geomorphology over time is needed to help build a predictive GIS model that can be combined with physical characteristics and forces simulated by computer modeling and fed by larger spatial-scale inputs from fetch modeling (Appendix D; see also MGS section below). A shoreline database of coastal bluffs will lend itself to both enhanced modeling and predictions as well as the more pragmatic approach to evaluation options for shoreline stabilization that consider both past erosion and how alternative designs compare in both sediment retention and bypassing relative to natural conditions.

Casco Bay Study Sites

Field work was conducted at bluff sites in Casco Bay to characterize bluff types by geomorphology, engineering types, stability, and historical change. Investigations were conducted by Mr. Whiteman and Professors Kelley and Belknap. Photographic documentation of case study sites was set up by Mr. Whiteman using marker flags, GPS positions, and multiple digital images of the bluff face. Data collected were uploaded into software for SfM. This method is the most efficient and cost-effective means of measuring land loss and the sediment flux from bluffs to the intertidal zone. SfM data processing was done at U. Maine and shows great promise for documenting earth movements on the scale of individual properties. An expanded set of ground and aerial surveys would provide a point in time from which future shoreline change measurements sediment budgets can be made. This process will help track future erosion and can be supplemented with MGS coastal engineering and fetch GIS data layers.

The U. Maine SfM study sites in Casco Bay were: (a) Little Flying Point and (b) Little River in Freeport as well as (c) Cousins Island in Yarmouth and (d) Bunganuc Bluff in Brunswick. The Freeport sites were eroding the fastest and thus selected for re-occupation for ongoing field observations and temporal data collection from June 2016 through September 2017. Field efforts were time-intensive but became more streamlined and efficient over time.

Field work in 2017 expanded to demonstrate the use of an advanced consumer-grade unmanned aerial vehicle (UAV) at study sites in Freeport at the Little River and Little Flying Point. Photography from the drone produced expanded three-dimensional models provides a larger section of shoreline than simpler ground-based digital photography. The U. Maine team demonstrated how GPS antennas within the aerial field of view could be used to get very precise positioning for the 3D topography generated in SfM in earth coordinates. The team also showed how drone images and ground images could be combined to capture bluff conditions for a specific point in time (Appendix D). This approach is critical to creating data for bluff erosion rates that otherwise has been elusive using traditional orthophotographs and lidar.

Cumberland County Soil and Water Conservation District

Bluff Assessment

In 2015 a subset of the team made a Casco Bay field visit on August 11th to Cousins Island in Yarmouth to review slope stability, sediment release from bluff failures, the role of deposition in the intertidal zone and the influence of fringing salt marshes at the base of the slope. Sediment budgets, traditional and green engineering were discussed on site. Professor Kelley and graduate student Whiteman joined Dr. Dickson and District Engineer Franceschi and Assistant District Engineer Will Savage of the Cumberland County Soil and Water Conservation District (CCSWCD). The team also reviewed regulatory standards and what restrictions and limitations exist for alternatives. Ms. Franceschi started in August 2015 with the CCSWCD and replaced the outgoing team member Chris Baldwin.

MGS and MCP met with District Engineer Franceschi on October 30, 2015 and reviewed project objectives, scope, and timeline that the District would work with. Ms. Franceschi subsequently left the District and Engineer and Geomorphologist Barry was hired as her replacement and joined the team. Watershed Analyst Yakovleff provided continuity in staff at the District throughout the project.

Mr. Barry developed a series of three analysis tools and a decision tree for site-specific analysis (Figure 7). These tools lead to alternative analyses to reduce bluff erosion through nature-based options. In his work, Mr. Barry determined that a more basic and introductory bluff Reconnaissance Level Assessment Tool would help provide “dashboard level” guidance before a detailed Shoreline Management Assessment is done. The process of bluff evaluation uses an Instability Assessment Rating form to assist in selection of shoreline treatments. These analysis tools and decision tree are provided in Appendix A.

