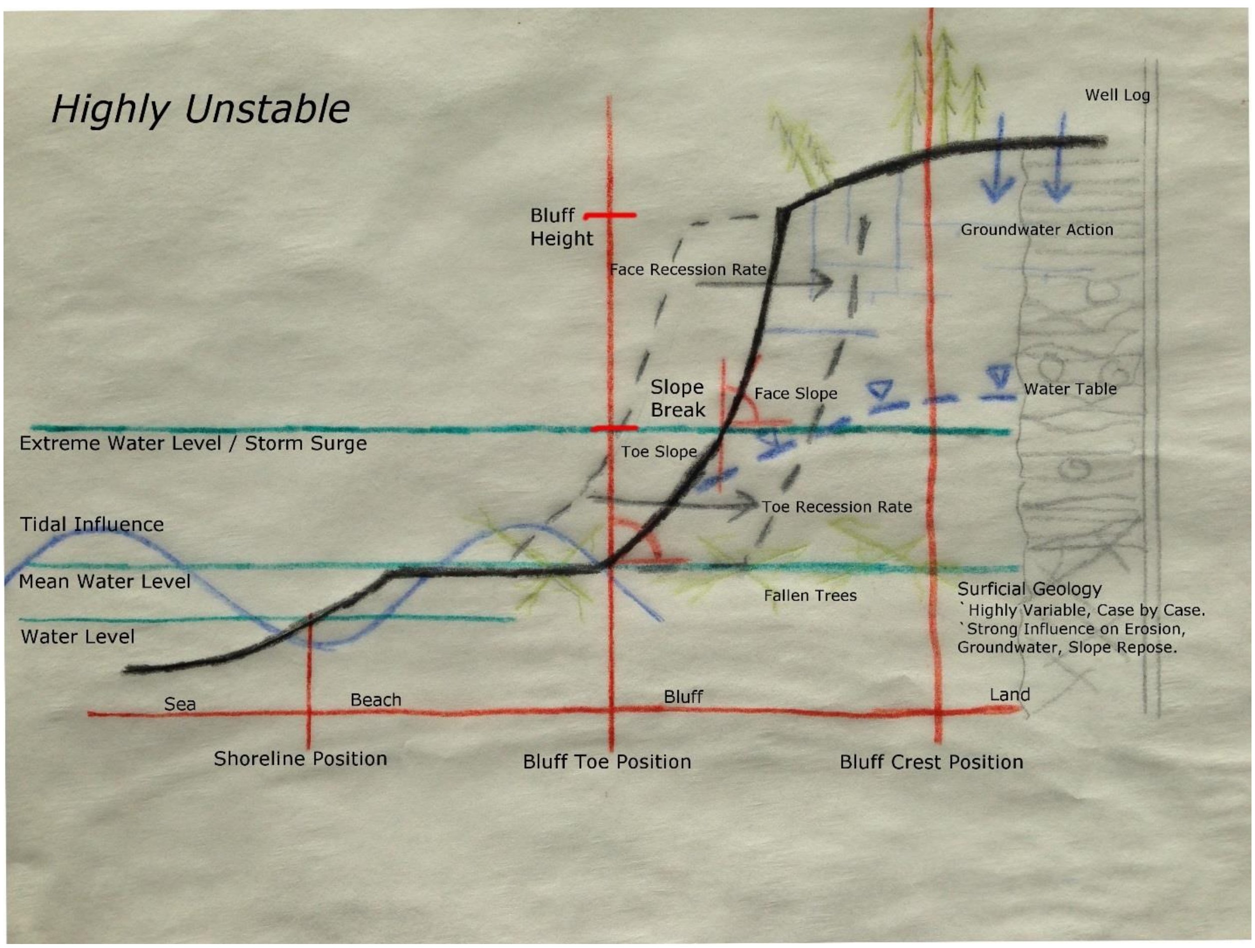
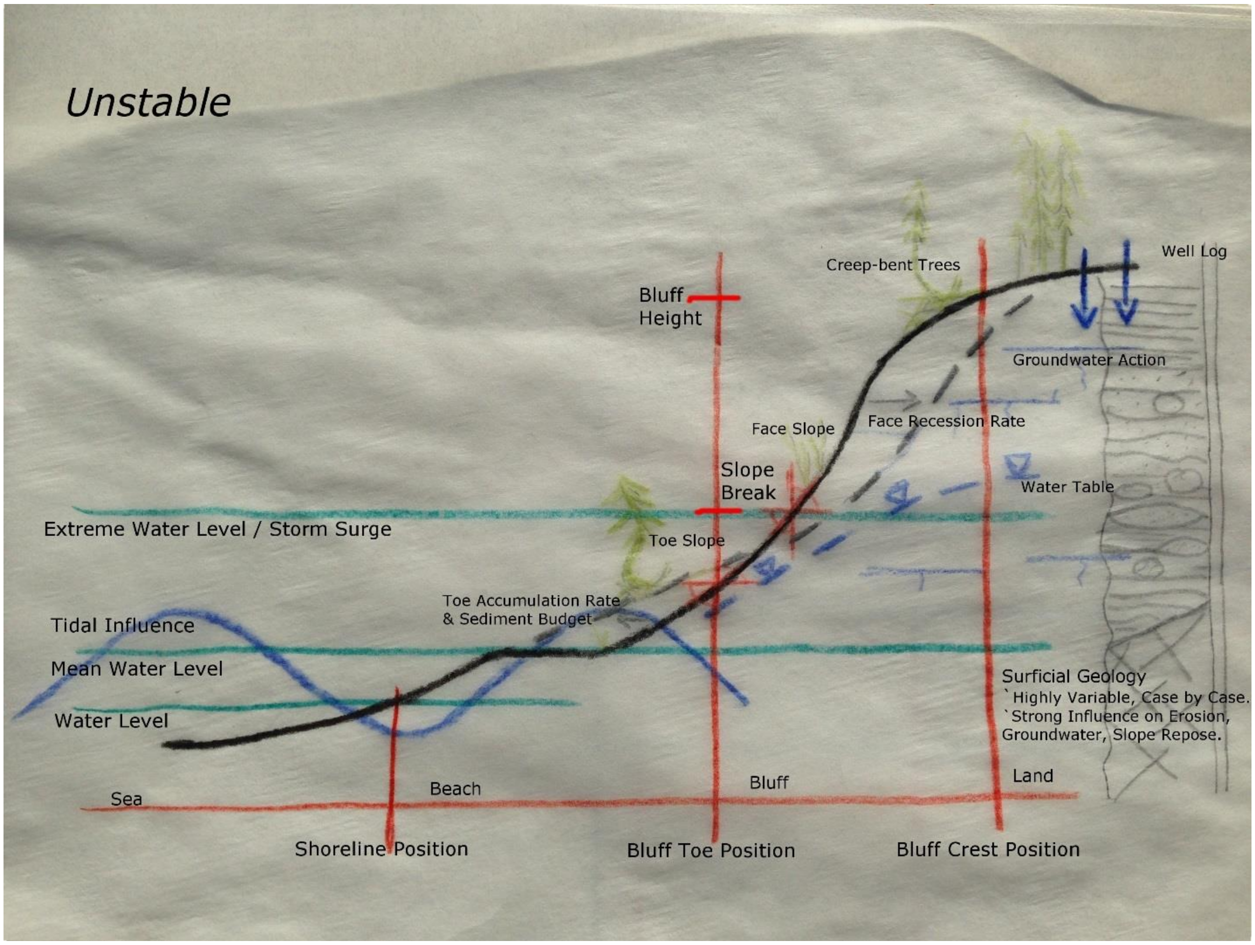
Introductory Concept Sketches & Contemplation

