Application of the Coastal Environmental Risk Index (CERI) to Barrington, Bristol, and Warren, RI

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1. INTRODUCTION

The Coastal Environmental Risk Index (CERI), a method to assess the risk and damage to structures and infrastructure in the presence of storm surges including the effects of sea level rise, has been under development since 2016, with initial applications to Warwick, RI and Charlestown, RI; the first representing application to an protected area in Narragansett Bay, where surge amplification dominates flooding and the later to a coastal community along the southern RI shoreline where waves and erosion are critically important in estimating flooding risk. The applications to these two communities have been documented in Spaulding et al. (2016, 2017a,b), Grilli et al. (2017) and Schambach et al. (2018). The method has also been applied to the eastern end of Matunuck Beach (2015-2016), Misquamicut Beach (2016-2017) and downtown Providence (2017-2018) in recent senior design studies in Ocean Engineering, University of RI. In the most recent senior design project it is being applied to assess the risk to waste water treatment facilities and selected above ground storage tanks in upper Narragansett Bay. This report summarizes the application of CERI to the coastal communities of Barrington, Bristol, and Warren (Figure 1). These towns were selected for application given the very low lying topography of the area and its exposure to storm flooding. A companion report provides visualizations of the impact for selected subareas including: bridges and marinas, Wampanoug Trail South and North, and Latham Park in Barrington (provided in Appendix; Becker et al., 2018).

Section 2 outlines the methodology used to generate the maps. Section 3 provides the results of the analysis. Information on the method and its application can be accessed via the STORMTOOLS CERI web site (http://www.beachsamp.org/stormtools/stormtools-coastal-environmental-risk-index-ceri/). The papers, referenced above, describing CERI and its applications to date can also be found there. The damage and risk maps for Barrington, Warren and Bristol can be found at https://crc-uri.maps.arcgis.com/

2. MODELING HAZARD

2.1. METHOD

The hazard is represented by the annual 1% Probability of exceedance event (100-year storm). The method used to define the representative 100-y storm is described in earlier work (Spaulding et al.2016, 2017a,b; Grilli et al., 2017). A 100-y Synthetic-Design Storm (SDS) is designed based on the output of the U.S. Corps of Engineers' North Atlantic Coast Comprehensive Study (NACCS; Jenssen et al., 2017) at local save points. It combines storm surge, wave and sea level rise (SLR). The risk associated to the 100-y storm is assessed at the residential scale combining the modeled hazard represented by the SDS propagating across the shoreline in the inundation zone for different SLR scenarios and the residential vulnerability as assessed by fragility curves developed for specific building types by the U.S. Corps of engineers (NAACS study; Simm, 2017).

Waves are simulated in the northern section of the Narragansett Bay (Figure1) for the 100-y extreme storm events using the Steady State Spectral Wave model (STWAVE), a phase-averaged wave model. Simulations are performed for a " no SLR scenario" as well as for four SLR scenarios, 2,5,7 and 10 ft. Simulations are performed on a 15 m grid to optimize accuracy and computational efficiency and mapped on a 5 m grid. Focus is on the Bristol, Warren, Barington area (BWB)

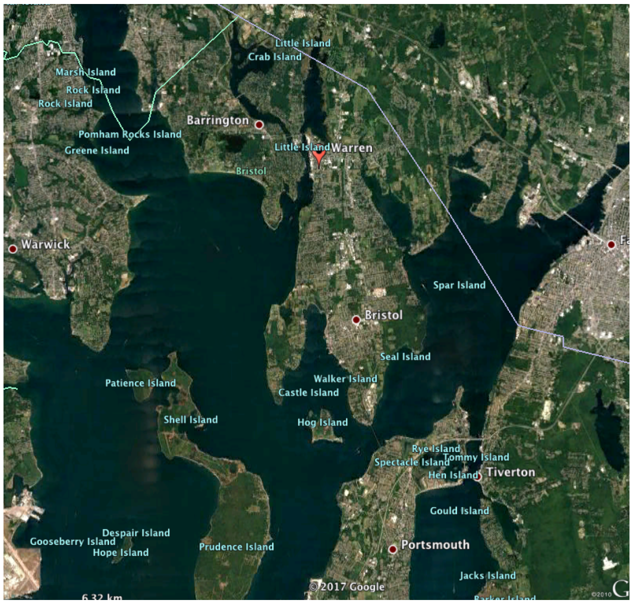


Figure 1. Study area

Environmental forcing

The wave model STWAVE requires in input the wave characteristics in the form of spectral parameters, significant wave height (H_s) , peak wave period (T_p), and main wave direction of propagation (*Wdir*) as offshore boundary conditions. Data used to set-up the model's computational grid and initial conditions include the bathymetry, the static water level (STWL) and the bottom friction.

The STWL is the water level resulting from the astronomical tide and the storm surge, including the static wave setup. It also includes the sea level rise (SLR). The friction is specified as a spatially variable Manning friction coefficient defined as a function of the land coverage provided on a 30 m grid (RIGIS, 2015). Bathymetry is provided on a 10 m grid (RIGIS, 2013).

While the wind is implicitly included in the storm surge and in the wave spectral parameters as defined in initial and boundary condition (100-year parameters results from wind forcing across the Atlantic Ocean), waves can be locally regenerated when the fetch is significant. This is occurs in the bay if wind conditions, speed (U) and direction ($Udir$), are favorable (landward wind). Therefore wave spectral parameters as well as local wind characteristics are provided in the model offshore boundary condition. The boundary conditions values are provided in Table 1. Wave and wind directions are specified according to the meteorological convention (clockwise from North).

The 100-y SDS is used in initial and offshore boundary condition (Grilli et al. 2015). STWL and wave spectral parameters (significant wave height (H_s) and peak period (T_p)) characteristic of the 100-year storm are extracted from the North Atlantic Coast Comprehensive study (NACCS; Jensen et al., 2016) database at the regional save points and interpolated along the offshore boundary of the computational grid, to reconstruct the local spectrum.

Five scenarios are considered for the STWL; the 100-y storm surge is estimated based on the NACCS values at save points (interpolated on the computational grid)

- Scenario 1: no SLR; 100-y storm surge defined as the 95% upper limit of the confidence interval of the 1% of exceedance event.
- Scenario 2: 100-y storm surge linearly combined with a SLR of 2ft.
- Scenario 3: 100-y storm surge linearly combined with a SLR of 5ft.
- Scenario 4: 100-y storm surge linearly combined with a SLR of 7ft.
- Scenario 5: 100-y storm surge linearly combined with a SLR of 10ft.

Table 1: Initial and offshore boundary conditions for the 100-y storm scenarios used for wave simulations.

Environmental Parameters used as offshore boundary and initial conditions							
SCENARIO	**WAVE**			**WIND**		**WATER LEVEL [STWL]**	
	H_s (m)	T_p(s)	*Wdir.* (deg)	*U* (m/s)	*Udir.* (deg)	Surge (m)	SLR (m)
#1 No SLR	10	20	165	35	180	NACCS 100y	0
#2 2ft SLR	10	20	165	35	180	NACCS 100y	0.61
#3 5ft SLR	10	20	165	35	180	NACCS 100y	1.52
#4 7ft SLR	10	20	165	35	180	NACCS 100y	2.13
#5 10ft SLR	10	20	165	35	180	NACCS 100y	3.05

Computational Grid

Characteristics of the STWAVE computational grid are provided in Table 2. The Cartesian computational grid is rotated from the x axis by α =85 degrees (counterclockwise) from its origin at the SE corner, resulting in a cross-shore axis of propagation I of about 42 km, expanding from the Rhode Island Sound to the upper part of the Narragansett bay. The width of the grid (J direction; 16.5 km) is designed to include both the East and West passages in the wave propagation modeling. The grid boundary is shown over the bathymetry/topography map in Figure 2.

Table 2 : Characteristics of the computational grid used for wave simulations. Coordinates are provided in UTM coordinates (zone 19N; m).