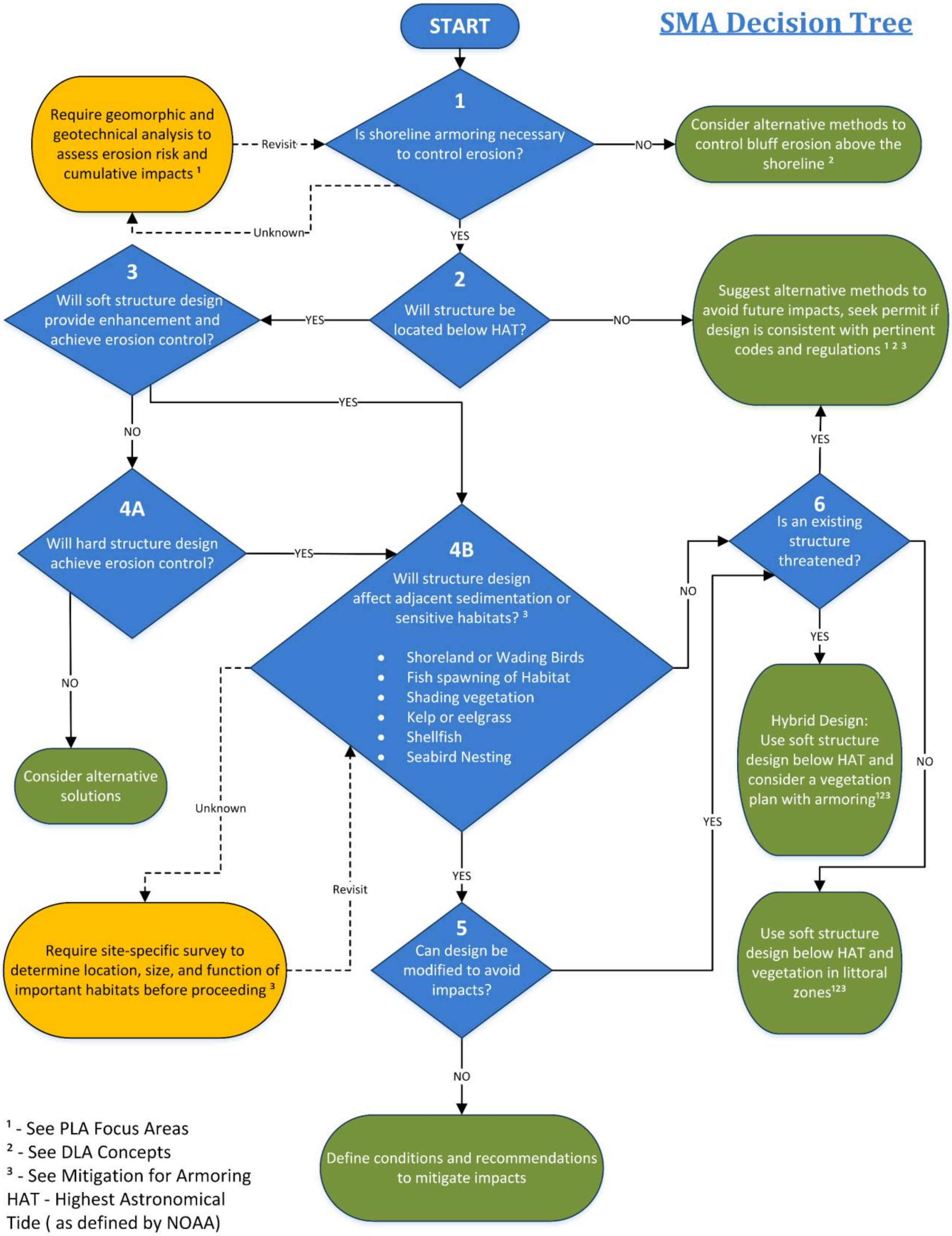


Figure 7. A decision tree developed by CCSWCD to assist with evaluation of coastal bluffs, choice of shoreline stabilization, and possible permitting alternatives.

Watershed Analyst Yakovleff created GIS models of surface drainage basins at a detailed level. Discharge points at the top of bluffs and through gully systems was important to site analysis and estimation of watershed area and runoff. In Maine, surface hydrology is a general proxy for groundwater flow direction and divides, so the work by Mr. Yakovleff provided important geospatial insight for hydraulic remediation to complement bluff-toe erosion control.

Mr. Yakovleff completed a surface water model for all Casco Bay watersheds. The ArcGIS Flow Accumulation tool produced a large dataset of natural drainage based on a lidar digital elevation model. This model indicated surface water flow that affects runoff on coastal bluffs. While it does not directly model groundwater flow, most groundwater flow directions in Maine can be deduced from relief and surface drainage so the model may help understand subsurface discharge at bluffs as well. Model results were used in the case studies and field site investigations by CCSWCD and U. Maine. The results will also be merged with the MGS analysis of fetch and other marine factors affecting the bluffs in Casco Bay.

Casco Bay Case Studies

The CCSWCD worked in the field on case study sites at: (a) Mitchell Field, Harpswell, (b) Mackworth Island, Falmouth, (c) Bustins Island, Freeport, (d) Mere Point, Brunswick, and (e) Tidewater Farm, Falmouth. The latter example is a naturally stable bluff setting with a fringing salt marsh that served as a control but was not fully developed into a case study since erosion control was not necessary there. Mr. Barry conducted field work at each of the case study sites. Each site was chosen for its different geological and geomorphic characteristics. In the process of doing the field work, Mr. Barry created and refined the shoreline assessment tools. Mr. Yakovleff tested the decision tools developed by Mr. Barry in the field at each site. Mr. Yakovleff mapped small sub-drainage basins for each case study site at a scale fine enough to use for bluff surface water evaluation and runoff management analysis.

Mitchell Field is a 120-acre park that includes a 500-foot long linear bluff on Casco Bay. The parcel is owned by the Town of Harpswell. In the last decade, the Mitchell Field Committee has developed a master plan and a waterfront access plan as well as many site improvements. The citizen-led committee recently became concerned about shoreline erosion and began to work with CCSWCD. The District developed this location as a case study and MGS evaluated the geology, morphology, ice, wave and tide processes, along with groundwater and surface water conditions at the site also.

Mackworth Island is a public parcel with bluff-top trails managed by the Bureau of Parks and Lands. Mr. Barry established 8 study sites at Mackworth Island for analysis. Mr. Yakovleff used lidar data to build a 2-foot contour map of the entire island and, from that, built a GIS watershed model to quantify drainage areas and discharge points along the bluffs (Figure 8; Appendix A). This bluff experiences sites where slope failure includes creep down the bluff face with resistance provided by tree roots. Significant runoff created gullies in the slope and erosion hot spots. Toe erosion from wave action in Casco Bay also undermines and steepens the bluff thus contributing to creep. MGS investigated the location and found examples where both dead and living trees slowed erosion. This site has supporting field evidence for the application of tree wads championed by Mr. Barry.

