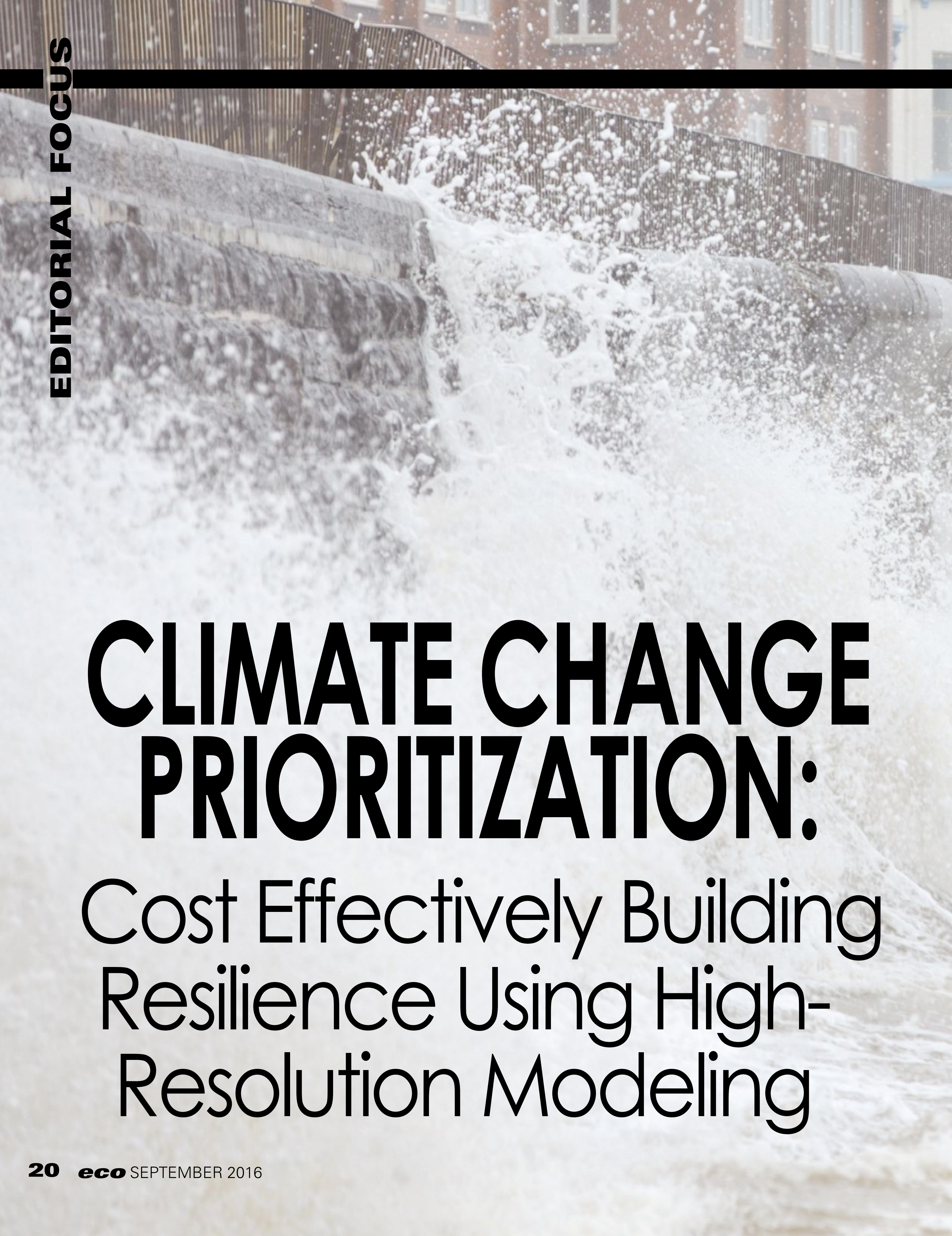