Grid	X0-SW corner (UTM 19N)	Y0-SW corner (UTM 19N)	α (deg)	N cells in I directi-on	N cells in J directi-on	Length I Direction (m)	Width J Direction (m)	Discretization (m)
Narragansett Bay	315000	4586300	85	2787	1394	41805	20900	15

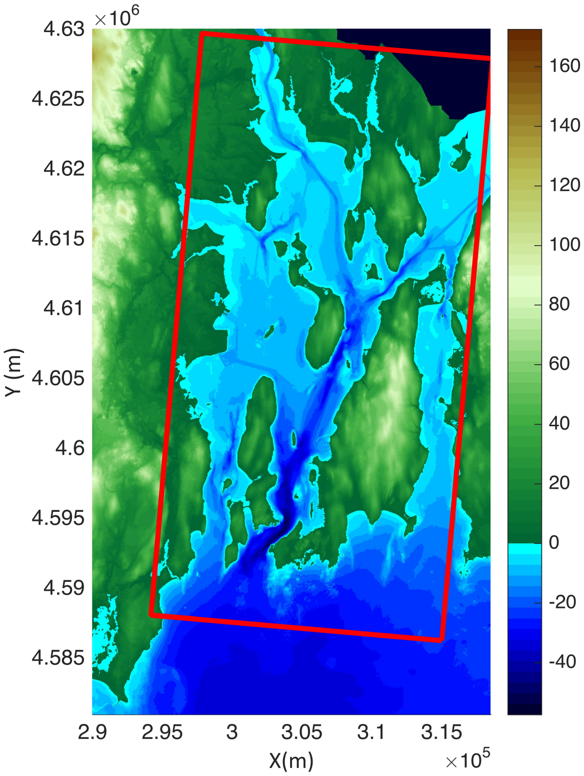


Fig. 2 Boundary (red box) of computational grid used in STWAVE wave simulations (UTM coordinates zone 19N). Bathymetry (<0) and topography (>0) are shown as a color scale (in meter).

2.2. HYDRODYNAMIC MODELING RESULTS

Results of the simulations are presented in the form of inundation maps, showing the total water depth (TWD), including surge, waves and SLR. TWD corresponds to FEMA's base flood elevation (BFE), however, referenced to ground level rather than to the standard vertical datum NAVD88. It combines storm surge, astronomical tide, wave set-up, the controlling wave crest, η_c , and the SLR, in the inundated area. The *controlling wave crest,* η_c *,* is defined, following FEMA's terminology, as the mean of the 1% of the highest wave. Assuming that waves are Rayleigh distributed, $\eta_c = C_1 H_c$, with H_c the controlling wave height and C_1= 0.7, and H_c= $C_2 H_s$, with H_s the significant wave height and C_2 =1.67. Let's note that in the following the " inundation zone" refers to the area above NAVD88.

For each scenario, we present maps of the following water level or wave characteristics:

(1) Total Water Depth (TWD) with TWD = STWD + η_c
(2) Static Water Depth (STWD), which represents the Static Water Level (STWL) referenced to ground level; STWL is the storm surge including astronomical tide static wave set-up and SLR referenced to NAVD88.
(3) Wave crest, η_c
(4) Base flood Elevation (BFE) , total water elevation referred to NAVD88, resulting from the combination of the 100-y (95% upper confidence interval) STWL and the corresponding wave crest elevation (η_c)as defined above.

Figure 3 shows the current shoreline and the local bathymetry, with water depth between 5 an 10 m in this upper section of the Narragansett Bay.

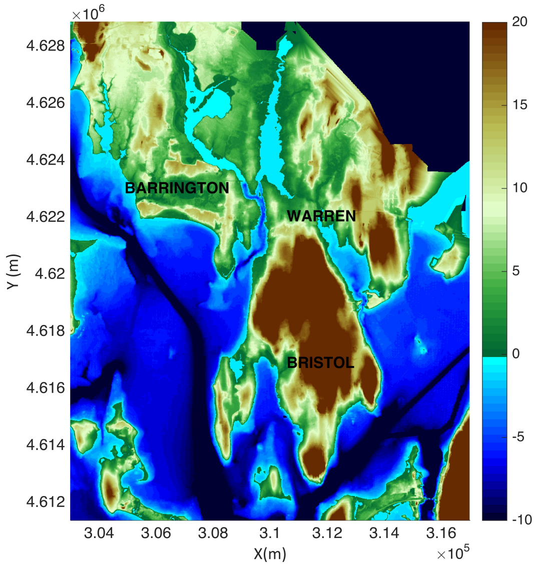
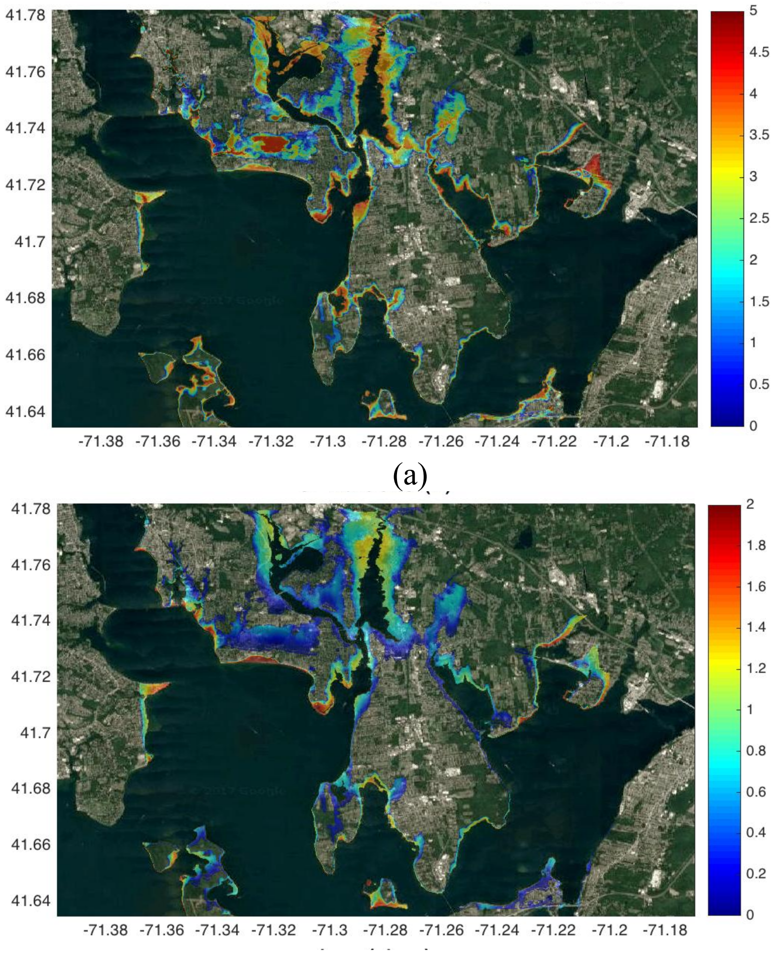


Fig. 3 Bathymetry and topography (m) of the study area for Mean Sea Level (MSL) conditions .

Scenario 1: No SLR

Figure 4.a shows the STWD in the inundated area ; Figure 4.b shows the simulated wave crest elevation (h_c); Figure 5 shows the TWD due to storm surge and waves relative to ground level in the inundated area (above NAVD88).

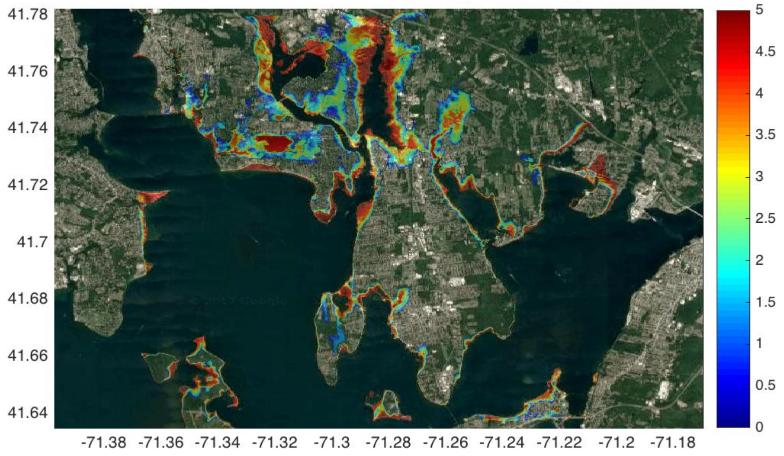
Barrington is the most sensitive area to inundation due to its low topography with many area under 5 m. Waves are generally smaller that 1 m except for few exposed area as the southern tip of Rumstick Neck, Rumstick point in Barrington, and Jacobs point in Warren.



