

QUANTIFYING RISKS OF CLIMATE CHANGE AND SEA LEVEL RISE TO NAVAL STATION NORFOLK (SERDP RC-1701)

Problem

The best available scientific evidence indicates that increasing atmospheric concentrations of greenhouse gases (potentially amplified by anthropogenic contributions) are warming the atmosphere and the oceans at an accelerated rate. As they warm, oceans are expanding and glaciers are melting, resulting in an overall increase in ocean volume. At the same time, many coasts are eroding and subsiding, contributing to the overall rise in relative sea levels. Unfortunately for coastal communities, the rate of sea level rise appears to be accelerating. Although the uncertainty surrounding the rate of rise cannot be resolved, scientists agree that its effects will be far reaching. Increased storm damage, more rapid erosion and shoreline change, saltwater intrusion into aquifers, rising water tables, and changes in tidal prisms are all predicted to become problems in varying degrees along the coasts. These effects act as hazards to assets and capabilities on coastal military installations, and as such pose a non-stationary risk to our nation's security (Figure 1). At present, coastal military operations tend to view these changes as strategic concerns – sea level rise impacts might not be realized for several decades, uncertainties surrounding climate change cloud the issues, and appropriately-scaled tools to support risk-based decision making at the installation level are virtually nonexistent. While commanders may be situationally aware of their installation's vulnerabilities, demonstrable risk-based assessments have yet to be developed that can assist them in proactively adapting military systems, processes, and protocols to meet these pervasive threats.

To meet this challenge, the Strategic Environmental Research and Development Program (SERDP) funded an initiative entitled "*Risk Quantification for Sustaining Coastal Military Installation Assets and Mission Capabilities (RC-1701)*" led by the US Army Engineer Research and Development Center, Vicksburg, MS. The study objective was to develop and demonstrate an integrated, multi-criteria, multi-hazard risk assessment framework that will be suitable for evaluating changes in risks to coastal military installation assets and mission capabilities in the Hampton Roads region due to global climate change effects, with a focus on SLR and associated phenomena. The primary intent was to quantify



Figure 1. Natural hazards (particularly coast storms such as Hurricane Earl shown here which hit the North Atlantic coast in September of 2010) can impair installation performance. Climate change and sea level rise act as threat multipliers to coastal installations generating more intense storms, and leading to an increase in both mission impairment and duration. What the military needs is a robust, scientifically defensible approach to quantify sea level risks and transparently communicate these to the end user, providing policymakers with relevant information to develop guidance that promotes sustainable mission performance, and empowering the on-the-ground military planners with the actionable information to make risk-informed decisions regarding threats to existing and future infrastructure development, in the face of climate change and sea level rise.

the risks of mission impairment during and immediately after tropical and extra tropical storms, assuming that sea level rise scenarios intensify these risks. The effort included a methodology to devise risk communication tools for the end-users (installation planners and managers) in visually engaging mediums (i.e., tables, graphics, and risk maps) that would transparently convey the potential individual and collective asset impairment, as well as duration of impairment immediately following the storms.

Technical Approach

To meet the objectives, the RC-1701 team developed a multi-scaled technical approach that involved six specific tasks including: (1) characterize the vulnerability of a groups of installations in the Hampton Roads area, and select a location to demonstrate a risk-based assessment approach thereon; (2) characterize the environment and predict potential changes to the coastline in this region; (3) simulate hurricanes and nor'easters moving across the region and then quantify the resultant forcings (winds, floodwater levels, and sedimentation), that in turn impact installation assets and capabilities; (4) devise a functional network model of the installation to capture the unique position and condition of its built infrastructure; (5) assess damage to structures and capabilities given the storm forcings at the local scale; and (6) quantify the risks of mission impairment due to coastal hazards simulated under a range of sea level rise scenarios considering system recovery efforts that occur after these events (Figure 2).

