

Date: January 8, 2018  
To: Andrew Dorr, Town Manager, Town of Vinalhaven  
From: Nathan Dill, P.E.  
Subject: Vinalhaven Resiliency Planning – Adaption Options Recommendations

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This memorandum summarizes the Sea Level Rise and Storm Surge Analysis we have performed for the Town of Vinalhaven (Town). The purpose of this analysis is to assist the Town in determining the combined risk of coastal flooding due to storm surge and sea level rise in the Downstreet area. This memorandum is also being provided to aid the Town in meeting deliverable requirements for a Coastal Communities Grant that was awarded to the Town through the State of Maine Department of Conservation, Agriculture, and Forestry (DACF), Coastal Program for Fiscal Year 2017.

To date, Ransom has previously provided the Town with a series of four memoranda that document our analysis, provide detailed hazard information, and recommendations for next steps in resiliency planning. In this latest memorandum, discussed herein, we first provide a brief overall summary of the previous analyses, while the reader is referred to the original documents for greater detail. We then discuss general recommendations for a variety of adaptation options that the Town may consider when planning to mitigate risks associated with coastal storms and future sea level rise.

## **SUMMARY OF PREVIOUS MEMORANDUMS**

On August 17, 2017, Ransom provided two memoranda to the Town. The first memorandum gives a review of the North Atlantic Coast Comprehensive Study (NACCS) that was completed by the United States Army Corps of Engineers (USACE) in 2015. The second memorandum describes the development and validation of a new, highly detailed, numerical model for simulating tides, storm surge, and waves in Penobscot Bay and vicinity.

In the first memorandum, we discussed how the NACCS study provides the climatological information and statistical framework necessary to estimate the probabilities associated with coastal flood hazards. The NACCS investigated the hazards using a suite of numerical models to simulate winds and atmospheric pressure, astronomical tides, storm surge, and wave conditions for a large number of coastal storm events, including historic extra-tropical storms (e.g.

northeasters), and synthetic tropical storms (e.g. hurricanes). The memorandum then describes how we identified a sub-set of storms that would be representative of the hazard for the Maine coast, and then obtained numerical model files from the USACE. We then compared the NACCS model water level results for the sub-set of historic storms to observation during those storms to evaluate the validity of the NACCS model. Through this validation effort we found that the NACCS model results had a negative bias in Penobscot Bay (i.e. on average they under predicted actual storm surge water levels), and that the bias was generally worse for more extreme storm events and for locations farther downeast. This negative bias suggests that the NACCS model results may underestimate the coastal flood hazard for Vinalhaven.

Our second memorandum prepared on August 17, 2017 documents how we developed and validated a new numerical model with detailed focus on Penobscot Bay using the same basic modeling techniques employed by the USACE in the NACCS. This new model is able to use the output data from the larger scale NACCS model to provide the necessary boundary conditions for simulating tides, storm surge, and wave conditions for the sub-set of storms that characterize the coastal flood hazards for Penobscot Bay. The new “downscaled” model has considerably higher resolution and accuracy for Vinalhaven, and through further model validation efforts it was shown to provide better, unbiased, simulation of coastal flood hazards for the Penobscot bay area.

On August 30, 2017, Ransom provided two additional memoranda to the Town. The first presents and discuss local sea level rise projections for Vinalhaven, while the second memorandum describes the analysis of present and future flood hazard estimates that incorporate sea level rise projections, so that they may be used for effective future planning.

The local sea level rise memorandum presents a set of sea level rise scenarios that are based on recent guidance from the USACE and the National Oceanic Atmospheric Administration (NOAA). We then discuss some potential pitfalls with scenario-based sea level rise guidance, which stem from a lack of understanding of the likelihood of the various scenarios. We explain how scenario-based guidance, by itself, leaves planners and decision makers in a difficult and uncertain position, as they must decide what actions to take to mitigate future risks. We then explain how that can be remedied by considering recent probabilistic sea level rise guidance that quantifies the uncertainty in future projections. With scenario-based guidance alone, decision makers simply cannot know if they are too strongly considering a highly unlikely scenario, or conversely, not adequately considering a highly likely one. By considering the probabilistic guidance as well, they can better understand the likelihood of the different scenarios and how that likelihood may change with time.

