Using boundary objects to stimulate transformational thinking: storm resilience for the Port of Providence, Rhode Island (USA)

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CASE REPORT

Using boundary objects to stimulate transformational thinking: storm resilience for the Port of Providence, Rhode Island (USA)

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Abstract Like many coastal ports around the world, Rhode Island's Port of Providence in USA is at risk for climate-related natural hazards, such as catastrophic storm surges and significant sea level rise (0.5–2.0 m), over the next century. To combat such events, communities may eventually adopt so-called "transformational adaptation" strategies, like the construction of major new infrastructure, the reorganization of vulnerable systems, or changes in their locations. Such strategies can take decades or more to plan, design, find consensus around, fund, and ultimately implement. Before any meaningful decisions can be made, however, a shared understanding of risks, consequences, and options must be generated and allowed to percolate through the decision-making systems. This paper presents results from a pre-planning exercise that utilized "boundary objects" to engage the Port of Providence's stakeholders in an early dialogue about the transformational approaches to hazard–risk mitigation. The research team piloted the following three boundary objects as a means to initiate meaningful dialogue about long-term storm resilience challenges amongst key stakeholders of this exposed seaport system: (1) a storm scenario with local-scale visualizations, (2) three long-term transformational resilience concepts, and (3) a decision support tool called Wecision. The team tested these boundary objects in a workshop setting with 30 port business owners and policy makers, and found them to be an effective catalyst to generate a robust dialogue around a very challenging topic.

Keywords Boundary objects · Transformational adaptation · Stakeholder engagement · Seaport adaptation

Introduction

Climate change has long been acknowledged as a "wicked problem" for planners and policy makers (Lazarus 2008) and for seaports decision makers, in particular (Gharehgozli et al. 2016). The uncertainties in rates of change, the feedback loops, and the misalignment of incentives all conspire to leave decision makers befuddled as to which adaptation option(s) to pursue, on what timescale, and on whose dime. To make matters worse, many coastal communities will be forced to adopt so-called "transformational adaptation" strategies, such as the construction of major new infrastructure, the reorganization of vulnerable systems, or relocating existing infrastructure locations (Kates et al. 2012). Such strategies can take decades or more to plan, design, find consensus around, fund, and ultimately implement (Savonis et al. 2014). Before any meaningful decisions can be made, however, a shared understanding of risks, consequences, and options must be generated and allowed to percolate through the system to those who deal with such issues (Weiss 1982). Rhode Island's Port of Providence on the Northeast Coast of the United States is at risk for climate-related challenges, such as catastrophic storm surges and significant sea level rise (0.5–2.0 m), over the next century (Sallenger et al. 2012; Tebaldi et al. 2012; Miller et al. 2013; DeConto and Pollard 2016). This paper presents results from a pre-planning exercise that utilized "boundary objects" to engage the

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port's stakeholders in the early dialogue about transformational approaches to hazard risk mitigation. Researchers piloted the following three boundary objects as a means to initiate meaningful dialogue about long-term hazard resilience challenges amongst key stakeholders of the Port of Providence, RI: (1) a storm scenario with local-scale visualizations, (2) three long-term resilience concepts, and (3) a decision support tool called Wecision. This paper begins with discussion of boundary work and boundary objects in engaging decision makers in meaningful dialogue. It then describes the case study site and workshop methodology in Providence, as well as the development and implementation of these three boundary objects. It then assesses their usefulness and shortcomings in helping participants find common ground and collective knowledge. It next situates these boundary objects within the context and theory of such tools in decision-making processes. Finally, it suggests how and why such tools can be utilized and improved upon in future processes.

Background

Wicked problems in port planning

Although progress has been made particularly with respect to changes in residential land use and building codes in USA and elsewhere (Melillo et al. 2014; WRSE 2014; USACE 2015), a few actions have yet been taken to protect the complex system of ports and shipping that facilitate a maritime-based freight economy (Becker et al. 2012; Ng et al. 2016). Indeed, while global port operators themselves acknowledge the important role that climate change will play in future operations (Becker et al. 2012, 2014), there are still a few examples of plans, let alone implementation of plans, to address adaptation. Seaport systems face a unique combination of natural hazard risks within the environmental, social, economic, and political landscape. They consist of complex and interdependent public/private decision-making governance structures (Notteboom and Winkelmans 2002, 2003), and their geographical and intermodal requirements constrain them to environmentally sensitive and exposed locations (Becker et al. 2013, 2016). In many areas, natural hazards associated with climate change, such as sea level rise (Parris et al. 2012; Strauss 2013) and more intense hurricanes (Bender et al. 2010), threaten these systems as a whole, as well as the individual organizations that depend upon the functioning of the system. Individual organizations and agencies often do not have the proper incentives or understanding of the system's interconnectedness to justify investment in long-term resilience (Becker and Caldwell 2015). Despite the availability of impacts assessment tools and established methods for stakeholder engagement in vulnerability assessment processes (McEvoy et al. 2013; Zhang and Ng 2016), overcoming barriers to resilience investments for complex systems such as ports remains a significant challenge due to conflicting timescales, institutional uncertainties about which organizations should lead or invest, and lack of resources, among others (Tompkins and Eakin 2012; Eisenack et al. 2014; Ekstrom and Moser 2014).

Boundary objects to engage stakeholders in wicked problems

Decision makers often find it difficult to engage in dialogue about high-risk, low-probability, events. Complex, wicked, challenges require new ways of knowledge production and decision-making that involve new collaborations between scientists from many disciplines and actors from both the private and public sectors (Kates et al. 2001; Lynch et al. 2008). Such collaborations, including government interventions and actions by private firms and non-governmental organizations, enhance coping capacity and reduce vulnerability (Adger et al. 2005). Preston et al. suggest that individuals and organizations can serve boundary-spanning functions, "dedicated to translating between social worlds, building trust and mutual accountability, and acting as experts in the process of making science useful" (Preston et al. 2013). "Boundary work" addresses complex problems (Batie 2008) through a "negotiation support process engaged in creating usable knowledge and the social order that creates and uses that knowledge." (Clark et al. 2002). In the field of sustainability science, boundary work consists of products and processes (i.e., boundary objects) that bridge communities, stakeholders, and disciplines and, most importantly, lead to links from knowledge to action. Boundary objects allow groups with different perspectives, backgrounds, or motivations to work together without prior consensus (Star 2010). In the concept developed by Star and Griesemer (1989), boundary objects may be material objects (e.g., maps), repositories (e.g., a collection of books), performances, computer operating systems, or take many other forms [for a fuller discussion, see (Star 2010)]. Such "boundary objects" have been shown to provide an effective way to jumpstart challenging dialogue and ultimately lead to co-production of resilience strategies and more successful policy and implementation of coastal management decision-making (Ward 2001; Bryson 2004; Few et al. 2007; Tompkins et al. 2008; Chapin et al. 2010).

This research created a boundary-spanning process and three such boundary objects and piloted them as a means of spurring knowledge exchange around storm resilience strategies from a variety of port stakeholders (Liverman and Raven 2010). It created a forum for engagement and participation, an essential component of adaptation to climate change (Wilbanks and Kates 1999; Eakin and Luers 2006) at the local scale that is aligned to management decisions (Cash and Moser 2000). In this case, there was no clear "management decision" to be made, thus researchers considered this a "pre-planning" exercise that lays the groundwork for future decision-making.

Methodology

Pilot study approach—the Port of Providence (RI)

This pilot project focused on the Port of Providence (Fig. 1), a small North Atlantic port in the State of Rhode Island (USA) with high exposure to hurricanes, where stakeholders were likely to be familiar with storms, and where the research could prove relevant for their future planning efforts. Though the State of Rhode Island has embraced climate adaptation planning in some of its policy and planning efforts (CRMC 2009b, 2015; RISG 2015; RIDP 2015), a little work had focused on the resilience issues facing the Port of Providence. Funded by the United States Federal Highway Administration (FHWA) and the Rhode Island Dept. of Transportation (RIDOT), this study brought 30 participants together to develop methods that would engage the public and private sectors in a challenging, and potentially uncomfortable, dialogue around the risks from a major hurricane at the port. Though it is motivated by climate change impacts, it was not designed to explicitly deal with climate change, as previous research suggested that participants would be more likely to be willing to engage in dialogue around near-term storm impacts, as opposed to long-term climate change (Becker and Caldwell 2015). Focusing on storms helped with recruitment to the study, which proved to be a challenge due to the busy schedules held by the target audience. In a half-day workshop, the project introduced transformational resilience concepts that could reduce the vulnerability of the port system as a whole. The process was not designed to make any particular decision or pick any particular path, rather it was meant as a pre-planning exercise to spark meaningful dialogue and raise awareness around the threats posed by major storms. It initiated dialogue about the eventual necessity for large-scale resilience improvements, which will likely be required as impacts of climate change increase over the course of the next several decades.