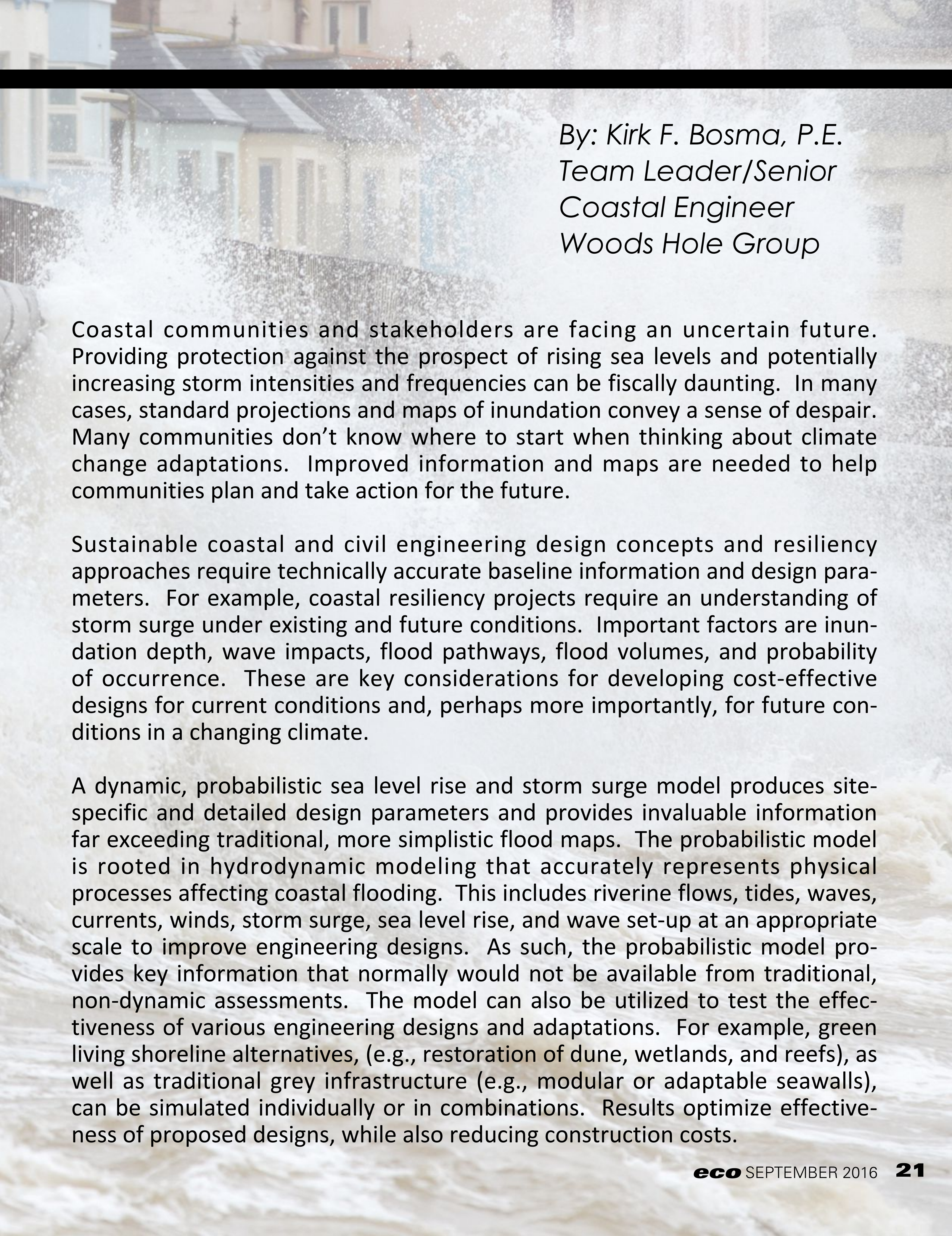
EDITORIAL FOCUS



