

Advancing coastal systems resilience research: Improving quantification tools through community feedback

By

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ABSTRACT

A large number of initiatives exist at the federal level to provide resilience tools to communities and decision makers, but quantitative assessments of resilience are limited. There is a need for objective evaluation of coastal systems that includes the community, economy, and environment. To meet this need, U.S. Army Corps of Engineers researchers at the Engineer Research and Development Center developed a tiered methodology to assess and quantify resilience for rapid assessment (Tier 1), planning and operations-level studies (Tier 2), and engineering applications (Tier 3). This paper describes the application of Tiers 1 and 2 with collaboration from the National Oceanic and Atmospheric Administration, Sea Grant, the University of Rhode Island, and the U.S. Committee on the Marine Transportation System during a pilot workshop in Mobile Bay, Alabama in March 2015. The results of this study centered on feedback received from two groups of professionals: workshop participants from the south Alabama region and a subsequent review of workshop findings by experts convened by the National Academy of Sciences. Feedback on the approach and community needs are required to best advance tools to quantify coastal resilience on variable spatial and temporal scales.

For coastal engineers, scientists, emergency managers, and community planners, the projections for the future of America's coasts point to a cacophony of risks and vulnerabilities — from increasing coastal populations, to climate change, cyber, human-induced threats, and budgetary restrictions. These issues are the present-day challenges for coastal professionals; the design, selection, and management of various solutions must incorporate resilience to recover rapidly after disturbances and to overcome these challenges in the long term. This paper outlines a joint effort by researchers from the U.S. Army Corps of Engineers' (USACE) Engineer Research and Development Center (ERDC) and the National Oceanic and Atmospheric Administration (NOAA) to test and evaluate a suite of tools to quantify resilience for a case-study site in Mobile Bay, Alabama, and surrounding Mobile and Baldwin counties. The process of validating tools that have only been applied conceptually as acceptable for practice in the field is often evolutionary, with periods of adaptation and incremental improvements, especially when the tools are evaluating a concept as broad as resilience. This learning process is referred to

as "action research" and is utilized within this paper to synthesize feedback and reactions from both community members and outside academics on our methodology and use that new knowledge to guide and inform future research and design (Scardamalia and Bereiter 1993). We ask that readers consider the feedback and recommendations we received and add their own thoughts and experiences to the ongoing discussion about quantifying coastal resilience through this progressive process of continuous improvement and refinement of methods.

The new emphasis on resilience, defined here as "*the ability to prepare, withstand loss in functioning, recover rapidly, and adapt*," is, in part, the result of many federal agencies working to integrate these concepts into their programs or initiatives, led by high-level directives by the President's office (e.g. The President's Climate Action Plan (2013), Executive Order 13653 — Preparing the United States for the Impacts of Climate Change, Presidential Policy Directive on Critical Infrastructure Security (PPD-21, 2013), Presidential Policy Directive on National Preparedness (PPD-8, 2011), Water Resources Reform and Development Act

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2014). The application of resilience concepts is quickly expanding in theory, methodology, and practice and several USACE and partner studies have emphasized the need for greater expertise in the subject (USACE 2015; Burkes-Copes *et al.* 2014; IPET 2007; MsCIP 2009)

Resilience has been interpreted and conceptually applied to a multitude of fields from ecology (Holling 1973), to human psychology, engineering, and social science (Masten 2001; Ewing 2014; Hollnagel *et al.* 2007). The amorphous nature of the term "resilience" often results in confusion (or distraction) about semantics or application between research groups and disciplines. However, this fluid definition is also a great strength because some of the best resilient solutions are interdisciplinary, flexible, and adaptable (Pickett *et al.* 2004). As the body of resilience work continues to grow, more agencies and academic organizations will offer insights and understandings gained through the ongoing development of resilience theories, design guidance, and applications. The principles of action research ensure that resilience applications are guided by open discussions that include feedback received from wide audiences — both the practicing community and academia — in order to guide the development of resilient solutions for our nation's coastal regions.

