Integrating Storm Surge and Sea Level Rise Vulnerability Assessments and Criticality Analyses into Asset Management at MaineDOT

Surge from Hurricane Sandy crashes over a sea wall in Kennebunk, Maine on October 29, 2012

December 31, 2014

MaineDOT

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13. ABSTRACT

This report presents the results of a Climate Resilience Pilot Project conducted by the Maine Department of Transportation and sponsored in part by the Federal Highway Administration. The project developed and implemented tools to prioritize vulnerable transportation assets in the face of rising sea levels and increasing frequency and intensity of coastal storm surge events. State-owned roads, bridges, and culverts were selected and ranked according to criticality and sensitivity metrics developed in reference to agency maintenance records, flooding histories, and the prioritization efforts of agencies in other states. For the highest priority assets in the towns of Scarborough, Bath, and Bowdoinham, alternative engineering designs were created that would be expected to be resilient to 3.3’ and 6’ of sea level rise. Depth damage functions were created for these designs and for the existing structures. The T-COAST software was then used to evaluate relative cost-efficiency of the designs in each location under a range of sea level rise and storm surge scenarios, and compare it to replacing each asset in-kind. Cost efficiency inputs included initial construction costs and cumulative expected repair costs over time given agency maintenance records, the depth damage functions created, and the sea level rise curves and storm surge scenarios selected. Results show which candidate designs would be the most cost efficient in each location and demonstrate there is no one correct design for the 3.3’ or 6’ sea level rise scenarios, even for similar asset types in adjacent towns. Local hydrology, topography, and tidal and storm surge regimes demand a site-specific approach to benefit-cost analysis of alternative engineering structures, at the conceptual design phase. Results also help identify relative contributions of risk from sea level rise and storm surge for each candidate design in each location, and provide insights about how to evaluate agency planning, budgeting, scheduling, and design procedures in an era of both rising sea levels and changing storm surge intensities and probabilities.

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CONTENTS

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INTRODUCTION

This report describes efforts conducted under a grant from the Federal Highway Administration (FHWA) to the Maine Department of Transportation to address goals described in a proposal titled "Integrating Vulnerability Assessments and Criticality Analyses into Asset Management at MaineDOT." The effort has been designed to dovetail with another, NOAA-funded, Project of Special Merit (POSM) involving several other state agencies and organizations, titled "Integrating Science into Policy: Adaptation Strategies for Marsh Migration," thus providing a transportation infrastructure component for this marsh migration work that will be of interest to municipalities as well as MaineDOT's asset management and maintenance programs. MaineDOT's project overlaid GIS maps generated for marsh and sea migration with state highways, bridges, and culverts in six coastal towns in central to southern Maine to assess the vulnerability of these assets under varying sea level rise scenarios established using both historic tide gauge data and inundation models. Assets under potential threat by climate-driven storm surge and sea level rise (SLR) scenarios identified within the defined geographic area were to be evaluated for the three components of vulnerability: exposure, sensitivity, and adaptive capacity. The six pilot towns (Bath, Bowdoinham, Georgetown, Phippsburg, Scarborough, and Topsham) were selected via a competitive application process through the POSM prior to FHWA grant funding awarded for MaineDOT's project.

Goals of the present project included:

- Assessing the feasibility of integrating vulnerability and criticality assessments into existing decision-making processes, which will ideally lower barriers to adaptation both within MaineDOT and participating municipalities (identified as a challenge in previous pilot studies); and
- Laying the groundwork for solid, measurable outcomes in terms of adaptation strategies, resource resiliency, and infrastructure management by providing a qualitative ranking scheme base on identified criteria, enabling the incorporation of cost and priority into MaineDOT's long range planning. Assessing the vulnerability of coastal assets might also provide the basis to evaluate current maintenance and emergency procedures to ensure that oversight is adequate during severe precipitation events.

Asset data was provided by MaineDOT's Bureau of Maintenance and Operations (M&O), working as a collaborator on this pilot with the Environmental Office (ENV) and the Bureau of Planning (BP). To address the project goals, and following the recommendations from the 2010-2011 FHWA-sponsored pilots, asset criticality was to be based on each asset's function in multiple systems (emergency evacuation, level of activity, commerce) and physical characteristics (condition ratings, corridor priority, replacement cost). Following initial steps in collaboration with other projects, including using overlying GIS maps generated for marsh and sea migration with state highways, bridges, and culverts, as a means of assessing general vulnerability of these assets under varying SLR scenarios, the chosen approach in this project was to:

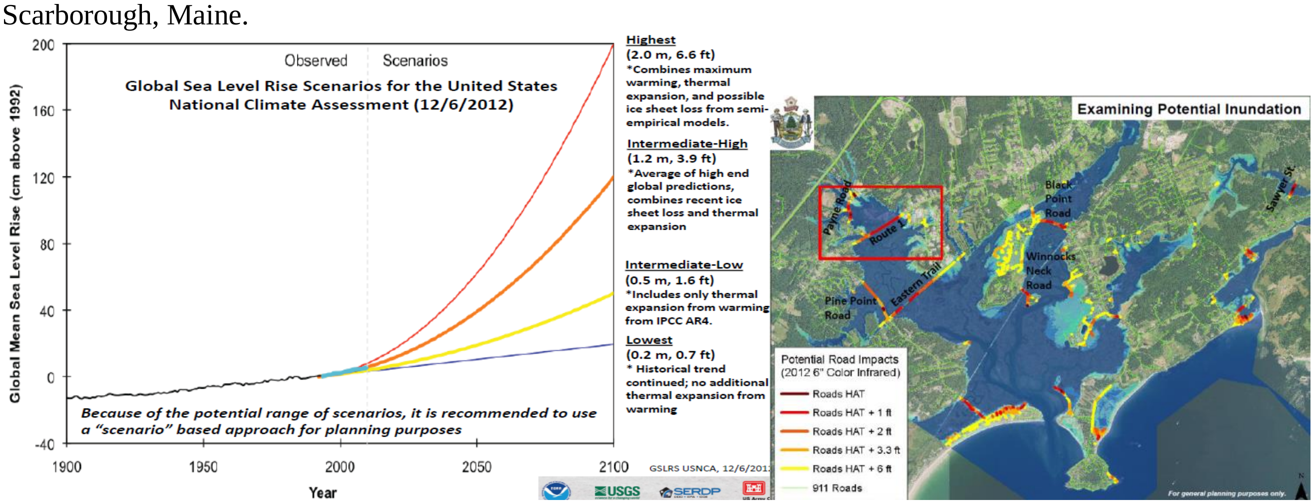
1. create a Decision Support Tool (DST) that would assist in ranking assets in each Project of Special Merit town;
2. select and prioritize vulnerable assets using this tool, based on criticality and sensitivity assets in each town;

3. enhance the COAST software tool to create T-COAST, which enable cumulative benefit-cost calculations for more than just parcels or other polygon-based asset layers (e.g., adding capability to conduct benefit-cost analyses on adaptation actions for line segments like roads or point locations like culverts);
4. provide preliminary conceptual design for candidate alternative engineering designs tailored to varying amounts of anticipated sea level, and customize depth damage functions for each design;
5. run the enhanced software for the selected assets in each town, under a range of SLR and storm surge scenarios;
6. report on benefit-cost results of the selected candidate engineering designs under these scenarios; and
7. provide lessons from the study for MaineDOT to consider regarding ongoing asset planning and management.

APPROACH AND DATA INPUTS

Initially, MaineDOT proposed that all candidate state transportation assets for each project town be identified, including all state roads, bridges, and culverts in each town. Initial screening was conducted based on projections from the Maine Geological Survey indicating those transportation assets more likely to be subjected to greater amounts of SLR and storm surge in the coming several decades (Figure 1). Inundation maps created for the POSM based on current trends modeled for SLR, a moderate SLR projection of 3.3', and a severe SLR projection of 6'. To develop the DST (see Appendix 1), ranking questions were created and revised by an interagency workgroup (Table 1). The DST is now complete and available for use in a range of settings. However, the data required to populate the DST and rank assets is not yet consistent for all of MaineDOT's asset types, nor is it consistent within any given asset type, although efforts are underway to update information regarding assets. Given the limited six town scope of this pilot, the collaborators opted to gather asset specific data (e.g. height of bridge chord over mean high water elevation) for those structures with a history of flooding during a 100-year storm, which is roughly equivalent to 3.3' of SLR. These assets would then be run through the DST to select one in each town for which design alternatives would be developed.

Figure 1: Global sea level rise scenarios for the United States and resulting inundation potential for Scarborough, Maine.



To narrow the number of locations where site-specific data would need to be collected, flooding histories were examined back through 2008, the year of the most recent precipitation event resulting in a federal disaster declaration. The record of reported flooding events revealed that only one location in most of the six towns had experienced repeated occurrences of water over the structure. With the sample size equal to one, the agency decision was to not use the DST tool after all, and instead manually select the highest priority assets for benefit-cost analysis from among the consolidated lists in each town. To summarize, this decision was made 1) to reflect substantial local knowledge about which assets were most vulnerable; 2) because in most towns there was only one frequently flooded asset to rank; and 3) quality and availability of specifications for assets of different types was quite variable. For the town of Scarborough, the selected asset was not the one where several flooding events had occurred, but instead the collaborators opted to include a crossing that carries the Dunstan River under US Route 1, a minor arterial along Coastal Maine. This location is not only a key connection for local and tourist economies, but has also been identified as a constriction to tidal flow into the upper reaches of Scarborough Marsh, one of the largest intact salt marshes along the North Atlantic coast. The perception is one of both providing a barrier to tidal flow and not being sufficient to block storm surge because in this location Route 1 sits only several feet above than the marsh elevation and, although specific conditions need to coincide for water to overtop the road surface (southerly wind, 500-year precipitation event, and a king tide), any level of SLR is certain to inundate the road bed more frequently or permanently. Looking more closely at the sites of the six candidates for this pilot study, it became clear that three of the six were not directly exposed to tidal action or storm surge. In Georgetown, Phippsburg, and Topsham, the assets with documented flooding histories were primarily subject to flows originating from uplands during storm events. Because this pilot was to focus on SLR and storm surge, assets in these three towns were also eliminated.

The assets selected as most vulnerable in the three remaining towns were: 1) a culvert crossing under a section of Route 1 running through the Scarborough Marsh in Scarborough, which would be converted to a bridge under the 3.3' and 6' SLR scenarios (Figure 2); 2) a bridge across the New Meadows River on Old Bath Road in Bath (Figure 3); and 3) a large culvert/bridge carrying Bridge Street Creek under Route24/River Road in Bowdoinham (Figure 4). Locations and site characteristics were verified by MaineDOT survey staff. For each location, candidate alternative engineering designs were created by MaineDOT bridge engineers. These conceptual designs were intended to be structurally resilient to 3.3' or 6' of SLR, to be consistent with related and concurrent projects under the POSM. Construction costs were estimated by MaineDOT engineers and included road elevation costs where appropriate (Table 1). They do not include additional costs it is reasonable to expect under the 3.3' and 6' SLR scenarios, such as right-of-way acquisitions or utility rerouting. Additional T-COAST iterations could include these and other structural and non-structural costs in the benefit-cost calculations if desired. This will be especially possible as a result of this project, which also enhanced the COAST software to be able to perform cumulative expected damage calculations on line files for roads and utilities and point files for bridges and culverts, rather than just for polygon files (as had been the case with the software tool prior to this study).

In collaboration with MaineDOT engineers, a depth-damage function (DDF) was then created for each candidate design and for the "replace in-kind" scenario. For purposes of this pilot, "replace-in-kind" means that the asset would be replaced to current design specification and standards. Based on MaineDOT maintenance records, these DDFs specified the amount of repair costs it is reasonable to expect would be incurred at different depths of inundation from storm surges of different intensities. A schematic for these DDFs, tailored to each candidate bridge design, is shown in Figure 5. Final

DDFs used are in Tables 2 – 4 and narrative descriptions of estimated repair costs at each increment in these DDFs are in Table 5. Repair costs indicated in the DDFs and in Tables 6 – 8 are in today's dollars (not discounted), although calculations were also performed with a 3.5% discount rate on cost of repairs and are available from Catalysis on request. For all replacement options the following design criteria from the Maine Bridge Design Guide were used:

- Road elevations are a minimum of 2 feet above MHW plus a 2-foot wave height.
- Bridges have a minimum of 2 feet of freeboard above MHW plus a 2 foot wave height.
- Culverts have a 0.9 headwater-to-depth ratio at MHW.

Besides these structure-specific inputs to the T-COAST model, the most recent LiDAR imagery was also obtained from the Maine Geological Survey and additional environmental parameters were confirmed. These include sea level rise curves derived from maximum elevations by 2100 of 3.3' and 6' (to be consistent with other SLR modeling efforts in the Project of Special Merit), using the US Army Corps sea level rise curve calculator (at http://www.corpsclimate.us/ccaceslcurves.cfm). Storm surge elevations, recurrence intervals, and probabilities were determined from each of the three nearest FEMA Flood Insurance Study data sources for each location.

Further inputs included base water elevation reference of MHHW (NAVD88 in feet), at 4.59' (Scarborough), 1.64' (Bath), and 4.51' (Bowdoinham). The VDATUM error for these sites is a published +/-13.2cm, and error on the LiDAR imagery used is roughly +/-15cm. Additional elevational error may exist on account of distance between VDATUM recording stations and each site location, as follows. Scarborough has good tidal data at Pine Point (the mouth of the Scarborough River), but tidal conditions near Route 1 road may be slightly different than at this location due to the length and sinuosity of the channel. In Bath, the nearest tidal station is a farther away, and there might be restrictions along the New Meadows River between the VDATUM site and the asset evaluated. In Bowdoinham, the tidal prediction station is near the evaluated asset, but no VDATUM data exists except at the mouth of the Cathance River as it empties into the Androscoggin River.