Our present and future flood hazard memorandum starts out with some background information to familiarize the reader with basic hazard statistics. It then describes an analysis of the Penobscot Bay model results for extra-tropical storms to quantify the probabilities associated with extreme water levels and wave conditions<sup>1</sup>. The flood hazard information is then combined with

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<sup>1</sup> It is noteworthy that this analysis did not include an analysis of the tropical storm simulations or pure tidal effects, and therefore, the hazard information may under estimate the likelihood of flooding associated with purely tidal events, or highly extreme tropical storm or hurricane impacts. We recommend that this analysis be updated in the future to include those analyses. In the meantime, the current analysis does provide reasonable estimates for the hazards associated with more or less frequent extra-tropical storm events like the storm that occurred on January 4, 2018. Therefore, the hazard information provided should

the probabilistic sea level rise guidance through a Monte Carlo technique to yield a series of hazard maps and flood hazard curves for present and future years. The resulting hazard information inherently includes increases in the hazards due to the full range of sea level rise scenarios, and therefore, this information can be used in future planning without the need to explicitly consider specific sea level rise scenarios.

To illustrate the Monte Carlo technique, a game called the Storm Surge Slot Machine (S3M) was developed and provided as an attachment. S3M can be used as an educational tool to help decision makers, stakeholders, and the general public understand how flood hazards are expected to increase in the future with sea level rise, and provide some basic hands-on understanding of the statistics used for assessing future hazards<sup>2</sup>.

A set of flood hazard maps for Carvers Harbor, that show the water level and wave crest envelop hazard levels for 2017 and each future decade until 2117, were provided as hard copy and pdf files. Hazard maps, showing a greater range of hazard levels, and for each 5-year increment until 2117, were also provided to the Town in the KMZ format that can be viewed in Google Earth. After the hazard information was presented, we also provided the Town with discussion regarding the timing of the flood hazard and future increases in the likelihood of flooding for low areas of Main Street. We also provided some recommendations on how to use the hazard maps to identify vulnerable areas and assets, and next steps necessary to employ a risk informed decision making process, when evaluating future risk mitigation and sea level rise adaption options.

## **ADAPTATION OPTIONS AND RECOMMENDATIONS**

Our analysis of present and future flood hazards for the Downstreet area in Vinalhaven is predicated on an understanding that problems with sea level rise will manifest through increasing flood hazards in the future. In other words, we consider sea level rise and coastal flooding hazards as inseparable processes, whose impacts are best understood through a framework that combines the randomness of flooding events with the uncertainty in future sea level rise. This allows us to estimate the probability of flooding today, and how that flooding probability will change in the future. Because flooding and sea level rise are essentially inseparable hazards, actions taken to adapt to sea level rise will go hand-in-hand with actions taken to mitigate present and future flood risks. Therefore, we recommend an adaptation approach that focuses on risk reduction and uses future hazard information as the basis for risk informed decision making.

During the course of our efforts, the Maine Coastal Program put forth a self-assessment tool for coastal communities to use to evaluate their vulnerability to flood hazards and community resilience<sup>3</sup>. This tool, called the “Maine Flood Resiliency Checklist”, was designed to help communities assess how well positioned they are to prepare for, respond to, and recover from flooding events, which will be exacerbated by sea level rise. It is also designed to help communities identify specific strategies to address their vulnerabilities. Now that this tool is

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be useful for planning studies that investigate options to prepare for similar events with future sea level rise.

<sup>2</sup> Ransom is currently working on an improvement to the S3M simulation game, which will replace the cumbersome hazard curve plots developed with the roll of dice with game spinners to simplify the game play. We hope to present this improved version of the game on a poster at the 2018 Maine Water Conference in Augusta, Maine on March 28, 2018.