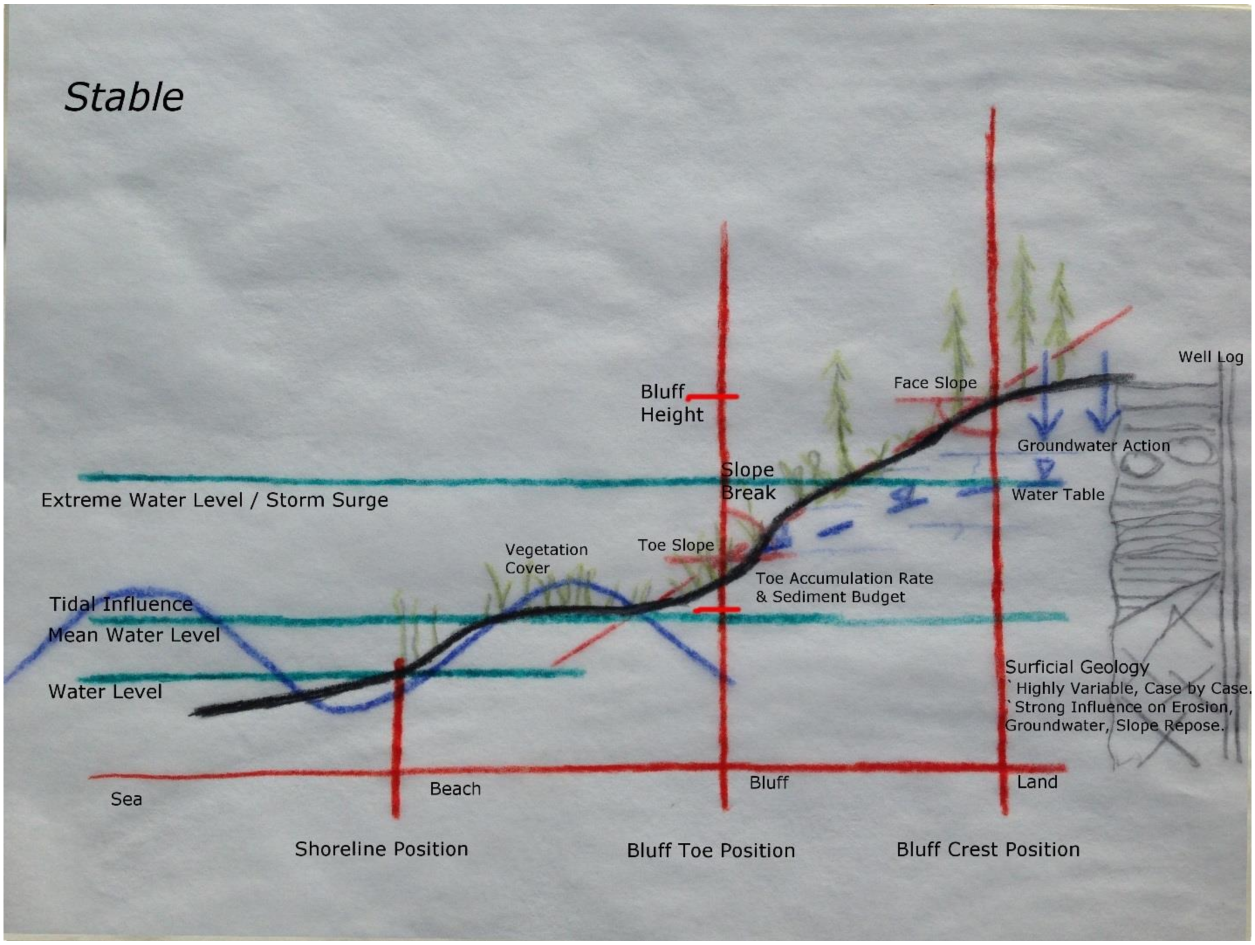
Prepared by Nick Whiteman

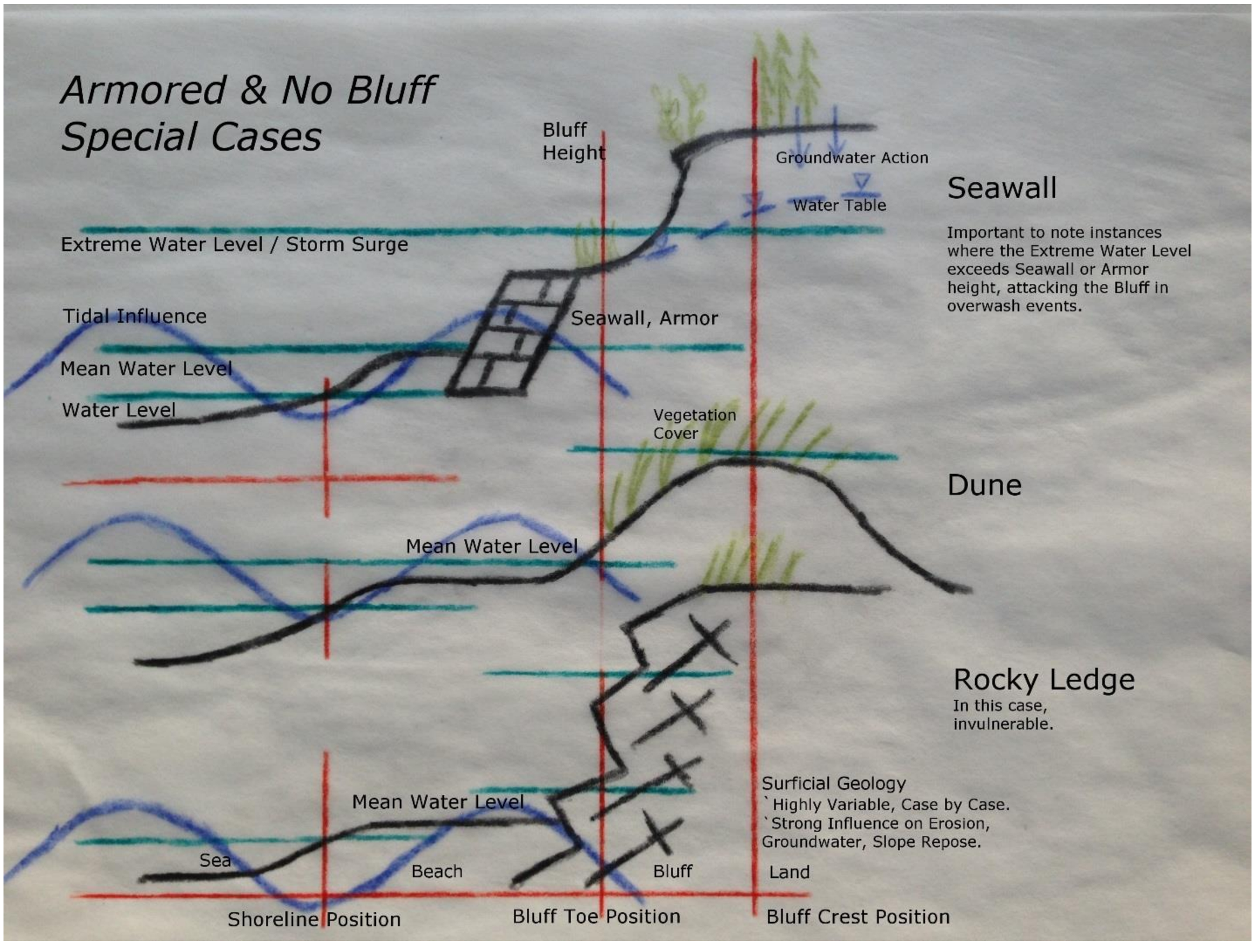
The figures are drawn to showcase four characteristic bluff profiles (as detailed by Joe Kelley and Steve Dickson circa 2000) to prompt discussion of, and prioritize, the many interactive variables governing the change in coastal forms. Resolution of these variables will support the construction of a GIS model.

As is, the figures are not set to a particular scale. They are shaped in a representative fashion and spaced in an approximate manner for the sake of demonstration. Details of surface geology, material sorting, and groundwater are in these instances imaginary. While inspired by the Presumpscot Formation, something as greatly variable as a glaciomarine deposit must remain unrefined until actual site assessments are made. Nonetheless they are included here as a reminder of their major influence on principles of mechanical erosion and groundwater actions.




Unstable
Creep-bent Trees
Well Log
Bluff
Height
Groundwater Action
Face Slope
Face Recession Rate
Slope
Break
Water Table
Extreme Water Level / Storm Surge
Toe Slope
Toe Accumulation Rate
& Sediment Budget
Tidal Influence
Mean Water Level
Surficial Geology
`Highly Variable, Case by Case.
`Strong Influence on Erosion,
Groundwater, Slope Repose.
Water Level
Beach
Bluff
Land
Sea
Shoreline Position
Bluff Toe Position
Bluff Crest Position


Stable
Bluff Height
Face Slope
Well Log
Groundwater Action
Slope Break
Water Table
Extreme Water Level / Storm Surge
Vegetation Cover
Toe Slope
Toe Accumulation Rate & Sediment Budget
Tidal Influence
Mean Water Level
Water Level
Surficial Geology
` Highly Variable, Case by Case.
` Strong Influence on Erosion, Groundwater, Slope Repose.
Sea
Beach
Bluff
Land
Shoreline Position
Bluff Toe Position
Bluff Crest Position


Armored & No Bluff
Special Cases
Bluff Height
Groundwater Action
Water Table
Seawall
Important to note instances where the Extreme Water Level exceeds Seawall or Armor height, attacking the Bluff in overwash events.
Extreme Water Level / Storm Surge
Tidal Influence
Seawall, Armor
Mean Water Level
Water Level
Vegetation Cover
Dune
Mean Water Level
Rocky Ledge
In this case, invulnerable.
Surficial Geology
`Highly Variable, Case by Case.
`Strong Influence on Erosion, Groundwater, Slope Repose.
Mean Water Level
Sea
Beach
Bluff
Land
Shoreline Position
Bluff Toe Position
Bluff Crest Position

POSM – Building Resiliency along the ME Coast –
Nicholas Whiteman, March 25, 2016.

I have been working to prioritize process-phenomena and data components that will serve to support the creation of a GIS concerning coastal resiliency; land loss resistance & remediation; and landslide hazard management in Maine's Casco Bay.

Many studies aiming to analyze soft-shoreline erosion with numerical models lament the necessity to either oversimplify model parameters or greatly extend the time series in order to produce an average rate of shoreline retreat, regardless of the often-episodic nature of the erosion events. Such generalized results are of little use to communities with site-specific concerns and, or, the need to consider the administration of coastal zones in a practical timeframe.

By working to model the situational environment in which coastal bluff erosion occurs in southern Maine a stronger understanding of dominant influences can be derived and more sophisticated analytical components could be refined with site-specific information. As the model matures, predictions of threshold conditions and hazard vulnerabilities could be made more reliable, fostering a greater 'resolution' of shoreline behavior and sedimentation budgeting for the numerous coastal compartments within Casco Bay.

Along with collecting supportive information such as DEMs and water level records I have been actively seeking existing numerical models that may serve the project such as SCAPE, *Soft Cliff and Platform Erosion*, recently made available through the iCOASST project; SWAN, *Simulating Waves Nearshore*; and FLAC, *Fast Lagrangian Analysis of Continua,* available to me at UMO for determining failure characteristics and mechanical properties of digital bluff forms.

An additional focus of my preliminary research has been to look to other communities to compare the many different approaches not only to modeling shoreline behaviors; hazard management; and land loss solutions; but to contrast a variety of geologic settings and perspectives across the United States and elsewhere in the world.

My coursework at the University so far has involved a detailed history of Maine glaciation, particularly focused on the Presumpscot Formation that makes up the local bluffs; exploring remote sensing techniques and geomatics practices while building proficiency with ArcGIS; working with numerical modeling applications to geodynamic systems; and examining wave energy influence on near shore sediments. I have also practiced building and querying databases in GIS by considering NOAA harmonic tidal predictions in Casco Bay and how the concurrence of storm surges and extreme tides can greatly alter the attack of surf at the bluff toe.

Looking forward there are many more concerning factors and I am currently curious about the role that groundwater plays in bluff stability as well as seasonal stressors. It will also be important to build a stronger understanding of how man-made systems may aggravate the sensitivity of the bluffs.

An effective GIS model will need to coordinate a complicated network of databases; present information in an readily accessible way; promote analysis; and be adaptable to further, if not perpetual, input and digestion of observational data once developed beyond the point of imitating historical records. Conditioning the system to fit real time sensory data to environmental parameters while actively analyzing site sensitivities will be important for the usefulness of the GIS; its adaptability; and potential for export to other areas along the Maine coast and beyond.

Modeling Bluffs, Key Parameters to Consider:

Geometry	Geotechnical
Height & Width measurements, estimates. Shoreline position of toe, top edge of bluff. "knickpoint" – the transition from Toe angle to more severe Face angle - position. Slope angles of Toe and Face. Undercutting or, conversely, "run-out" platforms. Existing engineering: armoring structures & extent of coverage. Scarps. Aspect/Orientation of Face. Comment on curvature of Face (In relation to both vertical profile and shore-normal perspective). Distance of Home or structure setback. Rock outcrops, "invulnerable" boundaries. Tidal Range, shore-normal extent of beach or berm. Apparent contrasts in Stability Class: >Do we see Unstable bluffs in relation to a developed property adjacent to more Stable or vegetated zones?	Information related to Mohr-Coulomb Plasticity: >Bulk & Shear moduli >Friction and Dilation angles >Cohesion >Tensile Strength Comment on heterogeneity of bluff composition Evidence for perched water, springs, coarse-sediment lenses, seepage faces. Existing engineering: drainage systems. Comment on vegetation coverage. >large trees vs small growth >debris at Toe >Presence of tidal grasses Sediment profiles: >Differences at Toe vs. Face? Bluff top vs. Beach platform? >large clasts and tooling vs. armoring potential Pore water pressure and any available groundwater information will be important but may be difficult to collect w/o formal study.