FINDINGS

The T-COAST calculator produced cumulative expected damage estimates for each site, allowing comparison of the relative financial efficiency of each candidate design. For each SLR scenario, the most financially efficient design in each location is the one with the lowest total of initial construction costs plus maintenance costs if the structure is repaired after each storm surge event.

Results show that in terms of total life cycle costs, the question of whether to replace an asset in-kind or design and build it to be able to withstand 3.3' or 6' of SLR *depends* on variables modeled by the T-COAST software, including differences between sites in 1) storm surge probability and elevation for a range of recurrence intervals; 2) tidal regime and local topographic idiosyncrasies; and 3) cost of the initial structures and how much repairs of different types are known to cost.

This dependence is illustrated by the highly divergent results in the three sites, even though the structures were exposed to the same SLR scenarios in the model runs. Specifically, in Scarborough the most financially efficient design is replacing in-kind, whether there is 3.3' or 6' of SLR (Table 6). In Bath, the most financially efficient design is replacing in-kind under a 3.3' SLR scenario, but in the

6’ SLR scenario replacing with a bridge designed for 6’ SLR is most efficient (Table 7). And in Bowdoinham, the most financially efficient design is replacing with a bridge designed for 6’ of SLR whether the 3.3’ or 6’ SLR scenario actually occurs (Table 8).

Another important result from the project is that the majority of damages (77% of all cumulative damages, for all scenarios combined) is from storm surge, not SLR. Of course damages from SLR do increase in the higher SLR scenarios, especially with structures that were designed for 3.3’ of SLR or replaced in-kind. These damages can even surpass the cumulative costs of storm surge repair, as in Scarborough, where there was zero or very little damage in the 3.3’ SLR scenario but in the 6’ SLR scenario damages from SLR are fully 16% greater than damages from surge (if the existing culvert were to be replaced in-kind in the near future and not converted to a bridge designed for 3.3’ or 6’ of SLR). But in general, surge is a much more significant source of the financial costs to be incurred for the bridge designs and environmental scenarios evaluated (Tables 9 – 11 for the three towns) because of its relationship to catastrophic versus cumulative damages.

LESSONS LEARNED

Results represent substantial utility for agency planning purposes, informing specific investment decisions about asset replacements or upgrades when they become appropriate at these locations. Results also show that in terms of fiscal efficiency, there is no one right answer the question “what design standard should we use?” Unfortunately, differences in local flooding patterns, tidal regimes, topography, and structural details about the range of candidate alternative designs conspire to demand that in general, benefit-cost analysis needs to be conducted at the site level to provide resiliency. This process can be streamlined, but does have implications for how MaineDOT might evolve its approach to asset planning, design, budgeting, permitting, and scheduling in an era of both rising sea levels and increasing frequency and intensity of storm surge events.

Further complicating matters is that although the clear financial results of this study might seem to suggest particular courses of design action, such as perhaps replacing the New Meadows bridge in Bath with a structure designed for 6’ of SLR (Table 7), these results need to be reconciled with other agency assumptions about how much SLR there is likely to be by 2100. For example some Maine regulations are written to anticipate 2’ of SLR by 2100 (Chapter 355, Coastal Sand Dune Rules), and the recently completed Martin’s Point Bridge between Falmouth and Portland was recently replaced to accommodate 1.6’ of additional SLR. If as these examples suggest the agency expectation may be that only up to 3.3’ of SLR is likely by 2100, then model results suggest that replacing the New Meadows Bridge in-kind is the best financial choice when this decision needs to be made (in the next several years). That is, the answer to the question “how high should we build this bridge” depends not just on environmental or design parameters or fiscal efficiency calculations as in this type of modeling exercise, but critically, also on agency expectations of the future in relation to those calculations.

In Scarborough, results suggest the better financial choice is to replace the existing culvert in-kind whether sea levels are rising rapidly or not in the next several decades. However regardless of this result, which focuses just on the culverts, at some point the remainder of the stretch of Route 1 in the Marsh may be in need of elevation lift. To evaluate this, these Route 1 Scarborough Marsh calculations could be run through T-COAST again using road elevation plus bridge elevation along the entire stretch, and subjecting them to updated SLR curves and storm surge estimates. Separate

DDFs would be constructed for each asset type, and initial costing could be structured to include ROW acquisition, etc. if desired.

In Bowdoinham, results continued to be consistent with the site-specific nature of this work as described above. This 10-foot diameter culvert replaced a smaller pipe in 2006. Prior to its replacement, this pipe routinely overtopped when heavy rainfall occurred during high tides; as it is currently, this location still floods over the road surface during king tides. Based on those results, it is recommended that when it is time to replace or upgrade the existing culvert that it becomes a structure designed for 6' of additional water at high tide, *whether 3.3' or 6' of SLR is anticipated* by 2100. However – if ten or twenty years pass before this upgrade becomes necessary, this conclusion may need to be reexamined based on recent SLR trends.

The advantage of basing design decisions on projected SLR is that the ocean levels change over relatively long planning horizons. Although structures exposed to SLR are currently designed to have 75 to 100 year life spans, sea levels can be re-evaluated every 10 to 20 years to verify whether prior projections are still valid. Because MaineDOT can neither predict nor control global fossil fuel consumption and other climate-affecting human behaviors, adopting a "no regrets" strategy appears most prudent. Such a strategy would incorporate increased resistance to storm surges and some allowance for SLR within a 20 year planning horizon, particularly where only a portion of an asset might be permanently affected (e.g. a crossing that is at a lower elevation than the road elevation on the approaches) or where an asset will only be affected during extreme weather events (e.g. storm surge over the road surface during an extreme high tide). Other key observations from the study include that under the ranges of likely storm surge scenarios, replacing structures so they are resilient to higher SLR in these three locations only became cost effective when 1) initial construction costs were relatively low or 2) as a combination of moderate construction costs and extreme sea levels. That is, although there may be a sentiment in some agency quarters that the greatest concern about SLR and storm surge should be placed on the largest structures, perhaps the smaller structures, requiring lower or moderate initial construction costs, might provide a more cost-efficient avenue in general. Allocating resources to increase the resilience of transportation infrastructure that will not be accessible should the more extreme SLR scenario come to fruition, for example, and raising the elevation of a replacement bridge when the approaches will still be inundated, might not be prudent unless resources are sufficient to raise the entire group of assets associated with that bridge. This hypothesis could be tested over a short period with several other benefit-cost comparisons, and might help inform agency priorities going forward.

Fiscal realities also play an important role in considering climate as a factor potentially affecting all assets, whether coastal or inland. Limited funding requires that some assets be rehabilitated to extend life spans versus replaced. In the case of rehabilitation or repair, budgets and scopes may make it difficult to incorporate any additional resiliency to climate impacts beyond additional armoring or scour protection. These may prove adequate for the SLR projections for the next 20 years and to ensure to the extent possible that a structure will remain intact after being subjected to typical storm surges. However uncertainty surrounds the subject of extreme weather events because while we can model the frequency of these events using historical data, we cannot predict the intensity of events out into the planning horizon used by transportation agencies. It is unlikely that funding levels or public policy will support replacing every asset to reduce its vulnerability not only to levels of highest projected SLR, but also to be resilient to a 500-year storm that may or may not occur within that asset's lifespan.

CONCLUSIONS AND NEXT STEPS

- The DDFs and cost estimates created stand as a significant initial effort in creating a data driven analysis to identify asset details that can be scored and compared amongst other assets. They can also serve as cost-saving steps in future related projects, where similar bridges could use the same or slightly modified DDFs and construction cost estimates. *Over time, a library of these reference materials will greatly streamline the vulnerability assessment and benefit-cost evaluation process under a range of SLR and storm surge scenarios.*

- In terms of assessing the vulnerability and criticality of either individual or categories of assets, typically the smallest proportion of funding is available for planning and preliminary, pre-candidate assessments, with increased funding allocated for preliminary engineering and the largest portion of funding allocated for construction. Performing detailed vulnerability and criticality assessments and evaluating alternative designs for a large number of assets per year using the DST at the planning stage does not seem practical in the current fiscally-constrained environment. Instead, a GIS-based screening layer that incorporates hydrologic issues, general vulnerabilities to coastal flooding, and criticality ratings similar to the layer MaineDOT currently uses to screen for threatened and endangered species, urban impaired streams, etc. seems appropriate. Overlaying such a GIS layer with work plan projects would identify those individual assets requiring a more detailed climate-based analysis during preliminary engineering when funding might be available to apply the DST to several design alternatives that address possible climate-related scenarios. *As one of its next steps, MaineDOT would like to pursue development of a GIS-based vulnerability and criticality screening layer.*

- With minor modification, the method used in this study could be used inland as well, as was done on another FHWA climate vulnerability pilot with the Minnesota DOT, in partnership with Parsons Brinckerhoff. In the Minnesota study, tidal surge and SLR were not issues; upland surge was calculated using wetland volumetric models, and cubic feet per second estimates for structures with particular openings were converted to elevations using HEC-RAS. These elevations, along with probabilities and recurrence intervals also derived through other methods, were then used to parameterize T-COAST and perform similar calculations as in this report. *Included in its next steps, MaineDOT would like to select an inland corridor segment on which to apply the T-COAST model.*

- T-COAST could also be used to estimate non-local, non-structural benefits and costs over time, as was additionally demonstrated on the Minnesota FHWA pilot regarding social costs and detours costs implied by bridge closures. MaineDOT made an agency decision not to pursue adding in these additional costs to isolate those costs/benefits that are solely the responsibility of the agency. However in a future effort the method could be combined with Delphi survey methodology to establish and evaluate ecological benefits and costs of candidate engineering designs. A Delphi survey was used in a recent marsh conservation project led by the Maine Departments of Inland Fisheries and Wildlife and Agriculture, Conservation, and Forestry to establish relative values of potential conservation parcels in terms of marsh ecosystem services. *We envision that using a Delphi survey as part of a system-wide vulnerability assessment would lend weight to proactive* *asset upgrades by identifying ecosystem benefits to be realized immediately and cumulatively versus those realized only within the context of storm events.* For example, upsizing a culvert carrying a cold water stream under a road so that it will pass a 100+ year storm event would likely improve passage for aquatic species and connectivity immediately upon project completion, while a major precipitation event is somewhere in the less predictable future. These immediately-realized benefits could add justification to costs for purposes of work plan priority, disaster mitigation, and risk management, particularly if a structure is deemed vulnerable to extreme weather.

- Even though the feasibility of applying this analysis increases with a limited number of assets to analyze, limited resources within MaineDOT are available to develop design alternatives and verify model outputs on vulnerability and criticality ratings. This pilot project was conducted as we believe T-COAST would be applied in a system-wide analysis; that is, using agency engineers and environmental staff to provide inputs such as DDF variables to the model. Given these limitations *it may be more realistic to gauge risk to Maine's transportation assets from SLR and storm surge on a case-by-case or corridor basis than it might be for an entire, more intensely developed landscape*.

- Characteristics of Maine's coast such as the large number of peninsulas that house infrastructure (e.g. water treatment facilities) and residences can pose a challenge in resiliency planning. The challenge of improving resiliency is further compounded by the shared responsibility of the state and municipalities for co-located assets. For example, along the coast many smaller state and local roads serve as sole access ways to islands and peninsulas; in cases where the road is a municipal responsibility yet a bridge on that road is a state asset, raising the elevation of a single state-owned crossing in isolation would result in a very resilient asset that could not be accessed because of adjacent flooding of the approaches. *MaineDOT's efforts to understand asset vulnerabilities through this project are thus a significant step toward defining the indictors of risk for assets on its roadway network*.

- Results also provide actionable management decision information about which specific engineering designs should be considered further in each location and identify the need for informed decision-making about local infrastructure investments. In summary, the work *demonstrates strength of the analytic approach and underscores the need for this type of scenario-based analysis if cost efficiency is to become a more regular part of asset planning.*

- Finally, efforts to reach the project conclusions identify a few key next steps to further the conversation and assessment methodologies within MaineDOT business practices. In addition to consideration of the asset-specific and other agency recommendations above, more general next steps to follow from this significant work effort include:
    - Undertake education/dialogue throughout the agency on the flooding issues and the benefit-cost methodology employed in this study. Discussions are currently underway on how to *change design standards for culvert sizing to consider the 100-year storm event.*

- *Use the results of this study to make the case for additional funding resources from the legislature or from other places for future flood vulnerability assessment and adaptation work.*
- *Share results of this work with other state and local agencies and establish a collaborative effort to better define and address risks in the most fiscally efficient manner possible.* A forum for sharing these results and vetting next steps exists as Maine's Aquatic Resource Management Strategy Workgroup (ARMS). ARMS is a diverse stakeholder group comprised of over forty agencies, non-government organizations, municipalities, and non-profits formed in 2012 to address natural resource and economic issues related to stream crossings. As such it provides a sounding board for issues that affect how infrastructure might be modified to account for future changes in Maine's landscape and climate.