(a)

(b)

Fig 4. (a) STWD (m) relative to ground level in inundated area (above NAVD88) and (b) wave crest (m) elevation above STWL for Scenario #1 [100-year storm].



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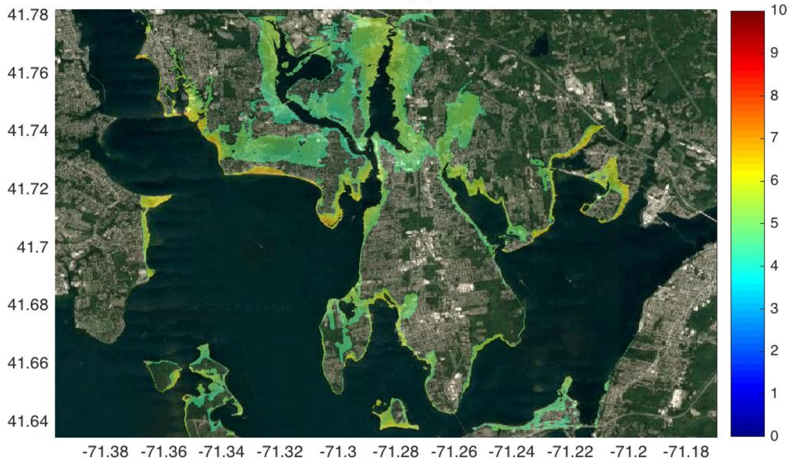
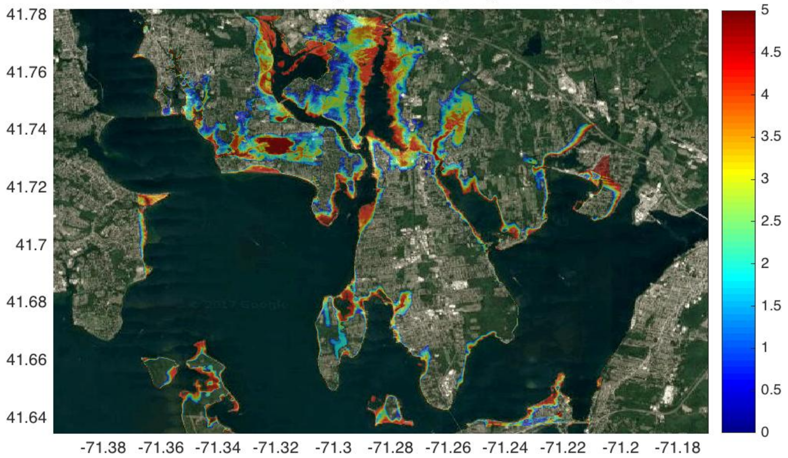


(b)

Fig 5. (a) TWD, total water depth (m) due to storm surge and waves relative to ground level and (b) BFE, in inundated area (above NAVD88) for Scenario #1 [100-year storm]

Scenario 2: 2 ft SLR

Figure 6.a shows the STWD in the inundated area ; Figure 6.b shows the simulated wave crest elevation (h_c); Figure 7 shows the TWD due to storm surge and waves relative to ground level in the inundated area (above NAVD88).



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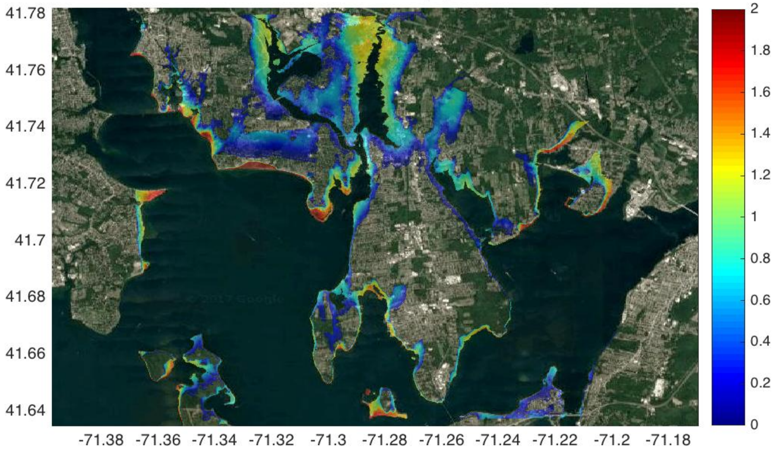
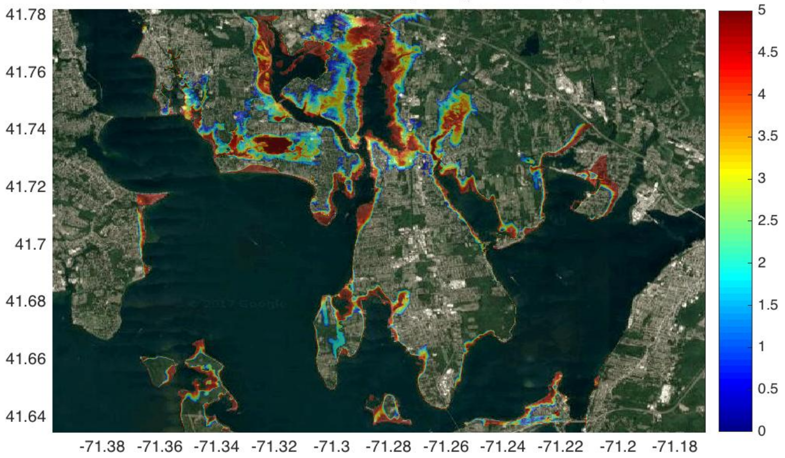


(b)

Fig 6. (a) STWD (m) relative to ground level in inundated area (above NAVD88) and (b) wave crest (m) elevation above STWL for Scenario #2 [100-year storm ; 2 FT SLR]



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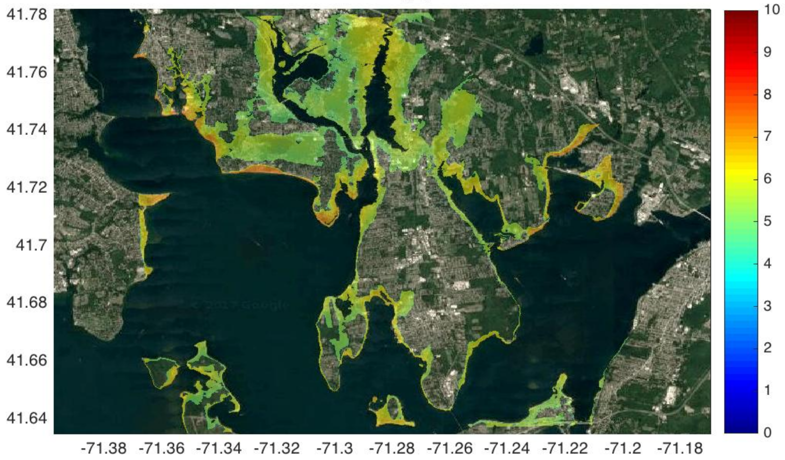
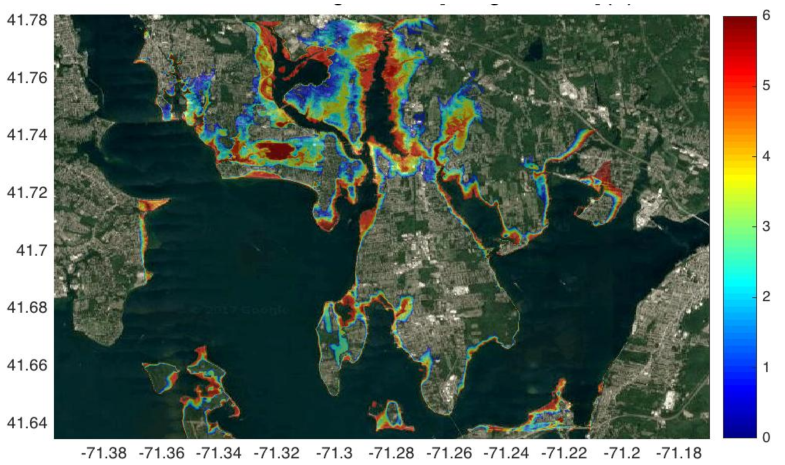