Resilience has been evaluated through qualitative, semi-qualitative, and quantitative tools and models that have utilized the four-part definition of resilience to evaluate or track the progress of fields of interest (Ganin *et al.* 2016; Bocchini *et al.* 2014;

Lam *et al.* 2014; Bruneau *et al.* 2003). At the federal level, tools to quantify resilience are necessary to remove ambiguity and provide information with which federal agencies and communities can readily act and realize improvement in their resilience and include a large cadre of resilience efforts (See Link *et al.* 2015 and Larkin *et al.* 2015 for a summary of federal efforts). Federal agencies must be able to conceptualize, and ideally quantify, how their investments in resilience-related information, data, actions and projects improve preparations, functioning, recovery, and adaptation of coastal communities on local and regional scales. The approach evaluated within this study was recommended by researchers at the ERDC and a team of interdisciplinary non-governmental, interagency and academic scholars who reviewed the state-of-knowledge on resilience and leveraged existing evaluation methods (Fox-Lent *et al.* 2015; Rosati *et al.* 2015; Schultz and Smith 2015) to recommend a three-tiered process for assessing coastal system resilience. This tiered methodology utilizes USACE projects and interests for initial development but can be implemented by interested agencies, organizations, and communities. The tiered methodology needed guidance and vetting from a community and Mobile Bay was selected as an initial pilot area because of regional high exposure to coastal storm risks and a history of significant community engagement with resilience evaluations. The area had experience with both the NOAA Sea Grant Coastal Community Resilience Index (hereafter Sea Grant CRI; NOAA 2014, Sempier *et al.* 2010) and the recently concluded Federal Highway Administration (FHWA) Gulf Coast Study on the ability of the multi-modal transportation network to function during current and future projected storms, including the Port of Mobile (FHWA 2015). NOAA's expertise in community-driven solutions and outreach was key to the pilot study, and by focusing on Mobile and Baldwin Counties, NOAA sought to encourage synergies between the Sea Grant CRI and ERDC's tiered data-driven approach to determine community requirements for accurate and helpful resilience standards and metrics.

The following sections describe the application of the toolset but focus in particular on the feedback received from a wide range of experts including Mobile-area county and emergency management professionals and a panel of resilience



Figure 1. The four principles of resilience shown in a cycle of continuous evolution.

specialists subsequently assembled by the National Academy of Sciences to review the project. Finally, by analyzing the input received from both groups we present the overarching challenges to quantifying resilience and how our methods could be better tailored to the needs of communities, ports, and ecosystems within coastal regions.

ERDC TIERED APPROACH TO RESILIENCE

Existing definitions of resilience address ecological functioning, human behavior, engineering design, and community sufficiency (Rosati *et al.* 2015). The USACE has adopted the definition of resilience as presented in Presidential Executive Order 13653, “the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions” (Federal Register 2013) and is applied herein as four broad activities within the cycle of resilience (Figure 1). Despite operating on similar resilience definitions, multiple levels of government, academia, and private industry have developed varied tools and methodologies that help communities evaluate their own needs and vulnerabilities (Lavelle *et al.* 2015) and progress has been relatively uncoordinated (Mitchell 2013; Larkin *et al.* 2015). The resulting differences in application of resilience concepts is a challenge to making a comprehensive assessment. Bocchini *et al.* (2014) described two aspects of resilience that strongly influence application for civil engineers:

(1) Resilience is a measure of a community's response to disruptions to its infrastructure.

(2) Resilience focuses on the ability to recover efficiently and effectively.

Another aspect significant to civil engineering is the timing of recovery:

(3) The recovery process involves two phases: immediate impacts of the disruption (response); and reestablishment of pre-incident operations (resumption).

Connecting with communities and integrating infrastructure performance as a part of a larger community system is pertinent to the USACE mission, which endeavors to reduce coastal system risks while simultaneously providing national security and socio-economic benefits. Holistic evaluation of infrastructure and community systems provides a framework with which to design and plan for future USACE coastal projects. Second, efficient and effective recovery can be quantified for infrastructure systems through the concept of function reliability and multiple recent studies have created resilience models that either weight or track the process of recovery (Baroud and Barker 2014; Cutts *et al.* 2015). Numerous authors have suggested that approaches to community resilience should be multidisciplinary and closely linked to the three pillars of sustainability: the environment, society, and the economy (e.g. Ayyub 2014; Bruneau *et al.* 2003; Keessen *et al.* 2013; Lam *et al.* 2014). The ERDC recognizes that successfully increasing coastal resilience depends, to a large part, on coastal infrastructure (including USACE projects, as well as natural and community assets) performing as an integrated system. The proposed methodology addresses this need by evaluating the performance and recovery of three types of infrastructure systems: navigation or water resource engineered water resource features (ENG), USACE, community, or naturally built ecological features (ECO), and community infrastructure (COM; Figure 2).