<sup>3</sup> [http://digitalmaine.com/cgi/viewcontent.cgi?article=1520&context=mgs\\_publications](http://digitalmaine.com/cgi/viewcontent.cgi?article=1520&context=mgs_publications)

available, we strongly recommend that the Town utilize this tool. The effort described in this memorandum should allow the Town check off some important items, while the exercise of considering the other items in the checklist may help the Town identify additional opportunities for adaptation, beyond the recommendations given below.

Options for adaptation fall broadly within three categories: accommodate, protect, and retreat. Measures to mitigate risk may include traditional structural measures, such as fill and hardened seawalls, non-traditional natural and nature-based features, such as marsh creation, as well as non-structural interventions including policies, warning systems, risk education, etc. For Vinalhaven, it is likely that a combination of these features will provide the best overall benefit in terms of risk reduction and efficient use of limited resources. Thus, it is recommended that the Town consider a range of possible actions when planning for sea level change adaptation. Adaptation planning should also be flexible and allow for evolution as guidance on sea level rise changes in the future and experience is gained with adaptation efforts.

### Accommodate

Accommodation means essentially living with the change. Accommodation is already happening and any plan for sea level rise adaptation in Vinalhaven will almost certainly include some degree of accommodation in the near future, at least. Accommodation may include non-structural features. Possible non-structural measures include:

- Performing studies, such as this one, to better define flood hazard.
- Implementing local policies to reduce flood risk (e.g. participation in the FEMA National Flood Insurance Program (NFIP), and development and enforcement of floodplain management ordinances that are more stringent than required by the NFIP)<sup>4</sup>.
- Development and implementation of early warning systems to inform stakeholders of impending flood events.
- Development and dissemination of educational tools to educate the public about their exposure to flood hazards, how those hazards are expected to increase in the future, and what may be done to mitigate risks associated with the increasing hazards.

For example, property owners could be informed of the likelihood of flooding on their property and be encourage to take action to accommodate that flooding. Such actions could include moving important items to higher floors in their buildings and elevating utilities, such as heating systems, fuel tanks, and electrical components, as they upgrade their utilities and/or perform renovations. A warning system could be developed and used to inform residents of an impending storm, and when they should take actions such as moving important building contents to higher

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<sup>4</sup> Please note, FEMA flood maps only illustrate one particular hazard level in coastal zones (i.e. the 1% annual chance flood), and they do not indicate how that hazard will change with future sea level rise. For this reason, we recommend that any educational tools developed for the general public make this fact clear, and provide the public with information on the full spectrum of present and future flood hazards, such as the combined sea level rise and coastal flood hazard information generated through this effort

floor. Considering the timing of future hazards, accommodation might be a reasonable option for adaptation for the next 20 to 30 years or so, until the likelihood of moderate to severe flooding becomes too great.

### Protect

Protection typically involves some type of structural measure to maintain current function in the face of rising sea levels and increasing flood hazards. This may include traditional structural measures, such as elevating roadways and buildings, filling wharves to higher elevations, constructing seawalls, bulkheads, and revetments, installing flood gates, etc. It may also include the use of natural or nature-based features such as man-made marshes to reduce wave energy. Possible protection actions for Vinalhaven may consider the following:

- *Elevating Low Lying Areas of Main Street.* We understand that the Town is planning for near term improvements to sidewalks in the area. As a synergistic addition to that effort, we recommend the Town also undertake a study to assess the feasibility of elevating the roadway as well. The feasibility study would consider a variety of alternatives for making improvements to the roadway, estimate the cost of implementing those alternatives, and weigh the costs against the benefits associated with reduced flood risk in the area to determine if such actions are feasible. Different alternatives would likely include a range of target elevations for the minimum road elevation. Greater elevation would provide greater benefit, but also require greater costs. The flood hazard information developed through this effort could be used to assess the benefits of raising the roadway for a range of elevations.