Some comments:

For the time being I will be informing the model simulations with existing case studies (say, from ME DOT) on the Presumpscot Formation for a substitution input of geotechnical information.

The more site-specific information we can gather the better to refine the simulations. The goal being to move from estimates towards measurements.

LiDAR DEMs have been useful for informing basic bluff geometries but are limited by their resolution. Information about slope profile; undercutting relief; or armoring coverage can be easily lost in a simple transect measurement. This is especially true for the more intertidal sites (e.g. Fore River) where overall relief may be more nuanced than sites such as Cousins Island.

It also follows that Aspect and Orientation of the bluff Face can be measured from GIS already, nonetheless it is important to consider

I am particularly interested in sites where it seems there is a back-up of mass-waste at the base or repeated superposition of failure units overtopping debris or armor structures at the toe.

It is important to keep an eye out for evidence of high-water run-up position, such as seaweed deposits or active erosion. Just as well, any evidence of rifting or extensional strain at the bluff top.

Comments on the overall environment will be appreciated: Land use, typical wave energy, etc. Is this bluff within a sheltered cove compartment or open to a larger bay and expansive wind fetch?

Photographs face-on and along-shore with a sense of scale will be greatly appreciated.

Geospatial positioning info, at least an address or basic GPS coordinate, will also be appreciated.

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, July 1st, 2016

I have been working to prioritize process-phenomena and data components that will serve to support the creation of a GIS concerning coastal resiliency; land loss resistance & remediation; and landslide hazard management in Maine's Casco Bay. At this time fieldwork has begun in a fledgling manner and has become the central focus of my efforts for the season. Interpretations and measurements obtained now will form the basis for the development of the end-goal predictive model and a foundation for future observations.

Project Objective as Stated by "Exhibit A," attached.

"Understand the implications of storms and shoreline change on bluffs by using existing bluff stability and landslide hazard maps; historical erosion rates; accelerated erosion rates driven by climate variability; and newly derived data to develop and apply a transferable predictive model for bluff erosion and landslide susceptibility."

Brief comments on the Objective:

Use of existing bluff stability and landslide hazard maps

Readily incorporated into efforts where applicable. Manipulation of the display of variables in the map file reveals trends and helps ID potential sites of concern. The criteria selected in the foundation of these map products guides much of the approach to understanding local scenarios and will be used and built upon in the development of the predictive model.

Historical erosion rates

Literature review finds that historical erosion rates in the area are few and far between. What information is available is useful for evaluating the acceleration of erosion rates and will be incorporated into the statistical element of the predictive model where appropriate.

Accelerated erosion rates driven by climate variability

Needs to be observed in action. Preparing a protocol for more detailed measurements, "perpetual" observation, and collection of more temporally significant erosion data as part of my efforts.

Newly derived data

New data will be generated by field study of chosen exemplary sites within Casco Bay and, with the refinement of the model, elsewhere along the shoreline. Primary sources will be measurement by *Structure From Motion* [SFM] software, and numerical outputs concerning slope failures as studied in select computer models discussed below (*FLAC 3D* and *SCAPE+*).

Predictive model for bluff erosion and landslide susceptibility & Understanding implications of storms and shoreline change

Many studies aiming to analyze soft-shoreline erosion with numerical models lament the necessity to either oversimplify model parameters or greatly extend the time series in order to produce an average rate of shoreline retreat, regardless of the often-episodic nature of the erosion events. Such generalized results are of little use to communities with site-specific concerns and, or, the need to consider the administration of coastal zones in a practical timeframe. The predictive model aims to blend, by use of GIS, more situational and cyclic

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, July 1st, 2016

information such as tidal extremes and meteorological trends with single or sudden events such as landslides and measured local retreats or mass failures.

By working to model the situational environment in which coastal bluff erosion occurs a stronger understanding of dominant influences can be derived and more sophisticated analytical components could be refined with site-specific information. As the model matures, predictions of threshold conditions and hazard vulnerabilities could be made more reliable, fostering a greater 'resolution' of shoreline behavior and sedimentation budgeting for the numerous coastal compartments within Casco Bay. Employing modern photogrammetry systems afforded by *Structure from Motion* software to make detailed measurements and detect changes over time in exemplary settings will greatly benefit the development of a model of bluff erosion.

From Objective: Proposed Work Flow
> Use GIS to manage historical and collected data
> Use GIS to identify locations considered to be at risk
> Use GIS to identify locations considered exemplary

> Survey chosen sites
Establish baseline measurements and controls
Develop individualized plans for continued observation and return visits
Archive photo-record.

> Compose models for each survey
Structure from Motion process
Export point clouds and 3D surface products *

X Analyze models
Derive measurement data
Test scenarios in FLAC3D and SCAPE+
Work from field observations and ground truths towards extrapolated situational understanding
Collect statistical resources for Predictive Model

X Process statistical relationships for forecasting and rate predictions

X Feed into GIS
Visualization and spatial relation of numerical output products
Plumb GIS for continued data input and statistical interpretation.

***Feedback into GIS.**
>-Ongoing
X-Awaiting

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, July 1st, 2016

Discussion of Progress:

Of primary concern is the ongoing uncertainty in the choice of Casco Bay communities and official sites of interest. This has stunted the ability to prepare for regular study and data collection. Due to the nature of the *Structure from Motion* photogrammetry system the initial set up and evaluation of each site chosen is far more time consuming than any return visits. Consequently it is important to establish these sites as soon as possible to handle their preparation carefully. Each chosen site must first be evaluated so that an individualized plan of action can be created in order to make the most of ongoing surveillance and detection of changes over time. For example, such a plan must consider site accessibility and useful vantage points, which can be sensitive not only to tides but greatly dependent on the degree of obstruction by seasonal variation in vegetation. Additionally, on the first approach, GPS control point measurement and placement of survey flags as targets for the photogrammetry is relatively labor intensive when contrasted with the simplicity of regular or event-specific return to each site for later collection of a photographic record. A survey postponed misses out on observational opportunity and prolongs the development of digital models for numerical inquiry. Aside from the necessary field visits most analysis and model development can and will be effectively conducted in the computer lab with only a few limitations, such as processing time. Again, few advances can be made beyond preparation, practice, and design until the specific locations are chosen.

Data collection and fieldwork:

Fieldwork

Fieldwork will be centered around the SFM survey of selected bluffs and sites of concern. This survey method encourages observation and attention to detail; will document changes over time; and promotes greater awareness of the coastal system and erosive processes. It is quick to learn and easily transferable to other users. As described earlier in the report the most demanding aspect is the initial establishment of a site. Once controls have been measured and a base set of photographs have been collected and modeled there is little more to do in the field but return for follow up photography when appropriate, for example after a storm or high-water event.

Coming into the summer season our efforts have been focused on finding familiarity with the SFM techniques, methods, and applications. Utilizing digital SLR cameras we have begun exploring the technology by making several trips to sites of interest, namely Little River in Freeport, ME and Cousins Island in Yarmouth, ME as well as investigating suspect sites nearby. These locations have been selected to start from for their ease of public access and obviously eroding bluffs. Following inspiration from literature and analogous studies conducted elsewhere we have begun to develop an adaptable survey protocol to be applied to bluffs chosen for the project.

We are planning to continue surveying the sites mentioned above and will establish new surveys as the team chooses the next locations.

SFM is discussed in greater detail below. Control points are established by GPS, at present by a system of flags placed a measurable distance from a sturdy rebar-pin on which a GPS antenna may be directly affixed. This allows for geolocation of the models in a GIS and application of a scale to each feature surveyed. Given the nature of the environment; bluff erosion process; and expectation of movement throughout the study a GPS control is favorable in comparison to the selection of a landmark feature such as a large boulder or distinct tree, which is common practice in many SFM studies.

Digital Models*

FLAC3D – ***Fast Lagrangian Analysis of Continua in 3D***

This program is used to study mechanical behavior, numerically, of 3D modeled mediums (such as a body of glaciomarine clay) under stress and strain as it approaches equilibrium or undergoes plastic flow. Models of chosen bluffs generated from SFM with attributed mechanical properties to match their composition can be tirelessly tested to explore threshold conditions of bluff failure such as over steepening, surface loading, groundwater surge etc. The numerical outputs of these test runs will be used in the development of the predictive model.

I have encountered a difficult learning curve with the software, though it is not insurmountable. There are many here at the University of Maine who have worked with the program and have offered guidance. At this stage in the project it is more important to pursue the generation digital surface models by SFM to later feed into, and test with, FLAC3D. Meanwhile I have been working to understand the program by designing mock-bluffs of basic geometric form and learning how to assign mechanical properties. Collecting data from Maine DOT surveys and other literature has provided basic information such as the tensile strength, bulk and shear moduli, and friction angles (etc.) of the Presumpscot Formation glaciomarine sediments predominant in the area. Further work needs to be done to understand how to properly apply boundary conditions to the models and to code for looping conditions such as excavation at the bluff toe or changes in ground water saturation.

SCAPE – ***Soft Cliff and Platform Erosion***

SCAPE works to evaluate the response of a shoreline and evolution of platform to changing sea levels by considering integrated erosive potentials across tidal fluctuations and managing 2D sediment "exchange," over longer timescales. As FLAC3D will be used to understand failure conditions and landslide hazard potentials, SCAPE will be used in conjunction to manage a changing shoreline in response to sea level rise and the consequent effects an altered shoreline will have on events such as wave run-up reaching a bluff or degrading any protective sediment masses in the foreground.

The SCAPE model has proven difficult to obtain. While mentioned in a fair amount of literature; used in many analogous coastal erosion studies; and declaratively open source; the program has not been available for download or experimentation, *yet*. We have been in contact with one of the model's creators and expect that we will be able to use the software. It has been revived and

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, July 1st, 2016

revamped for a coastal erosion project in the UK (iCOASST) and the organization is packaging and preparing to release the model soon. Again, it is currently more important to focus on the modeling of the bluff environments during this time of year.

Structure from Motion [SFM]

SFM software utilizes raster analysis and machine learning algorithms to detect unique surfaces and visual "textures" in a collection of photographs. From this, using digital models of camera geometries and the exploitation of parallax principles a computer has been proven capable of generating accurate 3 dimensional point cloud surface models akin to that of terrestrial LiDAR. The increased availability of more powerful graphics processors has fostered the Structure from Motion technique. The technology has rapidly been adopted as an affordable, efficient, and effective alternative to said LiDAR.

Survey by SFM is posed to make up the majority of fieldwork study and data collection for our contribution. From the photographs collected and the models generated a vast amount of information can be derived, supporting our understanding of the problem and exploring the concerns of the project; such as an effective method of determining a sediment budget based on detecting volumetric changes in the bluff form. At the very least these photographic records will greatly increase situational awareness that the project currently lacks.