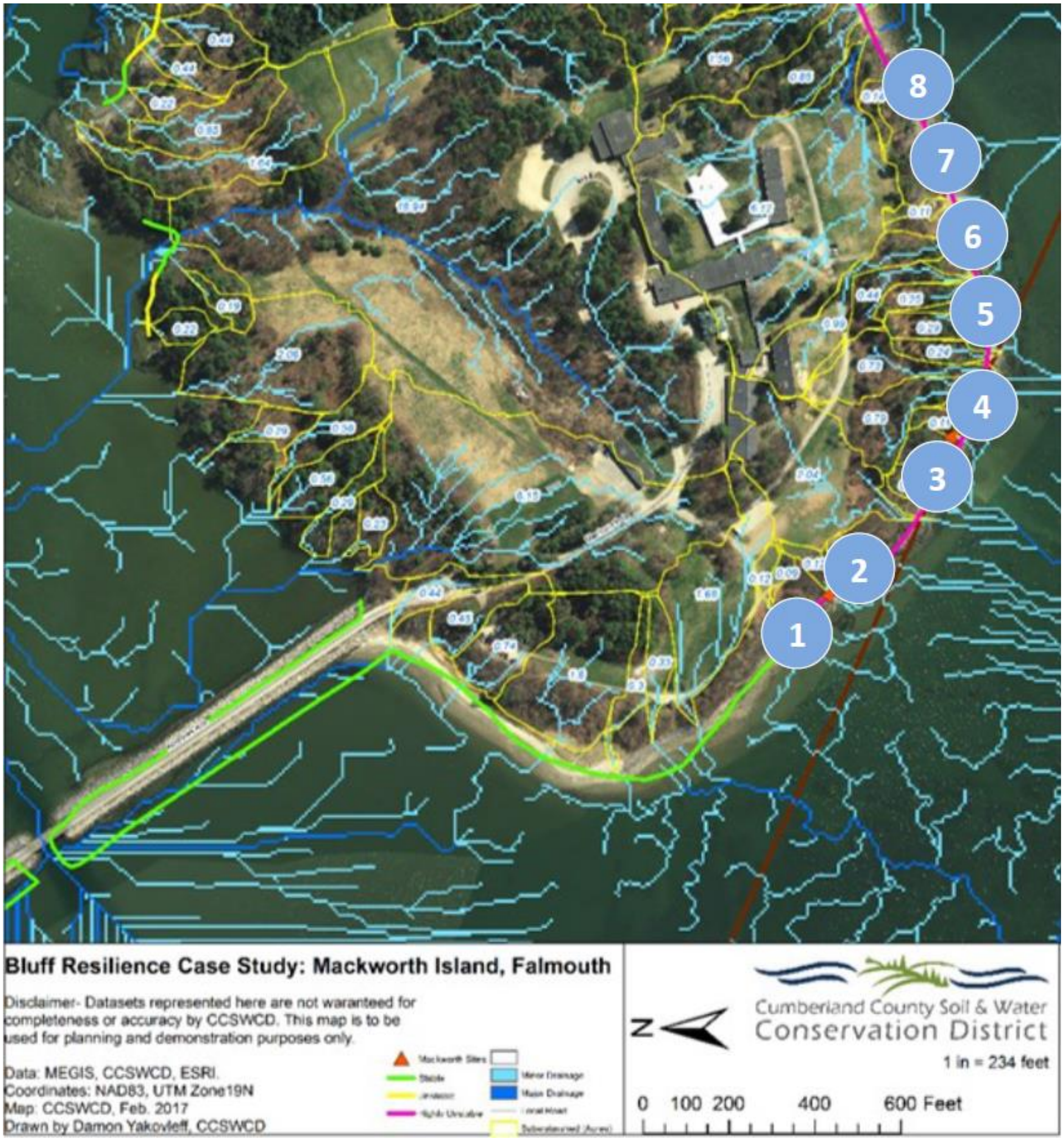


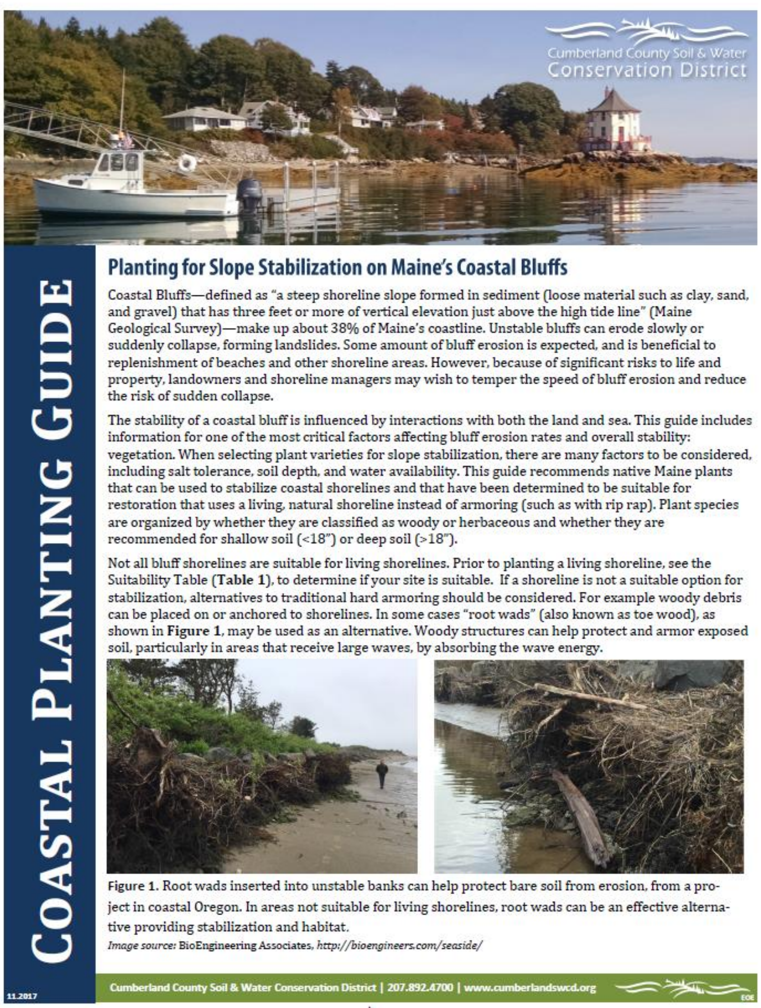
Figure 8. A portion of the Mackworth Island case study showing 8 study sites along the shoreline where drainage paths (blue lines) concentrate surface runoff on the bank. See the full map and related products in Appendix A. Graphic by D. Yakovleff.

Bustins Island has one bluff with a natural vegetated cover in one section and a traditional riprap section immediately adjacent. A high-resolution watershed model was also made for this location. This case study compared a natural bluff with one engineered with traditional riprap. Analysis suggested erosion could be minimized with better surface water runoff control and vegetative plantings on the bank. Homeowner engagement provided useful feedback for making the assessment tools and guidance developed by the District more user friendly.

Mere Point is a private property and typical Casco Bay bluff setting in a cove with a shallow intertidal zone. The cove shoreline is arcuate because of shoreline retreat between more resistant bedrock headlands. The upland consists of cleared land with considerable surface and groundwater discharge to the bluff. This site was chosen for a case study in 2017 because it experienced a landslide in the spring. This location could benefit from restoration of a fringing marsh, letting the landslide sediment be naturally reworked by tides and waves, and altering the upland drainage to reduce bluff-face runoff. All the case studies are available in Appendix A.

Bluff Planting Guide

Contractual work with the CCSWCD was amended to create a *Maine Coastal Planting Guide*. During this project, it became clear that more specific guidance was needed for bank stabilization with vegetation. Many bluffs experienced slope instability, in part, due to poor vegetation management. In many locations, invasive species or improper plants decreased bluff stability. The District created a bluff planting guide that is species-specific for different bluff positions and hydrologic conditions (Figure 9). The guide was developed with District expertise as well as the USDA-NRCS established database for Atlantic coastal restoration. Of note is how the guide addresses locations such as the top of bluff, bluff face, toe of bluff, gullies, freshwater wetlands, and coastal wetlands (Figure 9). The guide is intended for use both by homeowners and consultants and recommends readily plants that are common and readily available. The guide is hosted by CCSWCD and produced in formats for online and print use (Appendix A).