Meanwhile, additional effort would be required to assess the costs associated with construction and potential limitations on the roadway heights. For example, the height may be limited by curb heights and the threshold elevations of existing buildings. Other limitations that must be considered include the presence of underground utilities, geotechnical considerations related to the porous fill on which parts of the road have been built, and hydraulic considerations related to the sluiceway and bridge over the Carvers Pond inlet. Although available Light Detection and Ranging (LiDAR) data could be used to identify limits to the area of study, the feasibility study should also include a topographic survey of the area to provide greater detail and accuracy than can be provided by LiDAR alone.

- *Elevating Buildings on Main Street.* There are numerous buildings along Main Street that are located within the floodplain. Raising the elevation of these buildings is another action that could be taken to reduce flooding risks. We understand that most of these structures are privately owned, and therefore, the responsibility for any building improvements, such as increasing the elevation of the structure, will fall on the individual property owner. Because entryway thresholds likely limit the feasibility of the roadway elevation, we recommend the Town encourage property owners to consider the costs and benefits of elevating their buildings.

The benefits of building elevation, in terms of reduced risk can be estimated using the hazard information derived through this effort, along with an appropriate depth-damage function for the building, as described in our August 30, 2017 memorandum of present and future flood hazards. Although depth-damage functions are available for general structure types, property owners may be best served by evaluating the specific

consequences of flooding of their property and developing their own unique depth-damage function.

Another highly tangible benefit of elevating buildings can be recognized through reduced flood insurance costs for properties that are insured through the NFIP and/or private flood insurance. Property owners can contact their insurance agent to get estimates of these benefits. Property owners who purchase insurance through the NFIP should be aware that NFIP claims are limited and may not cover the full cost of damages to their property after a flood. Therefore, when assessing the benefits of raising their building, they should also take into account the cost of risk beyond what is covered by the NFIP insurance.

Assessing the cost of building elevation depends on the type of structure, where it is located, the type of existing foundation, etc. As such, property owners will be best served if they estimate the unique cost associated with elevation of their unique building. Construction contractors who specialize in repairing foundations and/or elevating buildings may be able to provide estimates of those costs.

- *Installing a Tide Gate at the Carvers Pond Inlet.* The inlet to Carvers Pond at the head of Carvers Harbor has a long history of modifications to capture tidal energy for beneficial uses. Another possible option, which could provide flood protection to properties subject to flooding from Carver's Pond would be to install a tide gate structure at the inlet, which would limit the potential for flooding in the pond. This presents a unique and interesting opportunity for the Town to highlight the historic use of the site, while also addressing modern issues related to flood risk management and the burgeoning interest around carbon free alternative energy sources. We recommend the Town consider the feasibility of this option in greater detail. This would require considerable study to better understand the hydraulics of the inlet and any possible environmental impacts from its modification. Any proposed plans to modify the inlet and install hydraulic controls would also need to consider plans for elevating Main Street and would likely require modifications to the foundation of the Tidewater Inn, which could include elevation of the structure to reduce flood risk. Any potential modifications to the Carver's pond inlet should take a long-term view of sea level change in their design, as they are likely to remain in place for a century or more, as the present hydraulic structures have.
- *Planning and Modification at the Ferry Terminal.* We understand the Town is concerned about potential sea level rise and flooding impacts to the Ferry terminal. Due to its location within the harbor and the need for boat access. It is probably unfeasible to install flood gates or similar structures that could limit high water elevations at the terminal. However, although waves are significantly attenuated by the natural setting of the harbor before they reach the Ferry Terminal, our analysis has shown that wave impacts at the Ferry terminal could be significant during an extreme storm event, and these impacts will become greater in magnitude and possibly more frequent with sea level rise. We recommend the Town consider the susceptibility of Ferry Terminal infrastructure to damages from wave run-up and overtopping, as well flooding by an extremely high tide. Such a study would require a detailed survey of the infrastructure and a vulnerability assessment to identify what is at risk. If it is found that the risk due to wave attack is considerable, it is possible that a breakwater could be used to reduce the wave energy that reaches the terminal during extreme storms. The cost of designing, permitting, and constructing a breakwater would be significant, so this may not be a

feasible option if the structures onshore at the terminal can be more easily hardened to withstand significant wave attack.