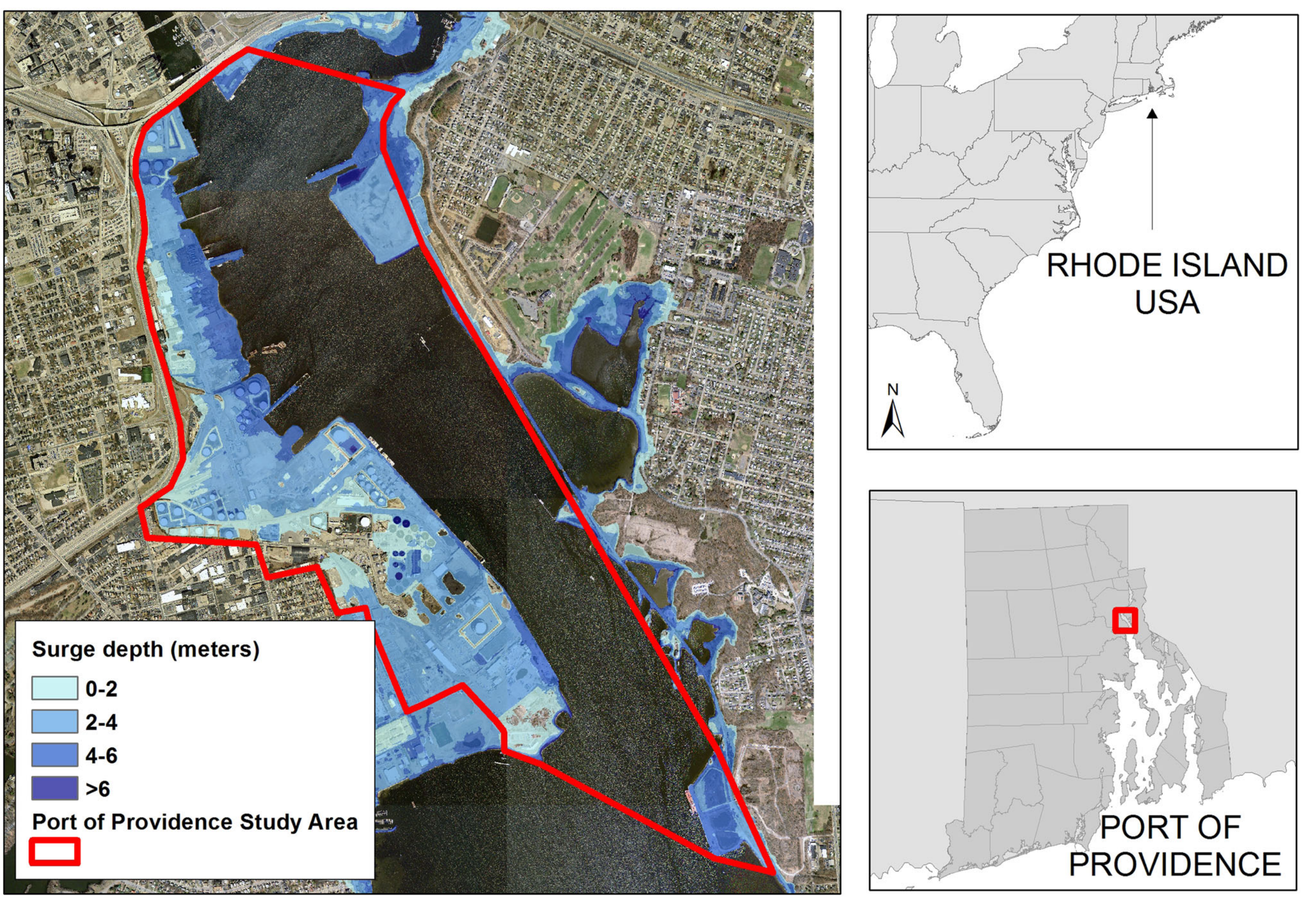

Fig. 1 Providence Harbor study area with results of SLOSH generated storm surge overlay, Providence, Rhode Island, USA

There is no official port authority in Rhode Island and the State plays no direct role in managing port operations or centralized planning, though the state's coastal agency (the Coastal Resources Management Council or CRMC) does regulate land use in the coastal area that the port occupies.

Together the business that make up the Port of Providence[1], most closely resemble a private service port (for a discussion of types of ports, see PPIAF 2013) that supplies the states of Connecticut, Massachusetts, and Rhode Island with petroleum products, and handles bulk and break-bulk imports and exports. Many businesses depend on the port's functionality, including: trucking companies, a rail line, dredging operations, hospitals, and institutions that use petroleum products for their power plants, manufacturing companies, marine pilots, and even the state airport, which depends on the port for jet fuel. In 2010, the Port of Providence handled approximately 3.1-million tons of cargo, making it the 46th largest port in the USA.

The study area for this project includes ProvPort, the main port terminal, and number of other waterfront businesses and industries, which together, take up nearly 93 hectares of waterfront in Providence and East Providence (Becker et al. 2010). ProvPort itself is about 42 hectares of land that are owned by the City of Providence and operated by a five board member non-profit organization, ProvPort, which contracts the services of Waterson Terminals LLC to operate and maintain the port. ProvPort alone generated more than $200 million (US) in economic benefits for the region and over 2400 jobs were attributed to port activities (PWWA 2010).

The port is located at the northern end of Narragansett Bay, an ecologically sensitive estuary, that provides breeding grounds for marine life in the region. The length and orientation of Rhode Island's Narragansett Bay, and its proximity to the Atlantic hurricane zone, make it susceptible to extreme storm surges from the southerly winds that are generated when a hurricane passes to the west of the Bay. As such, the United States Federal Emergency Management Agency (FEMA) considers Providence to be the "Achilles heel of the Northeast" (Rubinoff 2007). A recent study estimates the hurricane return period for Rhode Island to be 24 years, with the "major" hurricane return period of 94 years based on historical data (USGS 2010). The most recent major storm, Hurricane Carol in 1954, produced 5 m of storm surge in Providence. Most of the port lands in the study area are 1–3 m above mean high water. A 9-m hurricane barrier north of the port protects the downtown city area, but could result in higher storm surge levels at the port, as surge waters would accumulate in Providence Harbor instead of spreading throughout the low-lying region now protected inland of the barrier.

Development and implementation of three boundary objects to stimulate discussion

This study partnered researchers from the University of Rhode Island with representatives of local, state, and federal government and the private sector to develop a boundary-spanning process and test three boundary objects. An expert steering committee made up of 12 state and federal agency representatives helped guide the research process. It culminated in a workshop with 30 participants who represented 15 local maritime port-related businesses, three local planning departments, five state government agencies, four federal government agencies, and two academic or environmental groups. The project "integrated best available knowledge, reconciled values, and preferences, and created ownership for problems and solution options," core concepts, and design principles for trans-disciplinary sustainability research outlined by Lang et al. (2012). Workshop objectives included:

1. Understand and comment on a possible storm scenarios and consequences for the port area.
2. Review long-range resilience goals for the port.
3. Review transformational resilience concept alternatives for protecting port community against storm damage.
4. Weigh importance of resilience goals and assess potential of resilience concepts to meet these goals.
5. Assess this workshop methodology as a way to measure port vulnerability and initiate discussion on long-range resilience concept alternatives.
6. Identify collective action that needs to be discussed now and recommendations for next steps.

The half-day workshop allowed participants to interact with, react to, and contribute to three boundary objects developed for the project[2] through several activities. First, they learned from a representative from the Port of New York and New Jersey about the impacts that the 2012 Hurricane Sandy had on that port. Next, they discussed consequences to port interests from a hypothetical Category 3 hurricane landing near the Port of Providence (Boundary Object 1). Participants then evaluated and prioritized resilience goals for port businesses and explored three long-term resilience concepts (Boundary Object 2). Using the Wecision decision support tool developed by one

[1] More details on the study location and project methodology can be found at www.portofprovidenceresilience.org. The case location is also discussed in Becker and Caldwell 2015.

[2] Workshop materials, including graphics and more information can be found at the project website: www.portofprovidenceresilience.org.

of the members of the research team (Boundary Object 3), they then assessed these concepts with respect to goals and identified which alternative concepts provided the most value to different participants. These boundary objects were chosen and developed in consultation with the steering committee as a means to best engage participants and make abstract concepts more tangible. The researchers considered a number of other tools (3D animations of storm surge, the creation of a "generic port" as a discussion starter, instead of the Port of Providence, and a number of other multi-criteria decision support tools). Ultimately, these were rejected due to their complexity, expense, or, in the case of the multi-criteria decision support tools, the time required to master and adapt a new software product. The next sections discuss the boundary objects and their use in the workshop process.

Boundary Object 1—storm scenario and consequences for the port area

Visualizations of storm surge and sea level rise play an increasingly important role in decision-making processes (Yates and Stone 1992; Sheppard et al. 2011; Lindeman et al. 2015). Realistic portrayals of future conditions, such as inundation zones, help people localize and personalize what are otherwise abstract concepts (Lowe et al. 2006; Sheppard et al. 2013). When compared to the traditional maps, realistic visualizations can better communicate complex and nuanced information in a mode which humans have evolved to understand: imagery of the landscape. Since realistic can visualizations create emotional responses on the part of the viewer, they may be more effective tools for communicating risk (Sheppard 2015). Cognitive understanding of risk alone may create misperceptions of risk when not aligned with such emotional response, thus this project utilized realistic visualizations as a tool for risk communication (Slovic et al. 2005).

To stimulate thinking about long-term risk, researchers created a scientifically credible Category Three hurricane scenario based on historical data and a Sea, Lake, and Overland Surges from Hurricanes (SLOSH) (NHC 2015) model analysis (Fig. 1). For the Northeast USA, a Category 3 Hurricane has a return period of approximately 60 years (Ginis 2006), or a 1.7% chance of impacting the region in a given year. Using GIS and Google Earth, researchers produced 3D visualizations of a 6.4-m storm surge showing inundation levels along the Providence waterfront from the Fox Point Hurricane Barrier, south to Fields Point, and including the East Providence waterfront (Fig. 1). 3D images of specific properties along the waterfront from a number of perspectives and a flyover video allowed participants to see details of properties of concern to them (Fig. 2). In small groups, participants reported out on the potential cascading consequences of this simulated event in the weeks, months, and years after the event, as well as their top concerns. Participants were instructed to focus on long-term consequences, as opposed to what might happen on the day of the event.

Boundary Object 2—three long-range storm resilience concept scenarios for protecting the port community

Scenarios have long been used to help people to think about the future (Pulver and VanDeveer 2009). Emissions scenarios, for example, drive climate models that produce a variety of environmental conditions that may unfold over the next century and beyond (Melillo et al. 2014). Scenarios have also been used in visioning the future for business (Bradfield et al. 2005) and public processes around land use and comprehensive planning (Xiang and Clarke 2003) to stretch people's thinking about a range of plausible futures. The project employed a form of scenarios to sketch out three long-range resilience concept alternatives and help workshops participants deeply consider the implications of each.

In a Landscape Architecture class at the University of Rhode Island in Fall 2014, students helped develop the three broad, long-term, archetypal concept scenarios for building resilience of the port: Protect, Relocate, and Accommodate (Dronkers et al. 1990; Tol et al. 2008; Cheong 2011, IPCC 2012). Each concept featured a different approach to resilience, defined in this study as "the ability to bounce back to normal operations after an extreme event," from a long-term planning perspective. This research used 2050 as the planning horizon, thus emergency response options (e.g., improvements to evacuation routes) were not included in the concepts. Naturally, any actual strategy approach would likely combine aspects of all three design concepts, but these were meant to stimulate discussion and were, by necessity, simplified versions of what would inevitably be very complex projects. All three were expected to be cost intensive [on the order of $1 Billion (US)] and funding mechanisms were not discussed explicitly, as the purpose of the workshop was not to make a particular decision, but rather to begin the challenging dialogue about long-term resilience. Each concept included graphic representations and conceptual examples, as well as an overview of pros and cons developed together with the project steering committee (See Appendix 1). In preparation for the workshop, the steering committee offered suggestions about how to shape the concepts, as well as the overall advantages and disadvantages of each. All of this information was presented to workshop participants and included in handouts, followed by discussion. Climate

Fig. 2 Example of 3D visualization of storm scenario. *Left* image looks north toward the City of Providence and shows petroleum terminals and the existing Fox Point Hurricane Barrier at the northern end of the study area. The *right* image looks west and shows petroleum terminal on the west side of Providence Harbor (Image R. McIntosh)

change was not explicitly considered in the development of the scenario concepts, thus sea level rise and any changes in storm intensity or probability in 2050 were not included. Though the project itself is clearly motivated by climate change, the content of the workshop exercises focused more specifically on storm impacts that could result from a storm in the present or in the future. The following sections describe each concept in more detail.