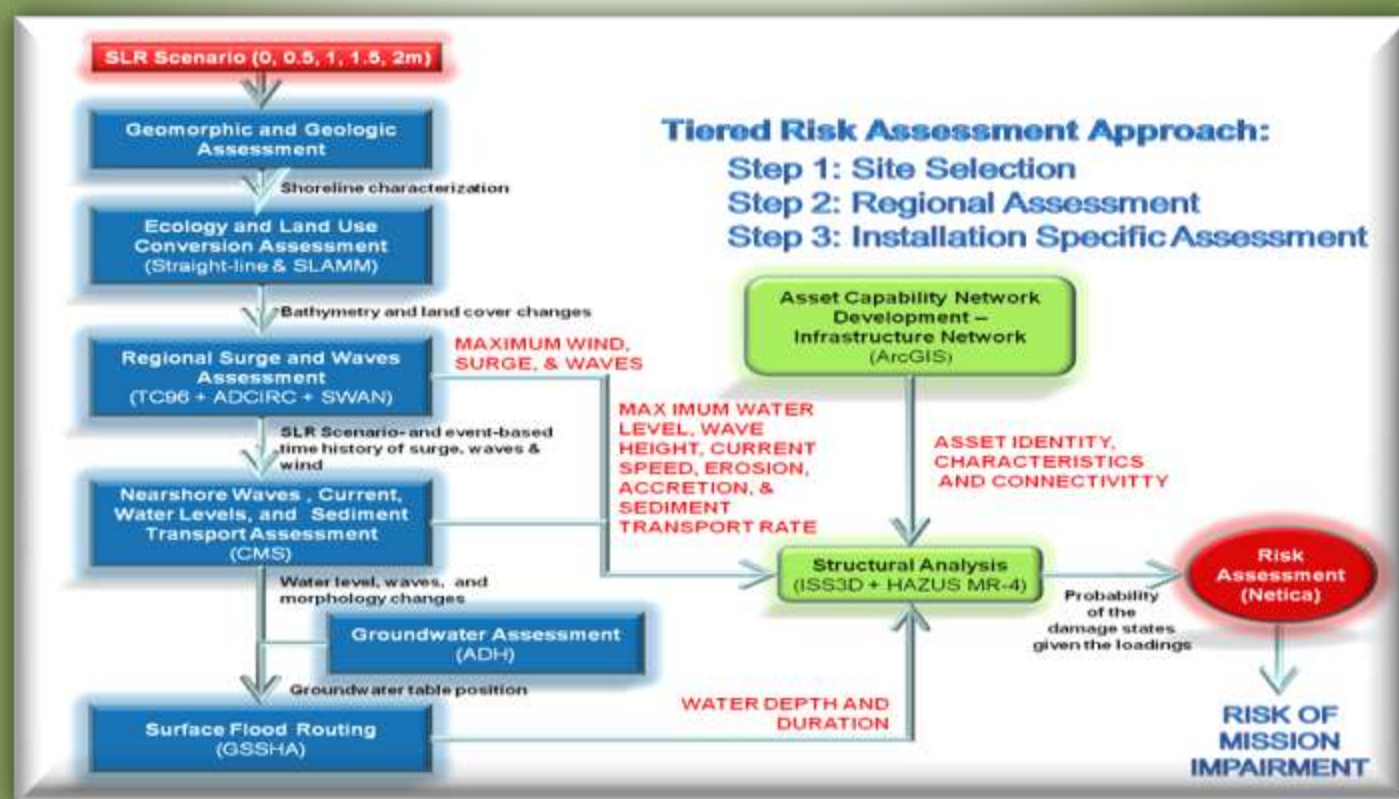


Figure 2. Simple rendering of the steps involved in conducting a tiered probabilistic risk assessment of the Naval Station Norfolk under the five sea level rise scenarios (red box) for the RC-1701 Project shown in context of demonstrating portability to and repeatability by other researchers. Blue boxes identify the high fidelity quantitative ecological and hydrodynamic models deployed in the project. Green boxes depict the asset decomposition and fragility curve development used to quantify asset vulnerability. Development of new materials and methods have been achieved through this research, building upon a foundation of previously published methods in a manner that both synthesizes prior works, as well as closes knowledge gaps for evolution of the operational risk assessment body of knowledge considered most relevant to the military installation community of practice.

