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Integrating assets vulnerable to sea level rise and extreme weather events into ongoing structural review decisions at MaineDOT.

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Abstract

MaineDOT has identified coastal bridge and culvert features along its coastal assets that are vulnerable, sensitive, and critical according to a range of technical, environmental, bureaucratic, and economic risk metrics. For the most critical assets it has then identified which engineering designs would be good investments given extreme weather scenarios in both coastal and inland areas, across possible environmental futures. The current project goes farther, using GIS to incorporate lessons from these efforts into ongoing asset management so that similar benefits can accrue to larger numbers of vulnerable assets on an ongoing basis. We report on 1) a GIS overlay method developed to be easily communicable between DOT programs and replicable each year as part of developing the next work plan iteration and 2) efforts to use results from the method to identify immediate and longer term actions to enhance resiliency of vulnerable road segments, bridges, and culverts. Lessons are drawn about fitting such targets into existing agency processes, satisfying federal requirements for risk-based asset management, and taking advantage of existing expertise.
Introduction

Work on resiliency of MaineDOT bridges and culverts has helped identify aging assets that are vulnerable, sensitive, and critical according to a range of technical, environmental, economic, bureaucratic, and other risk metrics (Maine DOT 2016, GEI Consultants 2015). For the most critical assets it has then helped identify which engineering designs would be good investments given extreme weather scenarios that are likely in both coastal and inland areas and given the combined threats of sea level rise (SLR) and storm surge (Merrill and Gates 2014, GEI Consultants 2015). These efforts are consistent with research suggesting design decisions intended to enhance resiliency in the face of sea level rise need to be site-specific (e.g. Lu et al. 2014). As a result, Maine DOT stands poised to make vastly improved engineering design decisions that will reduce odds of regulatory roadblocks during project development; reduce agency expenditures on maintenance and repair of these assets over time; and minimize chances of overbuilding or underbuilding given a range of possible futures.

Still needed, however, is to 1) streamline these efforts to make them cost-efficient for the agency to implement at scale and 2) to incorporate lessons from these efforts into ongoing asset management so that similar benefits can accrue to large numbers of coastal and inland roads, bridges, culverts, and multimodal assets vulnerable to extreme weather events and rising sea levels. In this project we developed a GIS-based means for this incorporation that is sensitive to existing agency structures and procedures. In combination with the design-specific alternatives analysis methods also used with success, it creates avenues for new communication between programs and outreach to affected communities.

Importantly, by identifying smaller scopes of work for some assets, funds become available to maintain other assets that require more involved scopes of work. In both cases the correct amount of funding is allocated to ensure the upgraded, replaced, or relocated structure is resilient across possible futures. That is, understanding the scope of potential vulnerabilities using practical and inexpensive methods such as these can help avoid large investments in data gathering and design that may never be needed. Instead, investments in infrastructure can be targeted according to current trends in storm surge frequency and SLR, and only for those assets that also rise to the top of other priority rankings, such as those on economically important corridors. This makes existing and future resources go farther while incorporating low-regrets design decisions into ongoing asset management.

Methods

Data types included MaineDOT assets, sea level rise inundation boundaries, and 100-year storm surge inundation boundaries. MaineDOT asset-specific features consisted of three shapefiles: 1) state jurisdictional roads in the form of polylines; 2) large culverts in the form of points located on state roads; and 3) bridges and multimodal locations where shipping and freight routes intersect, also called transfer stations, both in the form of points. All assets were located in MaineDOT Regions 1, 2 or 4. Sea level rise inundation boundaries consisted of 3 polygons that outlined areas flooded by 1, 2 and 5 ft of sea level rise. These polygons were created by NOAA and mark the location of water at Mean Higher High Water (MHHW), or the higher of the two daily high tides. NOAA used the VDATUM tool to also incorporate tidal variation along the coast of Maine. Sea level rise depths were selected by MaineDOT personnel and reflect their assumptions for low and high sea level rise in 2065 and 2115. Specifically, 1 and 2 ft reflect low and high sea level rise in 2065; and 2 and 5 ft reflect low and high sea level rise in 2115. These timeframes encompass 50- and 100-year planning scenarios on which future decisions
could be made. The sea level rise curves originated from the USACE Sea Level Change Calculator, which enables users to select NOAA and USACE sea level rise curves as well as specific timeframes. While the default timeframe ends at 2100, users have the ability to add additional years and the calculator interpolates those additional rises in sea level. The 100-year storm surge inundation boundaries consisted of multiple polygons that outlined areas flooded from storm surge during a 100-year event, or an event that has a 1% chance of occurring in a given year. The polygons were created by FEMA and were downloaded at the county level. Some of the polygons were current and are used today for planning and insurance purposes, while others were preliminary and could change should a municipality challenge FEMA on inclusion or exclusion of certain areas. For the purpose of identifying assets vulnerable to storm surge and not downstream flows, only coastal areas with a Base Flood Elevation (BFE) were used. It is important to note that sea level rise and storm surge were examined separately – meaning storm surge was not added to sea level rise. Doing so would have required modeling time outside the scope of this project, but more importantly, sea level rise and 100-year flood boundaries are separate data types for MaineDOT, thus integrating their impact into asset management is a more appropriate first step than high level storm surge modeling with varying base water levels.