The protect concept

The "Protect" concept reduces storm risk by decreasing the probability of occurrence of impacts (Tol et al. 2008). To do so, it proposes relocating the existing Fox Point Hurricane Barrier to a new location that would protect infrastructure in the study area (Fig. 3). The United States Army Corps of Engineers constructed the existing barrier, north of the study area, in the 1960s to protect downtown Providence, however it leaves the maritime infrastructure exposed to storm surge (Morang 2016). The "Protect" concept envisions the construction of a new barrier and berm system, with similar design to the Maeslantkering Barrier in the Port of Rotterdam (The Netherlands), along the southern edge of the study area (for discussion of barrier design options, see Dircke et al. 2012; USACE 2013). This design concept would span the mouth of Providence Harbor, tying into the existing elevation in Providence and East Providence. The floodgate could be closed in the event of a storm, effectively protecting Providence Harbor from forcing associated with hurricane level storm surge and wave action. When open, the gates would rest on dry docks on the east and west sides of the harbor entrance. To close, the gates would be flooded and each side floated and swings closed to meet in the center of the channel. A multipurpose levee located along the shoreline incorporates an earth berm and green wall along the landside, and a living shoreline along the waterside. A pedestrian/bike path might run along the top of the levee, and bleachers could be located on a portion of the landward side for viewing the adjacent sports fields.

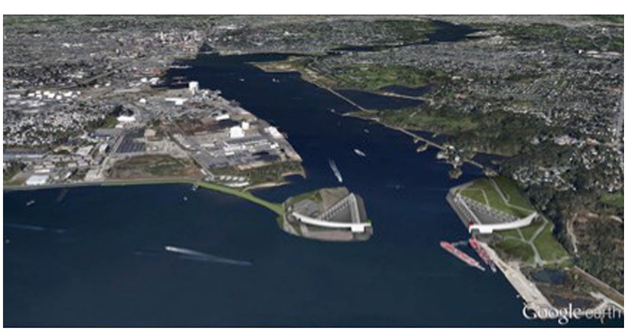

Fig. 3 "Protect" concept shows a new barrier located south of the study area at Fields Point. The design is based on the Maeslantkering Barrier in the Port of Rotterdam

The relocate concept

Relocate, also called "retreat" in the literature, reduces the risk of an event by limiting the potential negative effects through moving structures away from the flood plain (Tol et al. 2008). Historically, relocation has occurred after an event, when structures are damaged, abandoned, and rebuilt in an area further from shore or more protected (Frankhauser 1995). This strategy may be more appropriate for non-water dependent uses (e.g., residential housing), as opposed to coastal infrastructure. However, in some cases, infrastructure such as lighthouses (e.g., Cape Hatteras Light in North Carolina) have been moved back away from an eroding bluff. The "Relocate" concept proposed moving some or all of the current industrial uses in Providence Harbor out of harm's way. It suggested that other locations around Narragansett Bay could provide a less exposed area from which to do business, while still providing the infrastructure requirements (e.g., access to highway, rail, navigation channels, and pipelines) to operate. The current Exxon Mobil petroleum facility in East Providence

Fig. 4 The "Relocate" concept would move some or all existing uses out of the flood plain. In this example, a petroleum terminal's tanks are located upland at elevation 50', while the berth remains at sea level. The product is piped from the berth to the tanks

provided an example of such a location, where the berthing facility is located along the water's edge, but the petroleum product is piped upland and stored in a tank farm located well away from the floodplain at an elevation of 15 m (Fig. 4).

The accommodate concept

The "Accommodate" concept proposed a suite of strategies that allows businesses to remain in place, but enhances resilience through significant investments in upgrading, hardening, elevating, and flood-proofing infrastructure and buildings (see MassPort 2014; Massport 2015). Properties would be retrofitted to withstand flooding while retaining existing uses that could be operational upon receding of the floodwaters. Through smart planning and improved practices, debris impacts could also be limited, decreasing physical and environmental damage. The "Accommodate" concept proposed a major investment on a property-by-property basis (Fig. 5). Options that were discussed included:

- elevating buildings;
- constructing breakaway walls;
- flood-proofing utilities;
- creating floodable first floors;
- elevate land under structures;
- elevating critical utilities (e.g., power, water, and sewer);
- raising backup generators, air conditioning units, and oil or gas tanks above the base flood elevation or onto roof of building;
- wet flood-proofing foundations;
- using flood/salt tolerant construction materials;
- sealing around utility entry points;
- installing waterproof bulkheads;
- installing pumps with backup generators to pump out access water;
- reinforcing windows and doors;
- covering piles of material with debris tarps and strapping;
- constructing storm water detention ponds.

Fig. 5 "Accommodate" concept proposes major investment to armor individual structures and properties in place throughout the study area. Examples shown here include elevating utilities, elevating the land itself, and construction of new flood berms

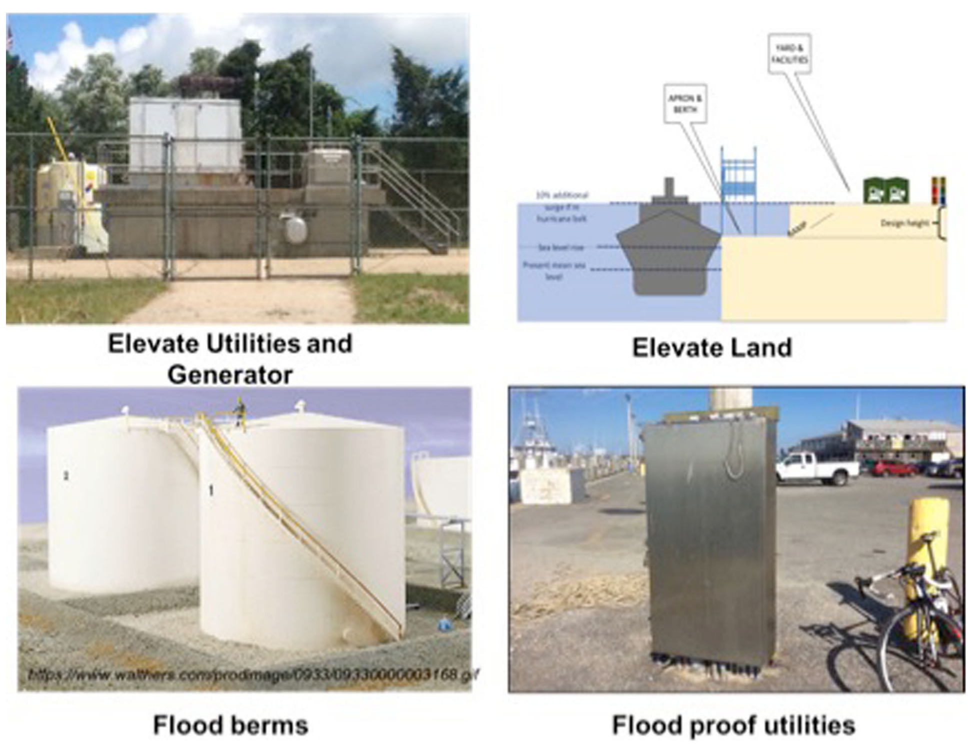

Fig. 6 An example of the Wecision interface as experienced by participants during the workshop

Do nothing

In addition to the three resilience concepts, the research team included a "do nothing" concept that would leave resilience levels as-is. The storm scenario (Boundary Object 1) exercise enabled participants to discuss details of "do nothing" (Appendix 2) as did the examples of Hurricane Sandy damages provided by the Port of NY/NJ. "Do Nothing" is, of course, a default alternative that would result in significant expense in the event of a storm, but no additional expense until that time. The research team discussed the pros and cons of "do nothing", along with the pros and cons of each of the other alternatives. Like the other concepts, "do nothing" does not reflect sea level rise or any other changes resulting from climate change. Rather, the concept presented to participants simply posited that, were no additional investments made in resilience, the result of a storm event could be something along the lines of what they discussed in the earlier exercise.

Boundary Object 3—decision support tool (Wecision)

For the third boundary object, the research team utilized a collaborative decision process tool called Wecision (see www.wecision.com) to facilitate a deeper dive into the relative advantages and disadvantages of the resilience concepts (Fig. 6). Decision support tools such as these have been used to help people understand complex problems with multiple (and conflicting) objectives (Keeney and Raiffa 1993). Though there are many such tools available, the research team chose Wecision, as the authors of the tool had previously expressed interest in expanding the use of it to accommodate new approaches to planning and decision-making. Thus, the tool authors were willing to join the research team and make necessary alterations to the tool, so that it might be applied to this exercise. Originally created as a tool for choosing optimal designs for large-scale infrastructure projects (e.g., train stations) based on stakeholder preferences (Haymaker and Chachere 2006), the tool was adapted to generate exploration and deep thinking. Wecision uses a cloud-based platform that helps facilitators gather stakeholders and experts into a social-network community around an issue, guides stakeholders through the definition and prioritization of goals, helps users define alternatives and aggregates this information to quantify and compare the amount of value individual alternatives provide to groups of stakeholders. Resulting graphs communicate participant preferences, scenario impacts, and stakeholder value and assist in a collaborative consensus building and decision-making process. While Wecision can allow groups of people to collaborate in real time to formulate all aspects of a decision, for this workshop, the organizers conducted much of the work of preparing the Wecision model in collaboration with the steering committee ahead of time.

Resilience goals

To generation discussion and for use in the Wecision exercise, the research team proposed seven "long-term resilience goals" for the port stakeholders to assess against the various resilience concept alternatives (see Appendix 2 for definitions and metrics for each goal). Due to time constraints in the workshop, the goals were created ahead of time by the project steering committee to capture important themes and concerns for port businesses. If more time were available in the workshop, the participants would have been asked to work together to identify their own resilience goals. Due to limited time, participants briefly discussed and agreed with the steering committee recommendations for the following seven goals:

1. ensure post-hurricane business continuity for waterfront business;
2. minimize hurricane damages to infrastructure and waterfront business;
3. minimize hurricane-related environmental damage from port uses;
4. build public support for hurricane resilience measures & port operations;
5. minimize hazard insurance rates;
6. foster port growth;
7. protect human safety and critical lifelines.