(b)

Fig 7. (a) TWD, total water depth (m) due to storm surge, SLR and waves relative to ground level and (b) BFE, in area above NAVD88 for Scenario #2 [100-year storm; 2 FT SLR]

Scenario 3: 5ft SLR

Figure 8.a shows the STWD in the inundated area ; Figure 8.b shows the simulated wave crest elevation (h_c); Figure 9 shows the TWD due to storm surge and waves relative to ground level in the inundated area (above NAVD88).



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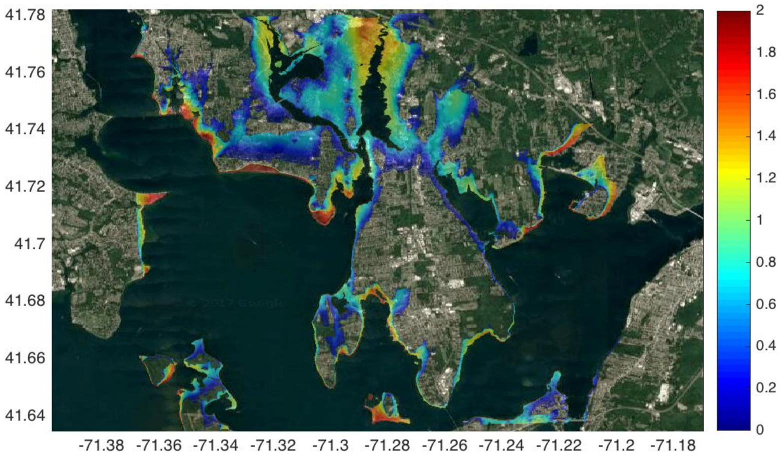
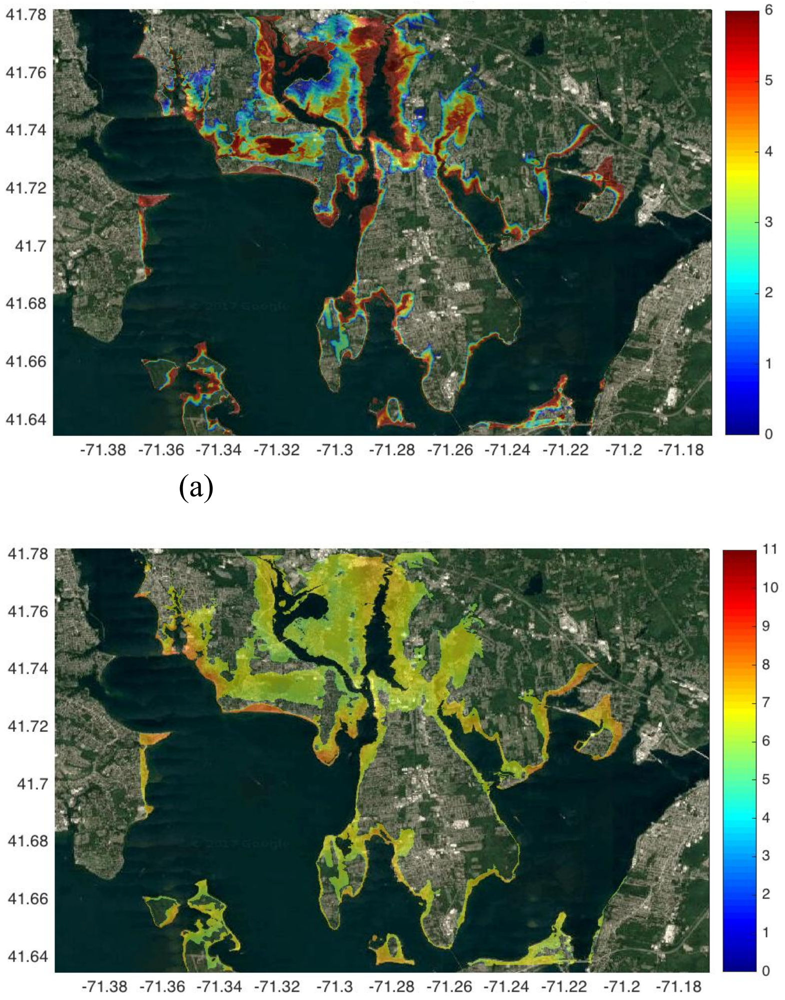


(b)

Fig 8. (a) STWD (m) relative to ground level in area above NAVD88 and (b) wave crest (m) elevation above STWL for Scenario #3 [100-year storm ; 5 FT SLR]



(a)

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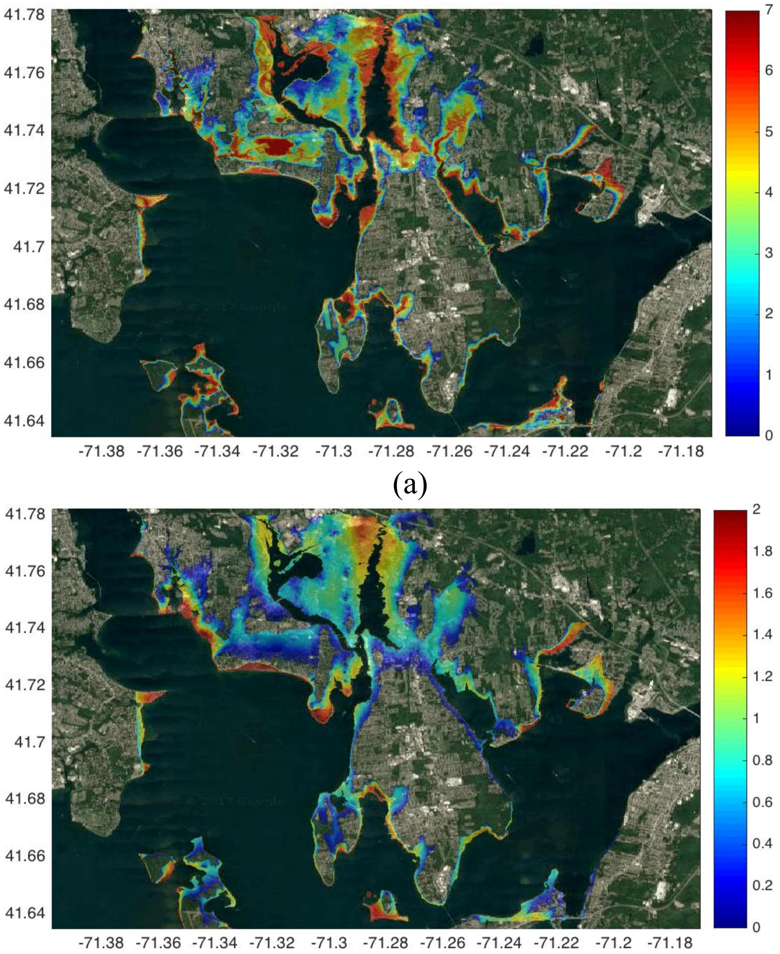
Fig 9. (a) TWD, total water depth (m) due to storm surge, SLR and waves relative to ground level and (b) BFE, in area above NAVD88 for Scenario #3 [100-year storm; 5 FT SLR]