Through literature review and discussion with other users of SFM we have found it to be an appealing and agreeable method for conducting survey of coastal bluffs and detection of changes over time. Studies have demonstrated centimeter-scale accuracy given proper controls and care in processing. This is a significant improvement on the Maine State LiDAR DEM featuring a two-meter resolution.

While open-source code is available; we have chosen a professionally packaged software system: *Photoscan* by *Agisoft* for its ease of use, reputation in the field, and to avoid hazard of error from inexperience with complex computer code. This software will streamline the generation of models from photographs collected in the field; guide measurement; and has already granted us a firmer understanding of how the computer "sees" so that we may be even more efficient with our photo collection surveys. We have seen early success with the use of Digital SLR cameras (Nikon D90, D3000, D3200) and should note the program is not reserved for any one type or brand of camera. The software is frequently used with UAV drone studies, affording us that option, and, perhaps more as a fun-fact, has even been shown to successfully interpret digitized historical stereo-aerial photos as well.

As promising as SFM is it is not without limitations. Complicated scenes, occlusion by vegetation, and scale of the environment all pose challenges that need to be considered. Processing requirements reward small, focused surveys of features, as opposed to grand, total-environment, photographic panoramas. Surface models may be compromised by misinterpretation of vegetation and therefore it seems better suited for exposed faces and scars following local bluff collapse. This does not directly capture pre-failure conditions of a bluff but will serve the measurement of volume of a mass movement as well as detect surface erosion and erosion rates along the bluff profile; granting information about the potential

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, July 1st, 2016

erosive energy in the environment. This information can be compared spatially to other bluffs in contrasting environments to support the development of the predictive model.

It is also worth mentioning here that the continued observation of a deteriorating bluff and capture of timeframes throughout the process will reveal kinematic information that can be measured accurately from the models generated. Observation of kinematics can be mathematically "reverse-engineered" to derive stress and strain characteristics of a dynamic and slow-flowing system. There is potential for such analysis of a changing bluff profile to reveal more about the role of groundwater and soft-sediment failures in the upper portion of a bluff, not simply erosion at the bluff toe. It may also be of interest to examine and model the contact between a recently armored shoreline and its adjacent natural setting. An engineered surface and/or the angular visual texture of rip-rap can be easily identified in a digital SFM model and used to measure consequent changes in more vulnerable or mobile material within the same photographic frame.

Statistical modeling:

Bayesian statistical analysis has been shown to be effective and constraining erosion rates to a matter of years vs. decades. The combination of our oncoming field observations with historical data, organized in a probabilistic network and managed by GIS will serve to forecast more accurate rates of retreat. Cheryl Hapke and Nathaniel Plant (2010) Demonstrated the technique in an analogous situation, also suggesting that a significant portion of the probabilistic network's success is the historical rates of erosion. It follows that, given the current lack of historical information, it is important to carefully establish our model and nurture it with further observations in order to grow its database of "historical" erosion rates and refine its accuracy

This is an end-goal of the model and will be approached by imitating literature, using and building upon criteria from the bluff stability and landslide hazard maps, incorporating numerical outputs from digital models and preparing for continued input from SFM measurements and surveys over time.

***I have included screen-captures from the FLAC3D and the SFM *Photoscan* workstations at the end of this report. It is important to acknowledge that a 2D snapshot of 3D models will inherently appear crude in this setting.**

Scheduling:

Initial conferences and the first team meeting have been successful and supportive. As the project begins to build momentum, now beginning fieldwork efforts, it will become more important to collaborate and coordinate. As a student I will need to improve my outreach to members of the team this coming year. I aim to more readily distribute useful literature as annotated, and to share the results of the various modeling products as I am able to generate them.

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, July 1st, 2016

Post Report Priorities:

The selection of participant communities and target sites for study.
Establishment of baseline surveys and control points at all sites.
Development of more coherent schedule for collaboration and feedback fostering greater communication and distribution of information amongst project team as fieldwork progresses.

Literature Review:

Is an ongoing and constant feature of the project. A small collection of selected works is listed below.

See Appendix E – Annotated Bibliography for literature.

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, September 30th, 2016

A Summary of Summer Efforts.

At this time we are preparing for a renewed focus on field survey. Seasonal vegetation growth at sites of interest has obscured bluff scanning *Structure from Motion* efforts during the peak of summer. Vegetation prevents the detection of a true bluff surface and can mislead measurements. Upcoming fall of foliage will allow for more clear surface models to be mapped in preparation for spring, which is expected to be most sensitive to slope failure.

Nonetheless photo documentation of the sites has continued. Some changes to the bluffs have been recorded, as wind has forced trees from their stand and drying effects have contributed to wasting of the clays. Photographs have also captured evidence of continued working by wave action at the bluff toe.

Much of the late summer focus has been on continued practice of refining the digital simulation of bluffs and landslides and building familiarity with the various software applications used to support the final predictive model. This also includes continued exploration of spatial trends of the bluffs in Casco Bay by GIS.

Some growing concerns have been the reliability of GPS controls at this time. Markers placed on the bluff or at its base are subject to movement or even burial during failure. Some trees at the bluff surface expected to be used as landmarks have already toppled. Constraints may need to be applied more remotely. This may be established by ranging from a steady rock ledge, or perhaps utilizing a UAV survey of the broader shoreline to better maintain a contextual record and easier georeference effort; the marriage of high-detail bluff scarp scans and meso-scale UAV flyover DEMs may provide a more robust surface model for the project. By combining scans at different scales (ie distance from bluff surface) a great level of detail at landslide sites may be applied to a more contextual 3D model of the surrounding environment.

Further progress has also been made with the FLAC3D model (described in earlier reports) and simple geometric representations of the bluffs are now stable for further testing. Stress and strain among other physical properties are easily monitored within any point in the model mathematical mesh. However, boundary conditions need to be further developed to more appropriately represent the regional settings. At present models mimic a bluff "lump" of glacial clay bounded by no-motion planar boundaries. A more appropriate approach will be to introduce a confining bed-rock surface and to drape glaciogenic clay models over this invulnerable layer. Working forwards groundwater fluctuations and cyclic excavation at the bluff toe are to be explored and scripted into the test models. Questions remain: how can vegetation stabilization be introduced into the FLAC model as a soft-boundary or added cohesion and mass at surface?

The next step will be moving from simple bluff representations to more natural models as drawn from *Structure from Motion* (SFM) scans. Changes detected in SFM scans over repeat visits can be input into the FLAC model to evaluate kinematics and deduce stress/strain behaviors from surface motion observations.

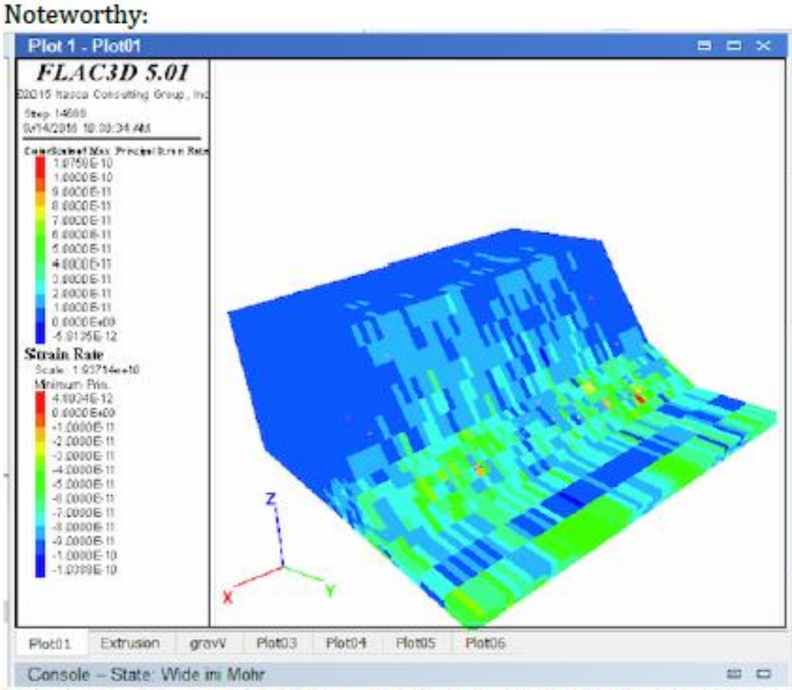
In other news, the SCAPE+ model (described in previous reports) has been released to the public by the iCOASST project overseas. Efforts to prepare the model with relevant information are underway but the model has not been run-through significantly at the time of this report. Originally designed for soft rock cliffs the

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, September 30th, 2016

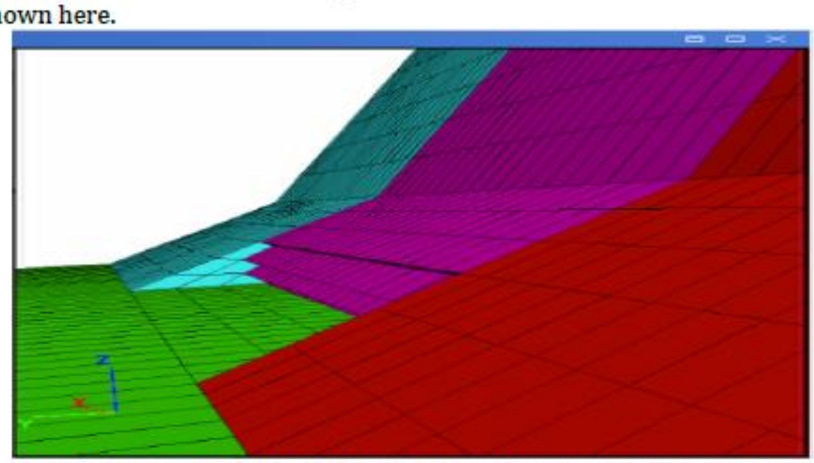
parameters may be adjusted as needed to better represent glacial clay and sediment systems. However it is unclear just how precisely the model appropriately alters profile and beach platform topography during each step. If any "failed" cliff material is simply deleted to represent erosion then this system may be inappropriate for our goals. It is important for a shoreline erosion model to account for changing beach topography in our context as mass accumulation at the base of a landslide resists further wave attack for quite some time. If need be some new particle based computer models may more reasonably approximate these cycles, but this alternative will not be pursued unless necessary at this time.

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, September 30th, 2016

Noteworthy:



Progress with the FLAC3D model. Heat map of principal strain rates of a representative bluff form (with representative material properties) under simple gravitational force. Strain is concentrated here in the bluff toe, and the more confined material exerts a stabilizing effect. Strain increases with surface loading, not shown here.



Another image of the FLAC3D model environment. Here a portion of the "bluff" is excavated to in preparation to induce a slump response. Color scheme is not a measure of stress but a categorization of physical properties assigned to each section.

POSM – Building Resiliency along the ME Coast – Progress Report
Nicholas Whiteman, September 30th, 2016

Bunganuc Bluff, Brunswick, ME. Newly visited site with a direct concern for private property. Site of a recent major rotational landslide (not included in photo). Highly unstable and expected to fail in near-time.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

Progress in relation to previous report, from March 31st, 2017 updated to October 2nd,2017.