This approach is intended to estimate existing coastal resilience and evaluate the contribution to resilience of alternative courses of action or investment for communities and outside organizations while highlighting the areas for which the USACE can most maximize its impact. The individual analyses in the methodology, or “tiers,” are intended to enhance coastal project planning, feasibility, operations and maintenance (O&M) and design activities within USACE but are envisioned

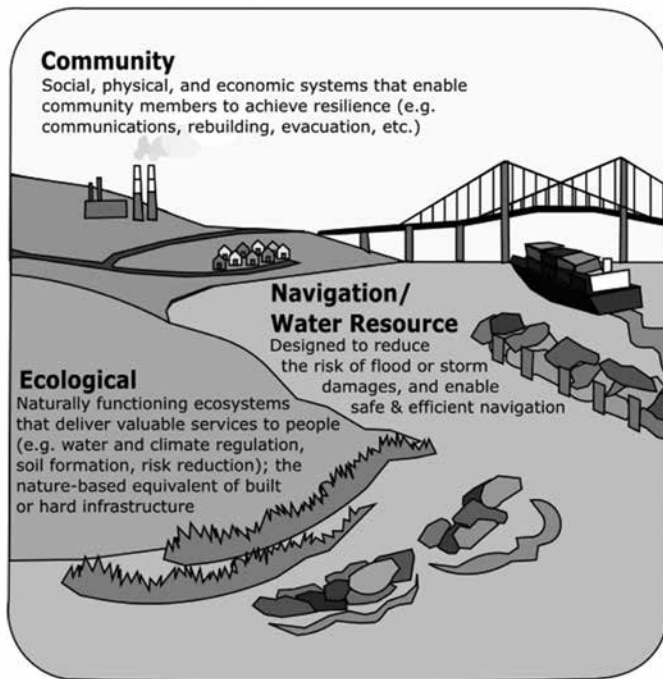


Figure 2. Community, Navigation/Water Resources, and Ecological infrastructure systems successfully support and operate together within a resilient coastal community.

to ultimately be available for use by other agencies or interested parties. Specifically,

Tier 1: System-Scale Assessment using the Resilience Matrix framework (Linkov *et al.* 2013; Fox-Lent *et al.* 2015) rapidly assesses system strengths and vulnerabilities, and is envisioned for rapid scoping-level studies;

Tier 2: Coastal System Infrastructure Assessment is intended to quantify relative infrastructure resilience, and identify alternatives during feasibility-level and O&M studies (Rosati *et al.* 2015); and

Tier 3: Risk and Resilience Analysis provides quantitative design-quality information for engineering optimization (Schultz *et al.* 2012; Schultz and Smith 2016).

The three tiers utilize existing methods proposed by the ERDC (Linkov *et al.* 2013; Rosati *et al.* 2015, Schultz *et al.* 2012). Tiers 1 and 3 were previously pilot-tested at Jamaica Bay, New York (Fox-Lent *et al.* 2015, Schultz and Smith 2016). During this study, we focused on feedback received from applying Tiers 1 and 2 in Mobile Bay, Alabama, to guide the formulation of a coastal system resilience research plan. Tier 3 requires significant data collection and more in-depth analysis which was outside the scope of the present study.