Scenario 4: 7 ft SLR

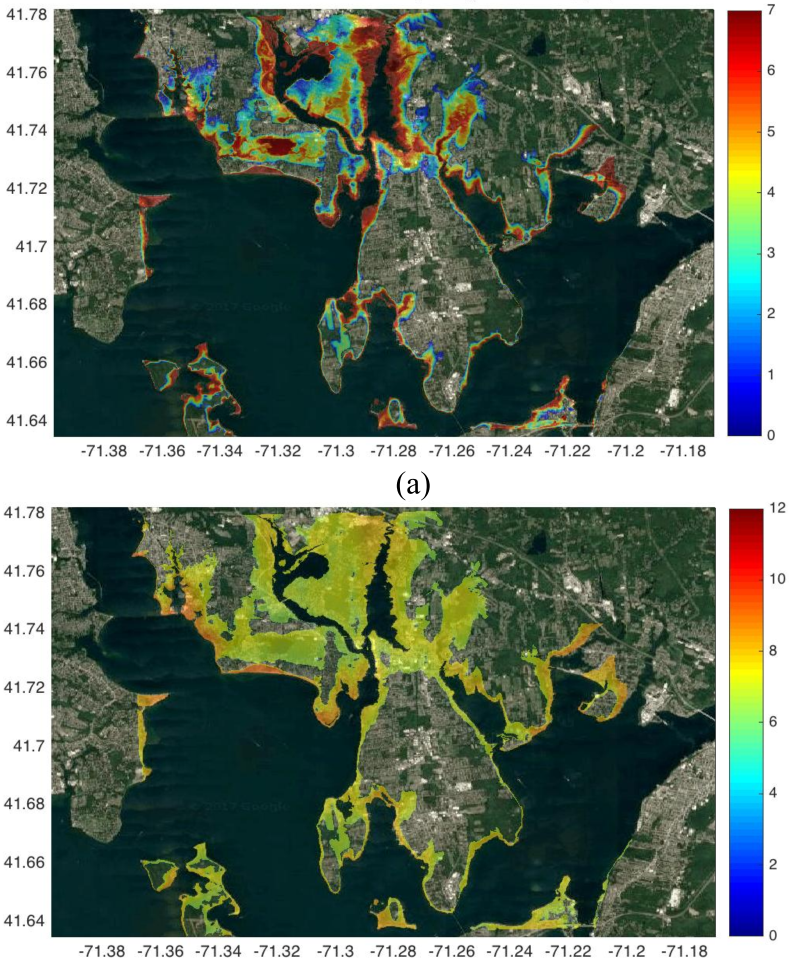
Figure 10.a shows the STWD in the inundated area ; Figure 10.b shows the simulated wave crest elevation (h_c); Figure 11 shows the TWD due to storm surge and waves relative to ground level in the inundated area (above NAVD88).



(a)

(b)

Fig 10. (a) STWD (m) relative to ground level in area above NAVD88 and (b) wave crest (m) elevation above STWL for Scenario #4 [100-year storm ; 7 FT SLR]



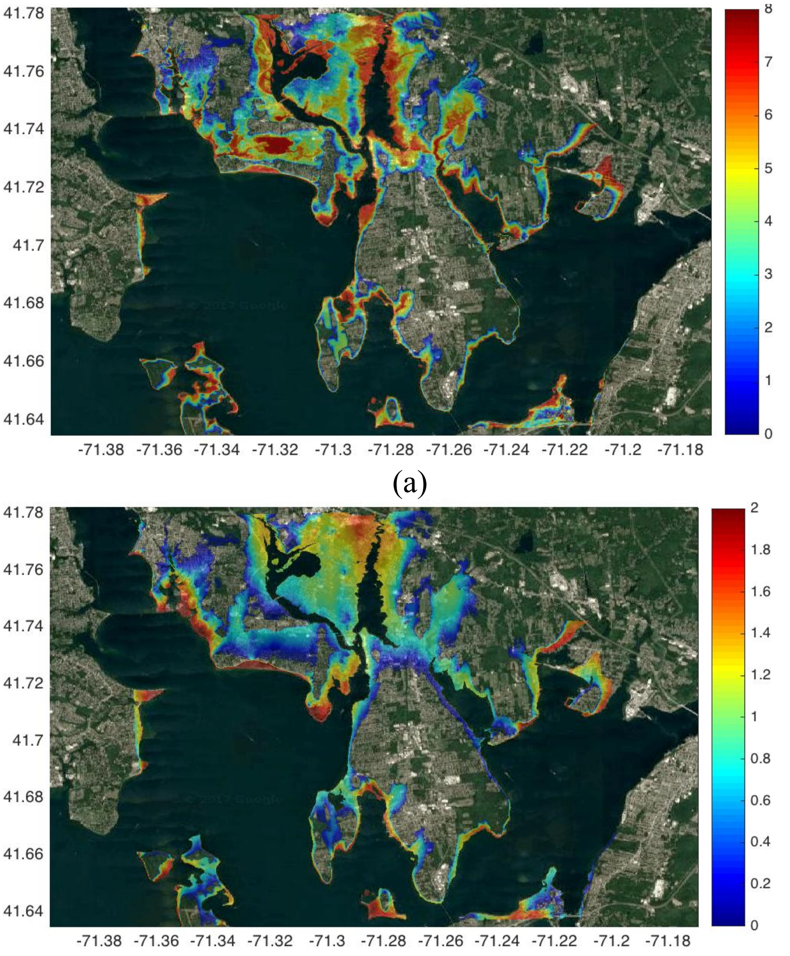
(a)

(b)

Fig 11. (a) TWD, total water depth (m) due to storm surge, SLR and waves relative to ground level and (b) BFE in area above NAVD88 for Scenario #4 [100-year storm; 7 FT SLR]

Scenario 5: 10 ft SLR

Figure 12.a shows the STWD in the inundated area ; Figure 12.b shows the simulated wave crest elevation (h_c); Figure 13 shows the TWD due to storm surge and waves relative to ground level in the inundated area (above NAVD88).



(a)

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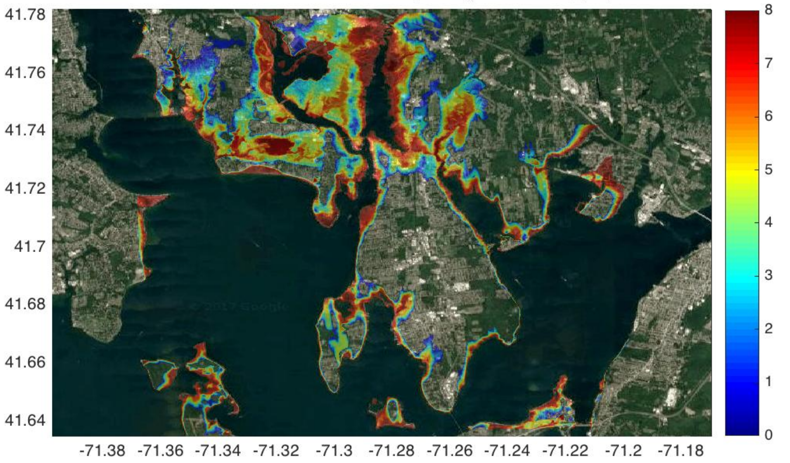
Fig 12. (a) STWD (m) relative to ground level in area above NAVD88 and (b) wave crest (m) elevation above STWL for Scenario #5 [100-year storm ; 10 FT SLR]



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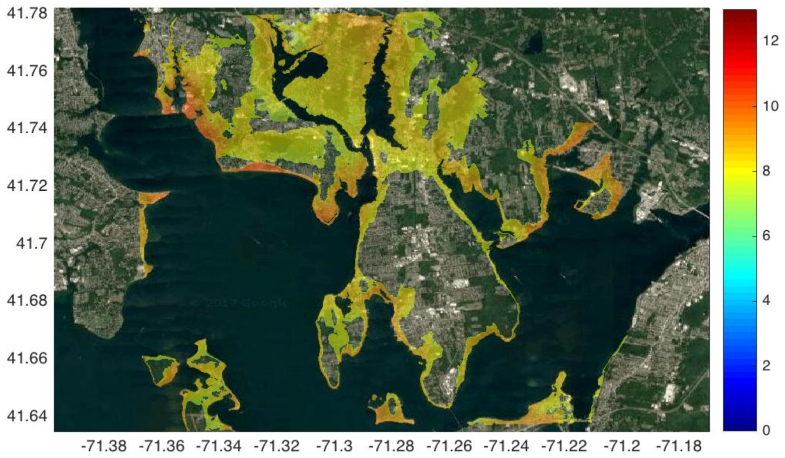