Key Findings to Date

To date, the RC 1701 team has completed construction of its tiered risk-based framework which quantifies the “forcings” (i.e., surge, winds, wave velocities, flood depths, and durations exacerbated by SLR) threatening the installation assets and missions on multiple scales for the project (focused on the Naval Station Norfolk, VA). It is important to note that the RC 1701 project team did not model climate change per se in this demonstration, but rather assumed SLR based on five scenarios prescribed by the SERDP (i.e., 0m, 0.5m, 1.0m, 1.5m, and 2.0 m) (Figure 3). This effort evolved in spiral phases beginning with a baseline characterization of the system and extending into a multi-criteria, multi-scaled assessment of impairment risks.

Initially, a regional survey of geomorphological and geologic conditions was undertaken to characterize the shoreline setting estimate change over time under the various SLR scenarios with regards to subsidence and protection. These results were incorporated into an assessment of land use conversion and habitat switching using a spatially-explicit, raster-based ecosystem response model called Sea Level Affecting Marsh Model (SLAMM ver. 6.0). Multiple applications of this model allowed researchers to evaluate both the sensitivity of the tool’s parameterization and compare its results with a straight-line (purely inundation-based or “bathtub”) to forecast land cover change under the five SLR scenarios.

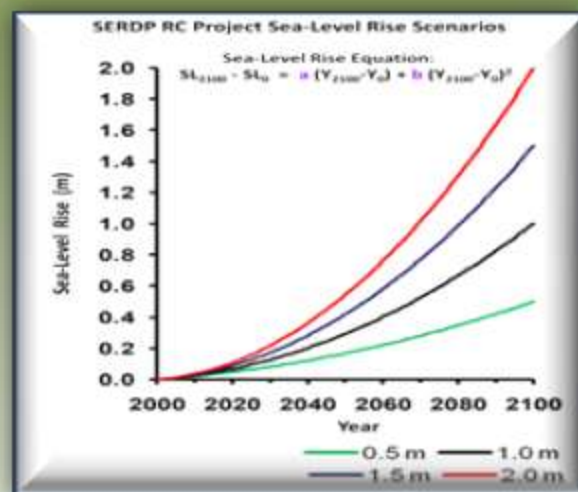


Figure 3. SERDP-mandated sea level rise scenarios used to evaluate risks under the RC-1701 demonstration project. In the equation provided, SL and SL_0 represent the sea levels at years Y and Y_0 , and “ a ” is the linear rate of sea level rise and “ b ” is the rate of increase in the rate of rise (acceleration). The units of “ a ” are L/T while the units of “ b ” are L/T^2 where L represents “length” and T is “time” in whatever units of measure are being used.



Figure 4. Over 500 hurricanes were simulated by FEMA in their recent floodplain re-mapping activities for the North Atlantic sea board. The RC-1701 project selected 17 of these storm tracks to use in this study. Ecological and shoreline data modeled under the five SLR scenarios were then used to re-parameterize the storms to generate the critical forcings (winds, waves, surge) for the regional assessment. These results were then handed-off to the nearshore and onshore modelers for further quantification of coastal storm impacts.

Regionally-based (western North Atlantic) surge and wave assessments were then conducted using these ecological and geomorphological outputs (Figure 4). All told, 17 individual hurricanes were simulated emulating 50-yr and 100-yr return periods with a changing coastline under five SLR scenarios using three numerical modeling tools. Hurricane winds are generated using the Planetary Boundary Layer (PBL) wind model referred to as TC96. Surge was simulated using the ADvanced CIRCulation (ADCIRC) model, while the waves were simulated using the Simulating WAVes Nearshore model (SWAN). In addition, three historical nor’easters and two smaller storms (emulating the 1-yr and 10-yr return periods) were modeled to capture more frequent, but less severe events.

Next, nearshore hydrodynamic modeling using the Coastal Modeling System (CMS) was undertaken to calculate the local water surface elevation, current, and sediment transport under combined influence of sea level rise, surge, tide, waves, and wind. The regional and nearshore hydrodynamic modeling assessments were then coupled with an interior flood-routing assessment (using the GSSHA – Gridded Surface-Subsurface Hydrologic Analysis model), as well as a groundwater level assessment (using the ADH - Adaptive Hydraulics model) to capture precipitation, surface water depth as well as infiltration and aquifer capacity reductions due to saltwater prism effects driven by SLR (Figure 5). These tools allowed the RC 1701 team to characterize and quantify “forcings” at a high-resolution 10-m grid scale on the site.