Flooding polygons were overlaid on top of road, culvert and bridge assets to identify those assets potentially flooded and vulnerable to the sea level rise and 100-year storm surges. Road sections intersected by inundation boundaries of each scenario were identified. Point assets (culverts and bridges) were ranked 0-4, based on whether they were inundated by only the 100-year storm surge (rank = 1), those additionally inundated by 5 ft of sea level rise and no less (rank = 2), those additionally inundated by 2 ft of sea level rise and no less (rank = 3), and those additionally inundated by 1 ft of sea level rise (rank = 4). All points that were either not flooded by any scenario, or points that were only flooded by sea level rise (and not storm surge) received a rank of 0. A 50-ft buffer was used to account for points that were offset by error.

Initial results showed that most assets were not contained by boundaries for sea level rise or a 100-year storm surge. However, most that were contained were contained by all flooding scenarios, on account of underlying terrain data used to create the inundation polygons. This terrain data did not include bridges, so many of the bridge points were located in the water and thus susceptible to any amount of sea level rise or storm surge. As a result, further analysis was needed.

Assets that had a vulnerability ranking greater than zero were re-analyzed using the terrain data and the depth grids for 1, 2 and 5 ft of sea level rise. Depth grids were added to the terrain grid to calculate water surface elevations for the various sea level rise scenarios. Asset points were manually moved based on aerial photography to locations that appeared to be the lowest point a car could reach, and thus the most vulnerable to inundation (Fig. 1). Available MaineDOT asset data did not contain attributes for structure elevations. Terrain and water surface elevation for each sea level rise scenario were then extracted at these new locations. Assets were considered flooded if the water surface elevation of the scenario being evaluated was higher than the terrain elevation. These new locations were also used to gauge whether the asset points were inundated by the 100-year storm surge. However, rather than using the polygon boundary, the BFE noted in the boundary file itself was used to compare to the terrain elevation of the asset. Then, new vulnerability rankings were calculated using these new inundation metrics.

Figure 1. Map showing asset point (bridge) moved to new location in preparation of terrain and water surface elevation analysis.
Results

Fig. 2 shows the number of 20 ft road segments inundated by 1 ft of sea level rise. While some segments are in excess of 800 ft, most are between 40 and 60 ft. Note however that the issue with points first being identified as flooded using the inundation polygons could not be corrected or improved for road segments. Many of these road segments are bridge spans that may not actually be flooded from 1 ft of sea level rise. Careful inspection of the data layer in a GIS is thus required for management purposes.
Figure 2. Flooded road segment lengths for coastal MaineDOT roads with 1 ft SLR.

For the coast as a whole and in each coastal Region, only a small percentage of bridges and culverts being considered for replacement or structural upgrades had high vulnerability rankings (Figs. 3 and 4).

The number of vulnerable assets changed substantially when those with a vulnerability ranking greater than zero were analyzed again, but using terrain and water surface elevations instead of inundation polygons. For example, 99 culverts had a vulnerability ranking greater than zero when using the inundation polygons and 40 had a vulnerability rank of 4; whereas when using the terrain and water surface elevations, there were only 16 non-zero rankings and only one rank of 4. Similarly, 261 of the 2,865 bridges had a vulnerability ranking of 4 when using the polygons, but this number reduced to 8 when terrain and water surface elevations were used. In total there were 98 bridges that had a vulnerability ranking greater than zero (more than half as many that originally had a ranking of 4).
Figure 3. Vulnerability to sea level rise and 100-yr storm surge for coastal MaineDOT bridges.