(b)

Fig 13. (a) TWD, total water depth (m) due to storm surge, SLR and waves relative to ground level and (b) BFE, in area above NAVD88 for Scenario #5 [100-year storm; 10 FT SLR]

3. ASSESSING RISK: COASTAL ENVIRONMENTAL RISK INDEX (CERI) APPLIED TO BWB

The risk faced by each structured is assessed using the Coastal Environmental Risk Index (CERI) as recently applied to other coastal communities (Spaulding et al. 2017a,b; Grilli et al, 2017). The method assesses the risk at the scale of individual structures in terms of predicted structural damage associated to a 100-year storm (1% probability of exceedance). The CERI represent the maximum predicted structural damage in fraction of the total structural value of the structure (%).

While the hazard is assessed in terms of the 100-year inundation depth and maximum wave crest elevation as described in the previous section, the vulnerability of each house is essentially based on its first floor elevation, as well as the house type, as defined by the US. Corps of Engineers (USCOE ; Simm et al. 2015). Structures are categorized in 12 types following the USCOE typology, depending mostly of the number of stories, the presence or absence of basement or if the structure is elevated on piles.

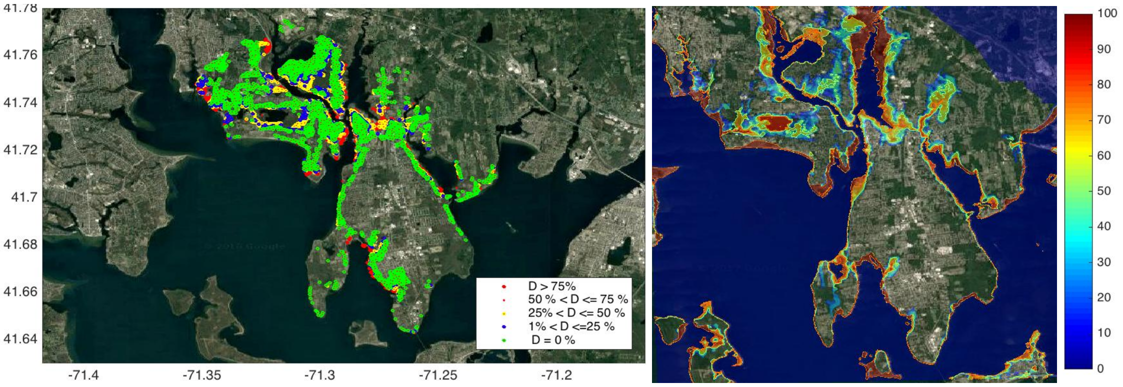
The risk is theoretically defined as the product of the hazard and structural failure probabilities. In this analysis, since the hazard probability is a priori specified as a constant value (1%), the risk is simply proportional to the probability of structural failure, as provided for each house type by the US ACOE damage curves relating structural damage and hazard (Simm et al. 2015).

In the following we have mapped the value of CERI for each structure located in the study area for each scenario (no SLR, 2, 5, 7, and 10 ft SLR). The color map used in CERI shows, for a 100-y event: in green, the structures which are expected to be “safe” and which would not suffer any damage; in blue, the structures which would experience some damage but less than 25 % of the value of the structure; in yellow, the structures which would experience larger damage between 25 to 50 % of the value of the structure; in magenta, the structures which would experience significant damage between 50 and 75

% of the value of the structure and in red, the structures which would experience damage larger than 75 % of the value of the structure. Structures shown in white will be under MSL, assuming the SLR scenarios.

In addition we have mapped the likelihood of any arbitrary structure experiencing total damage in all sites touched by the inundation (assuming the worst case scenario: maximum USCOE damage curve assuming a standard structure as defined by the USCOE type 6B). Area under MSL in the SLR scenarios are mapped in white. Areas not colored do not show any risk. Minimum risk is shown in blue areas maximum risk in red areas , with a transition zone of middle risk in green and yellow area.

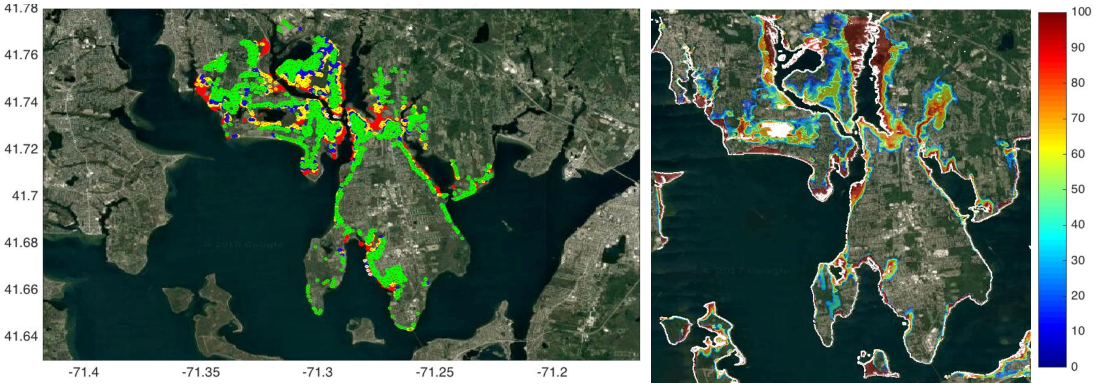
1.1 Scenario 1: No SLR



(a) **(b)**

Fig 14. For scenario 1 (no SLR): **(a)** CERI applied for each building; (b) sites affected by the storm hazard with colormap indicating the likelihood of total damage of any given structure in the "worse case scenario" (structure 6B/maximum damage curve).

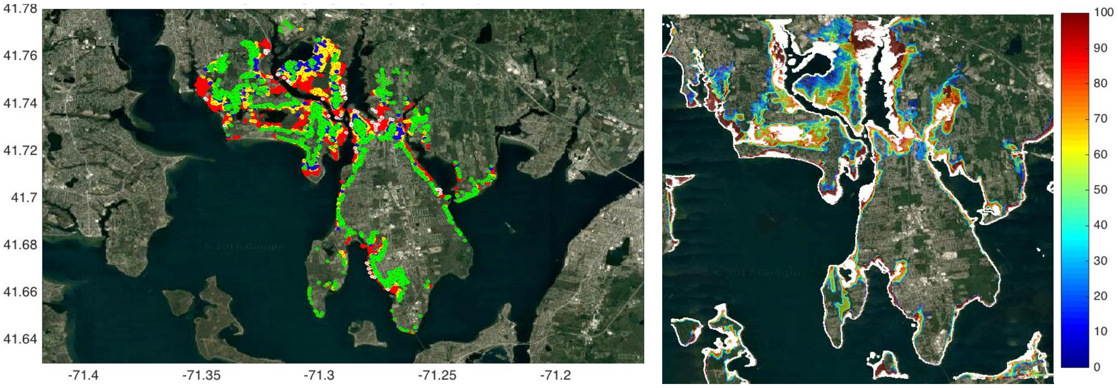
1.2 Scenario 2: 2 ft SLR



(a) **(b)**

Fig 15. For scenario 2 (2ft SLR): **(a)** CERI applied for each building; (b) sites affected by the storm hazard with colormap indicating the likelihood of total damage of any given structure in the "worse case scenario" (structure 6B/maximum damage curve). Area under MSL are mapped in white.