TABLES AND FIGURES

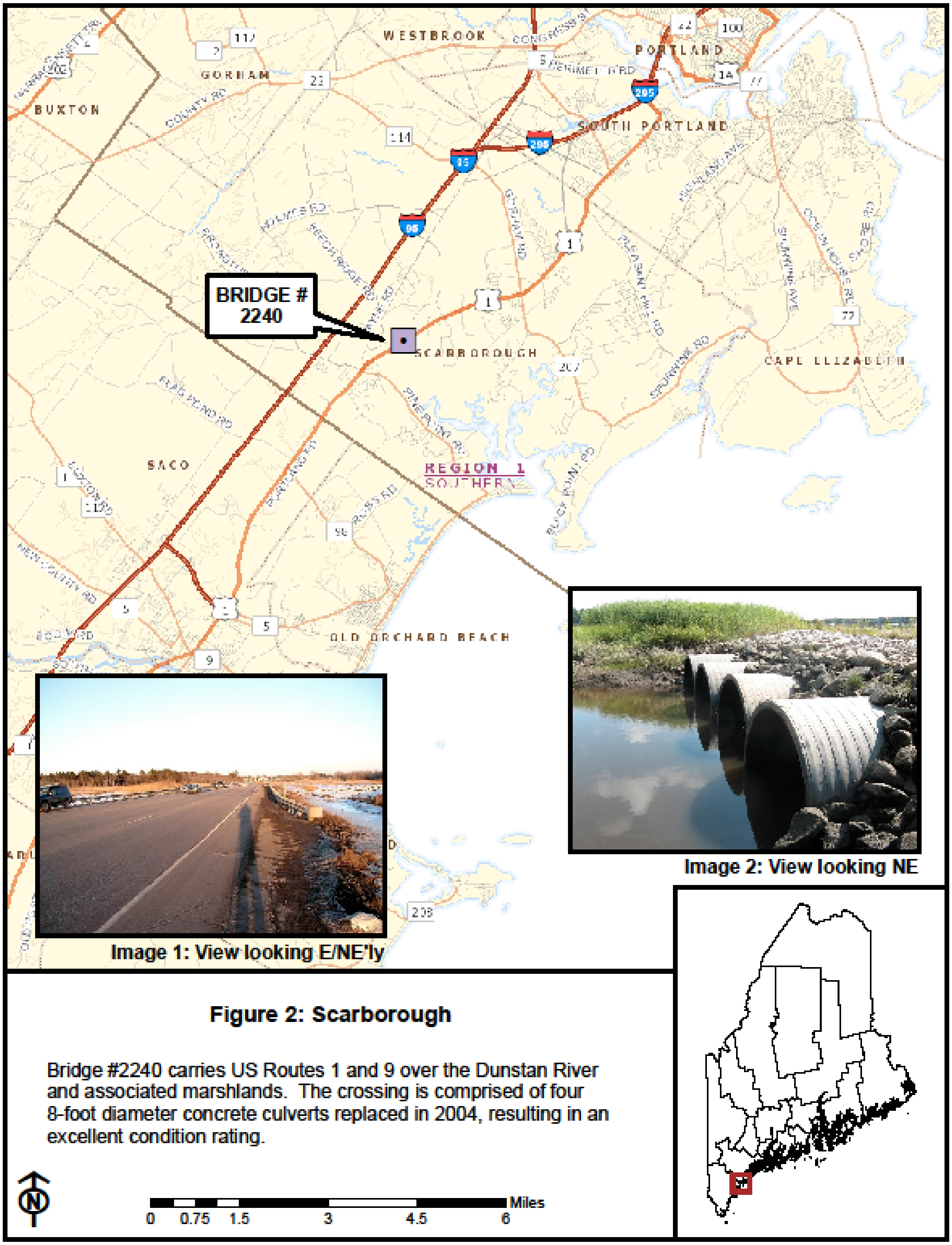


Image 1: View looking E/NE'ly

Image 2: View looking NE

Figure 2: Scarborough

Bridge #2240 carries US Routes 1 and 9 over the Dunstan River and associated marshlands. The crossing is comprised of four 8-foot diameter concrete culverts replaced in 2004, resulting in an excellent condition rating.

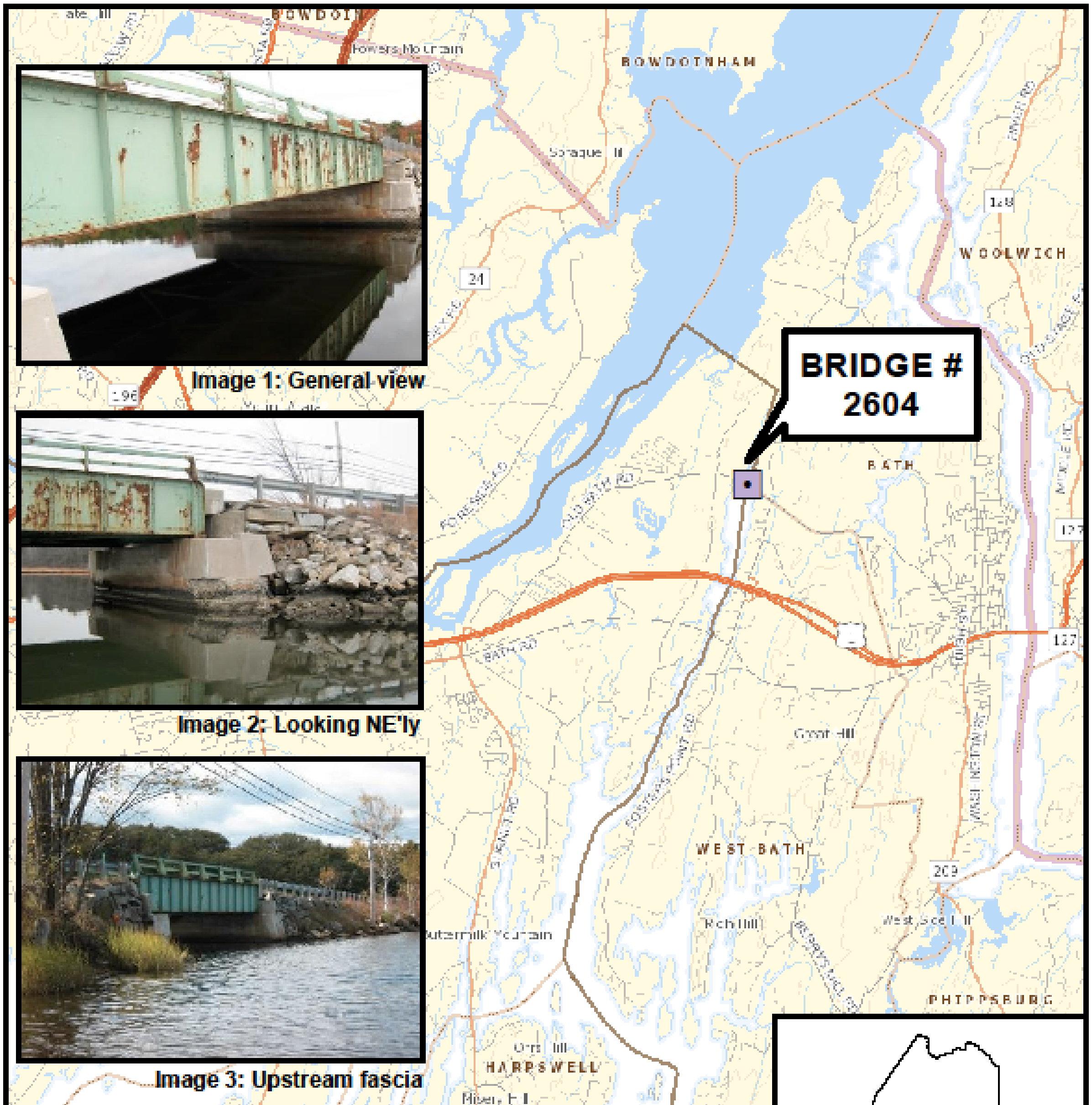


Image 1: General view

Image 2: Looking NE'ly

Image 3: Upstream fascia

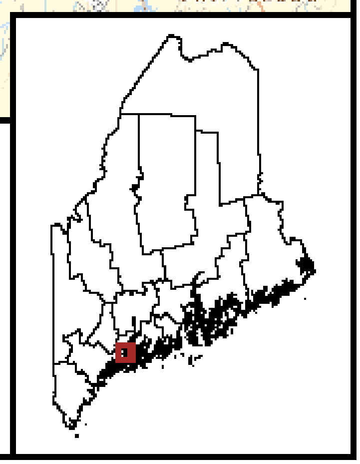
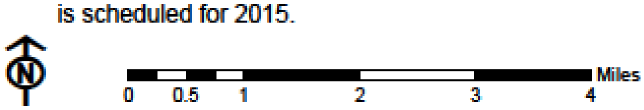


Figure 3: Bath

Bridge #2604 is a 58-foot steel span over the New Meadows River. This girder-floorbeam structure on Old Bath Road was reconstructed in 1974; the original bridge was constructed in 1918. Condition of this bridge ranges from poor (substructure) to satisfactory (deck). Preliminary engineering for replacement is scheduled for 2015.



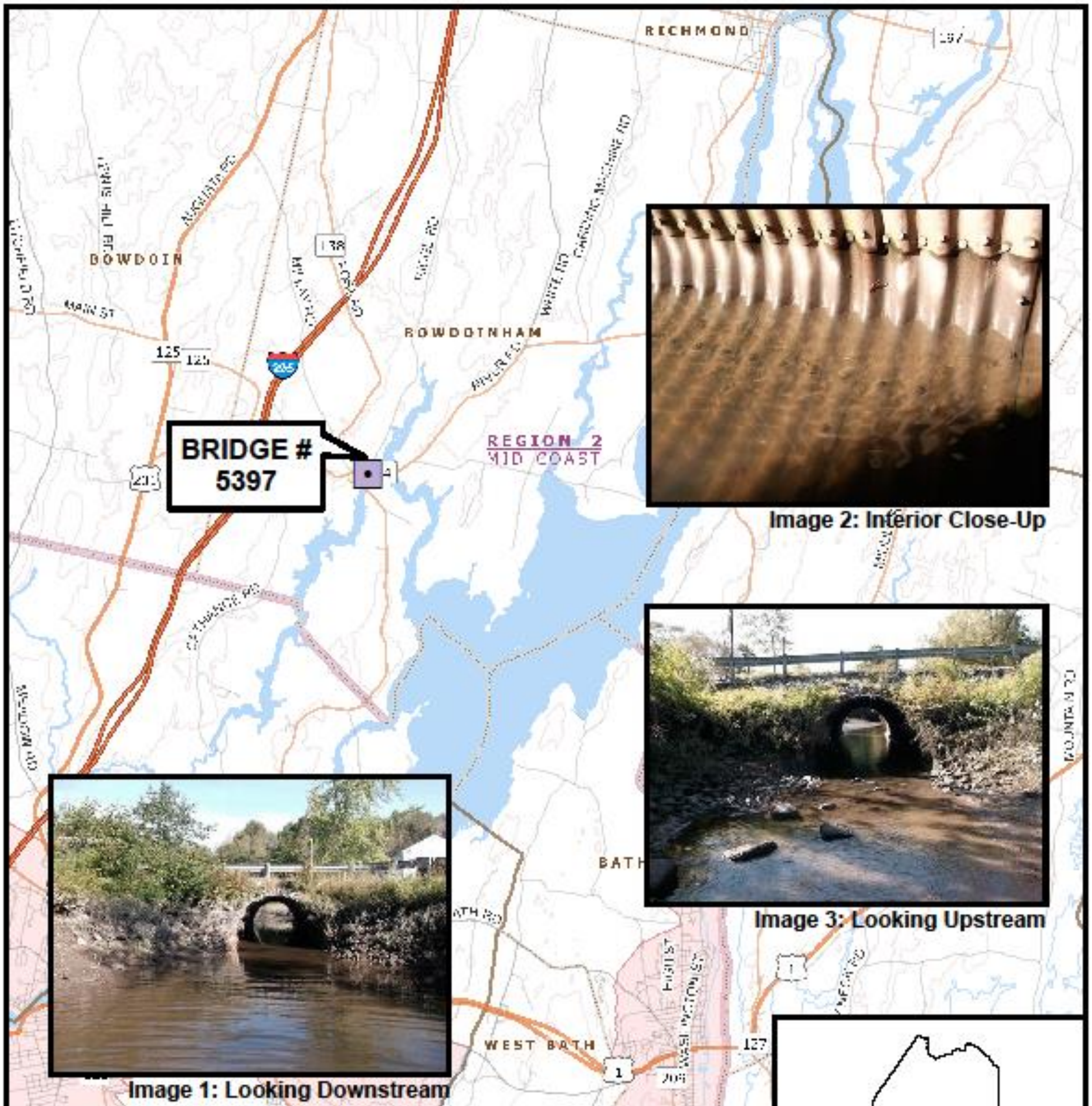


Image 1: Looking Downstream

Image 2: Interior Close-Up

Image 3: Looking Upstream

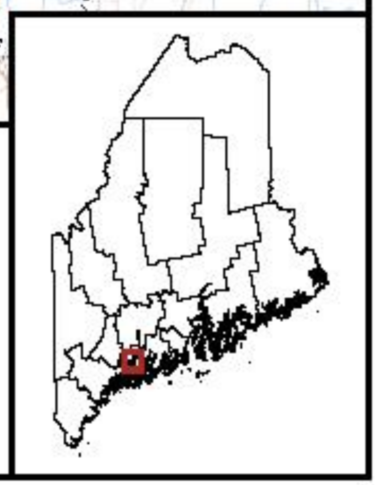


Figure 4: Bowdoinham

Bridge #5397 is a 10-foot diameter, corrugated metal pipe most recently replaced in 2006. This pipe carries Bridge Street creek under Route 24/River Road. Downstream portions of the creek are tidal.

Table 1. List of Decision Support Tool Ranking Questions for Assets in Each Town.

Scoring categories regarding sensitivity and criticality of each road or bridge evaluated are provided below. In each case, questions were determined and agreed upon through agency discussions and review other recent approaches and existing literature. Multipliers for the weight of each question were derived through expert opinion and agreement of agency and contracted personnel. Total score for each question was simply "score x weight" for each asset. The method developed, now available for agency use in other settings, is to use these total scores to rank which assets should receive more complete benefit-cost analysis at the conceptual design stage. The questions are now in the COAST DST, and can easily be edited to customize for other applications.