Cumberland County Soil & Water Conservation District

COASTAL PLANTING GUIDE

Planting for Slope Stabilization on Maine's Coastal Bluffs

Coastal Bluffs—defined as "a steep shoreline slope formed in sediment (loose material such as clay, sand, and gravel) that has three feet or more of vertical elevation just above the high tide line" (Maine Geological Survey)—make up about 38% of Maine's coastline. Unstable bluffs can erode slowly or suddenly collapse, forming landslides. Some amount of bluff erosion is expected, and is beneficial to replenishment of beaches and other shoreline areas. However, because of significant risks to life and property, landowners and shoreline managers may wish to temper the speed of bluff erosion and reduce the risk of sudden collapse.

The stability of a coastal bluff is influenced by interactions with both the land and sea. This guide includes information for one of the most critical factors affecting bluff erosion rates and overall stability: vegetation. When selecting plant varieties for slope stabilization, there are many factors to be considered, including salt tolerance, soil depth, and water availability. This guide recommends native Maine plants that can be used to stabilize coastal shorelines and that have been determined to be suitable for restoration that uses a living, natural shoreline instead of armoring (such as with rip rap). Plant species are organized by whether they are classified as woody or herbaceous and whether they are recommended for shallow soil (<18") or deep soil (>18").

Not all bluff shorelines are suitable for living shorelines. Prior to planting a living shoreline, see the Suitability Table (**Table 1**), to determine if your site is suitable. If a shoreline is not a suitable option for stabilization, alternatives to traditional hard armoring should be considered. For example woody debris can be placed on or anchored to shorelines. In some cases "root wads" (also known as toe wood), as shown in **Figure 1**, may be used as an alternative. Woody structures can help protect and armor exposed soil, particularly in areas that receive large waves, by absorbing the wave energy.

Figure 1. Root wads inserted into unstable banks can help protect bare soil from erosion, from a project in coastal Oregon. In areas not suitable for living shorelines, root wads can be an effective alternative providing stabilization and habitat.
Image source: BioEngineering Associates, *http://bioengineers.com/seaside/*

11.2017

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Figure 9. The Coastal Planting Guide provides information for slope stabilization with appropriate species. Many bluffs can be made more stable with proper vegetation management. Native species that are commonly available are recommended.

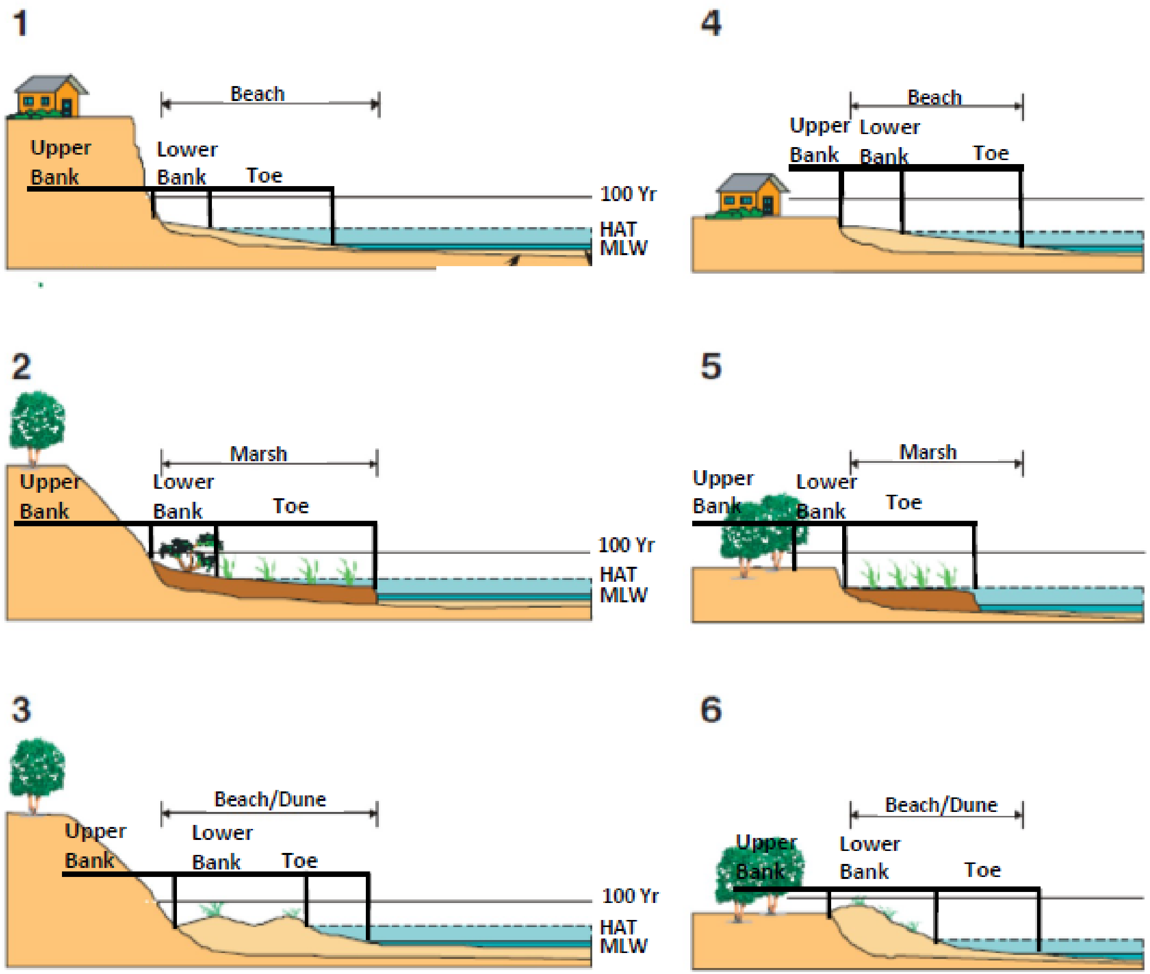

Figure 10. Cross-sections of coastal banks are divided into sections based on tidal and shore elevations. The Coastal Planting Guide recommends vegetation types for the toe, lower bank, and upper bank settings. Illustration from the guide by CCSWCD.

Municipal Planning Assistance Program

The project team's original approach to municipal outreach envisioned cooperative agreements with selected towns, whereby towns would work in conjunction with MPAP and MGS throughout the project period, working towards potential implementation of innovative bluff management provisions in the future. Due to the retirement of MPAP Director Liz Hertz, municipal liaison with Casco Bay towns was undertaken by the Cumberland County Soil and Water Conservation District and MGS. CCSWCD outreach products have been posted on the MGS and CCSWCD websites and widely publicized. The towns of Brunswick and Harpswell worked closely with the project team. See also the "Municipal Engagement" section of this report.