CLIMATE CHANGE PRIORITIZATION:

Cost Effectively Building Resilience Using High-Resolution Modeling



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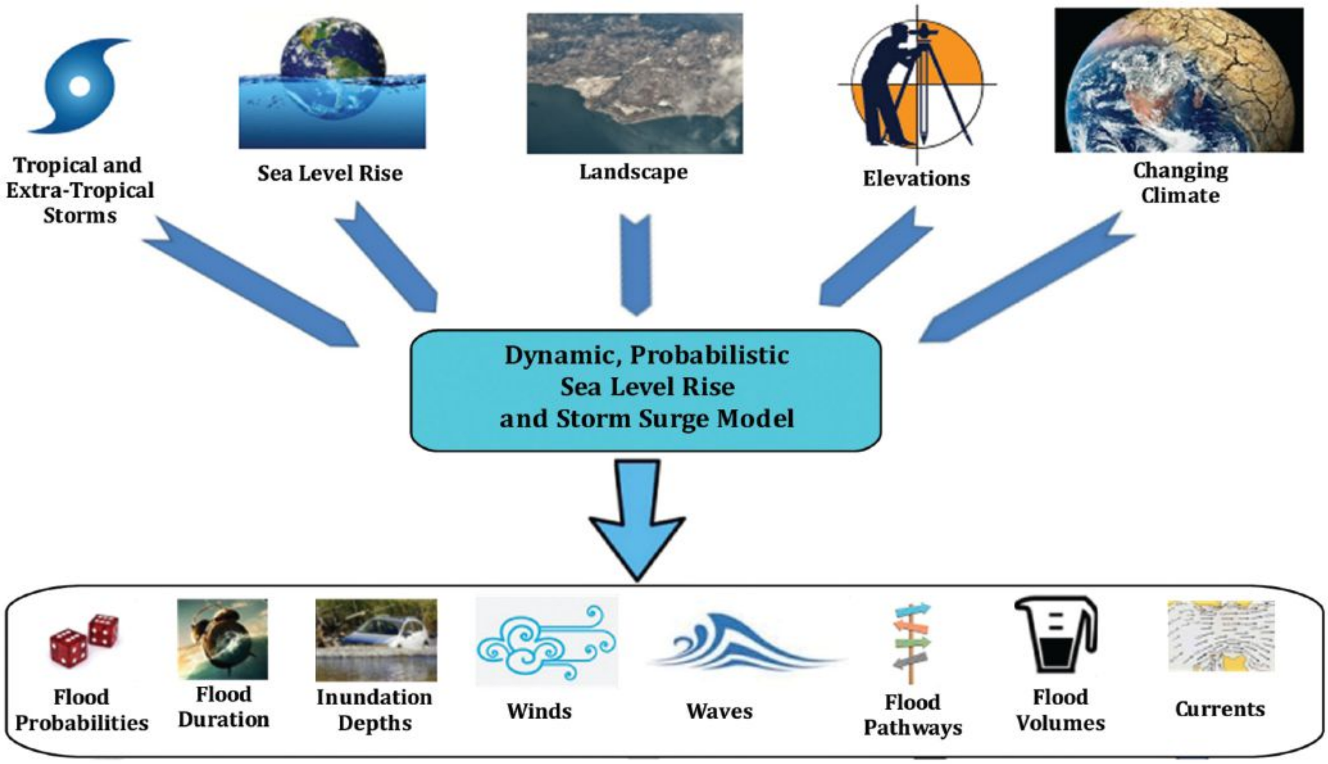
Coastal communities and stakeholders are facing an uncertain future. Providing protection against the prospect of rising sea levels and potentially increasing storm intensities and frequencies can be fiscally daunting. In many cases, standard projections and maps of inundation convey a sense of despair. Many communities don't know where to start when thinking about climate change adaptations. Improved information and maps are needed to help communities plan and take action for the future.

Sustainable coastal and civil engineering design concepts and resiliency approaches require technically accurate baseline information and design parameters. For example, coastal resiliency projects require an understanding of storm surge under existing and future conditions. Important factors are inundation depth, wave impacts, flood pathways, flood volumes, and probability of occurrence. These are key considerations for developing cost-effective designs for current conditions and, perhaps more importantly, for future conditions in a changing climate.