	Bridges - Sensitivity Questions	Entry Scale	Score	Multiplier	Total
q1	How many feet of freeboard are between the lowest chord of the bridge structure and the 100-year BFE? (Note: In tidal areas, use 100-year surge, if not included in 100-yerr BFE of FEMA FIS).	Over 5 feet, Enter 0 Between 1 and 5 feet, Enter 2 Between 0 and 1 foot, Enter 4 Less than 0, Enter 5		1	
q2	What percentage of the bridge length is at the height of the lowest chord, as answered in q1?	33% or less, Enter 1 34-66%, Enter 3 Over 66%, Enter 5		1	
q3	Are the approaches to the bridge subject to flooding before the bridge structure itself is compromised?	If Yes, Enter 5 If No, Enter 0		1	
q4	Is the bridge indicated as scour critical at its latest inspection?	If Yes, Enter 5 If No, Enter 0		2	
q5	Was the NBIS score at least 5 or above (FAIR CONDITION) at the last inspection?	If NBIS Score => 6, Enter 0 If NBIS Score = 5 (Fair), Enter 1 If NBIS Score = 4, Enter 2 If NBIS Score = 3, Enter 3 If NBIS Score = 2 or 1, Enter 5		3	

Table 1 (cont'd). List of Decision Support Tool Ranking Questions for Assets in Each Town.

	Roads - Sensitivity Questions	Entry Scale	Score	Multiplier	Total
q1	Are any segments at an elevation 5 feet or less above the 100-year BFE (freeboard)? (Note: In tidal areas, use 100-year surge, if not included in 100-year BFE of FEMA FIS).	Over 5 feet, Enter 0 Between 1 and 5 feet, Enter 3 Between 0 and 1 foot, Enter 4 Less than 0, Enter 5		1	
q2	How prone to failure are any culverts or drainage structures in the roadway, during rain or tidal storm events?	Enter 3 for Less than Once per Year Enter 4 for 1 or 2 times per year Enter 5 for More than 2 times per year		1	
q3	Has this road been included in any TIP for rebuilding and/or drainage improvements?	Enter 2 if in long range TIP Enter 3 if in Biennial TIP Enter 5 if Designed/Programmed		2	
q4	Is the road surface asphalt or concrete?	Enter 2 for concrete Enter 5 for asphalt		1	

Table 1 (cont'd). List of Decision Support Tool Ranking Questions for Assets in Each Town.

	Bridges - Criticality Questions	Entry Scale	Score	Multiplier	Total
q1	What is the functional classification of the roadway? (Classes 1-6 based on ADT - See Gulf Coast Study, Phase 2, Task 1 - Criticality, page 22).	ADT = 0-4,000, Enter 1 ADT = 4,001-10,000, Enter 2 ADT = 10,001-17,000, Enter 3 ADT = 17,001-34,000, Enter 4 ADT >= 34,001, Enter 5		2	
q2	Does the bridge carry utilities and/or other modes of transportation other than cars and trucks?	For each utility or mode, enter this value: railroad = 3; water = 1; sewer = 1		1	
q3	Is the roadway an identified evacuation route?	If Yes, Enter 5 If No, Enter 0		1	
q4	Is the roadway providing access to a hospital, or ambulance/police/fire emergency facility?	If no, Enter 0 If hospital or ems, Enter 3 If BOTH hospital and EMS, Enter 5		2	

	Roads - Criticality Questions	Entry Scale	Score	Multiplier	Total
q1	What is the functional classification of the roadway? (Classes 1-6 based on ADT - See Gulf Coast Study, Phase 2, Task 1 - Criticality, page 22).	ADT = 0-4,000, Enter 1 ADT = 4,001-10,000, Enter 2 ADT = 10,001-17,000, Enter 3 ADT = 17,001-34,000, Enter 4 ADT >= 34,001, Enter 5		3	
q2	Is the roadway an identified evacuation route?	If Yes, Enter 5 If No, Enter 0		1	
q3	Is the roadway providing access to a hospital, or ambulance/police/fire emergency facility?	If no, Enter 0 If hospital or EMS, Enter 3 If BOTH hospital and EMS, Enter 5		2	
q4	Does the road have associated utilities and/or other modes of transportation other than cars and trucks?	For each utility or mode, enter this value: railroad = 3; water = 1; sewer = 1		1	

Table 2. Depth damage functions used for three candidate designs in Scarborough.

	In-kind Asset		**Bridge designed to 3.3' SLR**		**Bridge designed to 6' SLR**	
Flood Elev. (Ft)	Repair Cost	% Damage	Repair Cost	% Damage	Repair Cost	% Damage
0	$0	0%	$0	0%	$0	0%
1	$0	0%	$0	0%	$0	0%
2	$0	0%	$0	0%	$0	0%
3	$0	0%	$0	0%	$0	0%
4	$0	0%	$0	0%	$0	0%
5	$0	0%	$0	0%	$0	0%
6	$0	0%	$0	0%	$0	0%
7	$0	0%	$0	0%	$0	0%
8	$30,000	1%	$0	0%	$0	0%
9	$75,000	3%	$55,000	2%	$0	0%
10	$75,000	3%	$55,000	2%	$0	0%
11	$1,300,000	54%	$300,000	13%	$0	0%
12	$1,300,000	54%	$1,600,000	67%	$55,000	2%
13	$2,400,000	100%	$1,600,000	67%	$55,000	2%
14	$2,400,000	100%	$2,400,000	100%	$300,000	12%
15	$2,400,000	100%	$2,400,000	100%	$1,800,000	69%
16	$2,400,000	100%	$2,400,000	100%	$1,800,000	69%
17	$2,400,000	100%	$2,400,000	100%	$2,600,000	100%
18	$2,400,000	100%	$2,400,000	100%	$2,600,000	100%
19	$2,400,000	100%	$2,400,000	100%	$2,600,000	100%
20	$2,400,000	100%	$2,400,000	100%	$2,600,000	100%
21	$2,400,000	100%	$2,400,000	100%	$2,600,000	100%
22	$2,400,000	100%	$2,400,000	100%	$2,600,000	100%
23	$2,400,000	100%	$2,400,000	100%	$2,600,000	100%
24	$2,400,000	100%	$2,400,000	100%	$2,600,000	100%

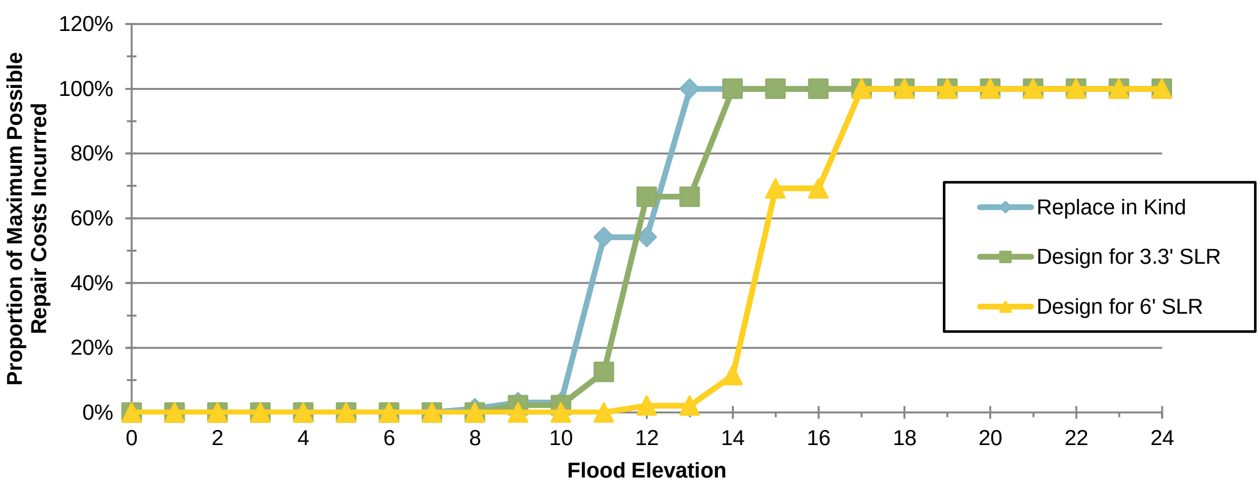


Table 3. Depth damage functions used for three candidate designs in Bath.

	In-kind Asset		Bridge designed to 3.3' SLR		Bridge designed to 6' SLR	
Flood Elev. (Ft)	Repair Cost	% Damage	Repair Cost	% Damage	Repair Cost	% Damage
0	$0	0%	$0	0%	$0	0%
1	$0	0%	$0	0%	$0	0%
2	$0	0%	$0	0%	$0	0%
3	$0	0%	$0	0%	$0	0%
4	$0	0%	$0	0%	$0	0%
5	$0	0%	$0	0%	$0	0%
6	$0	0%	$0	0%	$0	0%
7	$0	0%	$0	0%	$0	0%
8	$0	0%	$0	0%	$0	0%
9	$25,000	4%	$25,000	4%	$0	0%
10	$55,000	8%	$55,000	8%	$0	0%
11	$55,000	8%	$55,000	8%	$45,000	7%
12	$185,000	28%	$185,000	28%	$85,000	13%
13	$185,000	28%	$185,000	28%	$85,000	13%
14	$650,000	100%	$650,000	100%	$320,000	49%
15	$650,000	100%	$650,000	100%	$320,000	49%
16	$650,000	100%	$650,000	100%	$650,000	100%
17	$650,000	100%	$650,000	100%	$650,000	100%
18	$650,000	100%	$650,000	100%	$650,000	100%
19	$650,000	100%	$650,000	100%	$650,000	100%
20	$650,000	100%	$650,000	100%	$650,000	100%
21	$650,000	100%	$650,000	100%	$650,000	100%
22	$650,000	100%	$650,000	100%	$650,000	100%
23	$650,000	100%	$650,000	100%	$650,000	100%
24	$650,000	100%	$650,000	100%	$650,000	100%

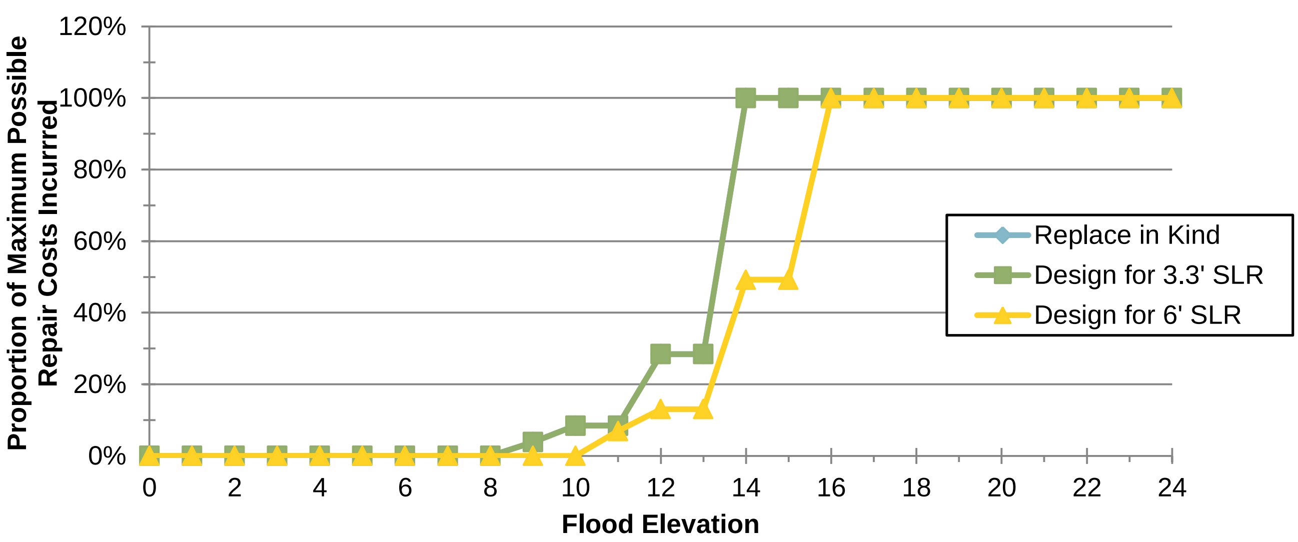


Table 4. Depth damage functions used for three candidate designs in Bowdoinham.

	In-kind Asset		Bridge designed to 3.3' SLR		Bridge designed to 6' SLR	
Flood Elev. (Ft)	Repair Cost	% Damage	Repair Cost	% Damage	Repair Cost	% Damage
0	$0	0%	$0	0%	$0	0%
1	$0	0%	$0	0%	$0	0%
2	$0	0%	$0	0%	$0	0%
3	$0	0%	$0	0%	$0	0%
4	$0	0%	$0	0%	$0	0%
5	$10,000	3%	$0	0%	$0	0%
6	$10,000	3%	$10,000	2%	$0	0%
7	$10,000	3%	$10,000	2%	$0	0%
8	$50,000	13%	$10,000	2%	$10,000	2%
9	$50,000	13%	$50,000	11%	$10,000	2%
10	$315,000	83%	$50,000	11%	$10,000	2%
11	$315,000	83%	$370,000	84%	$50,000	11%
12	$315,000	83%	$370,000	84%	$50,000	11%
13	$380,000	100%	$370,000	84%	$370,000	84%
14	$380,000	100%	$440,000	100%	$370,000	84%
15	$380,000	100%	$440,000	100%	$370,000	84%
16	$380,000	100%	$440,000	100%	$440,000	100%
17	$380,000	100%	$440,000	100%	$440,000	100%
18	$380,000	100%	$440,000	100%	$440,000	100%
19	$380,000	100%	$440,000	100%	$440,000	100%
20	$380,000	100%	$440,000	100%	$440,000	100%
21	$380,000	100%	$440,000	100%	$440,000	100%
22	$380,000	100%	$440,000	100%	$440,000	100%
23	$380,000	100%	$440,000	100%	$440,000	100%
24	$380,000	100%	$440,000	100%	$440,000	100%

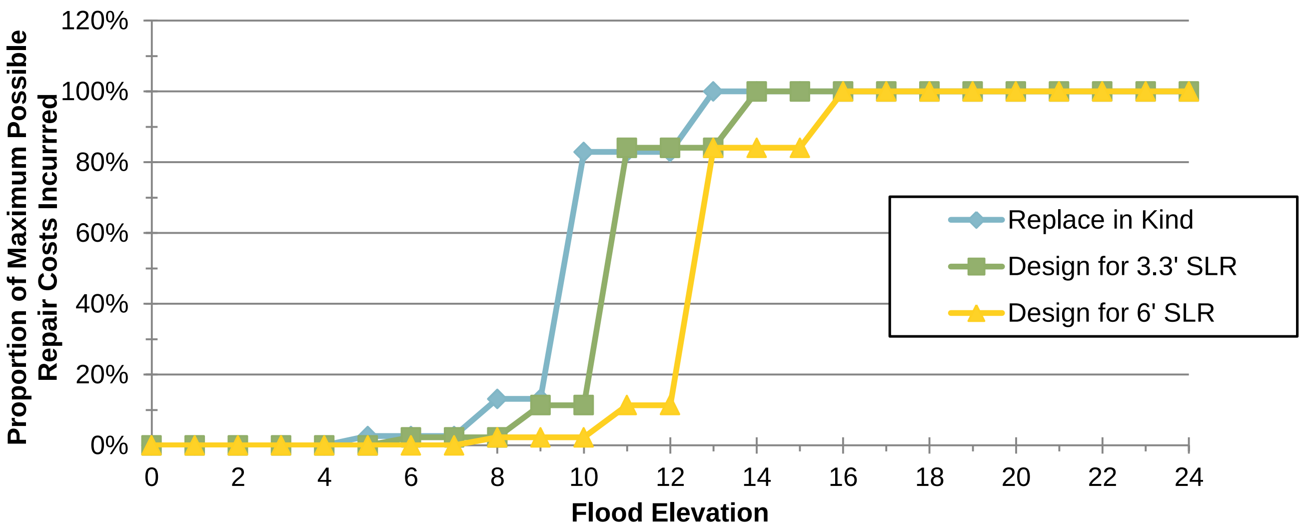


Table 5. List of construction and repair cost estimates at appropriate DDF increments, for all replacement structures evaluated.