At the close of the second project year, commentary will later be made on original project goals and future work.

Many of the results of this season's efforts exist as visual information: digital 3D bluff models; Photographic time-lapse observations; and fluid-dynamics simulations, for example. I have included some screen-captures and diagrams at the end of this write-up as a supplement.

Field observations continued through the spring and summer until seasonal growth of shoreline vegetation began to obscure erosional surfaces and therefore impair the productivity of photogrammetry efforts. As the season progressed, high-water events and passing tropical storms were targeted for limited surveys, and whether or not such events have made for noticeable changes in the coastal bluff geomorphology remains to be resolved.

The recent acquisition of an advanced consumer grade UAV (DJI brand Phantom 4) has dramatically impacted the efficiency of field survey efforts and quality of measurement products. Original expectations for the utility of SfM *("Structure from Motion," a continuation of an abbreviation from earlier reports)* as a method for coastal erosion observation are now more achievable than ever before with advances in UAV control and stabilization. Models available at the onset of research efforts were found to be more prototype than tool and their inability to remain steady prohibited their usefulness as tools for photogrammetric methods such as SfM. Advances in these devices undoubtedly will shape the future of management efforts.

As exclaimed above, SfM modeling has progressed. The lofted perspective afforded by flying cameras produce increasingly robust models and reduce error; this will be discussed further below. Continued teaching activities at the University of Maine have promoted a stronger understanding of SfM as a survey method and refined development of the project's models. It is worth noting here that the popularity of these UAV devices with the public lends itself to fostering community events centered around innovations in coastal survey, one of the original goals of the Building Resiliency project.

Field survey has continued to focus primarily on the Little River and Little Flying Point sites in Freeport, Maine for their ease of access, exemplary erosional behavior, and most consistent record of observation at this time. The focus on these sites arose from the physical and temporal demand on field survey, as it grew difficult to monitor more targets. It is exciting to announce that newfound flight capabilities will certainly increase capacity for individuals to monitor more and more sites of interest.

Supplemental images of SfM products and typical analysis goals are show in **Figures 1-3.**

As mentioned in the previous report: *"Accurate scale is imparted to each product by measurement in the field however ground control for geo-reference is still a challenge to be overcome." ... "This spring we hope to further explore the use of UAV drones for a broader-context scanning method in order to more properly geo-reference the individual models of erosional hot spots by relating more detailed regions to larger models of, say, the cove these hot spots occur in."* Two notable improvements in geo-referencing methods have been made this summer. 1) Broader photogrammetric survey swaths afforded by the ability of a UAV to "step back" from an on-foot perspective has enabled further testing of including GPS antennas within the SfM scans. Not only does this allow for a higher-precision refinement of GPS records than that of the UAV itself, but the known distance between antennas can be used for imparting a precise scale within the model. 2) Higher-altitude flights allow for the generation of SfM models to the scale of the local embayment. These "contextual" orthophoto-style scans can be appended with more high-resolution scans of erosional surfaces at the same time. This allows for a greater ease of geo-referencing the more focused bluff erosion SfM surveys. **(Figures 3a-e)**

Following the previous report, the geo-referencing concerns have been greatly reduced by the use of UAVs. Nonetheless such factors must be considered for every survey. It is unfortunate that many of the earlier surveys intended for erosion measurement are not nearly as secure in their ground control as the most recent demonstrations.

Numerical modeling updates, FLAC3D.

Work with the FLAC3D mechanical modeling has continued but has yet failed to meet early ideals. Success has been found in incorporating the SfM survey products directly into the FLAC3D environment. These "real-world" geometries greatly enhance the usefulness of the model as a demonstrative tool as well as bringing the exploration of failure conditions and thresholds of the bluff forms into three dimensions **(Figure 4)** beyond simple geometric approximations.

Despite real surfaces as captured by SfM, at the time of writing we have yet to successfully impart enough of the site specific physical properties of each bluff to imitate mass-movement and failure as observed throughout the survey within the FLAC3D simulations. Approximations of the material properties of the Presumpscot Formation, for example taken from local DOT reports, are not transferable enough with regards to local sedimentological variance or groundwater behavior as related to each site of interest.

Difficulty in discerning the internal characteristics of each site continues to be a major limiting factor on understanding the site-specific thresholds for failure that may lead to predictability of landslides regionally. Suspicion continues of internal groundwater presence and pore pressures as a leading agent in plastic failure of bluff bodies and landslide potential. Seasonal wetting and drying, as well as land use changes, has been observed to influence behavior of bluff failure but without a strong understanding of internal saturation of the Presumpscot Formation sediments with respect to individual sites resolution of such parameters remains elusive.

It is necessary to recall here that FLAC3D itself is an expensive and non-transferable piece of software. Its use at the University of Maine in support of the student project was designed to discern bracketing limitations of real world stress tolerance characteristic of the bluff erosion problem. The numerical results of these tests, once refined, would be transferable in a manner to serve the broader GIS system. Work continues to simulate bluff erosion as observed by field study and will continue to inform the final parameters of the modeling goals as they are refined.

Three-dimensional modeling efforts on landslide behavior must continue in order to better resolve failure thresholds in the local contexts of the sites chosen for study. With the construction of a general bluff failure model in response to local conditions more iterations of case studies can be readily produced, more informed by remote sensing than individual survey.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

Numerical modeling updates, DualSPHysics.

The previous report served an introduction to DualSPHysics (As described in the previous report. References, validations, and more information can be easily obtained at www.dual.sphysics.org) and its expected usefulness as an application of Smooth Particle Hydrodynamics (SPH) modeling methods to aid in the project

SPH modeling, empowered by DualSPHysics, can be made to work in concert with Structure from Motion products and FLAC3D finite element analysis of failure thresholds. This enables further examination of wave action at the bluff toe and inferences about the velocity of swash; forces acting on the bluff; and the transition to turbulence at the shoreline.

Envisioned as follows:

Realistic surface models of the bluff sites, as captured and produced by SfM, placed within an SPH environment can be subjected to simulated wave action.

Forces imparted by wave action at the bluff toe, measured within the SPH simulation, can be converted to stresses mathematically and applied to the same bluff surface SfM product; this time within the FLAC3D mechanical modeling environment.

Once the bluff surface model within FLAC3D reaches a failure condition, a new consequent surface may be outputted and then returned to SPH, once again to be subject to simulated wave action.

Repetition of this cycle can be used to further simulate the dynamic scenarios of the bluff erosion cycle.

The envisioned coupling of models to cycle through failure and response simulations has not yet been achieved, but remains a desirable goal. Presently, pairing SfM survey products with a DualSPHysics SPH simulation is easily achieved and modified to demonstrate interaction of varying water levels with the "real-world" geometries of the bluff forms and fore-marshes. This method provides and effective demonstration of the dynamic dimensionality of the shoreline environments. Redirection of incoming waves by obstacles at the toe of the bluff and the range of forces imparted by breaking waves on the uneven surfaces can be readily explored.

In contrast to the FLAC3D software, DualSPHysics is an open-source system and freely distributed. Its power as not only a visual aid for nearshore fluid dynamics but mathematically consistent tool is a promising addition to the collection of innovative model systems explored here, especially concerning flooding and surface runoff dynamics.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

Further discussion, revisiting original project goals.

Selected from original POSM Project description:

Gap #2. Need for evaluation of potential future risks – Currently available maps and datasets address existing risks and ignore potential future risks such as increased damaging storms and sea-level rise. Unlike beaches and wetlands, which can move landward while generally maintaining their existing features, coastal bluffs will erode in a one-way direction due to storms and rising sea level until lost. Existing stable bluffs may become unstable or even highly unstable in response. Currently, there are no scientifically sound, predictive models to understand and predict this anticipated change.

Goals, Measurable Objectives and Outcomes: Goal 1. Coastal decision-makers along the bluff coast have better data to assess and plan for predicted sea-level rise and more frequent storms.

Objectives:

1) Develop and apply a transferable, predictive bluff model using sound, scientifically proven methodologies and existing and newly available Maine datasets.

2) Assess model efficacy for use locally and bay-wide in Casco Bay. 3) Disseminate project results via technical assistance to municipalities, regional workshops, webinars, conferences and publications

Outcomes:

1) New datasets of local and regional vulnerabilities to bluff erosion and landslide susceptibility in Casco Bay for use by state and local decision makers.

2) Model available to other coastal states and territories.

Observations and surveys conducted throughout the project further highlighted the insufficient status of the datasets existing prior to the project. The dynamic environments, with bluffs changing more rapidly than expected, leave such datasets as already outdated. See the July 1st, 2016 Progress Report submission for comments on existing maps and erosion rate data.

Findings indicate a problem of a greater scale than anticipated and leads to the recommendation that observation efforts are further supported and continued in order to refine and resolve an awareness, both scientific and public, on the problem of coastal bluff erosion in order to attain the original goals and objectives. Resolution of preexisting datasets are too poor to produce a user-friendly and site-specific model without continued refinement of observational data and generation of case studies. It remains unclear which bluff erosion events and reports from the public could be considered extraordinary, or exemplary of the conditions of each site.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

It is also worth noting that a difficult to manage human element still exists in that so-called "midnight-engineering" projects occur where private land owners work to modify an eroding shoreline without acquiring permitting. Often, they choose to pay fines *post factum*. This challenges management efforts by not only further complicating shorelines and imposing edge effects on neighbors, but by further distorting the relationship between what may be mapped as one thing and in reality, exist as another. This is merely an example of the still-lacking public awareness issue.

Observation efforts throughout the project have worked to embrace the most recent advances in readily available survey technology to demonstrate an effective and efficient method of collecting the desired information necessary to support the original goals. As mentioned at the beginning of this report, advances in the capabilities of consumer UAVs have occurred throughout the course of this project. At the start, available models behaved merely as toys, and were too unstable to be reliable for photogrammetry surveys. Recent release of more capable, and readily stabilized devices has dramatically improved the feasibility of these surveys in the past year as tools for photogrammetric surveys.

It is expected and suggested that at this time, within the advent of these more attainable tools and the demonstration of survey methods, that the original Goal 1 may be more readily met. The potential to produce observations of a higher quality than before is now demonstrable to members of the community and should be promoted in order to inspire a state and local reaction to further the objectives of Goal 2.

Further discussion, revisiting GIS.

Prior reports have neglected GIS work in favor of demonstrating the pursuits of available modeling tools and survey methods. The resolution and scope of the pre-existing data did not allow for an admittedly ambitious original GIS model design. See Chart 1, in the supplement section, produced as a primer for a team meeting at the onset of the project for a reminder. Nonetheless, GIS remains an important tool in coastal zone management and ever-improving data promises that such a model design is still attainable. At its least, GIS should continue to be embraced as a method of cataloging and interpreting observations as the problem persists.