Please note, large damaging waves depend primarily on offshore wind conditions and can occur at any water level, regardless of the sea level rise. It is possible that climate change may lead to more frequent occurrence of damaging wave events, but this has not been investigated in the present study. It is also possible that climate change could lead to less frequent occurrence of extreme wave events, but when coupled with sea level rise, the events that do occur will be more extreme.

With regards to the Ferry terminal, we also understand there can be difficulty moving vehicles on or off the Ferry during times of extremely high water, due to the angle the vehicle ramp makes with the car deck on the Ferry. As sea levels rise, this is will become a more common occurrence. This problem can be remedied through structural modifications to the terminal, or by possibly adjusting the ferry schedule as required. Structural remedies are likely to be more costly, whereas the need to adjust the schedule (or suffer delays) will increase in frequency with sea level rise. To better understand this impact on the Ferry Terminal, we recommend the Town undertake a simple study to evaluate the cost of such modifications, and evaluate the future timing of problematic high tides. The study would require an elevation survey to identify critical water levels above which the Ferry is inaccessible to vehicles, and a tide study to determine tidal harmonics for the Ferry location. Because astronomic tides are highly predictable, this information could be combined with the sea level rise information to estimate future times when the Ferry would most likely be inaccessible. Comparing this information to the Ferry schedule would allow for an assessment of the impact. We expect that in the near-term problematic tides would be relatively infrequent and could be dealt with by adjusting the ferry schedule or allowing for delays, but in the long-term the problem may become frequent enough to warrant structural modification to the terminal. The recommended study would help the town identify when such modifications would become feasible.

### Retreat

In the long term, it is possible that sea level rise will cause some properties to be inundated daily, under normal tidal conditions. Because of the large degree of uncertainty in long-term sea level rise projections, we cannot determine precisely when this will happen. We must also consider that it is more likely that a structure subject to this type of flooding would be damaged by one or more storm events before sea level has risen enough for this concern to play out. Retreat may be a viable option for such properties, because the cost associated with damages and/or insurance requirements may soon outweigh the value of the property. Evaluation of the feasibility of elevating buildings, as recommended above, should consider retreat as a possible option.

With the information developed in this effort we can only estimate the probability of flooding in a given future year. For example, as described in our August 30, 2017 memorandum on present and future flood hazards, areas around Downstreet that are presently below an elevation of 9 feet (NAVD88) have about a 1-in-30 annual chance of being inundated in 2017, but that chance will increase to about 1-in-10 by 2057, and by 2117, it will become a nearly certain daily occurrence. If long-term plans are not implemented to protect these areas, so that they can accommodate daily flooding, as well as flooding from more extreme events, the best approach may be to remove structures from these areas (i.e., retreat) and manage the progression of the properties toward a

more natural state through the construction of natural or nature-based features, such as a constructed marshes.

For the most part, due to the economic viability of the Downstreet shorefront, retreat will probably not be the preferred option for most properties. However, it should still be considered as an option, particularly for residential properties and/or older lower value properties that are located on the harbor side of Main Street, where the risk of flooding is greatest.

## **SUMMARY OF RECOMMENDATIONS**

- Complete the Maine Flood Resilience Checklist.
- Update hazard information to include possible impacts from tropical storms and hurricanes, and purely tidal events.
- Evaluate the feasibility of elevating low-lying areas of Main Street.
- Provide property owners with educational tools and resources to evaluate the feasibility of elevating their buildings. Consider retreat as a possible option in certain cases, especially for residential buildings and/or properties with low value.
- Evaluate the feasibility of installing a flood gate at the Carvers Pond inlet.
- Evaluate the vulnerability of Ferry Terminal infrastructure to extreme wave impacts, and consider construction of a breakwater.
- Evaluate the timing when vehicle access to the Ferry boat will be difficult.
- Allow planning to be flexible and evolve with new information and experiences.