A dynamic, probabilistic sea level rise and storm surge model produces site-specific and detailed design parameters and provides invaluable information far exceeding traditional, more simplistic flood maps. The probabilistic model is rooted in hydrodynamic modeling that accurately represents physical processes affecting coastal flooding. This includes riverine flows, tides, waves, currents, winds, storm surge, sea level rise, and wave set-up at an appropriate scale to improve engineering designs. As such, the probabilistic model provides key information that normally would not be available from traditional, non-dynamic assessments. The model can also be utilized to test the effectiveness of various engineering designs and adaptations. For example, green living shoreline alternatives, (e.g., restoration of dune, wetlands, and reefs), as well as traditional grey infrastructure (e.g., modular or adaptable seawalls), can be simulated individually or in combinations. Results optimize effectiveness of proposed designs, while also reducing construction costs.

Why Use a Dynamic Model?

Sea level rise combined with storms has commonly been evaluated by a “bathtub” approach that simply increases the water surface elevation values and compares the new water elevation with the topographic elevations of the land. This rudimentary approach provides first order identification of potential areas vulnerable to sea level rise, but does not accurately represent what may actually happen and is certainly unable to represent the dynamic nature of storms. For example, the “bathtub” approach does not determine the volumetric flux of water that may flood low-lying areas or how long the flooding may last. The “bathtub” approach also does not account for critical physical processes during a storm, including waves and winds. In many cases, the rudimentary “bathtub” approach over predicts inundation where flooding will not occur and also misidentifies dry areas that would actually be inundated. Areas with critical infrastructure and/or complex landscapes require dynamic modeling of climate change and storms when designing and constructing significant investments to ensure proper siting and design.



Overarching approach using dynamic probabilistic modeling. Output provided by the dynamic model provides the ability for a more comprehensive assessment.

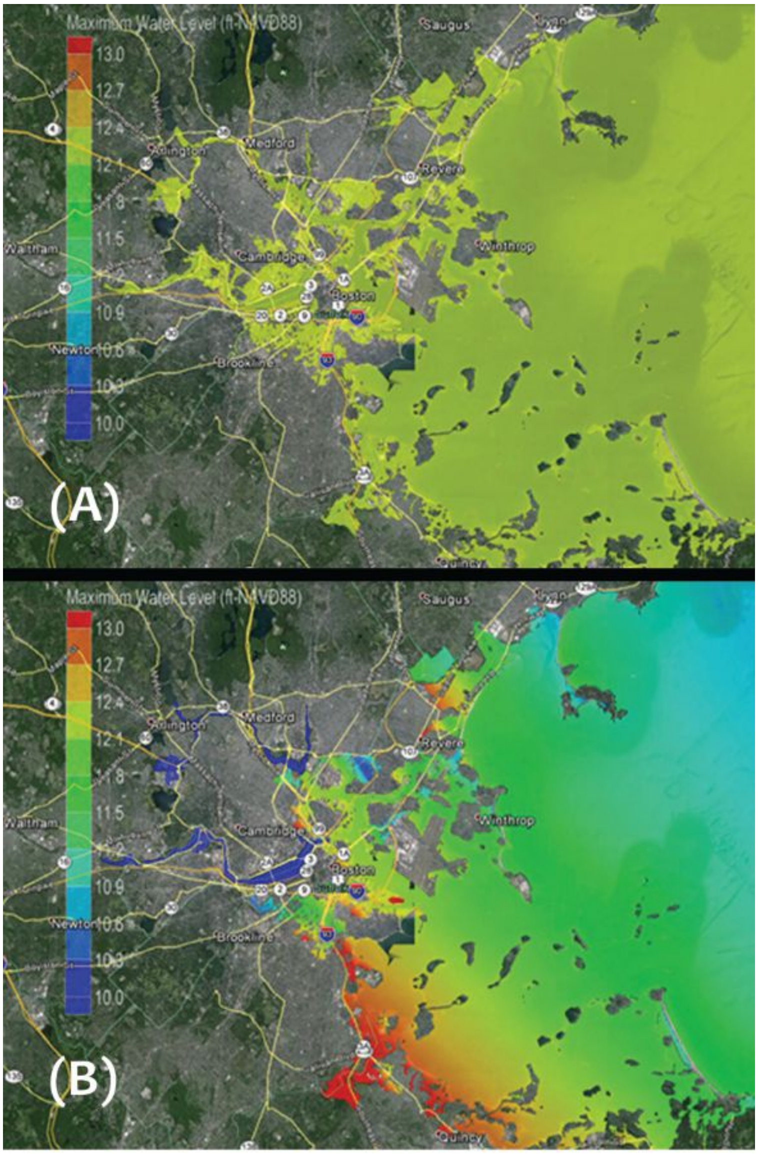
Accurate modeling of storm surge and future climatologic conditions, including sea level rise, requires improved representation of the physical processes as well as higher resolution inundation predictions due to the site-specific combination of sea level rise and storm surge. This is especially true for high value critical infrastructure as well as projects involving significant capital investment. In these cases, it is important to understand risk (present and future) and have accurate design parameters. This type of coastal hydrodynamic modeling should include the following:

- An extensive understanding of the physical system as a whole;
- Inclusion of physical processes affecting water levels (e.g., riverine flows, tides, waves, winds, storm surge, sea level rise, wave set-up, etc.);
- Full consideration of the interaction between physical processes, including the joint probability of flooding with storm surges, tidal variations, waves, sea level rise, and river discharge;
- Characterization of forcing functions that correspond with real-world observations;
- Resolution capable of predicting physical and energetic processes to identify site-specific locations requiring engineering adaptations; and
- Storm climatology that changes with time.

What Does Probabilistic Modeling Mean?

Storm events striking an area can result in significantly different impacts depending on factors such as the timing of the storm with the tide cycle, the storm track, radius to maximum wind of a tropical storm, the amount of precipitation, etc. Probabilistic modeling evaluates a statistically robust set of viable storm conditions that produces a spatial probability of flooding. Hundreds to thousands of storms are dynamically simulated to produce flood exceedance probabilities at high resolution. Using a statistically robust approach, probability flood exceedance can be defined as the probability of flood water inundating the land surface at a particular location. These maps can be used to identify locations, structures, and assets within different risk levels. For example, a building that lies within the 2% flooding exceedance probability zone would have a 2% chance (50-year return period) of flooding. In other words, there is a 2% chance that this location will get wet. Stakeholders can then determine if that probability level is tolerable or if some action may be required to improve resiliency, engineer an adaption, consider relocation, or implement an operational plan. Critical assets, such as hospitals and evacuation routes, have different risk tolerances than parklands or parking lots.

By mapping various future years (e.g., 2030 to 2050), flooding at individual structures, assets, and areas can be compared to determine changes over time and the overall influence of climate change can be evaluated. In many cases, large upland areas are flooded by a relatively small and distinct entry point (e.g., a low elevation area along the coastline). In cases like this, a more cost-effective and localized solution (rather than evaluating local adaptation options at each asset in the area) can be prioritized. A targeted coastal protection project at the flood entry point (e.g., increase seawall elevation, a natural berm, etc.) may protect a whole neighborhood or beyond.



(A) "Bathtub" results for Boston Harbor area with a combined sea level rise and storm surge maximum water surface elevation of 12 ft NAVD88. This represents a flat water surface elevation that spreads across the entire landscape. Flooding is shown in areas landward of flood control structure (e.g., dams), and there is no temporal limitation to the flooding (the storm lasts an infinite amount of time) such that water can penetrate anywhere on the landscape with elevations less than 12 ft NAVD88.