At present, GIS evaluations of sites must still be generated manually on a case-by-case approach, and in this way the goal of a transferable GIS model has not been met. As a transferable model must be considered useful for other users it will be important to program a GIS workflow that successfully utilizes the available regional data to determine the initial conditions of a bluff erosion and landslide hazard risk as well as further processes new observational inputs to refine its products. Goals for future work would involve refined programming design in order to more readily apply the model to new conditions and environments without building cases from scratch.

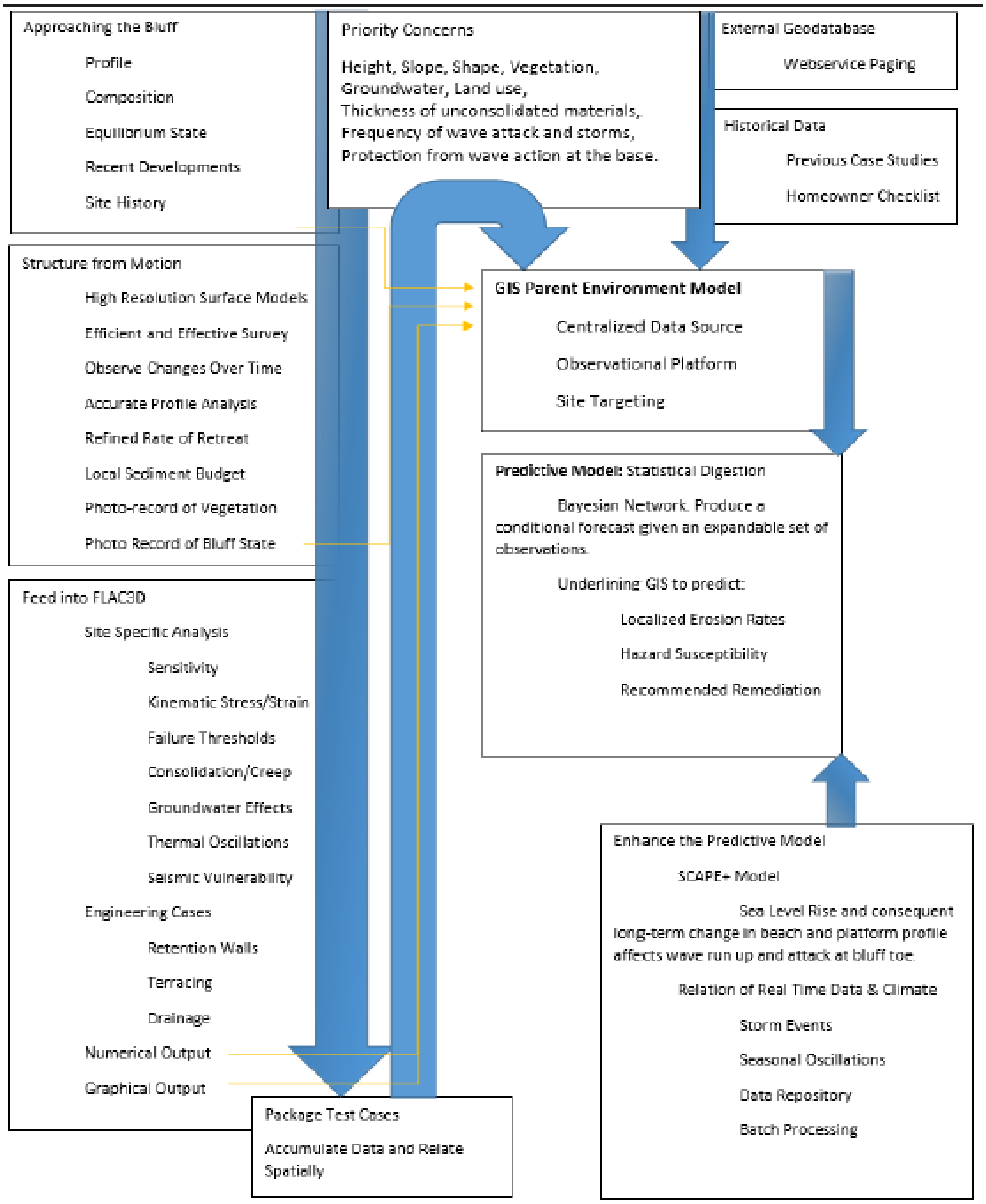
The fledgling GIS model remains an important tool in its own development. The more chronic and constrainable agents of coastal bluff erosion, such as tidal predictions and fetch lengths that control the arrival of water at the bluff body are spatially evaluated and prepared for each site of interest as a framework on which to compare more variant conditions such as wind direction, heavy rainfall or snow loading, and the coincidence of weather episodes. This contextual framework is more likely to remain unchanged season-by-season. The capacity for a GIS to produce an understanding of such context remains a crucial goal in developing a more applicable model.

The aspect of a bluff face alone is insufficient when considering vulnerability to storm direction. Casco Bay is a fetch-limited environment and modelling work must aim to weigh not only the coincidence of storm direction with the bluff aspect, but also with the length of fetch itself as a factor. Boundary selection for sightline-fetch approximation and ranking continue to be refined but the approach as a method of quickly defining the fetch-environment relationship to chosen bluff sites on a local scale is still considered worthwhile (**Figures 5a & 5b**). This measurement helps to constrain the range of variable water levels and coincident weather episodes that may act on some, but not other, bluffs during a given storm event.

Probabilistic modeling continues to gain attention and support within recent literature as a means of prioritizing management efforts on coastal projects where many agents influence the expected outcome. The present lack of awareness concerning the coastal bluff erosion and landslide hazard does not mean that a probabilistic model is unachievable, but instead implies that further observation of coincident events and bluff response will then lead to a more responsive and predictive system.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

Chart 1. A reminder of original modeling designs. Some changes, noted in previous reports, have occurred (*ie.* The abandonment of the SCAPE+ model, replaced by DualSPHysics) but the cooperation of GIS and a Probabilistic model remains an unchanged ideal.



POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

Supplemental Figures:

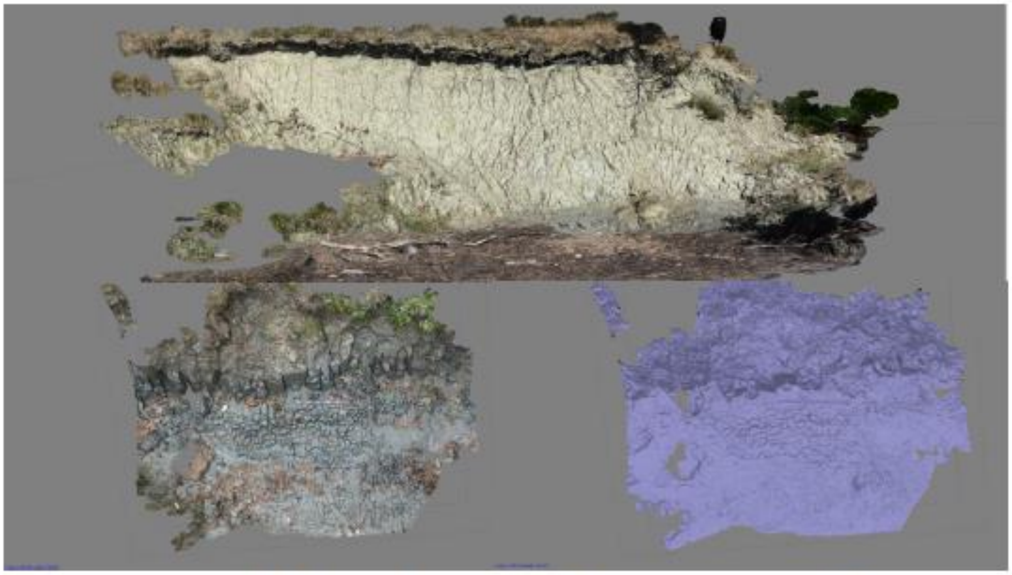


Figure 1. A selection of SfM products. Early work was limited to focusing on erosional surfaces exposed on individual bluffs. The frayed and tattered edges of the scan products are a result of both: 1) insufficient perspective and visual information in those areas and 2) an obscured bluff surface by vegetation.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

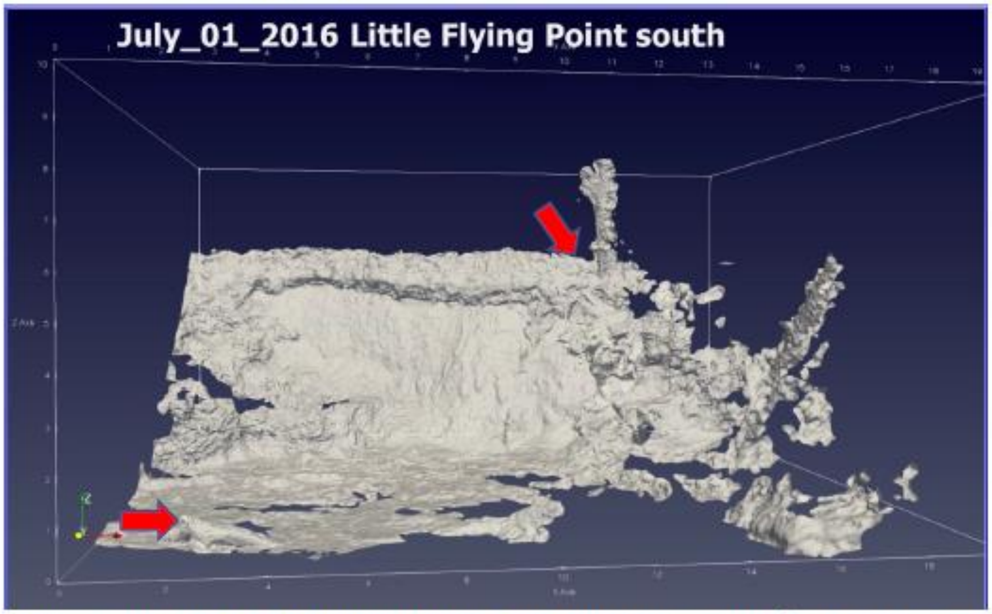


Figure 2a. One of the first SfM products from the Little Flying Point site, July 1st, 2016. As stated above, the unrefined edges are a product of poor coverage or conflict with vegetation. Consquently, the edges of the model are at present less reliable. The two offshooting figures at the right side edges are tree trunks, more easily captured by SfM than foliage. Numerical scale of axes are in meters.