Participants used personal computers to log onto Wecision to rank the importance of each of the seven resilience goals. Participants then discussed each of the four alternatives (i.e., protect, relocate, accommodate, and do nothing) and individually evaluated each against the seven resilience goals using a 1–5 metric defined for each goal (as described in Appendix 2). Participants input their preferences "on the fly" using personal computers, while a facilitator led them through the exercise. As such, individual responses remained anonymous, but results could easily be reported in aggregate almost immediately.

Results of the workshop exercises

The boundary objects utilized in the workshop stimulated discussion and deep thinking about a very challenging topic. Through four hours of dialogue, the participants discovered a wide range of potential storm impacts that they felt should be considered in future resilience planning. For example, the energy supply for the local hospital that is stored within the flooded area could become inaccessible after a major hurricane. They explained how an inundated sewage treatment plant could result in raw wastewater discharge and how possible spills from oil and chemical storage facilities might contaminate the Bay. Debris also proved to be a top concern, both in terms of clean up costs and the damage that debris could cause to port infrastructure, including: trees and branches, construction materials from destroyed structures, ships and boats, docks, tanks, and many other objects, could damage extant structures in and around the port area.

Participants hypothesized that storm damage to road and navigation infrastructure could take months to remove and/or repair, leading to ongoing disruptions in commerce. Debris in the channel, as well as displacement of navigational aids and sedimentation, might require extensive surveying and clearing before the port could be reopened for normal commerce. They noted that a bulkhead failure could result in erosion due to a release of shored-up material and lost business. Furthermore, as much of the land in the study area consists of brown fields, a bulkhead failure or other erosion event could lead to release of hazardous materials currently held in situ in the soil. As they got deeper into discussions, they identified how erosion along the riverbanks could also contribute significant sediment loading, requiring additional maintenance dredging of the navigation channel. Environmental and economic impacts would likely be felt for years after the storm scenario. However, participants felt unsure of the magnitude of these. As one participant stated, "Would our businesses be as attractive as they were before the storm?"

As participants moved from considering the impacts of the storm to considering the potential strategies, they quickly grasped the complexities inherent in pro-active planning. At the end of the exercise, Wecision aggregates participants' opinions of how well each resilience concept alternative performed against the seven goals, as well as weighting those goals based on participants' assessment of goal importance (Fig. 7). Results of the exercise showed in real time that participants felt that the "protect" strategy provided the greatest value to the group, followed by the "relocate", then "accommodate", and finally "do nothing."

The discussion that followed focused on the efficacy and cost of the resilience strategies, as well as a general distaste for the "relocate" option, despite the results of the

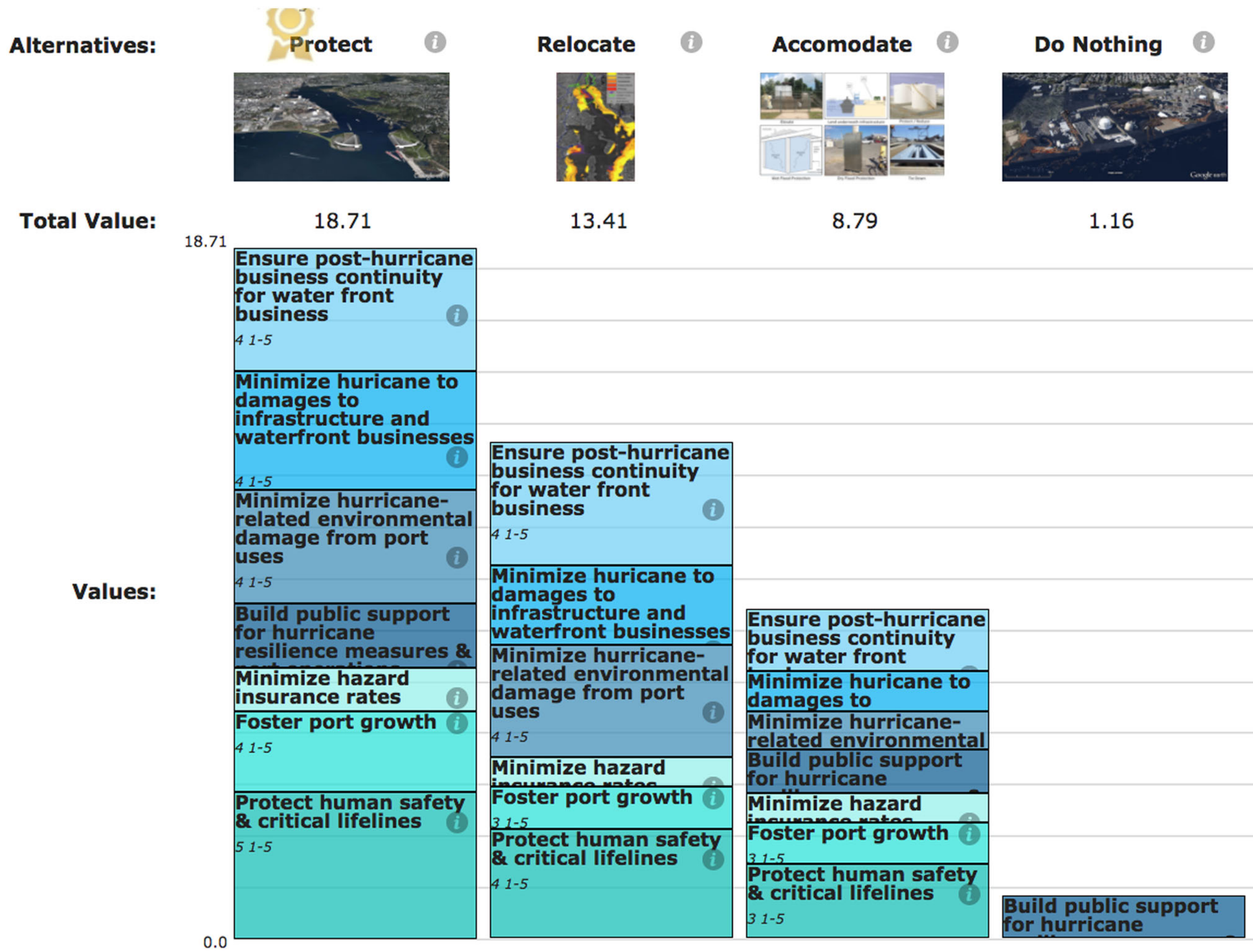

Fig. 7 Output results of the Wecision exercise. The thickness of each *color bar* represents how well the participants felt that the alternative would meet the resilience goal. Here, "*Protect*" was shown providing the greatest value to the group, based on workshop participant preferences and assessments

Wecision exercise, which showed it as having the second greatest value to the group. It is important to note that participants may have been pre-disposed to reject the relocate option, due to a long history of conflict between the maritime industries and the City of Providence's attempts to rezone parts of the waterfront for non-industrial uses, such as hotels and condominiums. Participants expressed that they did not want to open the door for relocation discussions, as they felt that there would be no viable alternatives to being located in the Providence Harbor. This was part of a robust conversation following the exercise raised a number of important questions, such as:

- How much would these strategies cost to implement?
- Who pays? And, in what proportions?
- How would the costs of a major storm hitting the port actually be?
- Who (or what organization) is best positioned to take the lead?

These questions have no easy answers. However, like many coastal communities, the Port of Providence stakeholders will need to start thinking deeply about them in the coming decades as sea levels rise and the threat of tropical storms intensify. This workshop exercise began a dialogue and lays the groundwork for future planning efforts.

Why are boundary objects necessary?

Boundary objects can engage participants in a challenging conversation about long-term pre-planning for low-probability, high consequence events such as a major hurricane. In Rhode Island, this conversation was unprecedented. Although State decision makers and planners engage in regular dialogue around emergency response planning (e.g., as spearheaded by the United States Coast Guard) and land use (e.g., *LandUse 2025* Rhode Island Statewide Planning's Land Use Plan), the likely consequences of a major hurricane have not been planned for, despite concern expressed by stakeholders in previous research (Becker et al. 2014). Since much infrastructure and land use planning were carried out over the 20th century using historical storm surge data (CRMC 2009a, In review), such a conversation in the past may not have been warranted—that is to say that, pre-climate change, future conditions could be expected to follow the same probability curves as past conditions (Milly et al. 2009). Since past flood-level probabilities were presumably considered in the design and planning, there would have been no need to consider making dramatic changes to the already-built environment to accommodate unprecedented events. However, with climate change, such discussions become imperative, especially given the long timelines necessary for infrastructure development and the immense expense (Savonis et al. 2014).

Previous research (Becker et al. 2014; Becker and Caldwell 2015) and these workshop results suggest a number of reasons that stakeholders find such dialogue so challenging and further reinforce the "wicked" nature of the adaptation challenge. Many of the general principles outlined by Rittel and Weber (1973) in their seminal paper aptly describe the circumstances facing decision makers in Providence and help explain why this dialogue is so difficult for stakeholders to enter into in a meaningful way (Table 1). For example, many participants had different perspectives on the actual problem of storm resilience. Though all expressed familiarity with hurricane preparations, few had experienced a major hurricane and none had a frame of reference for how wind, surge, and wave would affect the harbor during a major event such as the scenario presented. Many were unclear of their roles in building resilience and some even expressed concern that they would assume liability simply by acknowledging the risks. Even with the resilience concepts presented in the workshop, participants found it difficult to agree on the "goal" or "end objective" for a resilient port. Though discussion focused on one potential storm scenario, it was not lost on participants that other stronger or weaker storms could present a whole different set of outcomes. The implications of significant sea level rise, for example, would not be addressed through the "protect" scenario, which provided a storm surge barrier, but not a means to protect infrastructure from periodic inundation under new high tide levels. Other characteristics of "wicked problems" and how they apply to the Port of Providence situation are further outlined in Table 1.

The resolution of these wicked problems, the move toward transformational adaptation and the development of a resilient port system is confounded by yet another problem: there is, as yet, no clear decision to be made. Funding for resilience investments has not been secured, consensus around which types of resilience strategies to pursue had not been found, and the problems and solutions have not yet been clearly identified. However, long-term pre-planning can (and must) begin by planting seeds, sparking debate, and stimulating thinking about transformational concepts that ultimately would take decades to implement.

Boundary objects as a bridge—what was effective and what needs improvement?

The three boundary objects created for this project worked well to bridge these challenges by providing participants with a common focus that emphasized the regional and cascading implications of storms and storm resilience. As suggested by (McGreavy et al. 2013) and others, the objects created for this workshop represent flexible products and processes that are adaptable, but maintain coherence across the worlds of private business, public policy, and science. As a communication device, they allowed for both the invention of knowledge and a semblance of social order within a collaborative setting (Jasanoff 2004). However, there were limitations in each of them that are worth discussion (Table 2).