APPLICATION OF RESILIENCE QUANTIFICATION METHOD FOR MOBILE BAY, AL

In March 2015, researchers from the ERDC and NOAA's Mississippi/Alabama

Sea Grant Consortium invited local area professionals from the Mobile Bay area to complete and evaluate the Tier 1: System-Scale Assessment and Tier 2: Coastal System Infrastructure Assessment methodologies. In total, 31 professionals attended the two-day workshop to offer their thoughts and perspectives based on their institutional knowledge and experiences. The participants represented a wide variety of expertise: county and state planning, emergency management, port management, environmental assessment and restoration, and local commerce and tourism. Facilitators from the NOAA's Mississippi/Alabama Sea Grant Consortium and the ERDC first provided a background on the ERDC's tiered methodology including resilience concepts and the definitions of ENV, COM, and ENG infrastructure. Facilitators emphasized that the workshop was intended to evaluate the application and usefulness of the tiered methodology, and not to evaluate nor provide coastal resilience calculations for the Mobile community. Participants were asked to limit the tiered evaluation to the boundaries of Mobile and Baldwin counties for two coastal storms that would be used as benchmarks throughout the workshop: a historical storm, *Hurricane Georges*, and a hypothetical future storm, a direct-hit *Hurricane Katrina* accompanied by an increase in sea level rise of 0.75 m (Figure 3). *Hurricane Georges* made landfall in Biloxi, MS, as a Category 2 Hurricane. Its slow movement and torrential rains

resulted in precipitation between 50-76 cm in southern Alabama and 2.5 m of storm surge in downtown Mobile (Barry *et al.* 2015; NOAA 2012). The modeled Hurricane Katrina included 75 cm of sea level rise and resulted in a 6.7 m surge at Mobile Docks and bands of flooding west of downtown nearly to I-65 (Figure 3; modeling from FHWA 2015 courtesy SCE). These storms were chosen to utilize the FHWA's previously calculated storm surge, wave height, and wind projections from their Gulf Coast Study in evaluating the expected performance of the Mobile Bay system (FHWA 2015).