Figure 2b. One of the photographs from July 1st, 2016, used to construct the SfM product for context.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

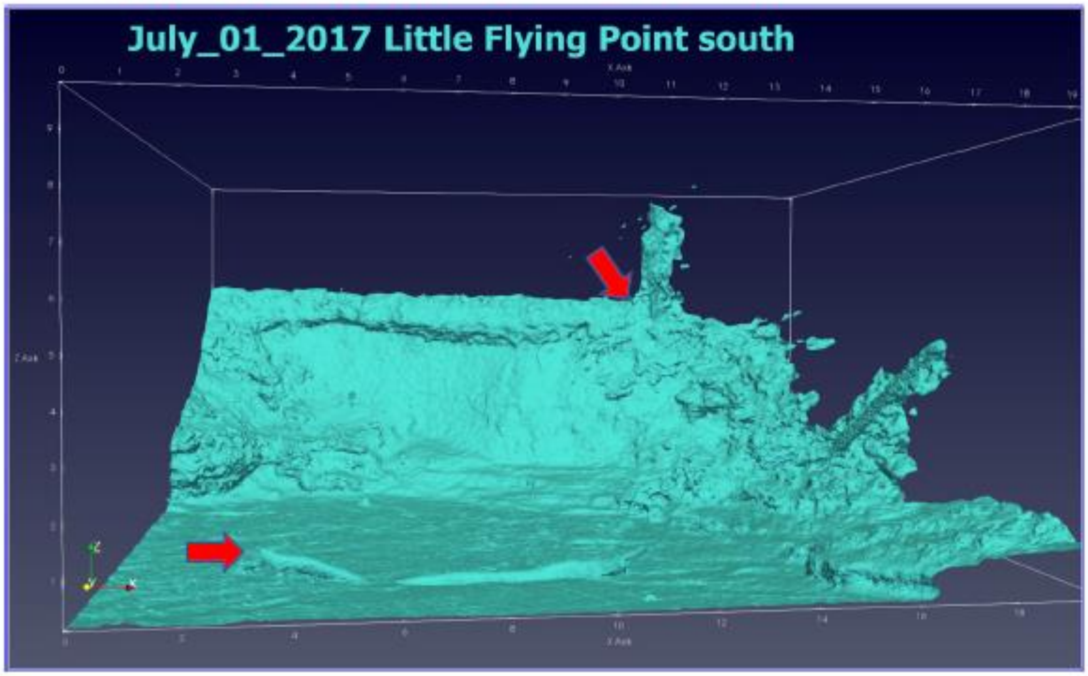


Figure 2c. One year later, the same site is represented here as its SfM product. Note the more well-prepared model surface as result of a year's survey experience working with the method.

Figure 2d.

Again, a photo used by the model, here for context. Note that the numerous orange flags placed during the first survey have not survived the year.

This particular photo was taken from atop the large driftwood log. It remains in the model as captured by many other photos in the scan.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

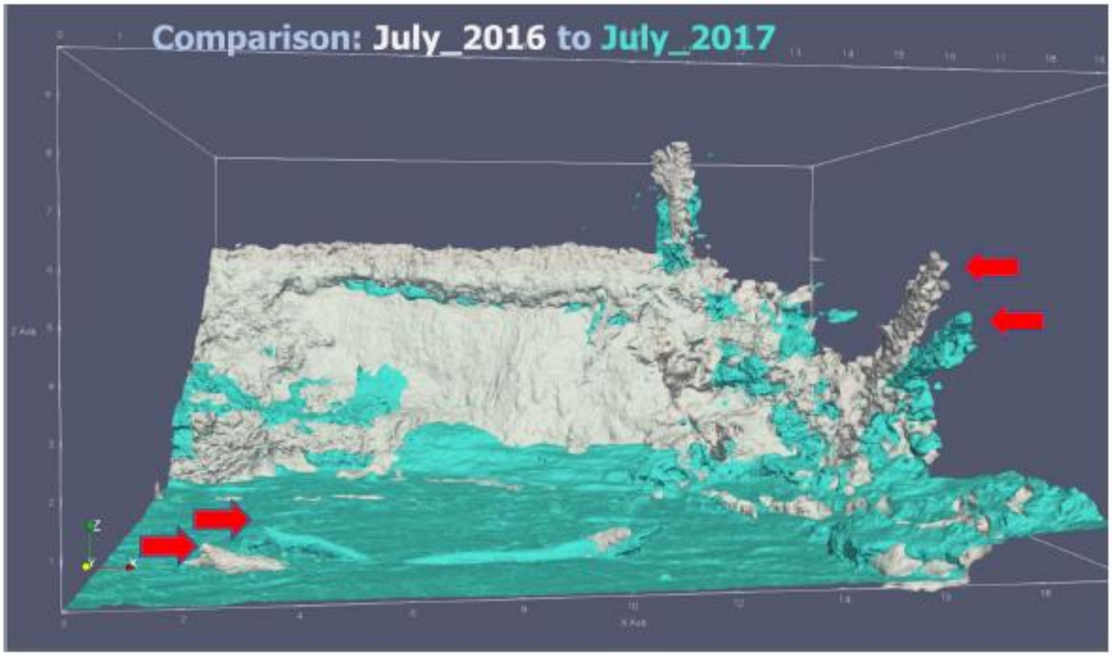


Figure 2e. A typical comparison of the site SfM products 1 year apart. Blue represent the more modern environment, therfore where it is obscured by the position of the previous scan (white), it is considered eroded or repositioned. Erosion estimates and profile analysis of the many surveys is ongoing, but follow in this manner to detect changes over time. As noted before, the edges of these models are less reliable as obscured by vegetation and poor scan coverage and so estimates must be limited to trustworthy surfaces. It can be read from the center of this comparison that material on the bluff face has been removed, and material at the toe has advanced. It is expected that this advance of the bluff toe is less an accumulation of captured sediments and more a forward slump and splay of material from the bluff.

Also noteworthy is the shifting of the large driftwood log, likely by winter storms, and the further creeping of the tree trunk captured by the scan at right (red arrows).

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

Figure 3a. A screenshot of the Agisoft Photoscan environment to introduce and call attention to the enhanced capability of surveying as aided by UAV flights. Note the blue squares in the upper-right edge of the image. Photoscan uses these to mark the position of each photo as used in the generation of the model. Unlike more traditional ranging systems, the position of the sensor does not need to be constrained by the user before generating the model but is instead position-independent. The sensor position is computed from the lens geometry and the parallax changes between the photographs the same way the model itself is built. .

Figure 3b. Perspective unattainable on foot. Note the landslide in the center of the photo, actively eroding (blue arrow), and the adjacent erosional surface behind the collection of drift debris (red arrow)

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

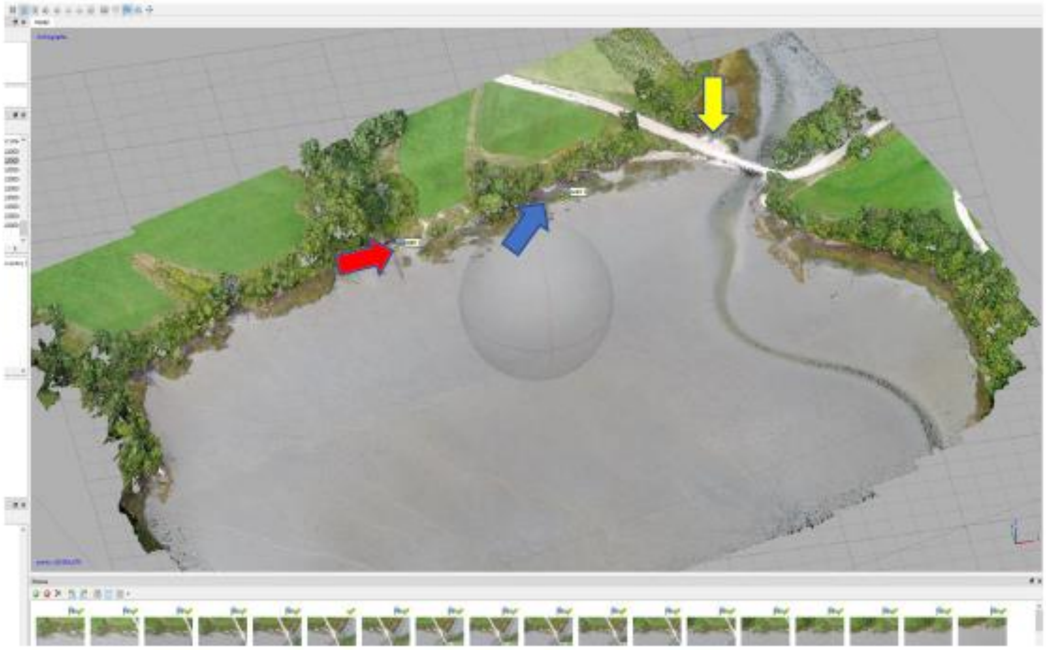


Figure 3c. SfM product of a UAV-flight enabled broad-contextual model of the Little River, Freeport Maine, site. The addition of modeling capabilities at this scale supports the project and ground control efforts with an increase richness in information. In conjunction with GPS antenna placed in proximity to the bluffs, features such as bedrock outcrops (Green Arrows) and the road aid georeferencing and an understanding of scale. The inclusion of the tidal flat within the scan is beneficial to DualSPHysics simulations and water flow behavior. The inclusion of the bluff tops is important for modeling the bluff as a more complete sediment deposit as well as more clearly demonstrationg land use scenarios. The perspectives used in **Figure 3a** and **Figure 3b** are marked by Red and Blue arrows respectively. A car, marked by the Yellow Arrow, will be noted in the next figure.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

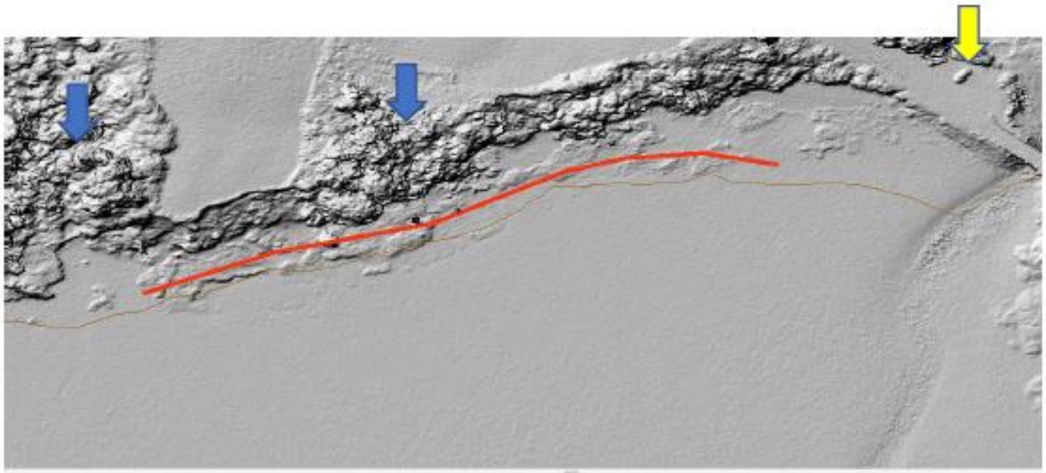


Figure 3d. Hillshade DEM generated from the SfM product displayed above in **Figure 3c.** The Red line is a segment of the MEGIS Coastal Bluff Hazards product (MGS, 2006) tied to this particular Little River site and the thin brown line is a 0-meter contour line. As above, a car is identified by a Yellow Arrow. While this product maintains an appearance akin to lidar, it must be noted that the tree canopies in the scan are returned as a surface, and are not easily filtered out. Two gullies are identified with Blue Arrows.