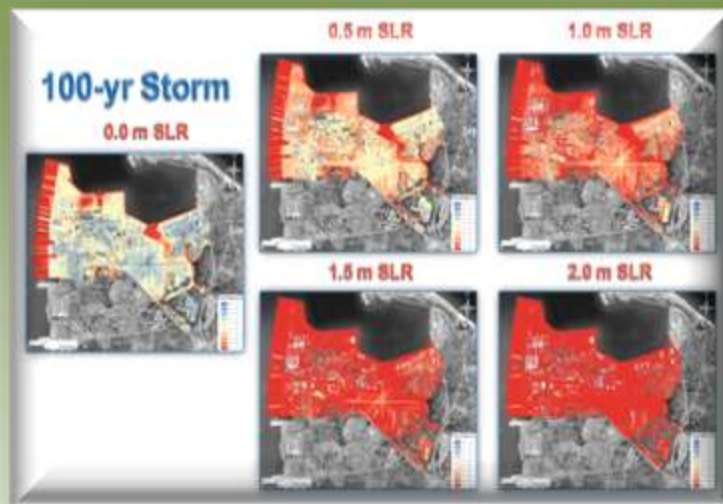


Figure 5. A series of “forcing” graphics have been developed as a “proof of concept” for the study on a model-by-model basis for each of the 25 SLR-storm combination scenarios. For example, based on the project’s simulations thus far, depths of flooding can be estimated onsite ranging from 2.6m (far left box = 0mSLR) to 9.3m (bottom right-hand box = 2.0mSLR) under the worse case scenario (100-yr return period). Similar risk-communication graphics have been developed for winds, surge, and sediment transport.

A comprehensive inventory of assets and mission capabilities was developed for the installation, and fragility curves were devised to estimate the probability of damage to these systems (water, steam, electricity, etc.) in a quantitative manner. A Bayesian network (Bn) was developed (Figure 6) to quantify: (1) the probability of asset damage states and functionality, (2) the probability of loss in capability (aka service interruption), and (3) the probability of potential losses in mission performance (specifically the mission focused on providing at-berth support for aircraft carriers at specific piers). In addition to these preceding capabilities, the RC-1701 Bn can be used to support risk management activities including the assessment of alternative system designs and/or retrofits in advance of the storms and SLR, as well as to identify knowledge voids (areas where more or better information on structural reliability should be obtained to improve the confidence in the network’s assessment capabilities).