<u>Scarborough: Route 1</u>

Location: 43.577273, -70.371450

Replace Culverts in kind: $1,200,000
Replace Road in kind: $2,400,000
Total Replacement Cost: $3,600,000

Replace for 3.3’ of sea level rise
Description: 4100ft of road raised 1.5ft to an elevation of 10ft. Culverts are replaced with a simple span bridge.
Cost: $4,300,000

Replace for 6’ of sea level rise
Description: Reconstruct and raise the road elevation 4.5ft for approximately 4300ft. Replace culverts with a simple span bridge.
Cost: $6,000,000

<u>Depth Damage Function for Existing Asset</u>

8ft – Minor Damage – Wave action up to edge of road. Possibly a few inches of water on shoulder.

Damage – Loss of riprap in isolated locations along causeway and around culvert ends. Some loss of pavement along edge of shoulders in isolated locations. Some debris on road.
Cost$: 30,000

9ft- Moderate Damage – 0- 6 inches of water over approximately 2000ft of roadway.
Damage- Loss of more riprap along entire length of slope. Loss of some pavement in shoulders and possibly in travel way. Debris deposited on road and inlet of culverts. Some minor damage to culverts.
Cost: $75,000

11ft – Approximately 2ft of water over roadway for about 4000ft.
Damage – High Damage – Failure of culverts and loss of section of road above and adjacent to culvert. Shoulders and lanes have loss of pavement and roadway material for about 4000ft. Significant loss of riprap on slopes for 400ft.
Cost: $1,300,000

13ft – Severe Damage – 3-4ft of water over road for about 4300ft
Damage-Loss of culverts and complete loss of road and roadway material for 200ft either side of the culverts. Heavy pavement and slope damage for 4300ft on causeway.
Cost: $2,400,000

<u>Depth Damage Function for New Asset Built for 3.3’ of Sea Level Rise.</u>

Description Reconstruct and raise the road elevation 1.5ft for approximately 4300ft. Culverts are replaced with a simple span bridge.

9ft – Minor Damage – Wave action up to edge of road. Possibly a few inches of water on shoulder. Bridge beams are partially submerged.

Damage – Loss of riprap in isolated locations along causeway and around bridge abutments. Some loss of pavement along edge of shoulders in isolated locations. Some debris on road and in bridge components.
Cost: $55,000

11ft – Moderate Damage – 0-1ft of water over road and bridge for approximately 2000ft.
Damage- Loss of more riprap along entire length of slope and around bridge abutments. Loss of some pavement in shoulders and possibly in travel way. Debris deposited on road and in bridge components. Some structural damage to bridge.
Cost: $300,000

12ft – Approximately 1-2ft of water over roadway and bridge for about 4000ft.
Damage – High Damage; failure of bridge. Shoulders and lanes have loss of pavement and roadway material for about 4000ft.
Cost: $1,600,000

14ft – Severe Damage - 3-4ft of water over road for about 4300ft.
Damage – Bridge failure and complete loss of road and roadway material for approximately 400ft. Significant pavement and slope damage for 4300ft on causeway.
Cost: $2,400,000

<u>Depth Damage Function for New Asset Built for 6’ of Sea Level Rise.</u>

Description Reconstruct and raise the road elevation 4.5ft for approximately 4300ft. Replace culverts with a simple span bridge

12ft – Minor Damage – Wave action up to edge of road. Possibly a few inches of water on shoulder. Bridge beams are partially submerged.

Damage – Loss of riprap in isolated locations along causeway and around bridge abutments. Some loss of pavement along edge of shoulders in isolated locations. Some debris on road and in bridge components.
Cost: $55,000

14ft – Moderate Damage – 0-1ft of water over road and bridge for approximately 2000ft.
Damage- Loss of more riprap along entire length of slope and around bridge abutments. Loss of some pavement in shoulders and possibly in travel way. Debris deposited on road and in bridge components. Some structural damage to bridge.
Cost: $300,000

15ft – Approximately 1-2ft of water over roadway and bridge for about 4000ft.

Damage – High Damage – Failure of bridge. Shoulders and lanes have loss of pavement and roadway material for about 4000ft.
Cost: $1,800,000

17ft – Severe Damage – 3-4ft of water over road for about 4300ft
Damage – Bridge failure and complete loss of road and roadway material for approximately 400ft. Significant pavement and slope damage for 4300ft on causeway.
Cost: $2,600,000

<u>Bath: New Meadows Bridge</u>

Location: 43.931572, -69.862467

Description- Replace Bridge in Kind and approximately 1000ft of approach section
Replace Bridge in kind: $ 400,000
Replace Approach in kind: $594,000
Replace in kind Total: $1,000,000

Replace for 3.3 of Sea level rise:
Description – Elevation of the road and bridge is high enough that a 6' sea level rise would not effect this location. Cost would be same as replacing in kind.
Cost: $ 1,000,000

Replace for 6' of Sea level rise-
Description Raise the bridge 2ft in order to give enough freeboard to the bottom flange of the bridge. This would include approximately 400ft of approach work. The rest of the causeway is high enough that it does not need to be changed.
Cost: $780,000

<u>Depth Damage Function for Existing Bridge</u>

9.5ft – Minor Damage – Water has reached the top of the abutment; wave action is hitting the beams under the bridge.
Damage – Some loss of riprap around bridge abutments. Some debris caught in bridge.
Cost - $25,000

10.5ft – Moderate Damage – Water elevation has submerged bridge beams; wave action is creating a few inches of water on roadway.
Damage – Significant loss of riprap around bridge abutments and along causeway. Minor bridge damage possibly some isolated loss of pavement in shoulders. Debris deposited on road and in bridge components.
Cost: $55,000

12ft – High damage – 0-6in of water over 1000ft of road and bridge.
Damage – Loss of riprap and erosion of slopes on causeway and around bridge abutments. Some loss of pavement in isolated locations on edge of shoulder. Heavy debris in bridge and along causeway. Some structural bridge damage.
Cost: $185,000

14ft – Severe Damage – Approximately 2ft of water over road for about 1000ft.
Damage – Bridge failure and loss of road adjacent to bridge. Heavy to damage road for 1000ft. Loss of pavement and roadway material in shoulder and in lane. Heavy debris in road.
Cost: $650,000

<u>Depth Damage Function for New Asset Built for 3.3' of Sea Level Rise.</u>

Description – Elevation of the road is not low enough to merit raising the road or bridge elevations. DDF does not change from DDF for existing asset.

Depth Damage Function for New Asset Built for 6' of Sea Level Rise.
Description – Raise the bridge 2ft to give enough freeboard to the bottom flange of the bridge. This would include approximately 400ft of approach work. The rest of the causeway is high enough that it does not need to be changed.

11ft – Minor Damage – Wave action is creating a few inches of water on roadway and hitting beams under bridge.
Damage – Loss of riprap around bridge abutments and along causeway. Minor bridge damage possibly some isolated loss of pavement in shoulders. Debris deposited on road and in bridge components.
Cost: $45,000

12ft – Moderate damage- 0-6in of water over road and bridge beams starting to be submerged.
Damage – Loss of riprap and erosion of slopes on causeway and around bridge abutments. Some loss of pavement in isolated locations on edge of shoulder. Heavy debris in bridge and along causeway.
Cost: $85,000

14ft – High Damage – Approximately 0-2ft of water over road for about 1000ft. Bridge is overtopped by 0-6in of water.
Damage – Bridge failure and loss of road adjacent to bridge. Heavy to damage road for 600ft. Loss of pavement and roadway material in shoulder and in lane. Heavy debris in road. Some structural damage to bridge.
Cost: $320,000

16ft – Severe Damage – Approximately 2-4ft of water over road for about 1000ft. Bridge is overtopped by 2ft in of water.
Damage – Bridge failure and loss of road adjacent to bridge. Heavy to damage road for 1000ft. Loss of pavement and roadway material in shoulder and in lane. Heavy debris in road.
Cost: $650,000

<u>**Bowdoinham: Route 24 Large Culvert**</u>

Location: 44.009339, -69.894960

Replace Culvert in kind: $250,000

Replace for 3.3’ of Sea level rise:
Description – Raise road elevation 1ft and replace culvert with a 15ft span x 9ft rise concrete box culvert. This would include about 200ft of approach work.
Cost: $394,000

Replace for 6’ of Sea level rise-
Description – Raise the road elevation 2.5ft and replace the culvert with a 15ft span x 11ft rise concrete box culvert. This would require about 300ft of approach work.
Cost: $491,000

<u>Depth Damage Function for Existing Asset</u>

5ft – Minor Damage – Headwater elevation has reached the top of the culvert. Wave action may reach edge of road.
Damage – Some minor loss of riprap and erosion of slopes around inlet and outlet of culvert. Possibly some isolated loss of pavement.
Cost: $10,000

8ft – Moderate Damage – A few inches of water over the road.
Damage – Loss of more riprap round culvert and some pavement along edge of shoulder above culvert. Minor damage to culvert ends. Debris deposited in road and at culvert inlet.
Cost: $50,000

10ft – Approximately 2ft of water over roadway at culvert.
Damage – Culvert failure. Loss of road above and adjacent to culvert. Heavy erosion of slopes 100ft either side of culvert. Heavy debris in road.
Cost -$315,000

13ft – Severe Damage – 3-4ft of water over road for about 4300ft
Damage – Complete loss of culvert and adjacent road. Significant damage to approximately 300ft of road including loss of pavement in travel way and heavy erosion of slopes.
Cost: $380,000

<u>Depth Damage Function for New Asset Built for 3.3’ of Sea Level Rise.</u>

Description: Raise road elevation 1ft and replace culvert with a 15ft span rise concrete box culvert. This would include about 200ft of approach work.

6ft – Minor Damage – Headwater elevation has reached the top of the culvert. Wave action may reach edge of road.
Damage – Some minor loss of riprap and erosion of slopes around inlet and outlet of culvert. Possibly some isolated loss of pavement.
Cost: $10,000

9ft – Moderate Damage – A few inches of water over the road.
Damage – Loss of more riprap round culvert and some pavement along edge of shoulder above culvert. Minor damage to culvert ends. Debris deposited in road and at culvert inlet.

Cost: $50,000

11ft – Approximately 2ft of water over roadway at culvert.
Damage – Culvert failure. Loss of road above and adjacent to culvert. Heavy erosion of slopes 100ft either side of culvert. Heavy debris in road.
Cost: $370,000

14ft – Severe Damage – 3-4ft of water over road for about 4300ft
Damage – Culvert failure and loss of road above and adjacent to culvert. Significant damage to approximately 300ft of road including loss of pavement in travel way and heavy erosion of slopes.
Cost: $440,000

<u>Depth Damage Function for New Asset Built for 6' of Sea Level Rise.</u>

Description: Raise the road elevation 2.5ft and replace the culvert with a 15ft span x 11ft rise concrete box culvert. This would require about 300ft of approach work.

8.5ft – Minor Damage – Headwater elevation has reached the top of the culvert. Wave action may reach edge of road.
Damage – Raise the road elevation 2.5ft and replace the culvert with a 15ft span concrete box culvert. This would require about 300ft of approach work.
Cost: $10,000

11.5ft – Moderate Damage- A few inches of water over the road.
Damage – Loss of more riprap round culvert and some pavement along edge of shoulder above culvert. Minor damage to culvert ends. Debris deposited in road and at culvert inlet.
Cost: $50,000

13.5ft – Approximately 2ft of water over roadway at culvert.
Damage – Culvert failure. Loss of road above and adjacent to culvert. Heavy erosion of slopes 100ft either side of culvert. Heavy debris in road.
Cost: $370,000

16.5ft – Severe Damage- 3-4ft of water over road for about 4300ft
Damage – Culvert failure and loss of road above and adjacent to culvert. Significant damage to approximately 300ft of road including loss of pavement in travel way and heavy erosion of slopes.
Cost: $440,000

Table 6. Comparison of construction and repair costs for three structural designs at a culvert on Route 1 in the Scarborough Marsh, under low and high SLR scenarios through the year 2100.