Figure 4. Vulnerability to sea level rise and 100-yr storm surge for large coastal MaineDOT culverts.
Discussion

One dilemma in enhancing resilience of any coastal transportation network is that while refined design-threshold analysis can clearly help select designs tailored to the range of flooding scenarios anticipated for any site, established organizational constructs can make it difficult to integrate this type of site-specific work into large-scale asset management programs. Traditionally, programming individual projects into agency work plans has been experientially-based, meaning that project scopes, budgets and schedules are established based on historical work adjusted to current costs. Considering the range of potential climate futures in asset management requires shifting work plan development to looking forward, leaving room in forecasting for alternatives that fit within the transportation agency’s risk tolerance. This may require less certainty in resource allocation; projects may end up costing less or more depending on climate trends within five years of significant rehabilitation or replacement based on calculations. The calculations also cost money themselves, an across-the-board cost unpalatable given that most agencies aim to limit preliminary engineering costs wherever possible.

Nevertheless, results of this study support efforts to enhance resilience of coastal roads, bridges, and culverts in a cost-effective manner. Calculation costs can be substantially limited by focusing just on those assets where 1) addressing vulnerabilities to SLR and storm surge will clearly require major coordination with a community (e.g., road realignment), 2) the agency is already deciding to take action on these assets because of their current position in the asset management program, and 3) other agency priorities have already been identified and clearly overlap (e.g., economically important corridors, culverts critical for fish passage). Once assets are identified that meet each of these agency priorities, it becomes cost-effective to use a site-specific approach to determining appropriate investments via culvert sizing and other design threshold evaluations. This can reduce preliminary engineering costs and minimize odds of overbuilding or underbuilding in the face of the combined threats of SLR and storm surge (Merrill and Gates 2014, GEI Consultants 2015, MaineDOT 2016).

As DOTs struggle to differentiate between an asset management approach and their existing programs, the added qualifier of “risk-based” poses additional challenges. Defining “risk” within the context of transportation asset management can occur anywhere along a continuum from academic (i.e., probability X consequence) to practical (i.e., past observations projected forward). Over the course of numerous climate readiness initiatives MaineDOT has focused on fitting new decision-making around risk into existing constructs. For example, risk can be considered on both short and long timeframes, with shorter timeframes defined by the three-year span of a work plan – a concrete list of projects and activities to be delivered. On a longer-term scale, incremental changes in temperature regimes, weather patterns, and sea levels are in different ways both easier and more difficult to address. This is because daily decisions regarding asset management are made in response to existing conditions. Asking asset managers to make decisions based on conditions 50 or 100 years in the future introduces potentially paralyzing uncertainty about what may be incorrect and irretrievable decisions to invest resources in an immediate adaptation response. For some assets such as bridges on roads serving peninsulas with no other means of approach, or road sections likely to be subject to high frequencies of inundation that also have parallel or other redundant routes in immediate proximity, these methods also provide the agency an opportunity to structure conversations about alternative choices, such as possible relocation or removal of the road segment. For example, MaineDOT has held structured conversations to explore these results among programs and is beginning to identify novel means to evaluate relocation possibilities for critically vulnerable assets where conventional engineering approaches will clearly not
be resilient to the range of environmental futures we expect during the useful life of the asset. For assets identified as critical community links, risk tolerance may be lower and the agency may opt toward the potential of overbuilding versus underbuilding an asset exposed to SLR and/or storm surge.

Overall, referring to any type of climate effect analysis as “prioritization” may create confusion both externally and within a DOT. Almost exclusively DOTs select work plan projects based on their condition, level of service, and safety of the traveling public. Based on these three criteria, MaineDOT determines its work “priorities” and allocates available resources accordingly; this process is not likely to change based on the projected exposure of an asset to SLR and/or storm surge. However, the range of possible alternatives for scope of work on an asset may change based on these risks as might logistical risks to delivering a “least risk” rehabilitation or replacement alternative. Rather than change the entire paradigm around how projects are selection for inclusion in a work plan, MaineDOT has opted to center the environmental risk surrounding an asset decision around the risks to project schedule and budget. Using recent history, presence of certain species or parameters set by regulatory agencies foretold significant consequences in terms of delays and cost overruns during project design and delivery. Therefore the consequence (in terms of delivery) can be considered known – longer permitting timeframes, higher costs associated with larger structures, etc. – and therefore more formulaic to introduce as part of a risk-based asset management process. The level of risk is then mostly influenced by the level of climate-based uncertainty posed in a specific location. MaineDOT has found it can draw boundaries around even this higher degree of climate-based uncertainty by considering the landscape setting of structures, much in the way FHWA’s Eco-Logical program (FHWA-HEP-06-01) considers the natural resources on a landscape or ecosystem basis. For climate, outer bounds of projections of sea level rise and storm surge elevations can be considered with a reasonable degree of confidence within a 50-year timeframe. If at that 50-year horizon, developed areas surrounding the transportation asset that are not now subject to inundation are projected to be inundated either by sea levels or surge, whether the transportation asset is resilient to those threats is moot (i.e., it is not just the asset that needs to be resilient, but the entire system around it). The implication is that these are not the assets or features in which to make large investments to increase elevations, but opt instead to reinforce against storm surges and begin conversations with communities to plan for alternate route investments. A government decision to merely abandon transportation infrastructure will not likely prove palatable. Given historical use of near shore areas along the Eastern seaboard, it is highly likely that communities will be integral to discussions of whether to reinforce, reconstruct, or relocate transportation assets critical to socially and economically important areas.