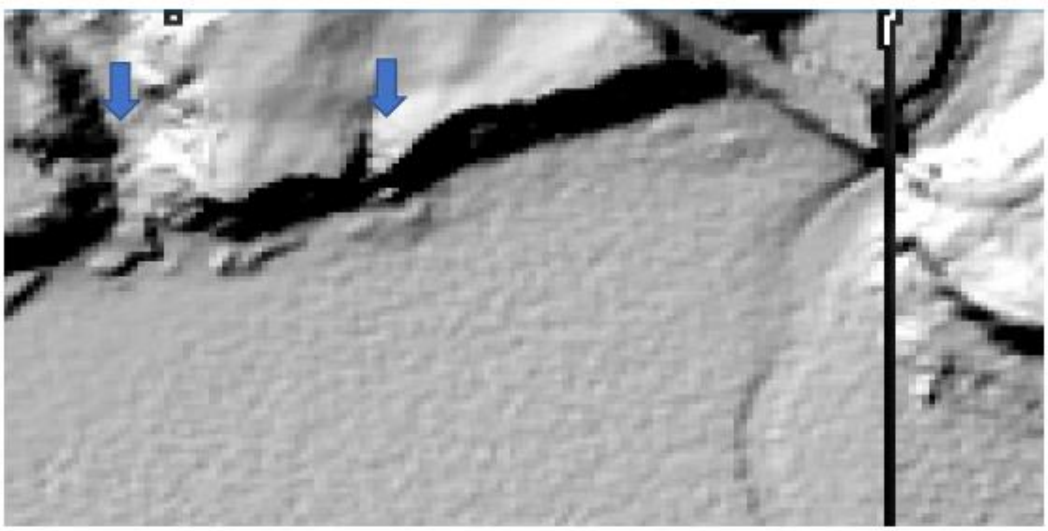


Figure 3e. Hillshade DEM generated from the coastal Maine LiDAR survey, detailing the same site, offered for comparison with the locally generated SfM survey facilitated by UAV flight.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

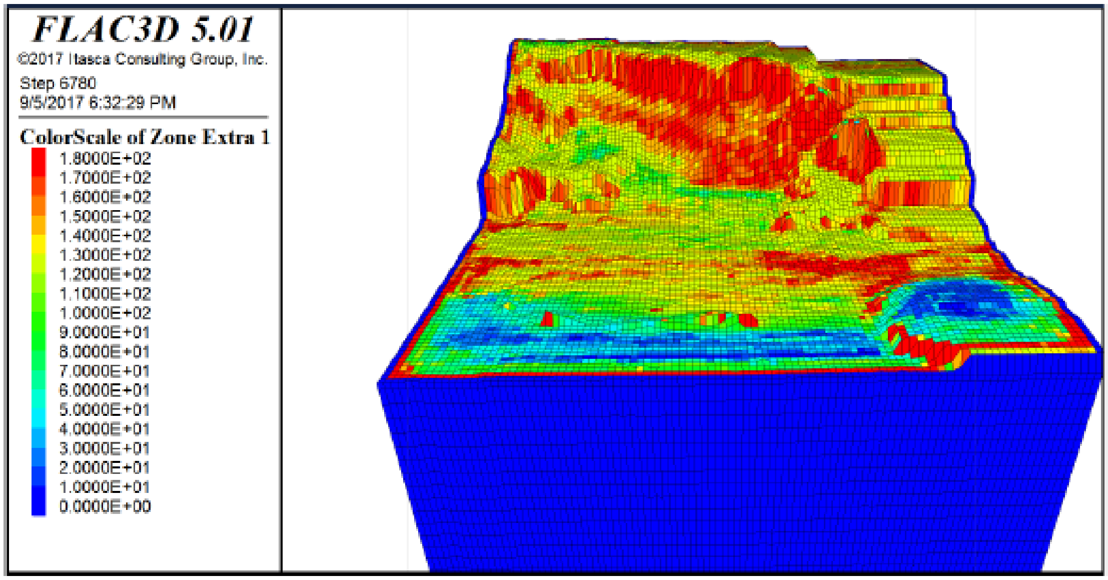


Figure 4. Screenshot from the FLAC3D workstation. Please excuse the legend in this example, "Zone Extra 1," is a placeholder term within the model scripting that is used to check stress/strain sensitivity in a general case. This image is included more to showcase the use of SfM products within FLAC3D, and as mentioned earlier in the report, the outputs of the FLAC3D experiments are not yet apropriately functional. This particular bluff form is from that of **Figure 2**.As could be expected however, the model shows that over-steepened surfaces exhibit a greater strain.

POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

Figure 5a. Commentary on following page.

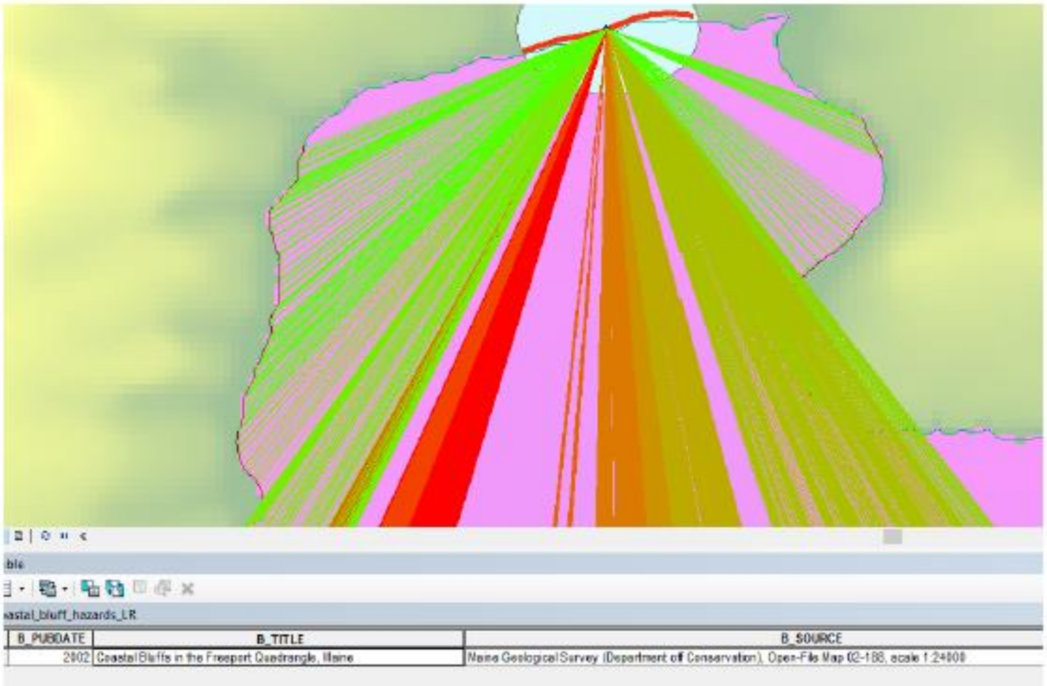
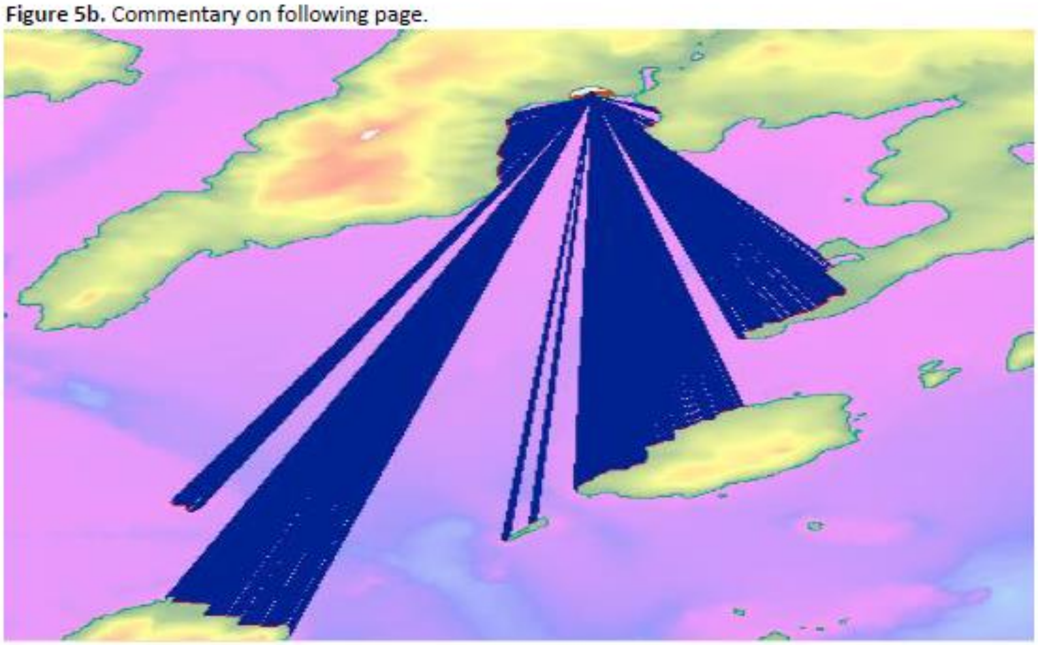


Figure 5b. Commentary on following page.



POSM – Building Resiliency Along the ME Coast – Two Year Progress Report
Nicholas Whiteman, October 2, 2017

Figures 5a & 5b. These crude images are included to help conceptualize earlier fetch-environment modeling efforts as described in the report. A bluff site is identified within a combined topographic and bathymetric DEM, and the process works to detect and discern the fetch limitations related to the site chosen. Ideal outputs would contain information on both the orientation and extent of possible fetch domains as well as identifying regions where fetch is unrestricted in a reasonable and workable manner.

The red band, highlighted in each image by the light blue circle, is the same feature as denoted in **Figure 3d** a segment of the MEGIS Coastal Bluff Hazards product (MGS, 2006) tied to this particular Little River, Freeport, Maine site. Note that the source attributes of this layer are visible in **Figure 5b.**

It is of course understood that these products are merely indicative of orientations of interest. Much more information and computational power would be necessary to properly approximate the behavior of a sea surface under given atmospheric conditions in a realistic scenario, let alone the potential for long-period wave refraction around corners. It follows as well that there are consequences of scale in such an approximation, as for example, the cove bounded in **Figure 5a** is almost entirely drained of water at low tide, and as such temporal coincidences most be considered as well.