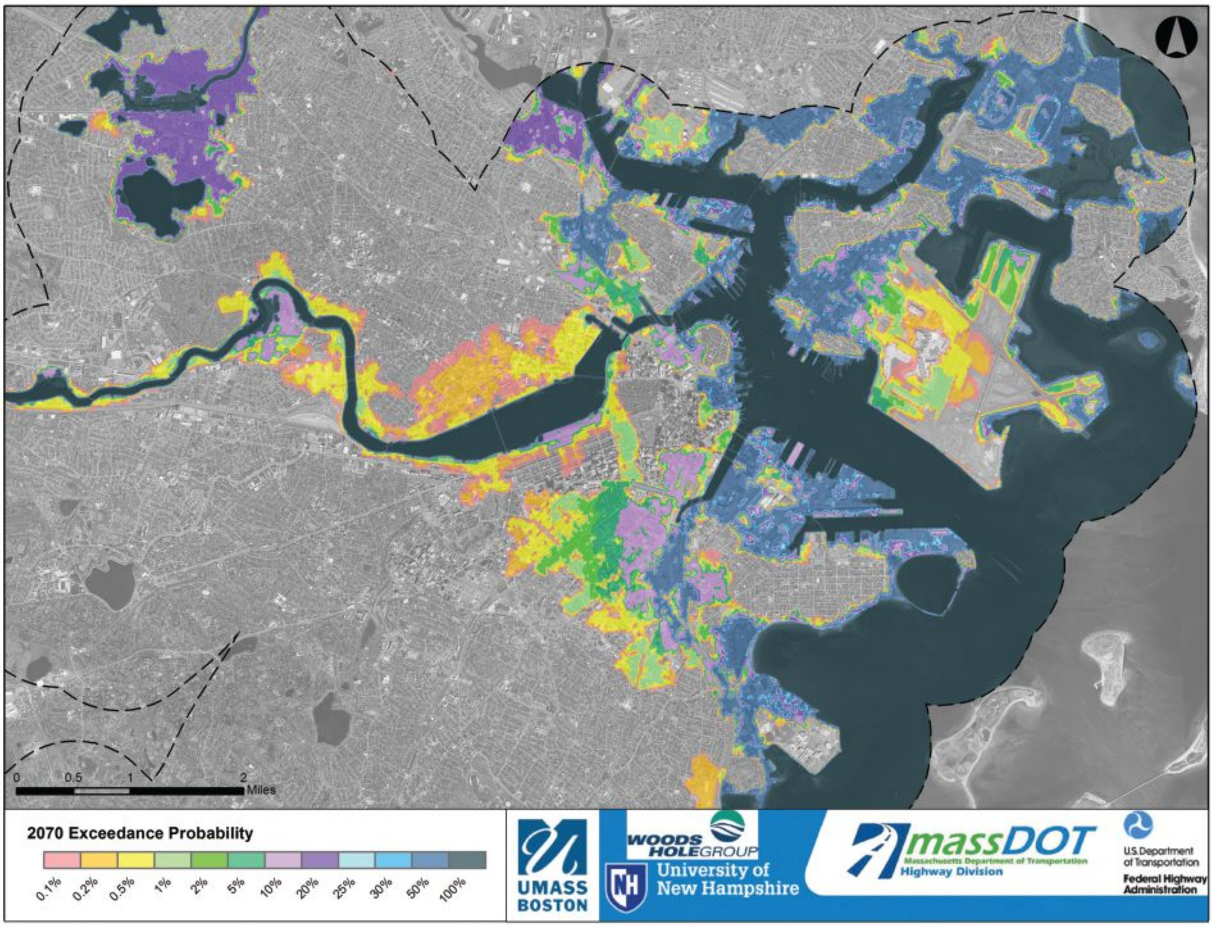
(B) Dynamic numerical model results for Boston Harbor area showing a storm that peaks at 12 ft NAVD88. Generally, the results indicate there is more flooding to the south as water is driven in that direction by the predominant wind and wave forcing. Similarly, there is less flooding to the north than the "bathtub" case, and the functioning of the dams and other urban features show reduced flooding in protected inland areas.

Maps showing the probability of flooding provide stakeholders with the ability to identify areas expected to be flooded and the probability of flooding. This helps weigh the tolerance for risk, evaluate when adaptation options may need to be considered, and, most importantly, prioritize funding to higher consequence areas.