Perhaps, the largest challenge in use of these tools lay in the time allotted to carry out the workshop. At the start of the project, the research team planned to spend a full day with workshop participants. This would have allowed each tool to be fully developed and explored. As the workshop date approached, participants made it clear that they could spend a half-day, but not a full day. This presented a number of challenges and forced the team to make compromises around each of the three tools. For example, the team would have liked to have spent 30–45 min on an exercise in which participants would develop and find consensus around their own set of resilience goals. The team would also have preferred to spend additional time in small group discussions around the pros and cons of the long-term resilience concepts. Finally, the team had to greatly reduce the amount of time spent on orienting the participants to using the Wecision tool, resulting in some confusion around using the tool and a lack of time for discussing the results.

Individually, the tools worked well, but nevertheless could be improved. The dialogue around the storm scenario, for example, raised a number of concerns that participants had not previously discussed as a group, but without laying blame or directly assigning responsibility for assuming the risk. The storm scenario visualizations brought these issues to light, without boxing any particular agency or business into the corner of having immediate responsibility to reduce that risk, thus allowing for a freer flow of ideas. Though ultimately "someone" will need to address the issues raised, the boundary object allowed for discussion in a non-threatening and collaborative environment, laying a foundation for future decision-making exercises.

Table 1 Port resilience as a "wicked problem" (based on Rittel and Weber 1973)

Characteristic	Wicked problems	Port of providence challenge	Contribution of this project
The Problem	No agreement exists about what the problem is/ Each attempt to create a solution changes the problem/the end solutions are not true or false, but rather better or worse with winners and losers	The problem of hurricane and sea level rise risk for the port of Providence, in itself, is very difficult to define and bound. Providence has experience numerous major hurricanes (e.g., 1817, 1885, 1938, and 1954), there has not been such an event in recent memory. None of the participants witnessed such a major storm hit the area, though many could recall hurricanes with far less power (e.g., Hurricanes Sandy, Irene, Bob, and Floyd). In addition, the port area has seen significant development since the last big hurricane in 1954	Coming together around one storm scenario, with visualizations and input from experts, allowed participants to better understand the complex nature of the problem and the interconnectedness of the long-term consequences of a major hurricane on an unprepared port system
Stakeholder roles	Many stakeholders are likely to have differing ideas about what the "real" problem is and what its causes are	Business owners sometimes fear that a discussion of risk can result in liability or culpability should an event occur and damages result. Some felt that acknowledging the true threat would leave them responsible for investing money to reduce these risks	The workshop and survey activities helped participants see the range of resilience strategies that could be implemented by private business (e.g., raising utilities) and the public sector (e.g., building a storm barrier). This broke down the "siloed" nature of the system and underscored the co-benefits of resilience investments.
The "stopping rule"	The end is accompanied by stakeholders, political forces, and resource availability. There is no definitive solution	Bounding the problem to a particular storm surge or level of sea rise can, in and of itself, be a major barrier to engaging in dialogue about solutions. How much protection is enough? Is a Category 3 hurricane the proper scenario to plan for? Why not a Cat 1 or Cat 4? Even if investments are made to protect the port against that Category 3, sea level rise and climate change will most likely only increase risk levels over the next several centuries	The exercise helped stakeholders think about the long-term implications of resilience strategies and to recognize that almost all solutions are temporary. This, though, helped them to see that investments must be considered in the context of the working life of the resilience measure implemented and that there is likely no "permanent" solution
Nature of the problem	Solution(s) to problem is (are) based on "judgments" of multiple stakeholders, thus there is no one "best solution" that can be quantifiably assessed The problem is associated with high Uncertainty as to system components and outcomes	In Providence, the issue of storm resilience is hard to pin down as "one problem" that can be resolved. Hurricanes result in a range of consequences, depending on wind speeds, storm surge, wave action, and precipitation. Different parameters will impact different stakeholders. Thus, differentiating the "wind problem" from the "surge problem" can be difficult for a group to undertake The long-term nature of the scenarios presented in the workshop also did not align well with the normal planning and investment cycles for business and even government	Through the use of the storm scenario, participants in the workshop were able to share their perceptions and concerns and find common ground around understanding the nature of the problem
Symptom of another problem	Resolving the wicked problem begins with a search for causal explanations of another problem	Though hurricanes have occurred in the past, the projected intensification and rising sea levels are symptoms of the larger climate change problem which is well outside the scope of Port of Providence stakeholders	Though not explicitly addressed in this project, exercises such as this (focused on resilience or adaptation) can lead to deeper levels of concern for the causes of the problem, which are exacerbated by CO2 emissions and links to global warming
Fuzzy mandates	Wicked problems do not have clear actors with responsibility to resolve the problem Often require a "champion"	Despite assembling an expert steering committee and including all waterfront business interests in the study area, no clear leader for long-term resilience planning emerged before, during, or after the workshop	The project clearly identified a leadership vacuum for resilience initiatives around the Port of Providence. A first step toward solutions is identifying that the problem exists and beginning a dialogue around which agencies or businesses are best poised to address it

Table 2 Pros and cons of three boundary objects used in workshop

Boundary Object	Short description	Pros	Cons
Storm scenario	Plausible, but extreme, storm event with 3D visualizations of local context.	Participants considered their own property in the context of the storm. Successful prompt for dialogue on wide range of direct impacts and cascading consequences. Elicited robust exchange between participants around interconnectedness of infrastructure and services. Helped participants to think "long term" about impacts in weeks, months, and years.	Participants requested a "probabilistic" scenario, as opposed to a deterministic. 3D visualizations could not effectively show wave, wind, and related impacts (e.g., debris fields). Some participants did not believe that such an event could occur. Some participants "shut down", because the event was so extreme that they felt nothing could be done to reduce impacts.
Long-range resilience concepts	Three transformational concepts (relocate, protect, and accommodate) presented in detail with pros and cons to generate discussion about potential for large-scale investment in resilience.	Participants considered game-changing strategies outside the normal scope of public/private planning.	Research team could not incorporate "costs" in anything but the vaguest of terms due to complexity of cost estimation for both storm damages and implementation of resilience concepts. Participants found it difficult to consider efficacy of concepts without considering the expense and who would pay for them. Transformational concepts are very difficult to simplify and incorporate into a 4-h workshop. Many nuances, many questions were raised that helped participants understand compexities.
Wecision	Web-based software multi-attribute criteria decision support tool.	Allowed participants to provide real-time feedback, anonymously, during the workshop. Promoted deeper thinking about the resilience and "do nothing" concepts Participants.	Tool was difficult to train people to use in the limited available time. Costs were not incorporated due to complexity of estimating both storm damages and the costs and benefits involved with implementing the long-term resilience concepts.

Although many participants found the visualizations engaging and plausible, some felt that the scenario was either too extreme to be realistic, while others would have preferred a probabilistic scenario. The steering committee supported the creation of a deterministic scenario that would result in a surge that comes up to but does not overtop Providence's Hurricane Barrier. Anything worse would result in a game-changing event that would flood out the entire downtown area. Some participants indicated that they would have preferred a scenario that utilized a probabilistic model (e.g., a 1-in-500 year event), as they felt more familiar with probabilistic models. In addition, the visualizations did not adequately represent many of the real damages that would likely occur. Debris, destroyed buildings, boats torn from moorings, and other likely impacts could not be represented with a degree of accuracy that would make them credible. As advancements in visualization technology make it possible to use increasingly realistic visualizations, it is important to further understand the implications and effectiveness of these types of tools.

The discussions around the long-term resilience concepts exposed participants to the very-real possibility that the landscape around the port might need to change dramatically over the next several decades. Rather than simply posing the problem, these concepts opened the door to discussion about transformational ideas, such as the construction of new barriers, the relocation of some businesses. Participants discussed how most incremental strategies (e.g., elevating utilities, building with floodable first floors) would be effective up to a point, but still fall far short in the event of the storm scenario presented, with its 6.4 m of surge. On the other hand, participants still found it difficult to consider the strategies without some context for cost and who would pay. In designing the concepts, researchers deliberately avoided estimating costs due to the high number of variables involved, including time horizons, scale, and system complexity. Future work should find a way to integrate some approximation of cost, as well as options for how costs might be distributed. For example, the idea of a split between public, private, and public/private investment could be introduced to better understand stakeholder preferences under a variety of cost-split scenarios.

Finally, the Wecision tool served as an entry point to a nuanced discussion around costs and benefits of the resilience concepts. The value lays in providing an objective reflection of the participants' own evaluation of the effectiveness and benefits of the resilience concepts that could be reflected back in real time. However, determining a quantifiable metric for the effectiveness of the various concepts, the lack of integration of costs, and the difficulty in assigning "who pays" left some participants feeling that the research team's use of the tool did not go far enough.

Conclusion

The research project utilized three boundary objects to help facilitate stakeholder dialogue around the wicked challenge of developing a more resilient Port of Providence, Rhode Island, USA: a storm scenario with 3D visualizations, three long-term resilience concepts, and an online decision support tool. In this case, the three objects bridged discussion between business, environmental, and policy decision makers, to help understand the physical impacts from a major storm event, and the social/environmental/cultural constraints of resilience strategies for the Port of Providence. The workshop results suggest that participants found the boundary objects to be a useful planning tool that engaged them in critical thinking to better understand shared risk and complexity inherent in implementing meaningful resilience strategies. Though it did not, by design, result in a concrete decision for action or specific plan, it represents an example of a pre-planning exercise necessary to lay the groundwork for future decision-making in the face of climate change-related hazard events. Without such boundary objects, stakeholders and decision makers could not effectively engage in dialogue around the challenge of long-term planning for natural hazard adaptation.