Low Sea Level Rise (3.3')

	Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$3,600,000	$349,128	**$3,949,128**
Replace with 3.3' SLR design	$4,300,000	$181,330	$4,481,330
Replace with 6' SLR design	$6,000,000	$3,323	$6,003,323

High Sea Level Rise (6')

	Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$3,600,000	$823,325	**$4,423,325**
Replace with 3.3' SLR design	$4,300,000	$642,948	$4,942,948
Replace with 6' SLR design	$6,000,000	$69,547	$6,069,547

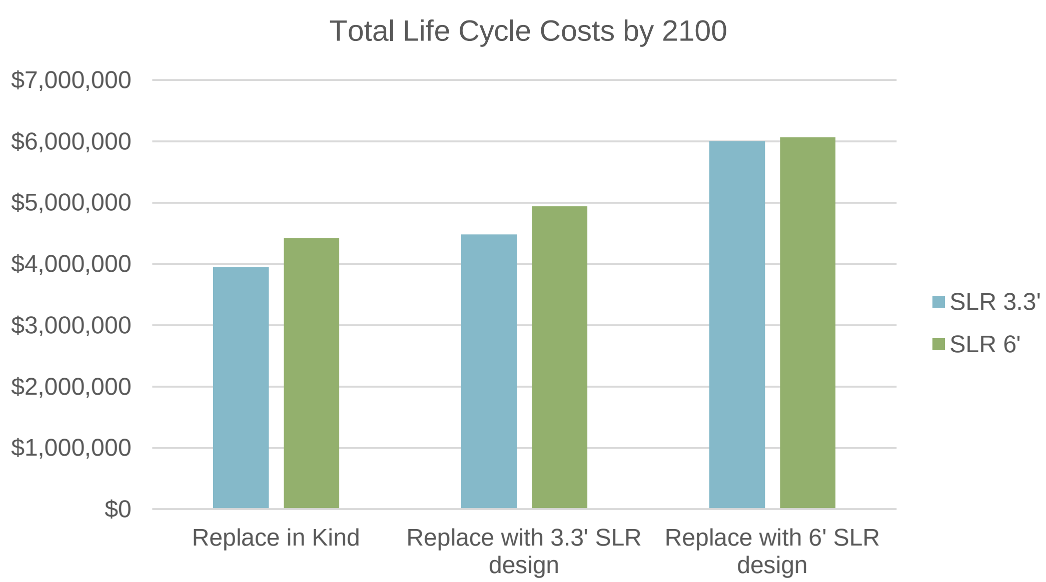


Table 7. Comparison of construction and repair costs for three structural designs at a bridge on Old Bath Road in Bath, under low and high SLR scenarios through the year 2100.

Low Sea Level Rise (3.3')

	Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$400,000	$697,476	**$1,097,476**
Replace with 3.3' SLR design	$594,000	$697,476	$1,291,476
Replace with 6' SLR design	$1,000,000	$281,242	$1,281,242

High Sea Level Rise (6')

	Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$400,000	$1,867,580	$2,267,580
Replace with 3.3' SLR design	$594,000	$1,867,580	$2,461,580
Replace with 6' SLR design	$1,000,000	$916,598	**$1,916,598**

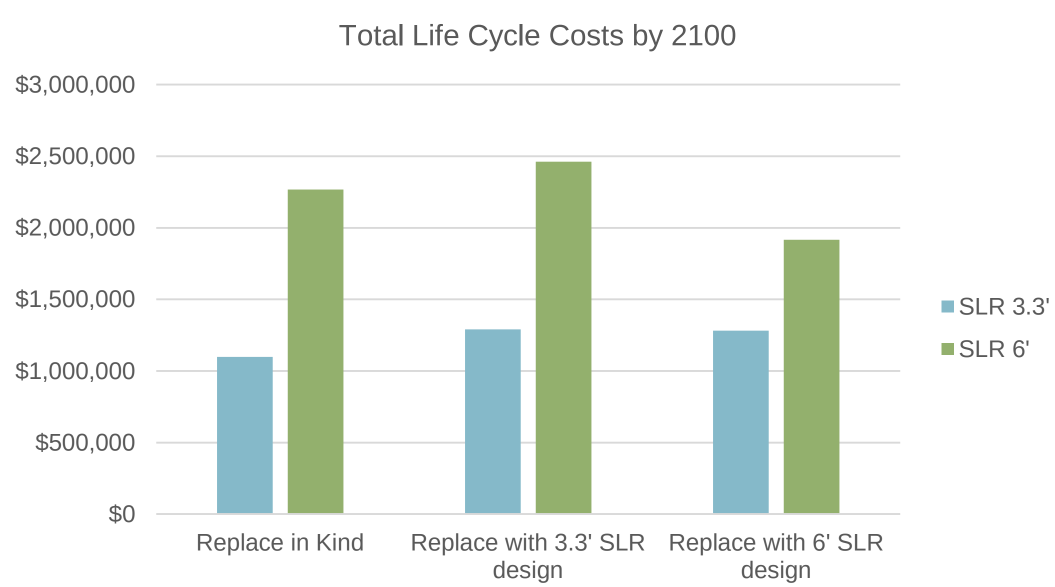


Table 8. Comparison of construction and repair costs for three structural designs at a bridge on Route 24 in Bowdoinham, under low and high SLR scenarios through the year 2100.

Low Sea Level Rise (3.3')

	Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$250,000	$1,656,830	$1,906,830
Replace with 3.3' SLR design	$394,000	$1,162,080	$1,556,080
Replace with 6' SLR design	$491,000	$205,159	**$696,159**

High Sea Level Rise (6')

	Construction Costs	Total Damage/Repair Costs by 2100	TOTAL LIFE CYCLE COST BY 2100
Replace in Kind	$250,000	$2,163,283	$2,413,283
Replace with 3.3' SLR design	$394,000	$1,900,813	$2,294,813
Replace with 6' SLR design	$491,000	$908,565	**$1,399,565**

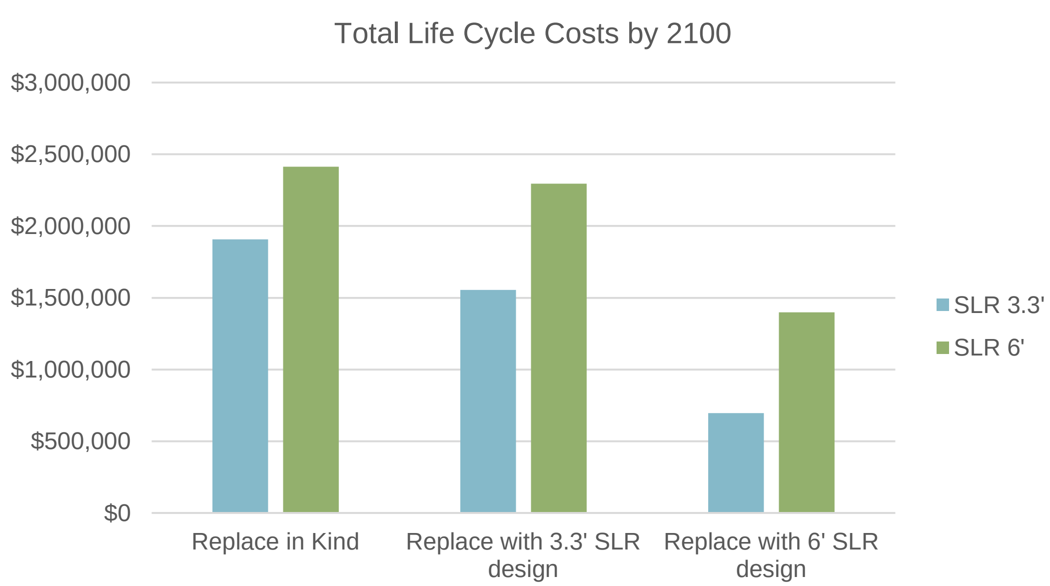
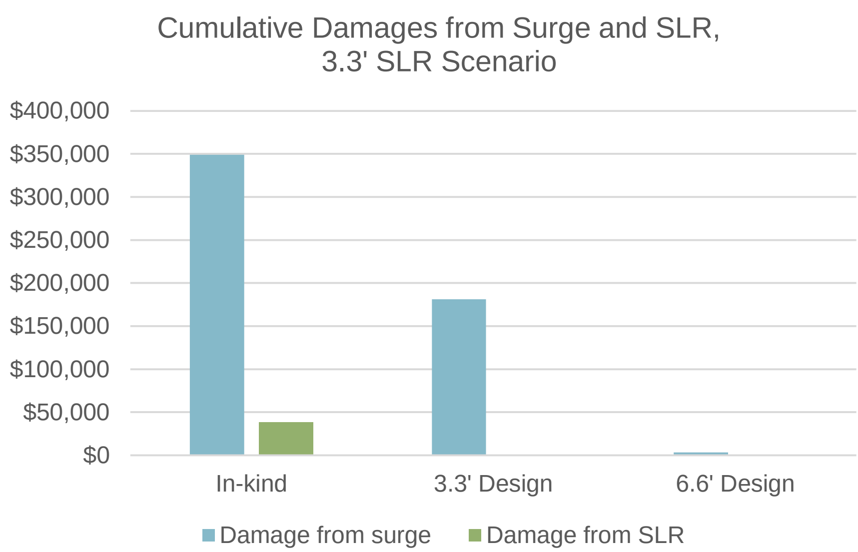


Table 9. Cumulative expected damages from storm surge and SLR for candidate designs of bridges in Scarborough through the year 2100.

Scarborough	Cumulative Damages from Surge	Cumulative Damages from Sea Level Rise
3.3' SLR		
In-kind	$349,128	$38,400
3.3' Design	$181,330	$0
6.6' Design	$3,323	$0
6' SLR		
In-kind	$823,325	$952,800
3.3' Design	$642,948	$283,200
6.6' Design	$69,547	$0



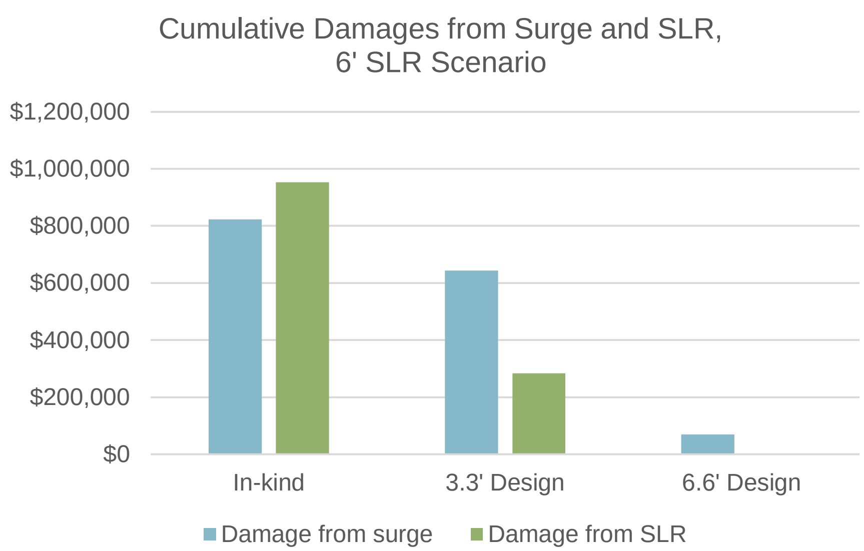
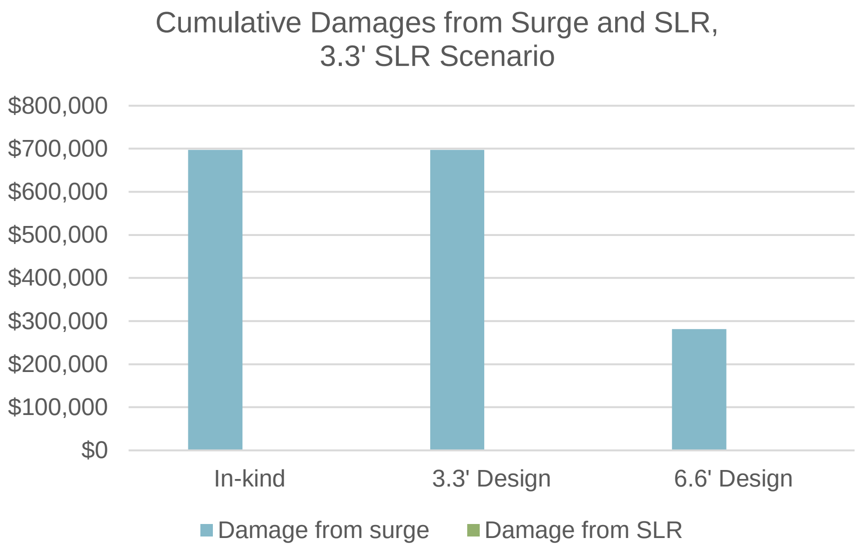


Table 10. Cumulative expected damages from storm surge and SLR for candidate designs of bridges in Bath through the year 2100.