In 2016, plans were made for outreach to Regional Planning Councils (RPCs). A November 16, 2016 workshop was hosted by DACF's Municipal Planning Assistance Program in Augusta. Senior Planners Ruta Dzenis and Jennifer Curtis extended invitations to a larger group of municipal planners in coastal communities, including Casco Bay, to include a wider audience with interests in coastal bluffs. Dr. Dickson, Mr. Slovinsky, and Mr. Barry co-presented project progress: (1) Overview of Coastal Bluff Land Loss in Maine, (2) The Bluff Cycle and Sediment Budgets, (3) MGS Bluff and Landslide Hazard Maps, (4) Bluff Map Modification Process, (5) Setbacks and Policy Choices, (6) Traditional Engineering Design, (7) Hybrid Shoreline Stabilization, (8) Living Shorelines, (9) Case Studies, (10) Site Suitability for Green Infrastructure, and (11) GIS Analysis for Living Shoreline Alternatives.

Regional Councils were invited to the September 11, 2017 workshop at the Greater Portland Council of Governments (see the Timeline below). The Coastal Program has secured additional NOAA Regional Resiliency Awards to continue work with Casco Bay communities on the development of living shorelines adjacent to bluff shorelines.

Department of Marine Resources, Municipal Shellfish Program

Mr. Nault participated in site visits for regulatory permits and provided feedback on the DMR standards for protection of shellfish and other intertidal commercial resources. Mr. Nault participated in team meetings and coordinated with MGS on project reviews (described above).

In lieu of contracting with a coastal ecologist, the team analyzed scientific studies relevant to shoreline stabilizations (Appendix E). MacKenzie and others (2014) provided scientific insight into the ecological differences in salt marsh ecology between shorelines armored and in a natural state in Casco Bay. This and other literature help support a regulatory basis for living shorelines.

Maine Sea Grant

The *Coastal Property Owner's Guide* remained with Sea Grant as its host. During this project, MGS offered to host the site. Maine Sea Grant revised its website in 2017 and retained the *Coastal Property Owner's Guide*. This guide is one of the most-visited web sites hosted by Maine Sea Grant. Project partners cited this source of information in work products, including those produced by CCSWCD.

The video production *Building a Resilient Coast* produced with assistance from MGS, and developed prior to this project, remains available for online streaming with sections on bluff management and erosion processes. These Sea Grant materials were part of the education and outreach provided during the project and will continue, via reference, in ongoing bluff management efforts in Maine.

Maine Sea Grant co-sponsored a living shoreline workshop at the Wells Estuarine Research Reserve in May 2017 where project results were presented by Mr. Slovinsky (see Timeline below)

NOAA Office for Coastal Management

Mr. Carter provided information on SfM studies of California bluffs being done by the U.S. Geological Survey. This SfM holds great promise for calculating both short-term and long-term bluff erosion rates. Mr. Carter also provided updates in September of drone surveys being tested in California (SF Bay NEER) and New Jersey (Cousteau NEER) that include SFM and terrestrial lidar data collection.

Throughout this project, Mr. Carter consulted with MGS on many aspects of geospatial work (described above) including radar satellite data evaluation, lidar, and shoreline mapping. Mr. Carter and worked closely with Mr. Slovinsky in the development of the fetch model and living shoreline analysis with GIS.

Regulatory Framework

Policy analysis funded by another NOAA award, but coincident with this project related to discovering regulatory roadblocks for living shorelines between (1) Mandatory Municipal Shoreland Zoning, (2) state Natural Resources Protection Act, and (3) US Army Corps of Engineers General Permit (GP). Additional information is provided in Appendix C. A case example from Miller Point in Brunswick highlighted the need for regulatory guidance and consistency to include timely and cost-effective consideration of living shoreline alternatives. As described above, MGS had designed a hybrid living-engineered shoreline that was approved through the state NRPA process (Appendix B). That design was altered (with reduced natural features) for both state and federal permits to expedite a Corps GP. The team attempted to find examples of completed small-scale living or hybrid shoreline projects elsewhere in Casco Bay but found very few. Consequently, there was very little field evidence that could be applied to evaluate of performance of hybrid engineering efforts that were previously permitted.

As part of the current state permit process, Dr. Dickson compiled historical bluff change, reviewed scientific studies, created a sediment budget, advised the DEP, and recommended consideration of a living shoreline component to a traditional engineering project using riprap and geotextiles (Appendix B); based on the Harbison-Slovinsky drone flight mentioned above). Project team member Mr. Nault also reviewed this project for benthic impacts to the intertidal zone.

The Maine Coastal Program's legal expert Todd Burrowes and Mr. Slovinsky crafted a summary document on the regulatory obstacles for implementing living shorelines in Maine. These obstacles were identified by the Maine living shoreline regulatory working group formed concurrently with this project. This group is comprised of state and federal permit review and commenting agencies. MCP and MGS also created a series of recommended actions related to how the State could move forward regarding implementing living shorelines in Maine. This information was shared with NROC project partners at a larger, regional workshop on regulatory barriers, and helped lead to the development of an NROC- and TNC-led proposal to NOAA for implementing and monitoring living shorelines across New England.

Timeline of Presentations, Workshops, Educational Outreach, and Publications

2014-11-12 A project kick-off meeting was held by the Maine Geological Survey (MGS) and Maine Coastal Program (MCP) of the Maine Department of Agriculture, Conservation and Forestry in Augusta November 12, 2014. Attending were Joseph T. Kelley and Daniel F. Belknap, faculty from the U. Maine, and District Engineer Christopher Baldwin of the Cumberland County Soil and Water Conservation District (CCSWCD). At this meeting the scope of work and contracting procedures were discussed. Project partners, relevant experience, and goals were covered at the meeting. Existing MGS landslide susceptibility maps, coastal landslide maps, and coastal bluff maps were reviewed along with discussion of coast-wide 2006-2010 lidar data for use in higher resolution mapping of susceptibility, locating additional historical landslides, and improving bluff maps.

2015-04-05 Meeting with the Town of Brunswick: Bluff erosion, hazards, sea level rise, intertidal geology, landslides, and sediment budgets presented by Dr. Dickson to the Code Enforcement Officer, Director of Planning, and Marine Warden along with engineering and architectural representatives of a proposed project for Miller Point. Subsequent project proposals contained new living shoreline and sediment management components.