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Appendix 1—workshop resilience concepts

This Appendix 1 describes the advantages and disadvantages of each of the long-term resilience concept alternatives. These were discussed with participants during the workshop. Each of the concepts was developed with the following assumptions:

- Resilience: *Ability to rapidly bounce back to normal operations after extreme (e.g., Cat 3) event*
- Long-term: Out to ~2050 (focus here is not on emergency response)
- Common objective to strengthen the port community
- Actual solutions would likely combine concepts
- High costs; funding mechanisms unknown at this time

1. Do Nothing
Advantages

- Low/no upfront costs
- No disruption until storm event(s) occur
- Easy
- Allows for investments in other priorities

Disadvantages

- Risk of major catastrophe after each storm event
- Risk of businesses leaving the State
- Risk of major environmental damage to Narragansett Bay
- Risk of channel closing for weeks/months
- Impacts to state's energy supplies

2. Accommodate—site-specific improvements to increase resilience
Protect/reduce

- Construct barriers and berms
- Reinforce windows and doors
    - Door barriers
- Debris traps
- Storm water detention
- Cover and move stock piles of materials

Wet flood proofing

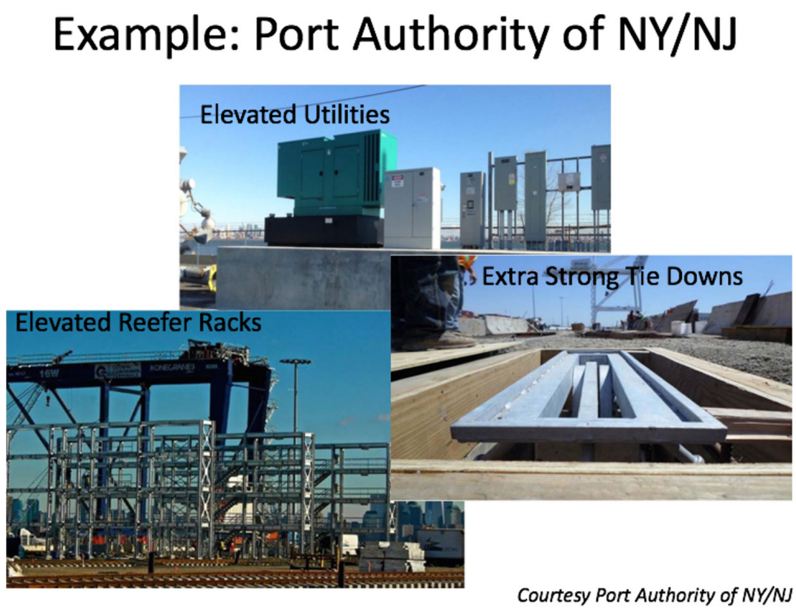
- Floodable first floors/foundations
- Breakaway/removable walls (reduces structure damage)
- Flood/salt tolerant constructions/materials

Dry flood proofing

- Seal around utility entry points
- Install waterproof bulkheads
- Install pumps with back up generators

Examples from MassPort (Boston)

- New design elevation: 20.5′ (Category 3 surge)
- Building retrofit elevation: 17.5′ (Category 2 surge + wave)
- Identifies all critical infrastructure and risk to flood damage
- Establishes flood-proofing standards for existing and new construction
- Defines permitable uses for accommodation strategies
    - ex. Dry flood proofing cannot be used in VE Zones.



Advantages

- Costs can be incremental
- Site-specificity
- Low-cost options
- Single business could improve its own resilience
- Could address SLR
- Does not disrupt port system as a whole.

Disadvantages

- Limited in ability to protect against major storm
- Does not address interdependent uses
- Storm could result in high levels of environmental damages
- Few tested examples for industrial waterfronts
- Less likely to protect navigation channel from debris.

3. Relocate—move port uses to less vulnerable locations
Advantages

- Removes hazardous materials from floodplain
- Tested strategy has been implemented elsewhere
- Opens floodplain as public waterfront space and/or environmental remediation
- Can account for SLR
- Reduces debris in navigation channel after storm
- Improves water quality to Providence Harbor.

Disadvantages

- Disrupts port network
- Limited land availability
- High costs
- May impact communities around relocation sites
- Complexities from dependence on utilities (e.g., pipelines, rail, and highway)
- May displace environmental damages to other places.

4. Protect—construct new storm barrier for Providence Harbor
Advantages

- Protects during all major events
- New public uses can be integrated (e.g., on berm)
- Does not disrupt shipping
- Creates safe harbor for new business
- Tested solution
- Very long-term solution
- Frees up land in city through removal of current barrier system.

Disadvantages

- Impacts of sea level rise are not addressed
- May impact tidal flows (water quality)
- Impacts sediment flow, water quality, discharge from watershed (sedimentation of navigation channel)
- High upfront costs
- May impact view of Bay
- May require pumping due to increased freshwater flows.

Appendix 2—resilience goals

As part of the Wecision exercise, the research team developed seven goals that were discussed and vetted by workshop participants during the workshop. This Appendix

2 describes each of the seven goals. Each goal is described and a 1–5 metric for assessing each is provided. Because time was limited, the research team provided a first pass for how well each goal would be accomplished by each of the four resilience concept alternatives. These scores were discussed in the workshop, but participants were free to enter their own scores if they disagreed. The limited time of the workshop proved to be a challenging obstacle. The exercise was limited to about an hour.

In sum, participants:

1. assessed and modified the goals defined by the research team;
2. weighed the importance of each goal from each participant's own perspective;
3. learned about and gave feedback about some of the possible resilience concept alternatives;
4. learned about and gave feedback to the research team's assessment of how well each resilience concept alternative achieved each goal;
5. considered and discussed the relative value of each alternative from individual stakeholder perspectives, and to the Port of Providence waterfront stakeholders as a whole.

The goals are outlined below.

GOAL 1: Ensure post-hurricane(s) business continuity for waterfront business

What does it mean?

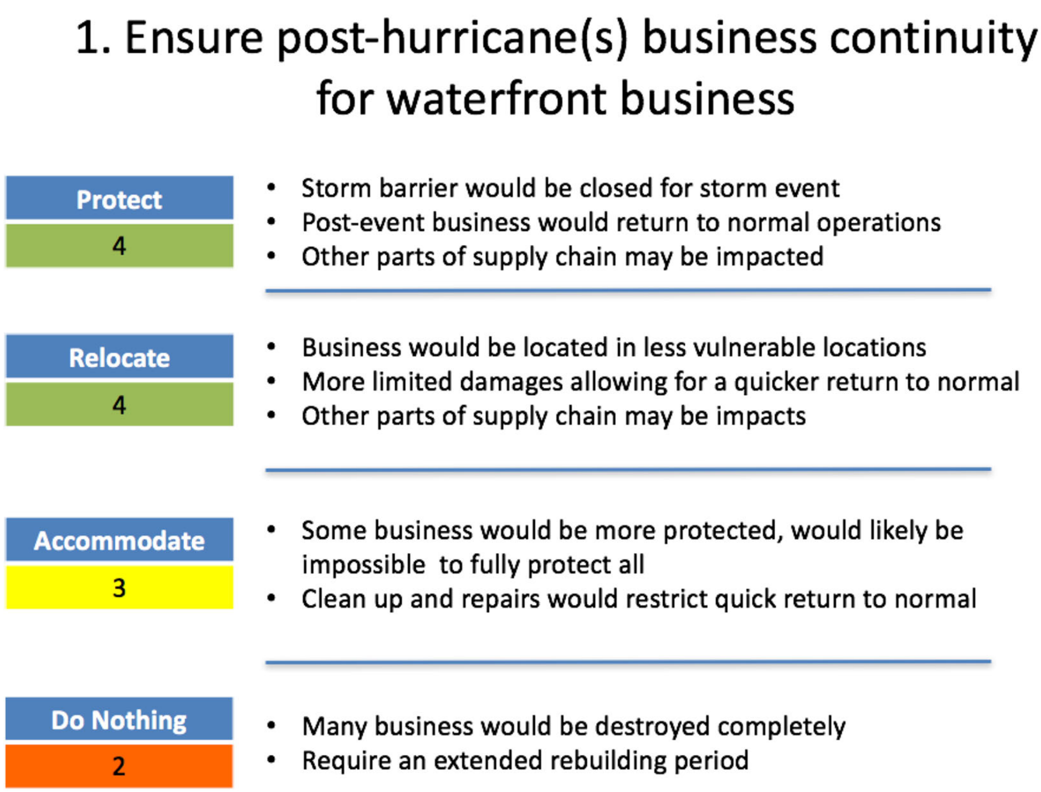
- ensure access to supply chain;
- minimize downtime after event.

Metrics:

In the months following a Cat 3 storm event, port-related businesses:

1 = Leave the State.
2 = Are down for up to a year.
3 = Operate at ~50% for 6 months after event.
4 = Operate at ~50% for 2–4 weeks after event.
5 = Are up and running at full capacity one day after event has passed.

Scores



GOAL 2: Minimize hurricane damages to infrastructure and waterfront business

What does it mean?

- Limit damage to buildings, equipment, and storage and protect space in/around terminals.

Metrics:
After a Cat 3 storm event:
1 = All structures and infrastructure are destroyed.
2 = >50% of structures and infrastructure are destroyed.
3 = ~50% of structures and infrastructure are destroyed.
4 = <50% of structures and infrastructure are destroyed.
5 = All structures are standing.

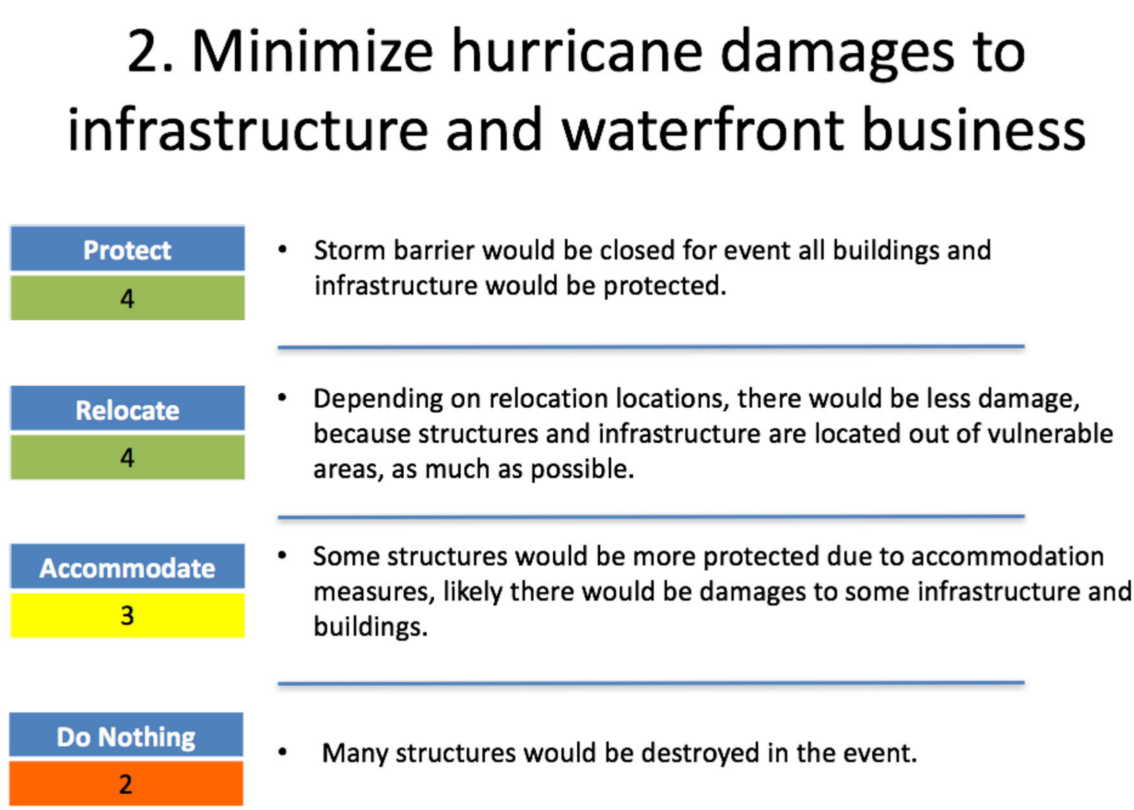
GOAL 3: Minimize hurricane-related environmental damage from port uses