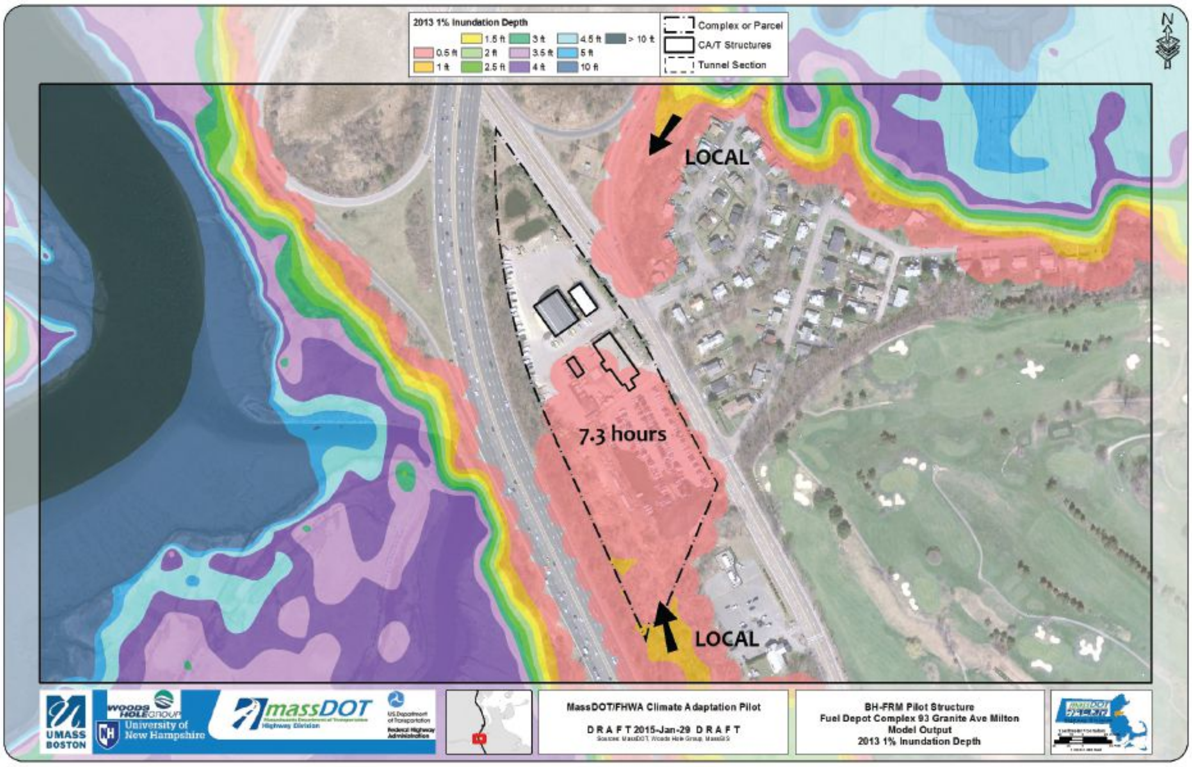
Perhaps equally as important is the magnitude, or depth, of flooding expected. The probabilistic model results also provide predictions of flood depth at high resolution (every 2 m, if needed). Depth of flooding maps can also be produced for any given flooding probability level. For example, if stakeholders determine a certain building is risk-averse and only willing to accept a 0.5% risk or less, then (1) the time this occurs could be identified from the flooding probability maps and (2) the associated depth corresponding to that risk level could be evaluated for engineering planning and design. The depth could then be used to design elevated structural components or ensure that critical systems, such as electrical systems, are elevated above the expected water surface elevation levels.

How Does Probabilistic Modeling Assist Resiliency Projects and Engineering Designs?
Probabilistic model results, at a site-specific scale, provide a breadth of information useful for deciding where protection is required, selecting adaptations, planning, and engineering design. The high-resolution model results offer detailed information down to an individual building and parcel level for assessment of existing or developing sites. While potential inundation probability and depths may be manageable under current risk levels, this may change over the service life of the asset. The dynamic model can also provide inundation residence time and flood pathways to the site. The residence time gives an indication of how long the flooding is expected to last for a given probability level. In many cases, this is important for determining economic impacts related to out-of-service timeframes. Understanding the volumetric flux and flood pathways gives another layer of information that helps inform design and consideration of local and/or regional adaptation measures. The flood pathway insight allows stakeholders to consider local measures (e.g., raising the elevations of the buildings on the parcel, flood proofing structures, local on-site berms or walls, etc.), and regional approaches (e.g., berms, tide gates, flood walls, etc.) to control the source of flooding for a region that may co-benefit other properties.