METHODOLOGY

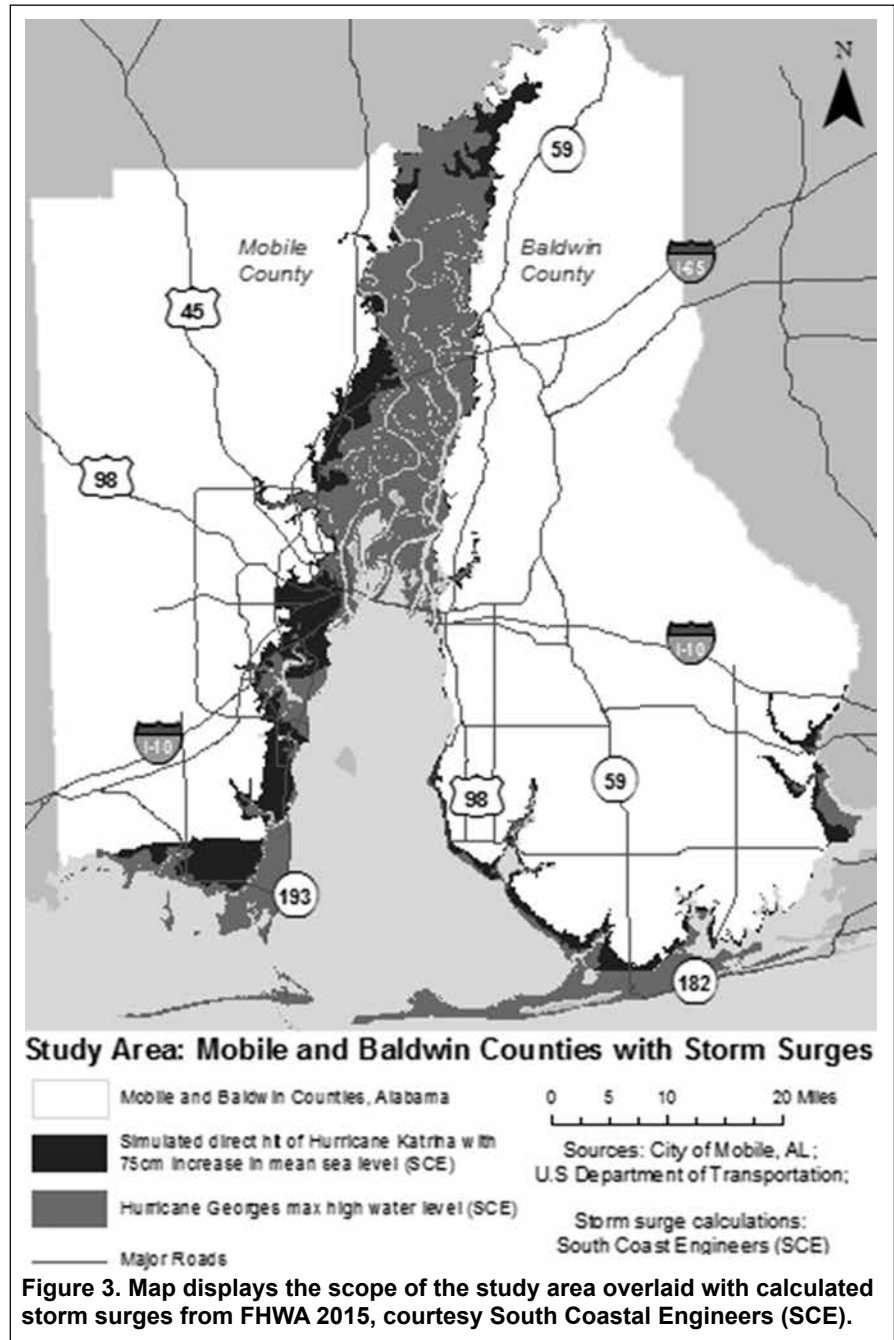
Tier 1

The Resilience Matrix framework (Linkov *et al.* 2013, Fox-Lent *et al.* 2015) was employed for the Tier 1 screening level resilience assessment of the Mobile Bay coastal system, and focuses on the community aspects of the coast – including the people, businesses, and properties adjacent to the shoreline and neighborhoods further inland. The matrix is a 4 x 4 framework where one axis lists the major components of a system and the other outlines the four stages of a disruptive event (Figure 4), through natural and built infrastructure, information, policies and social resources. Participants were divided into breakout groups representing four pre-selected *critical community functions*: residential housing and emergency shelter, the port industry, the beach and tourism industry, and ecosystem health. Facilitators prompted each group to identify indicators of performance for their assigned critical community function and to develop rough benchmarks of good, acceptable and poor performance for these functions. Next, the participants were given individual worksheets to rate the capacity of various components of the system to operate during a disruptive event. Participants considered system properties associated with resilience, including rapidity, robustness, flexibility, resourcefulness, diversity, dispersion, and centralization. Lastly, through the process of initial discussion and later feedback and revision within Tier 2, participants developed ideas for potential actions and projects that could improve resiliency of the system. The results of this exercise were plotted within the Resilience Factors Matrix across the four stages of resilience to evaluate the baseline condition of the system. Any

ideas for potential improvement projects were also plotted in order to observe how well the proposals aligned with the low performing areas of the system and to identify gaps where improvement was needed but not yet addressed.

Tier 2

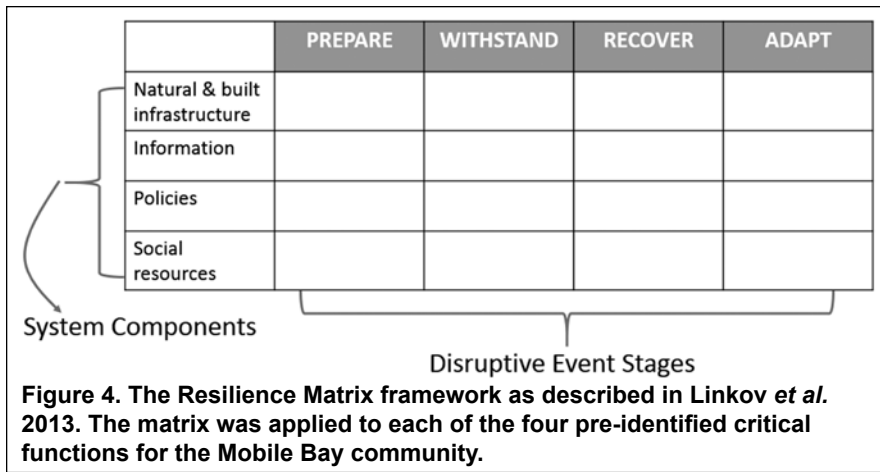
The remainder of the workshop focused on Tier 2: Coastal System Infrastructure Assessment. Participants were divided into breakout groups representing sectors that depend on ENV, COM, and ENG infrastructure types (i.e. natural resources professionals, emergency management professionals, port and navigation professionals). Each breakout was presented with a list of up to 12 *critical infrastructure functions* for the community, industry, or environment that their assigned infrastructure type was expected to meet. Critical infrastructure functions were defined as “site-specific descriptions of indispensable facilities, actions, and infrastructures that allow system resilience to be achieved during the *withstand* and *recover* phases of a disturbance.” A list of candidate critical infrastructure functions was previously developed with both local expert input and analysis of existing plans for coastal management and emergency operations for Mobile and Baldwin counties (e.g. communication, water quality, energy supply). Because of time limitations, participants were asked to narrow the list to their primary three critical infrastructure functions within their sector that each support the system’s overall health and performance through the resilience phases of a disturbance (i.e. prepare, resist, recover, and adapt). Participants then identified performance and recovery goals (e.g. performance: maintain wastewater treatment services; recovery: essential water services back online after three weeks) for each critical infrastructure function based on the occurrence of the two case-study storms. At the conclusion of the first day, ERDC researchers evaluated the prioritized critical functions and associated performance and recovery goals selected by the participants against storm modeling scenarios generated through the FHWA Study (FHWA 2015). These models were utilized to assign the success or failure of each selected performance and recovery goal for both the historical and future storms. During the second workshop day, a smaller group of local technical experts were asked to weight the relative