2015-04-08 Presentation by Dickson: *Maine Landslides: Inland and Coastal* at the Maine Coastal Erosion Control Workshop held in Portland for contractors, engineers, municipal officials, and state regulators. Keynote address by DEP Commissioner Aho with contributions by Maine Sea Grant and industry representatives showcasing hybrid shoreline designs from Maine, Massachusetts, and elsewhere in the United States.

2015-10-28 Presentation by Dickson: *Geomorphology of Presumpscot Formation Landslides* at the 2015 Symposium on the Presumpscot Formation held at the University of Southern Maine for a diverse audience including civil and engineering consultants, scientists, municipal officials, state regulators, academics, and students. Proceedings publication available online: Dickson and Johnston (2015).

2015-11-13 Presentations by Dickson: *Recycling the Presumpscot Formation, does Bluff Erosion Matter?* and by Slovinsky: *GIS Mapping of Potential Sea-Level Rise and Hurricane Inundation: Assessing Resiliency*. Geological Society of Maine, fall meeting: Using Emerging Technology on a Submerging Coast.

2015-12-11 Presentation by Dickson to the Maine Department of Environmental Protection: *Landslides in the Presumpscot Formation* as part of a Hydrogeological Technical Discussion/Meeting for department staff. DEP staff learned of factors contributing to slope failures include sediment type, surface runoff, groundwater seepage, toe erosion, and land use. The presentation highlighted how natural slope failures contribute to coastal wetlands and build resiliency to sea level rise.

2016-04-26 Project team meeting: Share progress and plan field work for the upcoming summer. The U. Maine graduate student Whiteman and professors Kelley and Belknap presented modeling work with the FLAC3D model, Structure-from-Motion (SFM) photogrammetric analysis, and the SCAPE+ model. The meeting introduced District Engineer and Geomorphologist Barry (CCSWCD) to the group. Analogs with green engineering and stabilization of rivers were discussed. A bluff checklist and decision tree was discussed by the group. Mr. Nault (DMR) provided information on important intertidal habitats and areas considered most sensitive from a regulatory and commercial perspective. Mr. Slovinsky, Ms. Whittaker, and Mr. Halstead of MGS discussed GIS shoreline engineering inventory of Casco Bay bluffs. Ms. Leyden (MCP) emphasized municipal engagement, bluff management districts, and the project timeline. A vacancy in the Municipal Planning and Assistance program (DACF) resulted in no attendance from that aspect of the team. Curtis Bohlen of the Casco Bay Estuary Partnership (CBEP) was unable to join the meeting. Mr. Carter and Mr. Marcy (NOAA, joined via telephone) were briefed and offered comments on remote sensing and studies in other locations and how little was known for cold climates that can be addressed in this project. Potential summer study sites were presented and discussed and additional locations suggested by the team.

2016-06-03 Meeting with Town of Brunswick staff to discuss this project and overlapping efforts between the town and state efforts.

2016-09-13 Living Shorelines regulatory working group meeting with state and federal agencies.

2016-06-03 Information exchange between MCP, MGS, TNC, CBEP, and Brunswick on parallel work living shoreline efforts, Casco Bay interests, and current and pending grants. Held in Brunswick at The Nature Conservancy office.

2016-10-03 Ms. Leyden presented an update on living shoreline work by Mr. Slovinsky of MGS to NROC. A Technical Working Group is providing feedback to the GIS mapping by MGS that intends to rate shorelines of Casco Bay for suitability for consideration of a living shoreline alternative or hybrid structure.

2016-10-14 Field Trip: New England Intercollegiate Geological Conference field trip A5 led by Whiteman, Kelley, Belknap, and Dickson: *Coastal Bluff Erosion, Landslides, and Associated Salt Marsh Environments in Northern Casco Bay, Maine* presented Structure from Motion (SfM) work by the U. Maine to 34 scientists, consultants, and students at several locations including SfM study sites at Freeport's Little River and Little Flying Point, and Yarmouth's Cousins Island (Figure 11). Trip guide provided and available online: Whiteman et al. (2016).

Figure 11. Geologists from around the northeast visit the Little Flying Point site with team members. Bluff science, hazards, and policy options were presented. Photo by W. A. Anderson.

2016-11-16 Regional Councils of Government Meeting: Presentations by Dickson, Slovinsky, Barry, and Leyden to a Regional Council meeting led by the DACF Municipal Planning and Assistance Program. Topics included how bluff maps are made, used in Shoreland Zoning, amended or updated by MGS, this project's progress identifying suitability criteria for living shorelines, and case studies from CCSWCD as examples of site evaluation process.

2016-11-18 Presentation by U. Maine graduate student Nick Whiteman: *An Introduction to Structure from Motion and a Trial Application for Measuring Coastal Bluff Erosion* to the Geological Society of Maine at the Augusta Civic Center. This meeting theme was Geographic Information Technology and Applications and was attended by over 40 professional geoscientists including U. Maine project partners Drs. Kelley and Belknap. Members provided supporting comments and questions and the work by Mr. Whiteman was well received.

2016-12-13 Presentation by Mr. Slovinsky at Restore America's Estuaries/The Coastal Society national conference, titled *Using Municipal Engagement to Increase Resiliency to Coastal Hazards: Maine's Projects of Special Merit.* The presentation included information on Maine's bluff and living shoreline project efforts. New Orleans, Louisiana.

2017-01-31 Meeting with Town of Brunswick on coastal bluff maps and shoreline erosion efforts. Brunswick pursuing formation of a shoreline/bluff working group to help facilitate best management practices within municipality for bluff management.

2017-04-21 Presentation by Mr. Slovinsky at the Maine Land Surveyor's annual conference on sea level rise, bluffs, and mapping efforts.

2017-05-04 NOAA Section 312 Review: Introduction to coastal bluff investigations with a field trip to

Webb Field Road on Mere Point in Brunswick (a case-study site). Participation by MCP, MGS, CCSWCD, Town of Brunswick, and NOAA review team.

2017-05-17 Workshop: Mr. Slovinsky and Mr. Barry jointly presented: *Living Shorelines and Decision Support Tools* at the Wells National Estuarine Research Reserve for a Coastal Training Program (CTP) Introducing Green Infrastructure for Coastal Resilience. Led by NOAA and Maine Sea Grant Extension for municipal officials and regulators.

2017-08-23 and 2017-09-15 Mr. Slovinsky met with MEDEP staff to discuss bluff management, living shorelines, and living shoreline decision support tool applicability.