An additional point to help guide asset management improvements in this area is that understanding the universe of coastal assets potentially vulnerable over the next 100 year planning horizon is only the first step, because it yields an overwhelming number of features on which decisions are presumed. Narrowing from a large number of dots on a map to a much smaller number of structures, where the asset itself poses the vulnerability and not its landscape, makes decision making manageable and less subject to investment regrets. In MaineDOT’s case, the original number of 3,967 potentially affected coastal culverts and bridges (and a much larger number of road segments) presented a challenge beyond foreseeable resources. Reducing this number to just the 8 bridges and 16 culverts vulnerable to sea level rise and storm surge helped make resiliency a reasonable action to pursue for these vulnerable assets. Further reducing the data by setting aside those features for which reinforcement is the adaptation response warranted by its exposure to surge, but not sea level rise, means that asset managers have a
realistic expectation to improve resiliency over the 50 to 100 year horizon, and for only those assets in greatest need. For roads, awareness of which segments were likely to be inundated in relevant time frames similarly helped inform decisions about which segments should receive more design attention. A subset of these observations is about the critical importance of high quality data. As above, results indicate that using generally available data for bridges and culverts did help produce estimates of which assets should receive greater attention in the current design cycle. But adding a more accurate estimate of each structure’s surface elevation greatly increased precision and utility of results. This was conducted manually in a GIS for the initially-identified vulnerable bridges and culverts, but the agency could enhance effectiveness of this approach by simply taking a GPS-based elevation estimate during routine inspection and maintenance. This study therefore illustrates a low-cost improvement in data quality that can greatly enhance ongoing asset management.

Perhaps most critically, MaineDOT is additionally integrating these results into other ranking systems that reflect regional economic importance, percent impervious cover in the drainage area, bridge scour scores, critical natural resource variables, and many other metrics. This further refinement in understanding which assets are most important each year translates into greater certainty and lowers the risk of regrets in considering adaptation alternatives. These “risk ratings” indicate the potential complexity associated with work on an asset, particularly risk to project schedules and budget, posed by the landscape setting, characteristics, and hydrology of that specific asset. These three descriptors consistently influence schedule and budget risk, and given that they are not expected to remain static over time, the risk ratings are intended to be dynamic in that they are updated regularly based on a GIS platform. This automation is in progress, using available, meaningful data in lieu of requiring large and expensive data gathering efforts. The concept of risk ratings as they apply to schedules and budgets has been vetted not just through planning, data management and environmental programs, but also through maintenance and operations and capital programs (i.e., the asset managers) to ensure integrity, understandability, and usefulness of results in decision-making going forward.

Finally, an important observation from this effort is of the utility of carefully identifying when to try to use ranking results such as these in an asset management program and how to integrate asset-specific evaluations into department wide processes. Being able to rely on a higher degree of both certainty and consequence warrants flagging assets as a matter of course, not waiting until their condition leads to inclusion in an actual work plan. Even with restricting the task to coastal infrastructure, manually assigning levels of project-delivery risk to each asset feature on an annual basis or even on a five-year cycle is daunting.

MaineDOT is relying on automation to make this assessment feasible by using characteristics of assets and their landscape setting that are routinely inspected, measured, mapped, or modeled. Relative contributions of each element to a technical expert’s decision making is reflected by a multiplier, with a total “score” or rating. The risk rating associated with an asset or specific feature serves as a flag for when to apply a higher level of analysis. This indication of risk is associated with the individual feature as it exists in MaineDOT’s data warehouse, where its feeds into decisions ranging from timing of community engagement to elaboration of a wide range of design alternatives. Increasing resiliency of coastal transportation infrastructure in the face of sea level rise and storm surge will undoubtedly require investments to increase elevations of, reinforce, or relocate assets. Understanding not only the literal risk to infrastructure but also risk to asset management responsibilities is critical to reasonable and prudent decision making.
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