importance of each critical infrastructure function within each breakout group (ENV, COM, ENG) and to review the assignments of success or failure against the storm scenarios and to adjust the performance and recovery goals as needed. After the adjustments were made, a resilience score was calculated for all three sectors and summarized by the achievements of the weighted performance and recovery goals. The second day technical experts were asked to comment on the strengths and weaknesses of the methodology, and offer recommendations to improve the methodologies and approach in the future.

RESULTS FROM THE MOBILE BAY WORKSHOP

The two-day workshop was designed to assess the methodology and identify requirements associated with coastal resilience characterizations. The results of Tier 1 and 2 were calculated and shared with the group but were only utilized as a prompt for discussion and not as representative coastal resilience calculations for the region. Participants provided feedback on how the methodology was applied, the utility of the results, and suggestions how to improve future iterations. Comments from participants concerned eight main themes and are sum-



marized in Table 1. In addition to comments, workshop attendees offered recommendations that addressed modifying the tool for future application. These recommendations are presented with associated comments in Table 1 (listed as Workshop Recommendation 1 (R1), R2, etc.).

REVIEW BY A PANEL OF EXPERTS CONVENED BY THE NATIONAL ACADEMY OF SCIENCES (NAS)

Following the workshop, researchers synthesized and presented results to a panel of industry and academic experts that was assembled by the NAS Transportation Research Board (TRB). Backgrounds of the experts ranged from ocean and coastal sciences to disaster recovery and transportation networks. The experts offered suggestions and feedback to address the concerns raised by workshop participants. The workshop comments and recommendations discussed in Table 1 were summarized into five statements as shown in Table 2. The expert panel offered suggestions based on their own experiences (listed as Expert Recommendation 1 (E1), E2, etc.) that addressed both improving the methodology's usefulness to field practitioners and specific issues that may arise when the methodology is presented to the academic community. Recommendations from the expert panel included: addressing communication barriers and trust in the data and modeling work (E1, E2, E3), strengthening technical input (E4), clearly defining end-user requirements and developing incentives for tool application (E5), and ensuring input from a tailored selection of stakeholders such that results are representative of the region (E6, E7). These recommendations are summarized in Table 2.

DISCUSSION

Using feedback to create guidelines for USACE tiered methodology.

There are many other products that are intended to be data resources and decision making tools for communities to assess and improve their own resilience. The USACE tiered methodology for assessing coastal resilience, which seeks to integrate engineering, ecological, and community systems, provides specific information relevant to the USACE planning and operations decisions but also needs to demonstrate clear added value to the communities themselves. After reviewing the feedback received from both the practitioners in Mobile and the experts at the National Academy of Science, the authors summarized recommendations for quantifying coastal system resilience:

The USACE needs to be able to characterize coastal system resilience and visualize these data in a way that facilitates rapid understanding of the data and temporal aspects of recovery and adaptation. The approach should first focus on coastal resilience of USACE projects and activities on a time-dependent, system-wide spatial map format based on scientific data, user input and validated with past experience. Community assessments utilizing companion methods (e.g. Sea Grant CRI) can then be incorporated into the framework to provide a holistic characterization of coastal system resilience.