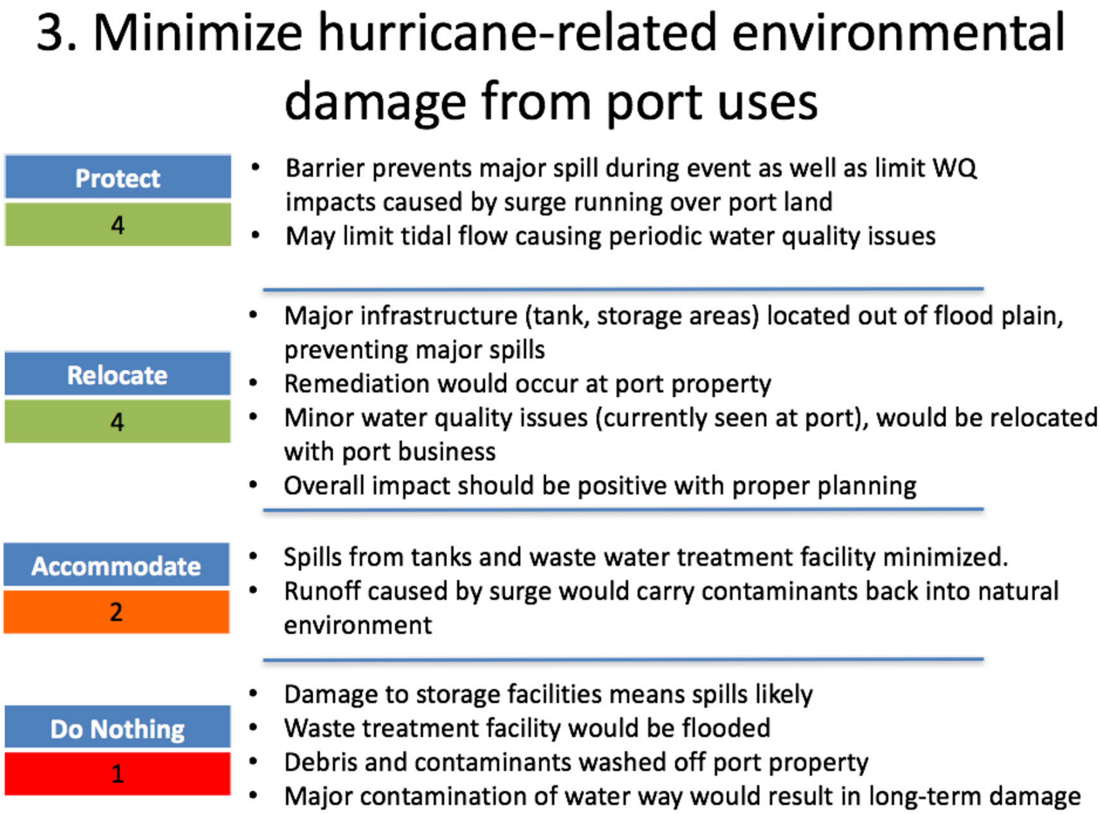
What does it mean?

- Prevent chemical and petroleum spills.
  - Prevent contaminated soils from entering waterways.
  - Minimize amount of debris generated on study area properties.

Metrics:
Between now and 2050:

1 = Catastrophic spills contaminate the Bay.
2 = Water quality is temporarily impaired by runoff and debris after storm events.
3 = Water quality is not impacted.
4 = Water quality is improved during short term events.
5 = Water quality is improved dramatically.





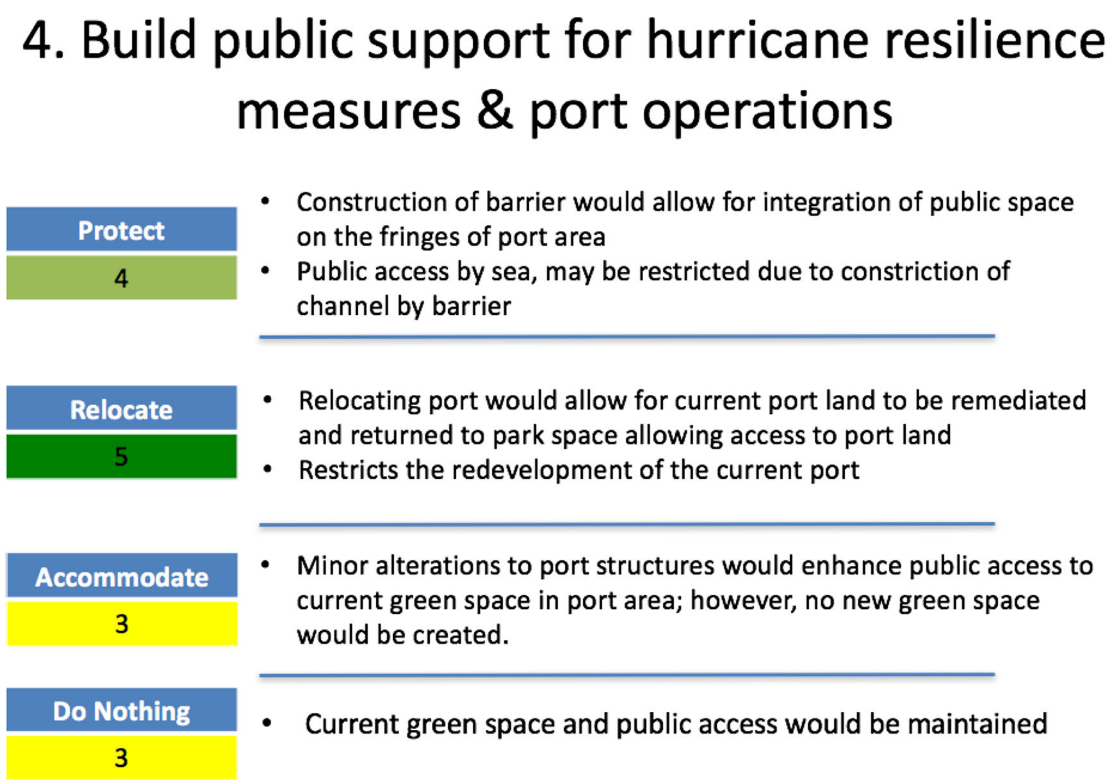
GOAL 4: Build public support for hurricane resilience measures and port operations

What does it mean?

- Create green space.
- Enhance public access for recreation and walkability.

Metrics:
Between now and 2050:

- 1 = Current green space and public space is converted for other uses.
- 2 = Current green space is impaired by new uses.
- 3 = Green space and public access are maintained.
- 4 = Green space and public space is enhanced.
- 5 = Green space and public access is greatly enhanced.



GOAL 5: Minimize hazard insurance rates

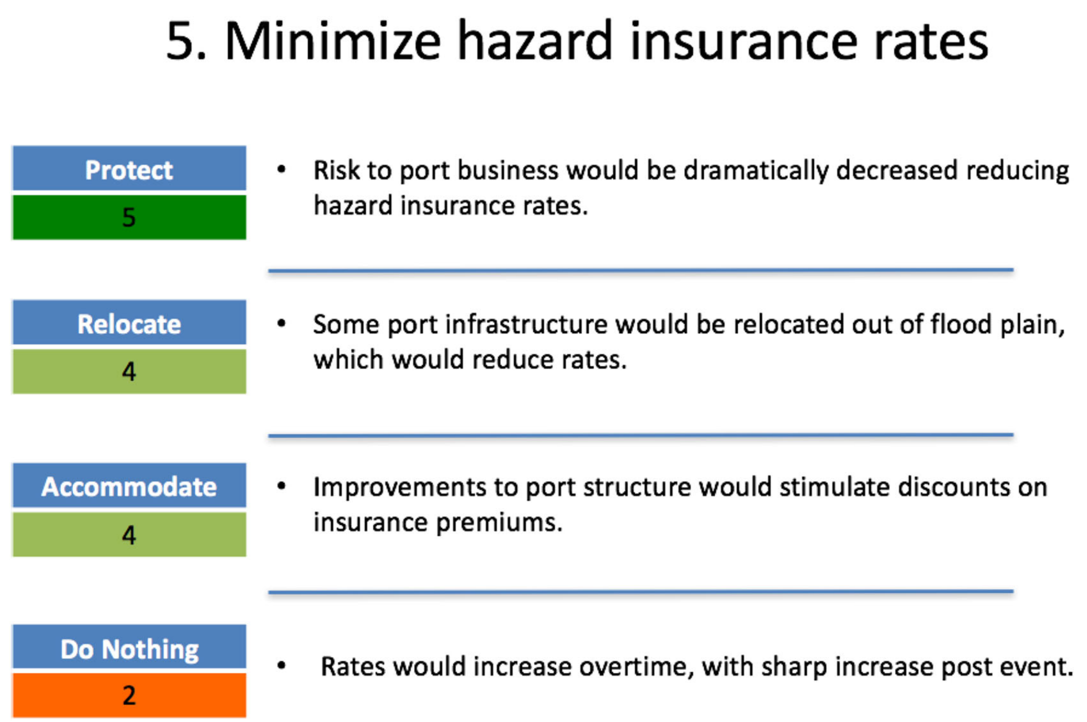
What does it mean?

- Hazard insurance rates are kept low.

Metrics:

By 2050, the costs of hazard insurance (adjusted for inflation):

- 1 = Are completely unaffordable after a Cat 3 event.
- 2 = Increase slightly due to increased risk overtime.
- 3 = Remain about the same.
- 4 = Reduced slightly due to new resilience investments.
- 5 = Drop dramatically due to resilience investments.