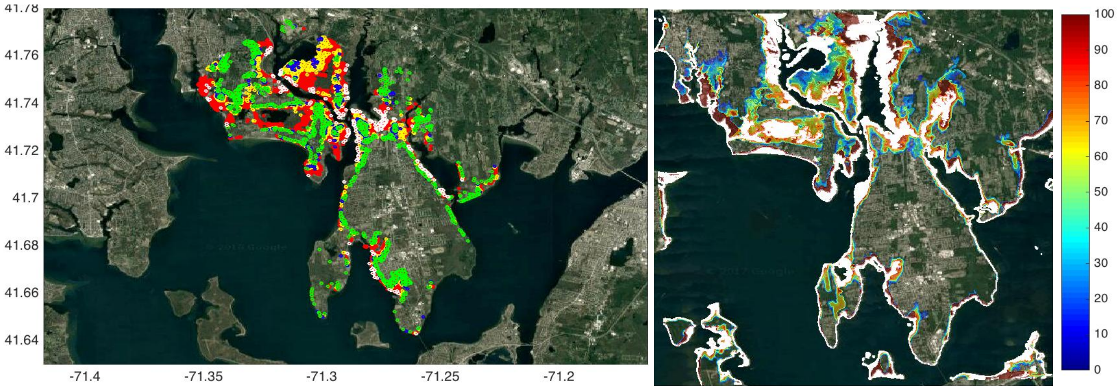
1.3 Scenario 3: 5 ft SLR



(a) **(b)**

Fig 16. For scenario 3 (5ft SLR): (a) CERI applied for each building; (b) sites affected by the storm hazard with colormap indicating the likelihood of total damage of any given structure in the "worse case scenario" (structure 6B/maximum damage curve). Area under MSL are mapped in white.

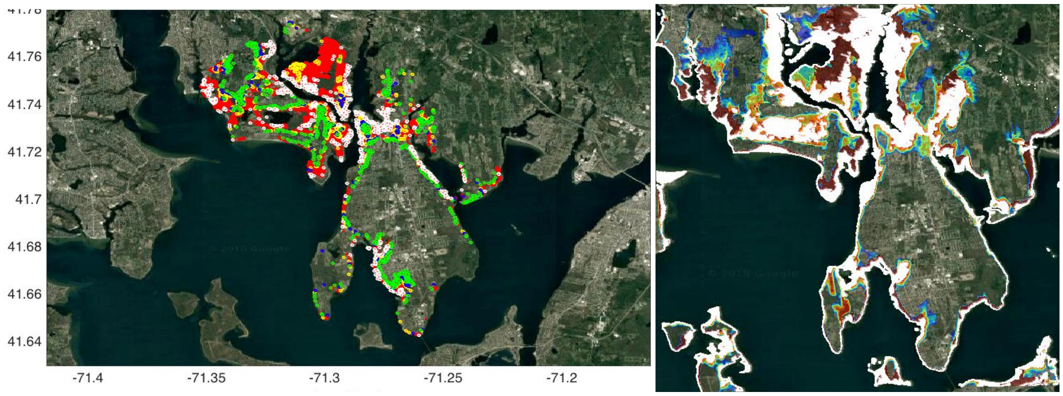
1.4 Scenario 4 : 7 ft SLR



(a) **(b)**

Fig 17. For scenario 4 (7ft SLR): (a) CERI applied for each building; (b) sites affected by the storm hazard with colormap indicating the likelihood of total damage of any given structure in the "worse case scenario" (structure 6B/maximum damage curve) . Area under MSL are mapped in white.

1.5 Scenario 5 : 10 ft SLR



(a) **(b)**

Fig 18. For scenario 5 (10ft SLR): (a) CERI applied for each building; (b) sites affected by the storm hazard with colormap indicating the likelihood of total damage of any given structure in the "worst case scenario" (structure 6B/maximum damage curve). Area under MSL are mapped in white.

2. SUMMARY

A summary of the expected likelihood of structural damage for a 100-y event for each SLR scenario is provided in Table 3. Statistics of the expected structural damage is provided for the minimum, mean, and maximum damages curves providing a confidence interval to the expected damage. Let's note that CERI maps are designed using the maximum expected damage curve. The fraction of houses expected to be under MSL for each SLR scenario is also provided (e.g. 1 % for the 5ft scenario and 16 % for the 10 ft scenario); the fraction of houses likely experiencing 100% of damage is also extracted from the 75-100% category and provided in the Table (e.g. 5 to 6 % for the 2ft scenario and 19 to 25 % for the 10 ft scenario).

For example, from Table 3, we see that if the 100-year storm occurs today (no additional SLR), the no-SLR scenario shows that 62 to 63 % of the houses would be "safe" and likely not impacted by the storm; only 3 to 4 % would be fully destroyed (loss of 100% of the structural value).
If an identical storm would hit the coastline in 50 years from now (assuming NOAA high scenario , SLR = 5ft), we shall select the 5ft scenario. 1 % of the houses only would be under MSL but the fraction of the safe house would be reduced to 34 to 35 % and 9 to 12 % of the houses would likely be fully destroyed; 20 to 35 % of the houses would likely have more than 50% of damages.

Table 3: Expected frequency of each of structural damage category with confidence interval [minimum, mean, maximum expected values] for each scenario

CERI - EXPECTED LIKELIHOOD OF STRUCTURAL DAMAGE FOR 100-YEAR STORM FOR THE 5 SCENARIOS FOR BWB [scale 0 to 1] WITH CONFIDENCE INTERVAL [MIN-MAX]

	NO SLR			2 FT SLR			5 FT SLR			7 FT SLR			10 FT SLR		
STRUCTURAL DAMAGE %	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean	max
75 - 100	0.03	0.04	0.05	0.05	0.06	0.09	0.09	0.12	0.18	0.12	0.16	0.24	0.20	0.26	0.33
50 - 75	0.02	0.04	0.07	0.04	0.09	0.11	0.11	0.16	0.17	0.15	0.20	0.19	0.16	0.18	0.16
25 – 50	0.11	0.16	0.17	0.16	0.20	0.20	0.22	0.23	0.21	0.22	0.22	0.20	0.18	0.17	0.14
1 - 25	0.21	0.14	0.09	0.23	0.15	0.10	0.23	0.14	0.09	0.19	0.11	0.06	0.14	0.08	0.05
0	0.63	0.62	0.62	0.51	0.50	0.50	0.35	0.34	0.34	0.27	0.26	0.26	0.16	0.16	0.16
UNDER MSL	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.05	0.05	0.05	0.16	0.16	0.16
TOTAL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	0.03	0.04	0.04	0.05	0.05	0.06	0.09	0.09	0.12	0.11	0.12	0.16	0.19	0.2	0.25

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Author Contributions: Annette Grilli was primarily responsible for inundation, wave, and damage modeling. She and M. Spaulding, co-led the project. Implementation in GIS and providing access of the output via ArcView was provided by Chris Damon. Teresa Crean led the outreach effort and was responsible for interfacing with the three communities. Grover Fugate advised on the design of the system to meet the needs of coastal managers and planners. Austin Becker, Jose Menendez , Peter Stempel coordinated the effort to develop and apply to the area the visualization tool presented in appendix.