After taking time to understand the unique needs of each sector and the connections between them, it is important to build flexibility into the tool framework to accommodate the varied needs of communities across USACE jurisdiction. To accomplish this quickly, the tool must include a library of relationships for ENG, ECO, and COM performance including

information on fragility (how will feature perform under time-dependent wave, current, wind, and water level, as well as erosive and accretive conditions?), damage (under what conditions will feature fail?), and recovery (how rapidly will feature recover, naturally and through human activities?). The library framework would serve to identify gaps in knowledge, which would guide federal, local, and state research, as well as field and laboratory studies. The library framework would also facilitate review and improvement of the media in an open-source manner, as well as provide transparency in the analyses.

The USACE needs better visualization of hypothetical conditions to improve communication of these conditions to decision-makers and communities. For example, color-coding performance ("withstand/absorb" or "recover/adapt") as a function of hazard and time in an easily-viewed spatial map would provide information on time-dependent vulnerabilities and critical linkages in a readily-understood format.

The USACE method must be amendable to scenario analysis in order to evaluate the effect of changes in COM physical and governance structures, rare patterns in climate change or extreme events, as well as evolution of ECO features and ECO/ENG project-level alternative analysis. Accounting for trends like ecological evolution and climate change requires recovery to be viewed as both a short-term response and long-term resumption of function.

Because the method must ultimately incorporate community values and needs, the USACE's method must employ an iterative approach with community reviews as development proceeds.

CONCLUSIONS AND NEXT STEPS:

While the technical details and methodology of the tool are critical to the evaluation, equally important are forging new and strengthening existing partnerships by working towards solutions together. This process can be challenging as communities often find it difficult to internalize and consider consequences of high-risk, low-probability, events. Complex so-called wicked problems require new ways of knowledge production and decision making that involve collaborations between scientists from

Table 1. General comments and recommendations for future assessments gathered from the Mobile Bay workshop.

Comments:

- (C1)** The historical storm, Hurricane Georges, only flooded downtown Mobile and had an insignificant impact on the region as a whole; another historical storm would be more appropriate to evaluate present-day coastal resilience.
- (C2)** Understanding and assessing impacts of the hypothetical direct-hit Hurricane Katrina with 0.75-m increase in relative sea level on coastal system resilience was a challenge. It was difficult to view maps of water levels, winds, and waves and understand implications for performance and recovery of the various sectors in the system.
- (C3)** Recovery data were not known, although these data may exist within the local professional community in various forms including some available and some inaccessible repositories.
- (C4)** It was not clear how results of the assessments would be utilized by federal agencies and communicated more broadly to other organizations and communities. There was concern that results potentially would limit opportunities for local, state, and federal funding.
- (C5)** It was not clear how the methods added value to results from other coastal community resilience assessments.
- (C6)** The spatial scope of the study including both Baldwin and Mobile counties was too large. The temporal aspect of recovery was unclear and would vary depending on whether ENG, ECO, or COM sectors were evaluated.
- (C7)** Input from additional agencies and organizations were needed at the workshop to provide a more complete assessment of ENG, ECO, and COM functions within the region.

Workshop recommendations:

- (R1)** Participants should be engaged ahead of future workshops to select storms for assessment that are appropriate for their region.
- (R2)** Tools are needed to visualize and quantify storms in terms of their impacts to critical functions of ENG, ECO, and COM operation within the system.
- (R3)** Need to harness federal & local agencies to document and communicate post-storm recovery for ENG, ECO, and COM infrastructure in a common, widely accessible databank.
- (R4)** Need to define actions that would be associated with results of varying magnitudes, and how these results would be communicated within federal agencies and publicly.
- (R5)** Need to identify how these assessments are distinct from other coastal resilience assessments.
- (R6)** Need to focus the spatial domain for future assessments, and allow variation in recovery time scales for ENG, COM, and ENV sectors.
- (R7)** Document required attendees to ensure balanced representation for future workshops.