Bath	Cumulative Damages from Surge	Cumulative Damages from Sea Level Rise
3.3' SLR		
In-kind	$697,476	$0
3.3' Design	$697,476	$0
6.6' Design	$281,242	$0
6' SLR		
In-kind	$1,867,580	$1,066,000
3.3' Design	$1,867,580	$1,066,000
6.6' Design	$916,598	$227,500



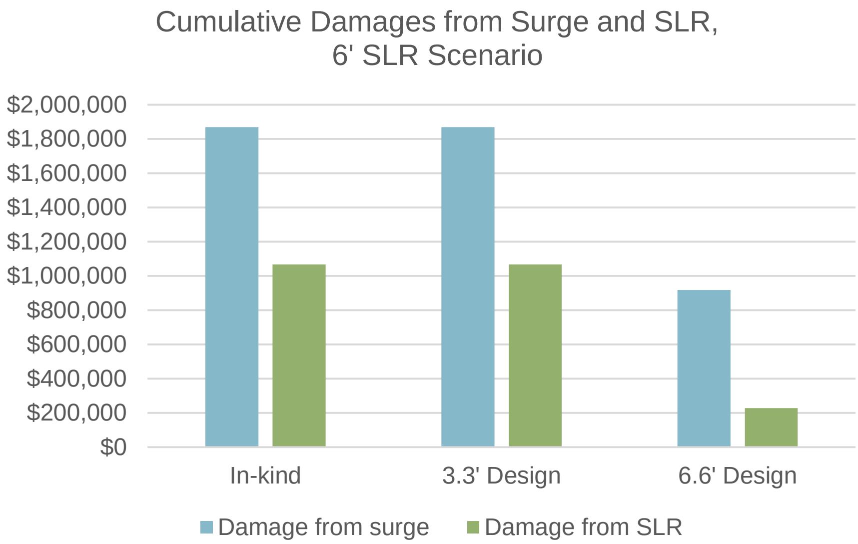
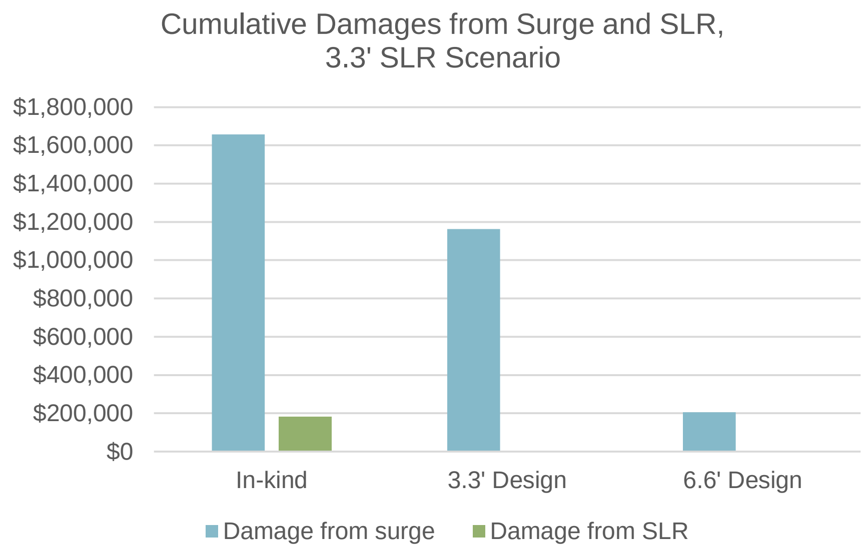


Table 11. Cumulative expected damages from storm surge and SLR for candidate designs of large culvert/bridge in Bowdoinham through the year 2100.

Bowdoinham	Cumulative Damages from Surge	Cumulative Damages from Sea Level Rise
3.3' SLR		
In-kind	$1,656,830	$182,400
3.3' Design	$1,162,080	$0
6.6' Design	$205,159	$0
6' SLR		
In-kind	$2,163,283	$684,000
3.3' Design	$1,900,813	$237,600
6.6' Design	$908,565	$52,800



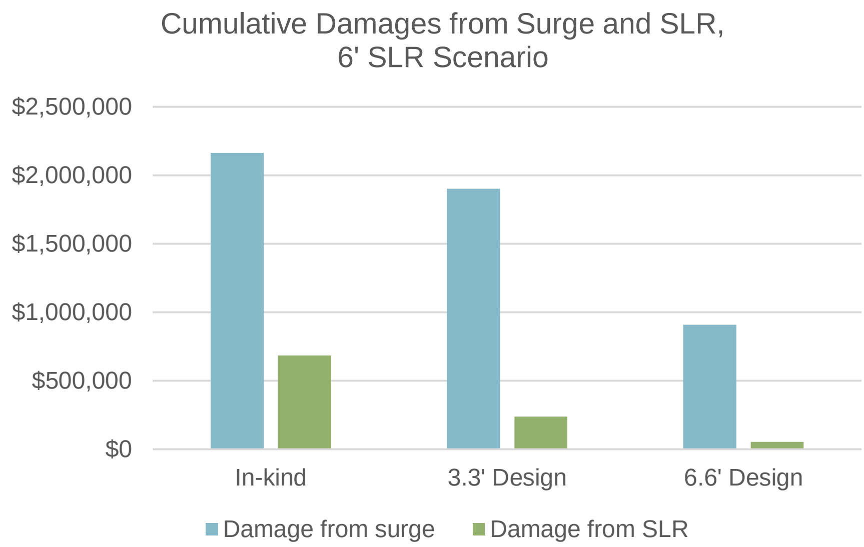
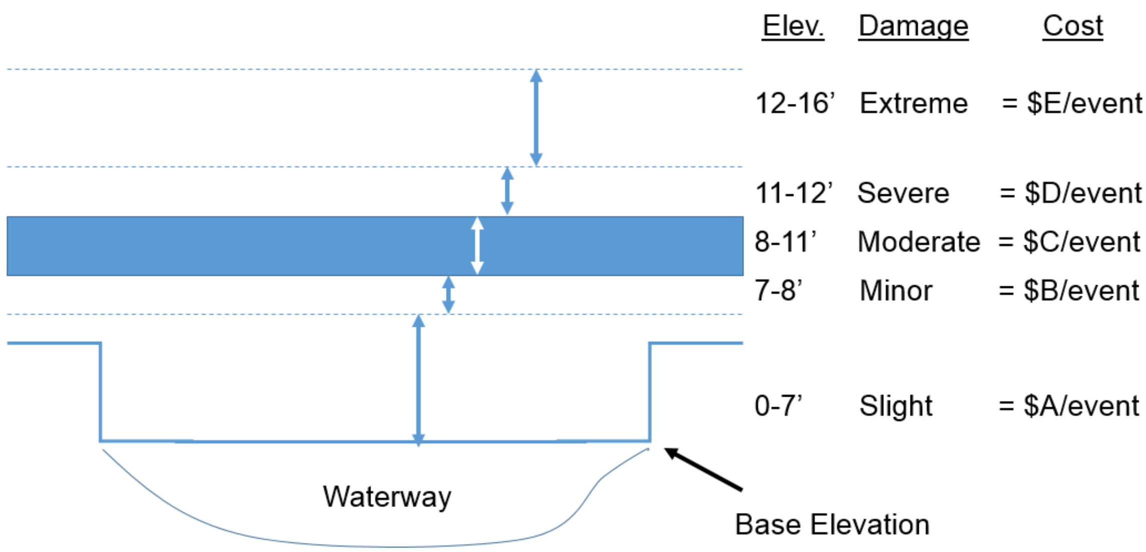


Figure 5. Schematic of Depth Damage Functions used for each candidate alternative design.



V.2.0

COAST Decision Support Tool v2.0

Reference

Introduction

This document provides a reference and tutorial for the COAST Decision Support Tool. The COAST Decision-Support Tool (DST) assists users with the task of evaluating various assets to determine which asset in an area is the highest priority for inclusion in a COAST damage assessment model scenario. Users of the DST will add criteria such as the condition of each asset, its age, expected life, commerce loads, and other metrics of criticality and vulnerability. Each criterion will also have a weight associated with it, so that more important criteria will be given greater prominence. The DST will process the criteria and their weights to produce a rank-order evaluation of which assets are the highest priority for repair or replacement.

Before you begin this process, and in collaboration with Catalysis Adaptation Partners, LLC or via other arrangement, you will need to involve your civil engineers and municipal planning staff to determine the questions you want to ask in order to prioritize vulnerable assets. You should organize this information in a way that makes it easier to enter it into the DST tool. The subfolder called SampleData in the location where the DST is installed contains a spreadsheet that illustrates one way of organizing this information. It contains the questions to be asked and some criteria should be used to define the metric values. This spreadsheet was used as the basis for creating the sample DST documents in that same directory.

Terminology

DST Document The data associated with the current DST processing. This consists of the metric and metric value type definitions, and the asset definitions and scores. This data is stored in a single file with a ".dstx" extension.

Metric A characteristic of the asset in question (e.g., its age or current condition) that can be used as a criterion for evaluating the priority of the asset for inclusion in a COAST model. In the DST, users assign metrics a value from 1 to 5, with 1 being the lowest priority and 5 being the highest.

Metric Value Type This defines the range of values that can be associated with a metric, and provides a short description of the meaning of each value. The users assigns a value to a metric for an asset by selecting it from a list.

Score The weight multiplied by the metric value for an asset.

Total Score The sum of the scores for an asset. The DST ranks assets by their total score to determine which asset has the highest priority for inclusion in a COAST model.

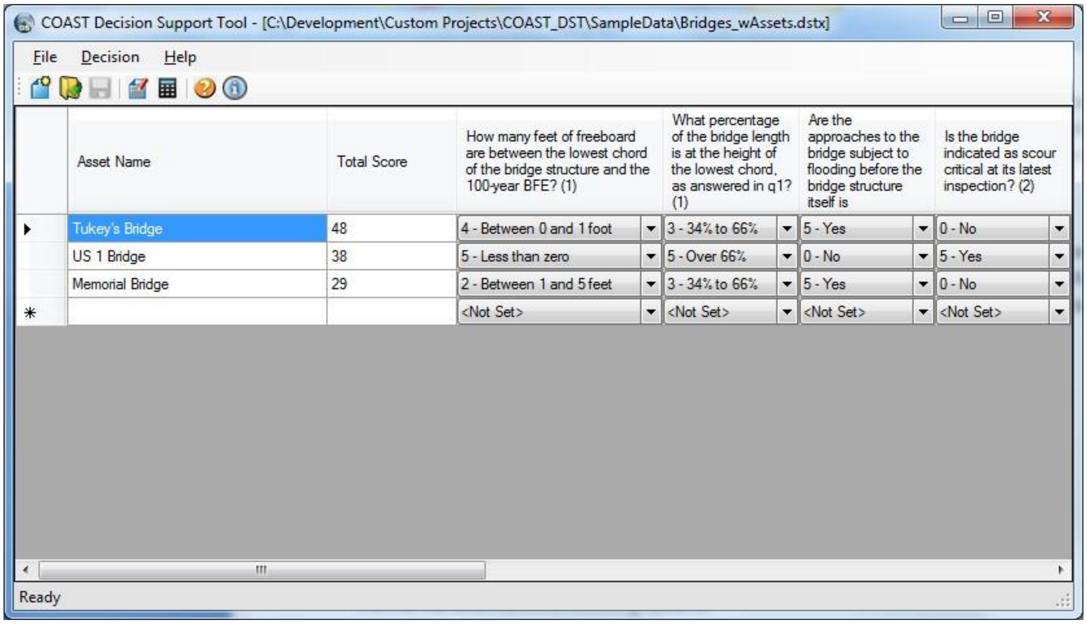
Weight The importance associated with a particular metric value that defines the impact that metric has when calculating the total score. The DST multiplies the weight by the metric value to produce the score for an asset. Weight will be assigned a value from 1 to 5, where 1 is the lowest weight and 5 is the highest.

COAST Decision Support Tool Reference

The following section describes the components of the COAST DST. The DST documents containing the data used in the screen captures can be found in the folder where the DST is installed, in a folder called SampleData. There are three samples, one for prioritizing roads (Roads.dstx) and another for evaluating bridges (Bridges.dstx), and a third that has the metrics for bridges and a few bridge entries in the grid.

Main DST Window

This is the main window for the DST program. The window title contains the path and file name of the current DST document. It displays the assets and the criteria for scoring the asset priority. After the scores have been calculated, the DST sorts the data in descending order by the Total Score column. The user can initiate various actions by selecting a choice from one of the menus, clicking on a toolbar button, and right-clicking on the grid and selecting an item from the pop-up menu.



Menus

The main window contains a menu with the options described in the following sections.

File Menu

The File menu contains the following options:

New — Creates an empty DST document. The empty document contains no asset definitions, and no metric or metric value definitions.

Open — Opens an existing DST document, and displays the asset definitions and scores. You can use this option to open the sample DST documents.

Save — Saves the current DST document.

Save As... — Saves the current DST document to a new file. If you want to use one of the sample documents as a template, you can open it, then use this option to save the contents as a different file.

Exit — Closes the program.

Decision Menu

The Decision menu contains the following choices:

Edit Metrics... Displays the Edit Metrics Dialog, allowing the user to define the metrics to be used in the current DST document. Typically, this is the first step in setting up a DST scenario.

Compute Asset Scores Calculates the scores and sorts the assets in descending order by Total Score.

Help Menu

The Help menu contains the following options:

Program Help... Displays the help file for the COAST DST.

About ... Displays information about the COAST Decision Support Tool, including its version and copyright.

File Toolbar

The File toolbar contains buttons that perform the following actions:

New Creates an empty DST document. The empty document contains no asset definitions, and no metric or metric value definitions.

Open Opens an existing DST document, , and displays the asset definitions and scores.

Save Saves the current DST document.

Decision Toolbar

The Decision toolbar contains buttons that perform the following action:

Edit Metrics... Displays the Edit Metrics Dialog, allowing the user to define the metrics to be used in the current DST document. Typically, this is the first step in setting up a DST scenario.

Compute Asset Calculates the scores and sorts the assets in the current DST document in **Scores** descending order by the Total Score

Asset Data Grid

The main window uses a grid to display and modify the asset data. The user can edit the asset information directly in the grid by selecting a value in each metric column. The first two columns, Asset Name and Total Score, appear in all DST documents. The user defines the additional columns using the Edit Metrics dialog.

The question displayed in the header of each metric column comes from the metric's definition, and can be modified by the user. The number in parentheses following the question is the weight for that metric. When the user hovers the mouse over a column heading, the DST displays a tool-tip containing the metric description, which is also part of the metric's definition. The user can reorder the metric columns by dragging them to the desired location using the mouse. When a DST document is saved and reopened, the metric column order will be preserved, with the exception that, when the document is opened, the Asset Name and Total Score columns are always placed first and second, respectively.

The drop-down list of choices for each metric comes from its Metric Value Type definition. The user can choose a value for each metric by selecting it from the drop-down list using either the mouse or keyboard (by typing the number associated with the value.) When a new metric is added, all of its values are designated as "not set." When calculating the score for an asset, if a value is "not set" it is treated as zero.