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Appendix: Visualizations for Bristol, Warren, and Barrington (RI)

Visualizations Team: Austin Becker (PI), Jose Menendez, Peter Stempel

The Marine Affairs Visualization Lab (MAVL) at the University of Rhode Island has developed methods to create engaging 3D visualizations of storm impacts based on ocean modeling and damage functions ((Stempel et al. 2018, Spaulding et al. 2016). These methods link ocean and damage modeling outputs to visualization pipelines to create dynamically-updatable 3d models of structures and natural features *(Figure 1).* Easily understood 3d visualizations of recognizable places that engage the audience can improve risk communication (Sheppard 2015, 2012). This may be especially important in the face of impending storm events, as emergency managers indicate that people tend to underestimate the power of storm surge (Morrow and Lazo 2013). More generally, Lindeman et. al. indicates that there is a need for improved communication materials and message delivery at community planning scales (Lindeman et al. 2015).
Traditional visualization workflows are often ad hoc and difficult to scrutinize because they are embedded in proprietary software requiring specialized skills. (Sheppard 2005, Lovett et al. 2015). In contrast to this, the methods adopted by MAVL employ the open-source programming language "R" for all key data processing tasks, such as determining damage (Stempel 2016). This minimizes the amount of work done in proprietary visualization software and maximizes transparency of the process. The use of R, which is

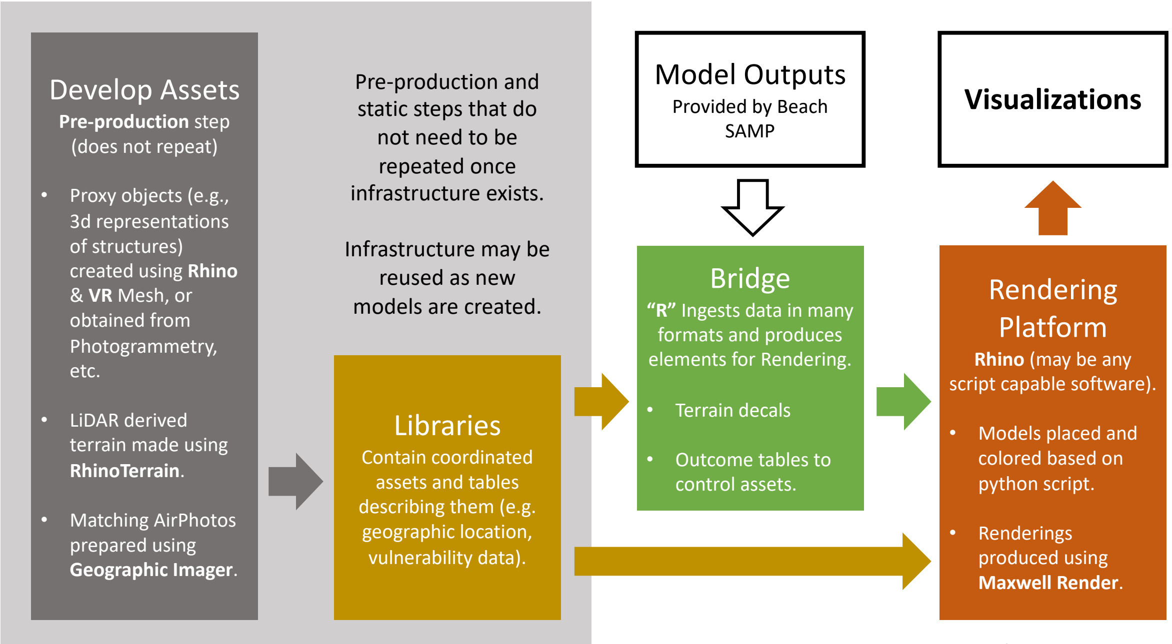
widely understood and recognized in the scientific and statistical community, ensures that procedures and algorithms that determine outcomes can be easily scrutinized.

Fig. A1 Inundation effects of a 100-year storm|0 feet sea level rise for Marina & Bridges in Barrington, RI, by MAVL and the ITS Lab, for Beach Special Area Management Plan. Structure Risk Index data provided by RI STORMTOOLS coastal Environmental Risk Index (CERI). Water depth at ground elevation data provided by RI STORMTOOLS Coastal Environmental Risk Index (CERI).

In 2017 and 2018, students at the lab developed sea level rise visualizations created for the coastal towns of Warren, Bristol, and Barrington in the state of Rhode Island. Outputs are used in the Beach Special Area Management Plan process being led by the RI Coastal Resources Management Council. The visualization illustration set for Barrington, Bristol, and Warren has fostered a collaboration between the Dept. of Marine Affairs and the URI's Information Technology Services, Student Technology Assistants (STA) program, which trains undergraduate students in computer programming and three-dimensional modeling techniques.

For these visualizations, the Student Technology Assistants were divided in two groups: the modelling team and scripting team (Figure 1).The modelling team drew three dimensional terrains and structures of Barrington, Bristol, and Warren using Rhino 3d software. The research involved compiling topographical information of Barrington, Bristol, and Warren from the Rhode Island Geographic Information System (RIGIS) database of aerial photography. The aerial photos were assembled using Geographic Imager in Photoshop. The compiled aerial image was imported into Rhinoceros 3D— a computer graphics and computer-aided design application software to generate a three-dimensional topographical landscape. Further computer modelling work focused in detailing the coastline to ensure connection between the topographical mesh and the bathymetric mesh. Site landmarks and buildings with specific features valued by the community by their economic, historic, or cultural importance were drafted by the students using Rhino. While some unique features are custom 3d models of specific feature, the bulk of the content is procedurally generated, meaning the form of the object is guided by a set of algorithmic instructions and publicly available data such as E911 data or assessors' records. The 3d content is stored in widely recognized formats such that it is not specific to a single platform.

The scripting team developed output tables for existing structures and inundation maps based on the Coastal and Environmental Risk Index outputs *(Figure 2).* These tables provide all the necessary information for automatic specification and placement of 3d content in the visualization environment, in most cases using the Python programming language (Stempel 2016). The data processing conducted in R thus bridges ocean modeling outputs and visualization control using python in the visualization platform. Output tables can be configured to drive multiple output platforms, from web-based maps to rendered, realistic, 3d visualizations and virtual environments.



Rapidly repeatable workflow.

Fig. A2 Workflow Diagram for developing the visualizations for Bristol, Barrington, and Warren.

The visualizations illustrate the inundation water depth at ground elevation for each of the site locations and the existing structures risk damages with two sets of color gradients. The color gradient for the structure risk index shows the structures percentage of risk as moderate (0-25%), high (25%-50%), severe (51-75%), and extreme (76-100%). The color gradient for the inundation water depth at ground elevations shows the 100-year storm plus sea level rise effects on each location. The color gradient shows a range of depth from no water depth to 17 plus feet of inundation depth. The aerial views for each location were generated using Maxwell, a Rhino plugin rendering software, to show three scenarios: 100-year storm with 0 feet of sea level rise, 100-year storm with 2+ sea level rise, and 100-year storm with 5+ sea level rise (Figure 3).

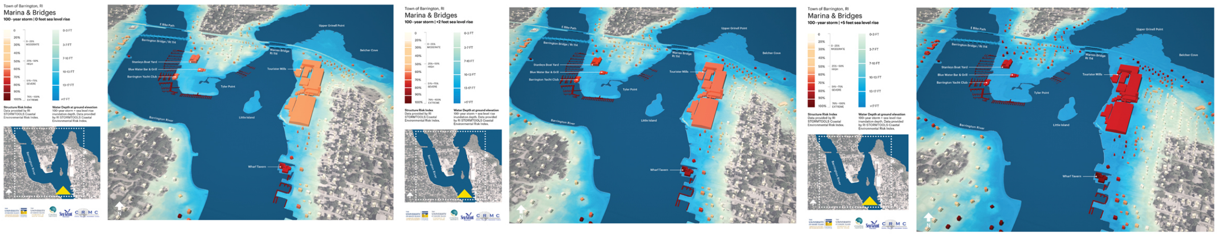


Fig. A3 Examples of visualizations showing impact for Marina & Bridges for the town of Barrington RI.

The methods developed by MAVL are broadly applicable. In the context of Rhode Island, MAVL has established extensive libraries of 3d content (over 150,000 structures), and algorithmic methods for generating 3d content based on typical patterns of development. Scripts and content libraries are being operationalized such that they can be continually updated and reused as new storm models are produced by multiple labs at the University of Rhode Island.

With increased use of data mining and algorithmic content generation, it is possible to deploy these methods in other states and locations. Although some custom 3d content representing landforms and other highly identifiable landmarks need to be created for a given area, once created this content is infinitely reusable. In some cases, the needed 3d content can be generated using photogrammetric methods, such as models provided by Pictometry (a company specializing in developing this content using airborne cameras), or produced using consumer level drones. MAVL continues to innovate and develop improved methods for creating 3d representations of storm impacts.

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