many disciplines and from the private and public sectors (Kates *et al.* 2000, Clark *et al.* 2002). Such collaborations, including government interventions and actions by private firms and non-governmental organizations, enhance coping capacity and reduce vulnerability (Adger *et al.* 2005). Through the Mobile Bay workshop, we found that the structure of this collaboration must be clearly articulated. There must be measures to invite a diverse and representative group of professionals to workshops and to make sure that the communication of both the methodology and purpose of and intended actions based on the evaluation are well understood. Preston *et al.* (2013) suggested that agencies 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 2013, p. 154). Further development of our assessment of coastal system resilience must embrace the concept of “boundary work” to address 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 that bridge communities, stakeholders, and disciplines and, most importantly, provide a transition from knowledge to action. Regardless of the “characterization of coastal resilience” that eventually would emerge from this type of exercise, different perspectives, backgrounds, or moti-

vations benefit from working together to jumpstart dialogue and ultimately more successful policy and implementation of coastal management decision making (Ward 2001, Bryson 2004, Tompkins *et al.* 2008, Few *et al.* 2007, Chapin *et al.* 2010, Carpenter *et al.* 2009).

The ERDC Tiered approach to quantifying coastal resilience was developed in order to answer the simple question of whether or not a selected coastal system is resilient to episodic forcing (e.g. coastal storms and inland flooding) with consideration of long-term change (e.g. sea level change, USACE operations, aging USACE infrastructure). The tiers allow for flexibility in study aim depending on the goals of the user – from rapid, planning level assessment to in-depth engineering analysis — and quantify coastal resilience

Table 2: Recommendations generated by the Mobile workshop’s synthesis of comments and feedback (Table 1) from the NAS Panel of TRB experts.

Workshop findings:

The storm severity was not appropriate for the region and the effects of the storm were difficult to envision.

The datasets and modeling efforts that were used to evaluate the system were outdated.

The impacts and communication plan for the findings were unclear.

The spatial and temporal scope of the study was too large.

Key stakeholders were not included at the workshop.

NAS Panel recommendation:

(E1) Communicating risk is a critical aspect of quantifying resilience. Use “lessons learned” from past events within coastal and non-coastal communities to initiate conversation.

(E2) Visually present extreme catastrophic scenarios, ensuring that these are based upon scientific datasets and modeling.

(E3) Gather data and public-facing information and populate a resilience framework before approaching a region for analysis.

(E4) Methods must be enhanced to have technical input regarding uncertainty, depth/damage functions, fragility and recovery curves, and direct application for the user to distinguish the methods from others and provide quantified, reliable, and transparent analyses.

(E5) Working with communities is an important aspect of quantifying resilience. Engage communities to consider end-user requirements and possible incentive programs for tool application.

(E6) Find a different process that combines stakeholder input with scientific assessment to set more realistic critical infrastructure functions and performance goals (i.e. a dashboard that can be altered according to the community’s specific needs).

(E7) Comprehensive representation from all agencies, organizations, and active responders within a region of consideration must be captured in the analysis. The methodology must demonstrate significant value to encourage participation. Incorporate a local champion within a community to bring together competitors and provide a “safe space” for discussion.

through a variety of community, expert and data-driven input on the entire coastal system. A coastal system may be characterized by three different types of infrastructure: community, environmental, and navigation/water resource, and the interactions between them. This approach suggests 1) that resilience is not only the response of physical infrastructure to storm damage but a property of a community and its interaction with the infrastructure system, and 2) that resilient solutions should be focused on effective performance and recovery in both the short and long-term. The key results of the Mobile Bay pilot study were the comments and recommendations received from both groups of reviewers and the

guidelines that were developed as a result. These guidelines for tool development will frame both future versions of the methodology and help guide and justify new research within the broad field of coastal resilience. In addition to synthesizing guidelines for the development of new tools, we also recommend that the process of action research should guide future coastal resilience quantification efforts to ensure that the voices of multiple stakeholders are both heard and utilized during the tool development process. Consciously partnering to ensure better communication and to provide better services to coastal communities is the true value of a resilience quantification methodology.

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