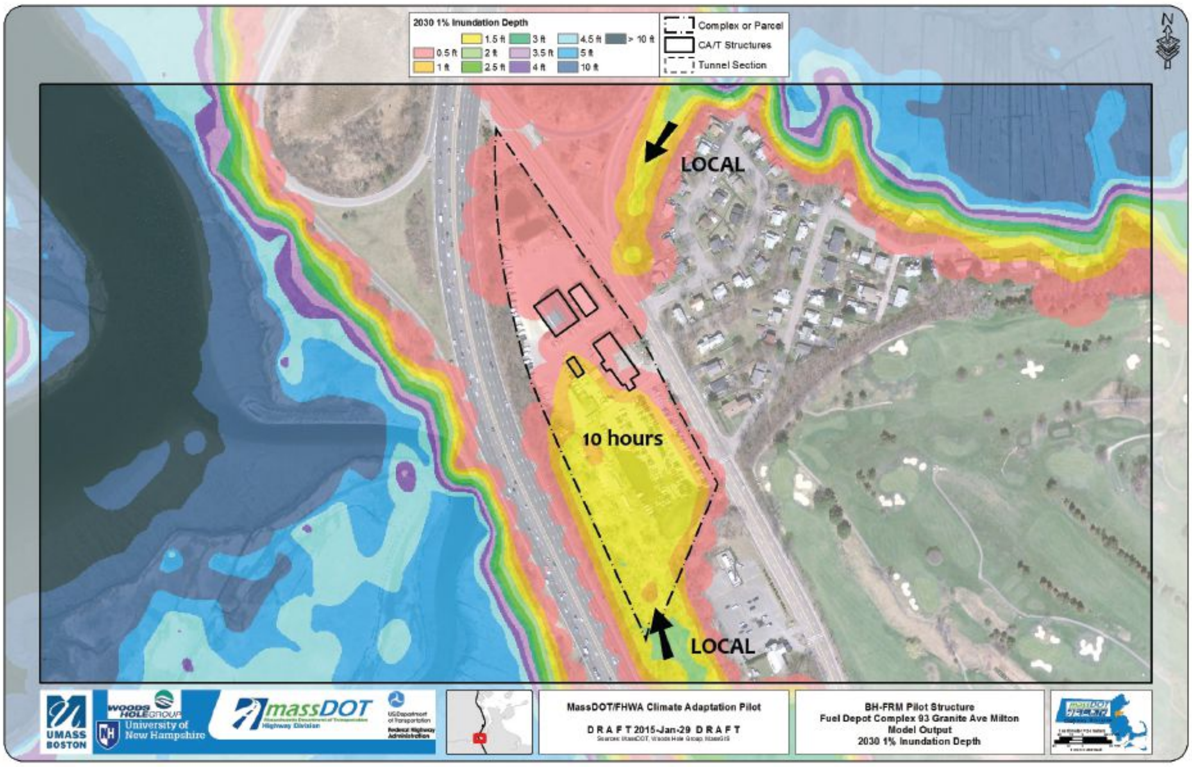
Numerous communities and stakeholders are using probabilistic modeling results to complete comprehensive vulnerability assessments; develop engineering adaptations; and design resilient green, gray, or hybrid solutions. The probabilistic results, as a function of time, have given communities the ability to prioritize adaptations and start to build resilience in more strategic and fiscally manageable increments. Communities and landowners can take action to manage imminent risks, while waiting for more certainty in long-term climate change projections that may not have near-term impacts.



Results of dynamic, probabilistic modeling showing probability of flooding in 2070 for Boston, Massachusetts.



Model results showing flooding depth for a 1% inundation probability in 2013 at a site-specific level. The dashed black line shows the parcel of interest, while the solid black lines show the existing structures. Accessibility to the site (via Granite Ave.) remains viable for the 1% return period water level in present day conditions. The flooding remains at the site for 7.33 hours before it recedes (and peaks at 0.5 ft).



Model results showing flooding depth for a 1% flooding probability in 2030 at a site-specific level. Flood depths have now increased to an average of 1.5 ft, with depths reaching 2 ft. There is also inhibited accessibility. Residence time has reached 10 hours.