2017-09-11 Workshop: Building Resilient Coastal Bluffs, Cumberland County Soil and Water Conservation District and project partners, Greater Portland Council of Governments, for municipal officials, consultants, state agencies, regional planners, and homeowners. Presentations by Dr. Dickson, Mr. Slovinsky, Mr. Barry, Mr. Yakovleff, Mr. Woolston (Brunswick Planner) showcasing state of the science, living shoreline suitability determination, site evaluation decision trees, regulatory considerations, and possible engineering designs. Attended by 40 with engagement and positive feedback from attendees (Figure 12; Appendix C).

Figure 12. The workshop Building Resilient Coastal Bluffs brought together federal, state, and local officials. Consultants, municipal planners, and citizens rounded out the attendees. Workshop presentations are in Appendix C. Photo by A. Strause.

2017-10-23 Presentation by Mr. Slovinsky and Mr. Yakovleff titled *Assessing Suitability of Living Shorelines on Coastal Bluffs* at the annual Maine Stormwater Conference, Portland, Maine.

2017-10-26 Workshop attended by Mr. Slovinsky on Living Shorelines, Portsmouth, New Hampshire. Brought together contractors, consultants, and regulators to discuss living shoreline projects in New England.

2017-11-01 Presentation by Mr. Slovinsky titled *An Update on Living Shoreline Project Efforts in Maine: NOAA Regional Resilience Project* at the annual ME/NH CCAP-CAW meeting, Wells, Maine.

2017-11-14 Presentation by Mr. Slovinsky titled *Assessing Living Shoreline Suitability on Coastal Bluffs*, Maine Watershed Manager's Meeting, Augusta, Maine. Attended by watershed managers and engineers throughout the New England region.

Municipal Engagement: Brunswick and Harpswell

The Town of Brunswick is directly benefitting from this project. MCP, MGS, and CCSWCD have met multiple times with municipal officials to develop a better understanding of bluff hazards, shoreline stabilization options, and policy revisions that include changes to Municipal Shoreland Zoning. Brunswick established a Shoreline Erosion Working Group with participation by Mr. Slovinsky and Mr. Barry. Mr. Nault (DMR) was directly involved in this project. State Soil Scientist David Rocque (also of DACF) contributed to the Brunswick working group as did representatives from the Department of Inland Fisheries and Wildlife, and Maine Coast Heritage Trust. This full working group represents the most significant municipal engagement during the project period. The team helped the town develop shoreline management best management practices for eroding bluffs and investigated the use of living shoreline approaches (Brunswick, 2017).

The Town of Harpswell expressed interest in technical assistance to deal with bluff erosion at Mitchell Field. Mr. Barry, Mr. Yakovleff, and Dr. Dickson met with the town's Mitchell Field Committee on March 6, 2017. The CCSWCD provided an overview of the case study findings and MGS provided the geological context driving erosion and background on regulatory standards. The committee is interested in additional assistance for planning shoreline stabilization (more below; Figure 13). This location would be an excellent location to install a variety of living shoreline designs to test and evaluate their performance under a similar physical setting.

Figure 13. A section of eroding bluff at Mitchell Field shows exposed glacial till and slope creep in a birch tree trunk. Toe erosion here could be mitigated with revegetation, tree wads, and cobble beach nourishment. Photo by S. M. Dickson.

State Engagement: DACF Bureau of Parks and Lands

MGS and MCP met with the Bureau of Parks and Lands in the process of finalizing the Coastal State Parks Project of Special Merit. As a result of case study work at Mackworth Island (a BPL property) MGS suggested to BPL in March that there was a public safety need to manage erosion and hiking trails along bluffs at the park (Figure 14). Subsequently, MGS has reached out to begin engagement with the regional parks manager and the Mackworth Island ranger. Work by CCSWCD has been shared with BPL and additional work on the property, site evaluations, and recommendations are a goal for the upcoming summer.

Figure 14. Erosion enhanced through surface water runoff and wave action destabilizes a bluff at Mackworth Island. Land loss next to a trail poses a public safety hazard. Photo by S. M. Dickson.

Permitting Innovations

Lubec, Maine: Cobble beach nourishment to reduce bluff erosion and restore a shoreline at a former herring canning factory; historical structure relocated to an area landward of a bluff and avoiding flooding from additional sea level rise and hurricane surges (DEP Permit L-26861-A-N; Appendix B). This was the first application of **coarse-grained beach nourishment** to protect a bluff while mimicking a natural shoreline (Appendix B). This approach has potential application at the Mitchell Field case study site in Harpswell.

Brunswick, Maine: Consideration of a living shoreline to isolate riprap stabilization from direct wave attack and upper intertidal scour in Merepoint Bay (location 8 in Figure 1; inner Casco Bay). Pre-application consultation with MGS provided the Town of Brunswick with its first significant project related to Shoreland Zoning, sediment budgets next to commercially important tidal flats, and a general understanding of the limitations of existing development standards. The applicants were willing to **recycle bluff sediment** removed during installation of riprap to build a **fringing salt marsh** fronting stone riprap (Figure15). Working with the applicant's construction firm, living shoreline concepts and economic savings (from re-using bluff sediment on site) were scoped and designed. Consultation with DEP led the first consideration of a waiver of a fee for filling a coastal wetland. The U.S. Army Corps of Engineers permit requirements for ecological study of the impacted coastal wetland led to additional cost and uncertainty so the applicant scrapped the living shoreline concept. The Town of Brunswick issued a moratorium on Shoreland Zoning projects of this type until its regulations and standards could be better written. This project led the Town of Brunswick to participate with this project and partners in advancing municipal standards for subsequent projects (DEP Permit L-26631-4D-A-N; Appendix B).

Figure 15. A fringing marsh near Miller Point (in the background) provided a natural example of a living shoreline that could be established in inner Casco Bay. A 30-foot high vegetated bluff rises above the marsh. More about Miller Point is in Appendix B. Photo by S. M. Dickson.

Brunswick, Maine: Landslide site remediation and further bank stabilization to reduce landslide risk at Bunganuc Bluff in Maquoit Bay (inner Casco Bay) was necessary with traditional engineering methods. MGS recommended a **living shoreline alternative** approach to repurpose landslide sediment to benefit the intertidal zone and local "mud budget" to keep a more natural shoreline and to reduce environmental impacts. This concept acknowledged that the sediment at the toe of the slope was **sacrificial** and require periodic maintenance, just like a natural landslide toe would be at this location. DEP Permit L-27186 allowed for a traditional shoreline stabilization but remaining landslide sediment could become reworked naturally by waves and tides in the bay (Figure 16; Appendix B).