<u>Context Menu</u>

When the user right-clicks in the data grid, the following menu items will be displayed (the exact list depends on the specific location within the grid that is clicked, and the current state of the asset data):

Clear Row(s) Resets the contents of the selected row(s) to "not set".

Delete Row(s) Removes the selected rows from the grid.

Clear Column Resets the contents of the selected column to "not set".

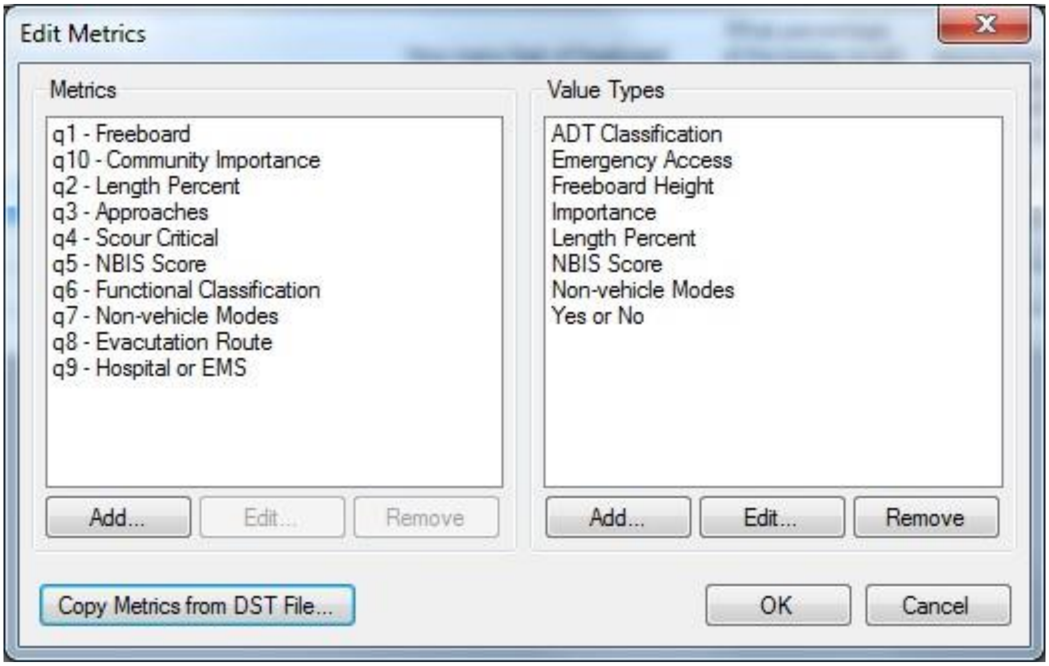
Delete Column Deletes the selected column from the grid, and its associated metric from the metric list.

Edit Metric... Displays the Edit Metrics Dialog, with the metric associated with the column under the cursor used as the selected metric.

Compute Asset Scores Calculates the scores and sorts the assets in the current DST document in descending order by the Total Score.

<u>Edit Metrics Dialog</u>

This dialog allows the user to define the metrics and metric value types to be used in the DST.



The Edit Metrics dialog contains the following user interface elements:

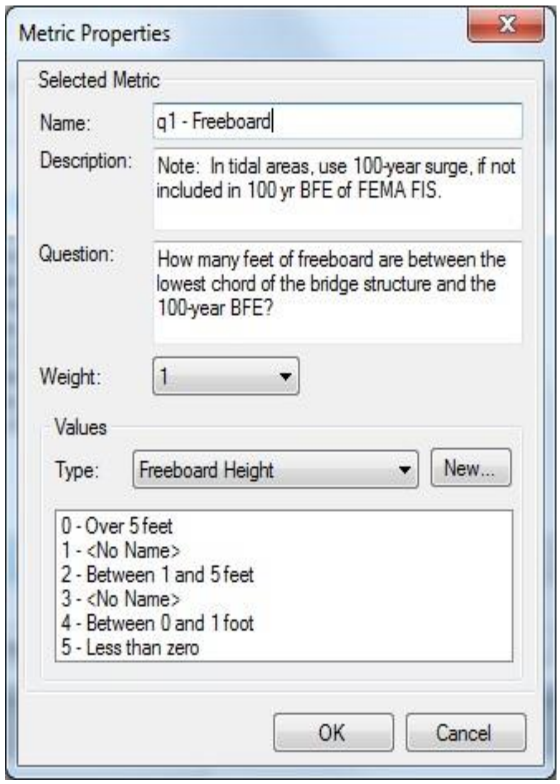
Metrics	This section contains the list of the names of currently defined metrics, and buttons that enable the user to modify the list.
Add	Opens the Metric Properties dialog and initializes the definition. After the user has completed editing the definition, the DST displays the new metric name in the list.
Edit...	Displays the Metric Properties dialog and allows the user to change the metric's definition. The user can also double-click on a metric name in the list to modify its definition.
Remove	Removes the selected metric from the list.
Value Types	This section contains the list of currently defined metric value types, and buttons to add, edit, and delete them.
Add	Opens the Value Type Properties dialog to define a new value type. When the user has finished the definition, it is added to the list.
Edit...	This button opens the Value Type Properties dialog to allow the user to modify a metric value type in the list. The user can also double-click on a metric value type name in the list to edit it.

Remove This button allows the user to delete the value currently selected in the list. A metric type cannot be removed if it is currently being used in a metric definition.

Copy Metrics from DST File Allows the user to copy the metric definitions from another DST file. The metrics will be added to the list in the current document.

<u>Metric Properties Dialog</u>

This dialog allows the user to define the details associated with a DST metric:



The Metric Properties dialog contains the following elements:

Name This is the short name that appears in the list of metrics.

Description A description of the metric. This will appear as a tooltip when the user holds the mouse over a column header. This can be used to provide additional information to help the user decide which value to select.

Question This field contains the question that the metric attempts to answer. The question will appear in the header for the associated column on the main window.

Weight This allows the user to select the weight for this metric. The weight defines the metric's relative importance. A weight of 1 is the least important, and 5 is the most important.

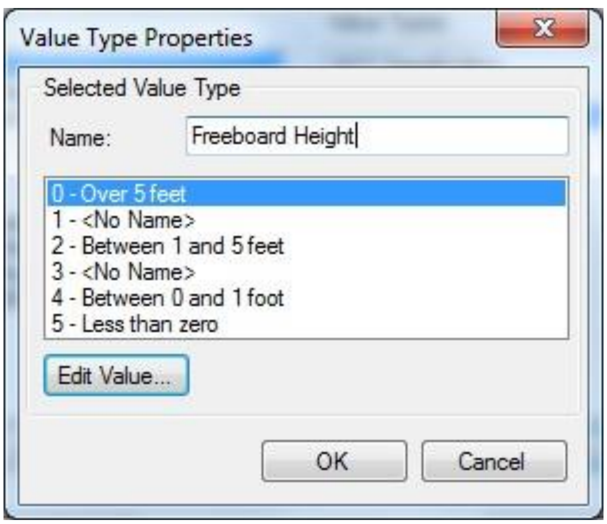
Values This section contains a list of the metric value types that can be selected for this metric.

Type This field contains a list of the names of the currently defined metric value types, and allows the user to select one for use in the selected metric. The list that follows contains the metric values defined for this type. The values in this list cannot be changed from this screen. To modify the values in this list, edit the metric value type on the Edit Metrics dialog.

New... This button opens the Value Type Properties dialog to enable the user to create a new metric value type. Once the definition is complete, the new metric value type will be added to the list and selected.

<u>Value Type Properties Dialog</u>

This dialog allows the user to define or modify a metric value type.

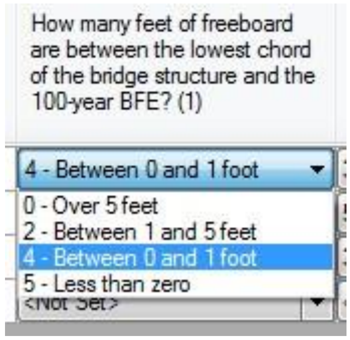


The Value Type Properties screen contains the following elements:

Name This is the short name for the metric value type that appears in the list of metric value types.

List Contains the values that make up the value type. For each value type, the numeric value and its associated meaning are displayed. Double-click on an item in the list, or press the Enter key, to edit its definition. The range of value is from 0 to 5. Using zero allows the user to set up a "not applicable" value in the value type, and allows an associated metric to be excluded from the total score. The best rating for the criterion should be associated with value of one, and the worst with the value of five, since typically, the worst value would be associated with the highest priority for repair or replacement.

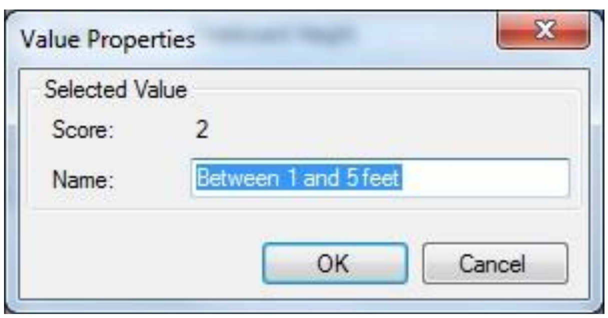
The user does not have to define every value from zero to five. A new value type will have all of the entries set to "<No Name>". Any entry in the list that has a value of "<No Name>" will be left out of the drop-down list in the associated grid cell. This allows the user to use only a subset of the possible values as in the response to a question. In the screen capture above, the drop-down list will contain entries only for 0, 2, 4, and 5, as shown below:



Edit Value... Opens the Value Properties dialog, and allows the user to update the meaning of the selected value.

Value Properties Dialog

This dialog allows the user to change the description associated with a metric value.



The Value Properties window contains the following elements:

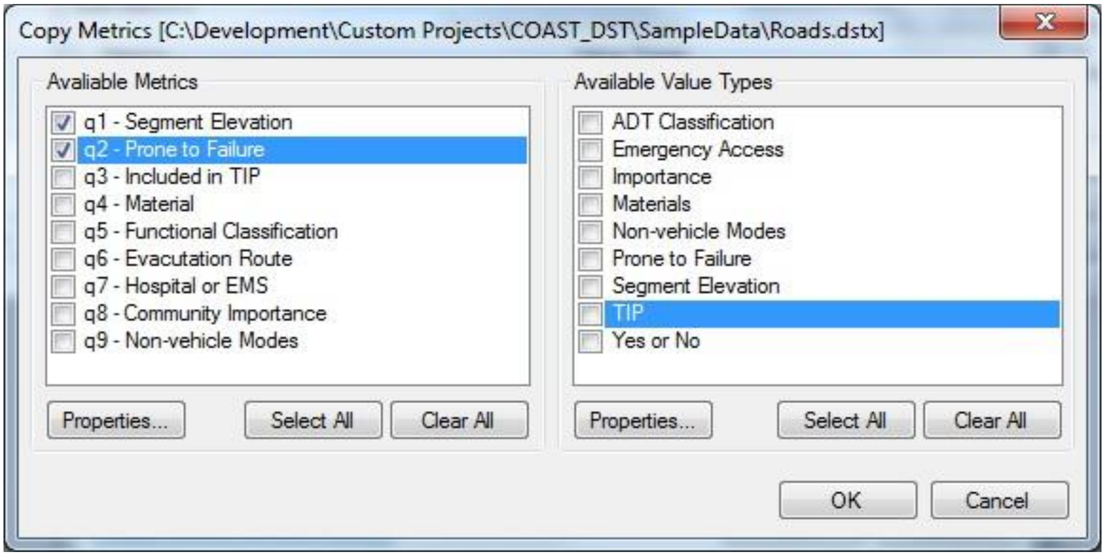
Selected Value This section contains the definition for the currently selected metric value.

Score This is the numeric score associated with this value. This value cannot be changed.

Name This name that will be displayed in the list of values, and associated with the Score. In order to change a value so that it will no longer be in the drop-down list, type "<No Name>" in this field.

Copy Metrics Dialog

This dialog allows the user to copy metric and metric value type definitions from another DST document file to the current document. The window title contains the name of the DST document file that the user selected.



The Copy Metrics dialog contains the following items:

Available Metrics This section lists the metrics that are available to be copied from the specified DST document. Place a check next to the name of each metric to be copied. When a metric is chosen, its associated metric value type will be copied to the current document even if it is not selected in the Available Value Types list.

Select All Places a check next to all of the available metrics.

Clear All Removes the check next to all of the available metrics.

Available Value Types This section lists the metric value types that can be copied from the specified DST document. Place a check next to the name of each metric value type to be copied.

Select All Places a check next to all of the available metric value types.

Clear All Removes the check next to all of the available metric value types.

About Blue Marble Geographics

Blue Marble Geographics was subcontracted to provide software development services to enhance the COAST tool with this DST. For over two decades, Blue Marble Geographics has been at the forefront of the GIS data processing software business. Pioneering work in the field of geomatics and spatial data conversion quickly established this Maine-based company as a key player in the GIS software field. Companies and organizations in every corner of the world, who appreciate the importance of maintaining the quality, integrity, and interoperability of their critical data, have come to depend on Blue Marble software.

The Geographic Calculator established the benchmark for highly accurate data conversion. Employing the most extensive library of geodetic calculation parameters, this renowned software has won recognition in many fields and industries throughout the world. The power of the Geographic Calculator is available to software developers in the GeoCalc and GeoCore SDKs and is embedded in many leading GIS and survey seismic software solutions.

In addition to industry standard coordinate transformation software, Blue Marble offers Global Mapper, Global Energy Mapper and Global Mapper SDK. This ever-popular GIS application is used by hundreds of thousands of GIS professionals and map enthusiasts worldwide, supports over 200 file formats, a variety of free online data sources, a 3D viewer and a digitizer tool for editing and creating geometry and attributes. The Global Mapper SDK is the basis of the COAST software tool.

Blue Marble embraces and thrives on a philosophy of customer-focused product management, development, sales and most importantly support. The Blue Marble professional services team is available for training, consulting and customer software development for Blue Marble products or other leading GIS tools. Learn more at www.bluemarblegeo.com.