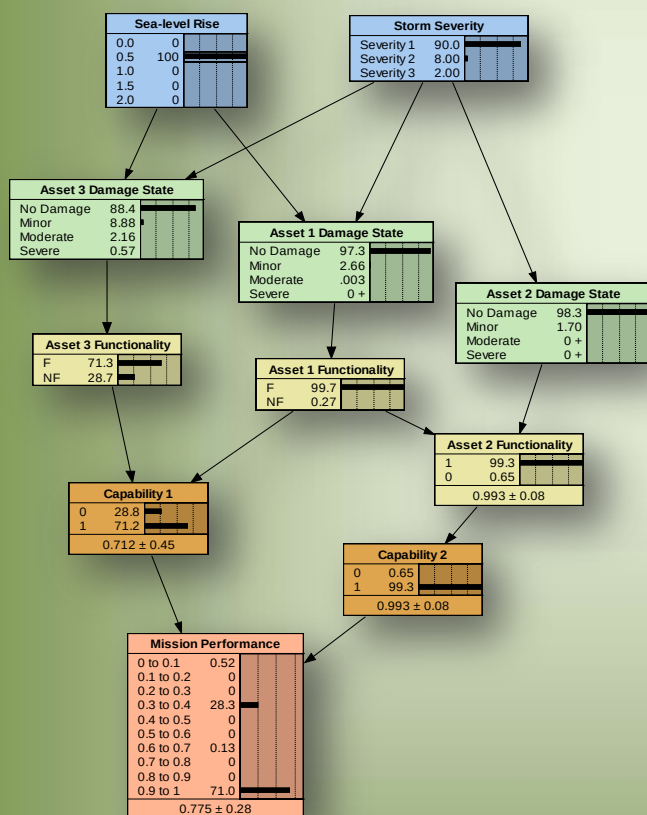


Figure 6. in the RC-1701’s Bayesian network (Bn), risk to mission performance is dependent upon capabilities (i.e., providing electricity, water, steam, etc. to the piers) that rely on systems of assets (boilers, steam lines, electricity, etc.) that are threatened by forcings impacting both their probabilistic damage states and therefore their functionality. The “beta” version of the RC-1701 Bn consists of 95 individual assets providing 23 separate capabilities that quantify the probability of mission performance based on more than 13,000 underlying probabilities in the construct. Here, the generic construct of the RC-1701 Bn is illustrated. The drivers (sea level rise and storm severity – blue boxes) impact the asset damage states (green boxes) which in turn determine asset functionality (yellow boxes). Multiple capabilities (orange boxes) supported by the functionality of numerous assets determine the probability of mission performance (pink box). In this hypothetical scenario, a 0.5 m SLR combined with a low-level coastal storm (1-10yr return period) results in a probability of 77% mission performance (a 33% chance of mission impairment).

Ultimately, installation vulnerabilities to climate change must be communicated to the end-users (installation planners and managers). To meet this challenge, the RC-1701 Team has developed a series of tables, graphics, and risk maps that transparently convey the potential not only of impairment, but duration of impairment immediately following a storm. Armed with this information, installation planners are now able to discern thresholds where minor annoyances (on the order of ~1 to 2 hours of delay in performance) turn into catastrophic events (i.e., resulting in weeks of mission impairment) (Figure 7). These critical decision thresholds can then be communicated to the end-user in an actionable construct so that managers and policymakers can consider altering the status quo to incorporate proactive management strategies to prevent or anticipate impairments based on the quantified risks.

Obviously, risk-informed decision making implemented within the traditional military planning process requires information produced through the conduct of decision-relevant risk analysis at the appropriate scales (i.e., local, regional, national, and global). In effect, the capabilities developed under the RC-1701 project afford installations the opportunity to evaluate relative performance of existing conditions and future no-action conditions, as well as structural and non-structural risk mitigating alternatives to sustain military installation assets and mission capabilities at multiple scales. The final product of the RC-1701 study will provide DoD with a robust, scientifically defensible approach that transparently communicates vulnerabilities and risks to the end-user and helps policymakers develop guidance to promote sustainability in the face of climate change and sea level rise. (Anticipated Project Completion: September 2012).

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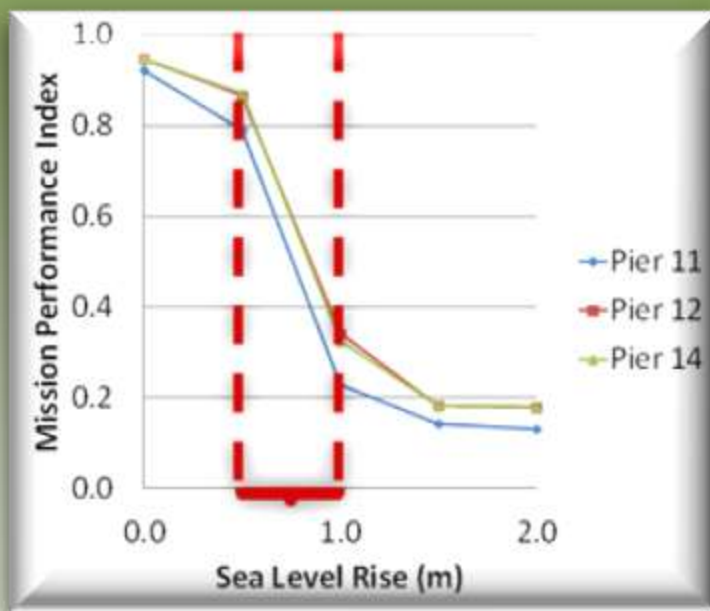


Figure 7. The RC-1701 risk-assessment strategy is capable of pinpointing critical decision point (i.e., thresholds where minor annoyances turn into catastrophic events, communicating the need to focus on particular scenarios when adaptively managing installation assets and operations. Preliminary findings indicate a critical decision-making point exists between the 0.5m and 1.0m SLR scenario (shown in red), suggesting planners and managers on the installation should consider incorporating a 1.0m SLR into their alternative formulation and adaptive management activities to assure sustainability and resilience in the future.