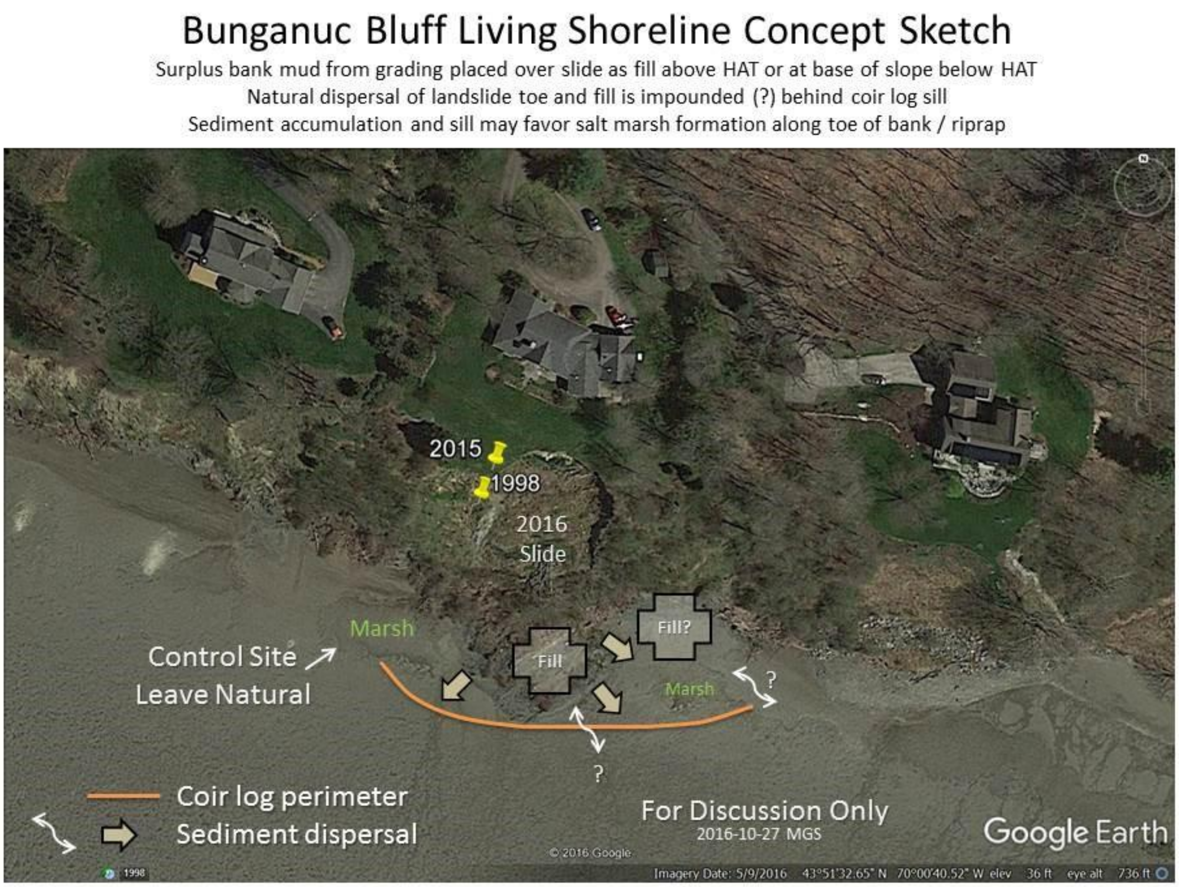

Figure 16. Bluff retreat from landslides in 2015 and 2016 created an urgent need for stabilization at Bunganuc Bluff. Ways to use living shoreline features were explored so that the intertidal sediment could be retained and possibly support a fringing salt marsh. MGS comments on a stabilization project here are in Appendix B. Graphic by S. M. Dickson.

Continuing Outreach

Maine Soil and Water Conservation Districts

The CCSWCD web site hosts information on erosion and runoff control and is used by many municipalities and contractors. The newest District news release provided a source of information from this project through their web site (Appendix A). The District provides ongoing news updates distributed to all the individuals and organizations on their mailing list who will continue to receive information on project materials.

Tom Gordon (DACF, Soil and Water Conservation Program Coordinator) provided outreach to all of Maine's coastal county Soil and Water Conservation Districts to alert them of new resources created in the project and distributed via the Cumberland County SWCD.

Municipal Planning Assistance Program

The Department of Agriculture, Conservation and Forestry's MPAP hosts guidance documents for communities to use. Topics include ordinances, infrastructure, and water quality. The MPAP web site includes planning materials, informal guidance on comprehensive plans, and additional resources. This information is available for regional planning organizations and municipalities as needed to plan for coastal change.

MGS Web Site and Web Mapping Portals

Mr. Halsted developed an online MGS web mapping portal that allows custom mapping of shorelines with multiple data layers. Additional data layers can be imported and applied using this portal. This includes the MGS Coastal Buff Map and Coastal Landslide Hazard Map layers. The most useful layers for bluff site evaluation are lidar-based topography, surficial geology, depth to bedrock, intertidal geology, and property boundaries. Additional layers that can be of use in some locations includes well depth, yield, overburden and significant sand and gravel aquifers. These data can be combined with the Highest Annual Tide (regulatory) position and inundation from various sea level or storm surge scenarios. Other resource agency data such as tidal waterfowl habitat or endangered species locations can be added.

The Maine Geological Survey web site has a considerable amount of information on coastal bluffs and erosion. MGS has maps of bluff stability that are on a base map called a topographic quadrangle (not too detailed). These maps are used for local Shoreland Zoning setbacks for new or significantly modified real estate. If a site is mapped as Unstable or Highly Unstable on one of the Coastal Bluff Maps, then the setback starts at the top of the bluff. Areas mapped as Stable have the setback from the Highest Annual Tide. The MGS Coastal Hazards web site provides the position of the Highest Annual Tide and higher static water levels from a variety of scenarios. This site-specific information can be used for local surveying, mapping, and bluff stabilization projects.

Maine Sea Grant

The Maine Sea Grant web site has information on evaluating bluffs that MGS helped create prior to this project. In addition in 2009, Maine Sea Grant in collaboration with Oregon Sea Grant created streaming videos that include MGS description of coastal bluff processes: Building a Resilient Coast: Maine Confronts Climate Change.

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See Appendix E for more references with annotations.

Appendices

Appendix A – Cumberland County Soil and Water Conservation District Products

Appendix B – Regulatory Examples

Appendix C – Workshop Materials

Appendix D – University of Maine

Appendix E – Annotated Bibliography