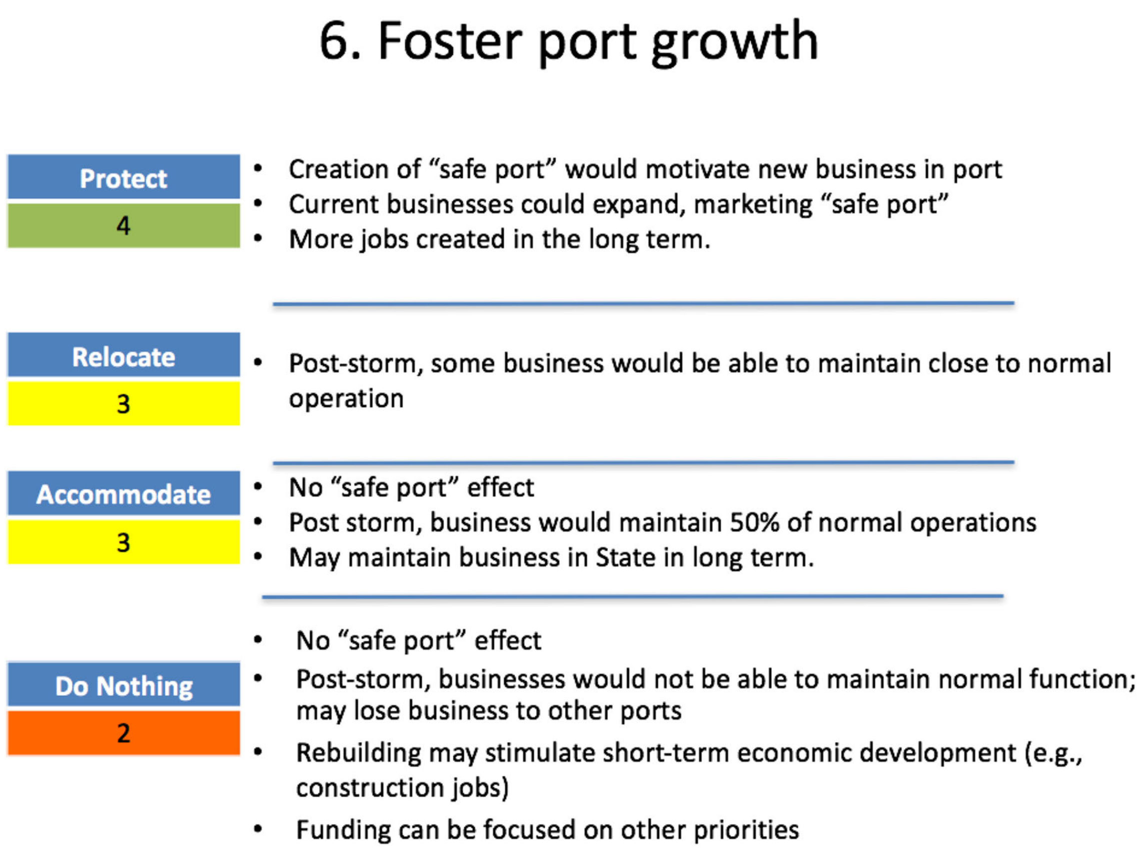
GOAL 6: Foster port growth

What does it mean?

- Create storm resilience setting that would attract new waterfront businesses.
- Create opportunities for current businesses to grown.
- Improves public perception of port operations.
- Increase cargo value and volume of cargo.

Metrics:
By 2050, the economic growth rate of port businesses:

1 = Decreases dramatically.
2 = Decreases.
3 = Remains the same.
4 = Increases.
5 = Increases dramatically.



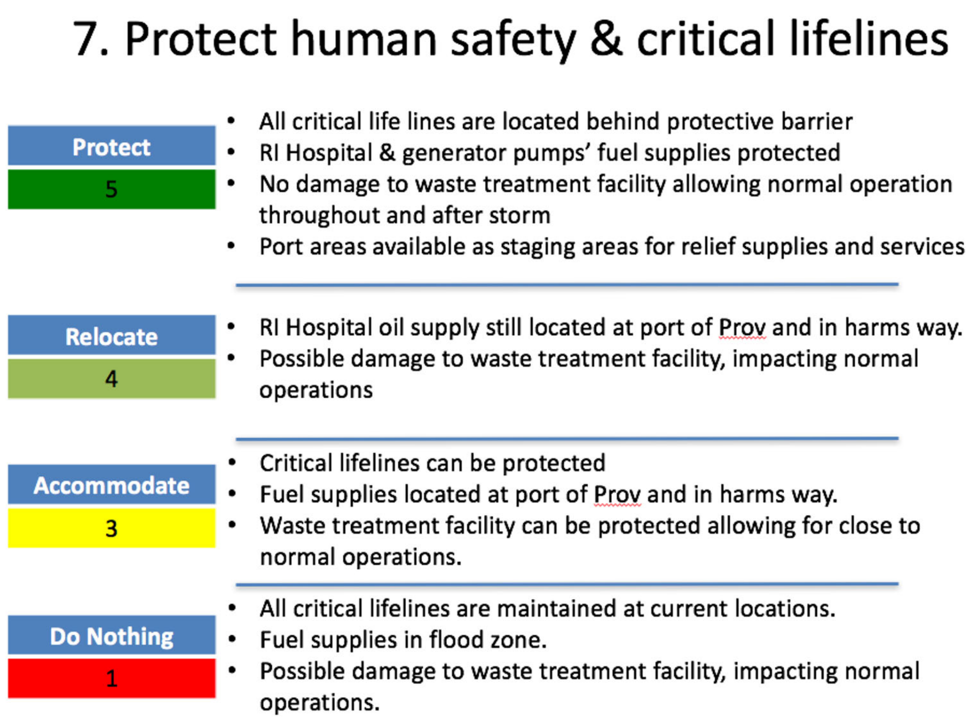
GOAL 7: Protect human safety and critical lifelines

What does it mean?

- Minimize loss of life and harm to people within study area boundaries.
- Protect critical lifeline services and ensure access to lifelines is secure (e.g., fuel for hospitals and hurricane barrier pumps).
- Provide staging area for relief supplies operations.
- Provide access to waterway for survey vessels.

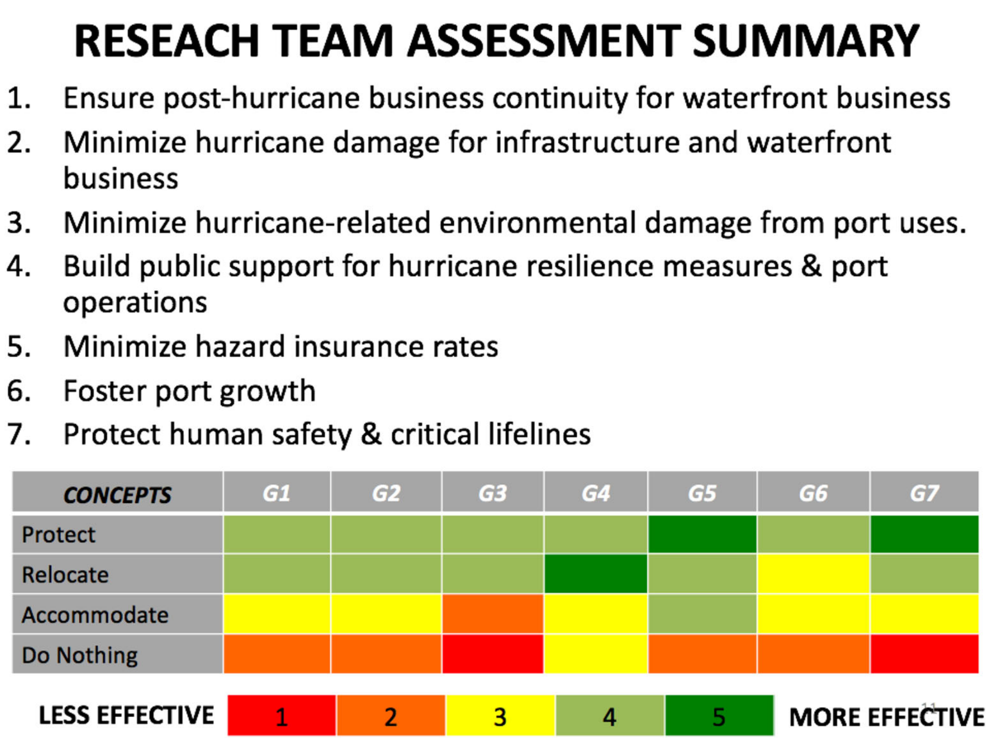
Metrics:
By 2050, hurricane impacts on the study area:

1 = Severely affect human safety and critical lifelines.
2 = Affect human safety and critical lifelines.
3 = Minimally effect human safety and critical lifelines.
4 = Reduce effect on human safety and critical lifelines.
5 = Greatly reduce impact on human safety and critical lifelines.



Summary of resilience concept alternative scores

Through the workshop, the scores proposed by the research team were summarized as follows (see Fig. 8).



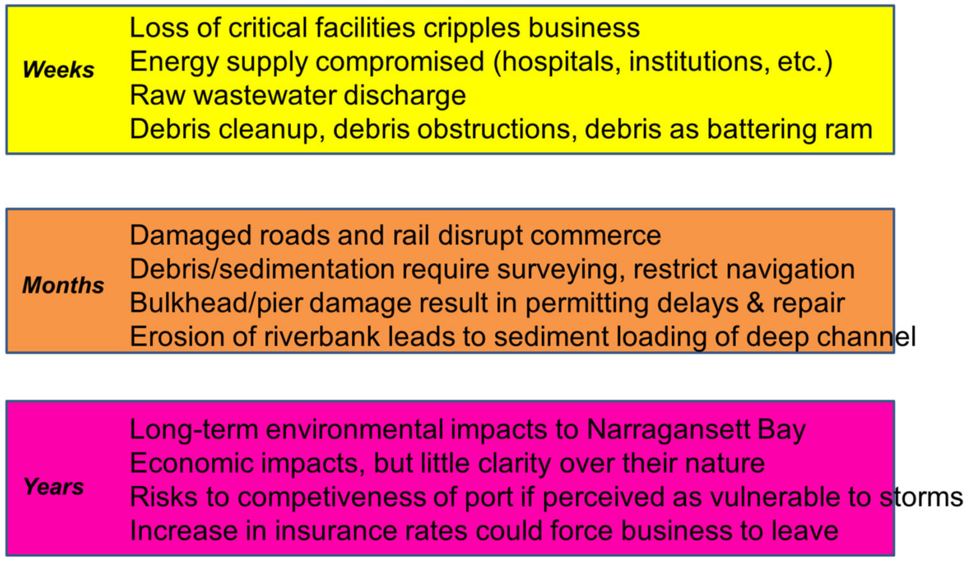


Fig. 8 "Do Nothing" concept was also included in the Wecision exercise for participant evaluation. Below shows examples of the storm impacts identified by workshop participants

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