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# A matrix approach to community resilience assessment: an illustrative case at Rockaway Peninsula

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**Abstract** Existing community resilience assessment methods lack explicit reference to temporality of disruptive events and often use standard metrics that may not be universally appropriate. Linkov et al.'s (Environ Sci Technol 47(18):10108–10110, 2013a; Environ Syst Decis 33(4):471–476, 2013b) Resilience Matrix (RM) framework utilizes local stakeholder-informed metrics aligned with the temporal stages of the National Academy of Science definition of disaster resilience. Here we demonstrate the application of the RM to coastal community resilience at Rockaway Peninsula, New York. We present the flexibility of the RM methodology by using both qualitative and quantitative metrics drawn from post-Hurricane Sandy reports. The presentation of the case study results reveals opportunities to prioritize investments and collaborate among responsible parties.

**Keywords** Community resilience · Resilience Matrix · Rockaway · Resilience assessment

## 1 Introduction

Coastal communities are subject to frequent disruptive events such as hurricanes, but traditional risk reduction measures are difficult to achieve when physical improvements are voluntary (elevating homes, waterproofing basements) or culturally unpopular (high seawalls). Given this challenge, recent policies at the federal government level have focused on instead increasing the resilience of these systems (Larkin et al. 2015). Yet unlike systems that are predominantly technical, e.g., cyber networks, transportation networks, or electrical grids, those with strong social components have no single managing authority to clearly define optimal functionality and determine acceptable trade-offs to achieve resilience (Linkov et al. 2014). Instead, for socio-technical–ecological systems such as coastal communities, "soft" capacities such as collaboration, communication, and decision making can be an equally important factor in achieving resilience (Mendonça and Wallace 2006).

Resilience is a property of a system that describes the capacity to continue performing critical functions through disruptive events. The Resilience Matrix (RM) described by Linkov et al. (2013a, b) provides an organizing framework for assessing system resilience that can be applied successfully to communities as systems. Researchers have generally converged around the National Academy of Science (NAS) definition of disaster resilience—"the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (Committee on Increasing National Resilience to Hazards and Disasters 2012)—as the guiding concept. The RM identifies four broad domains of complex systems that include both physical assets and "soft" capacities and considers the performance of each of these domains at each of the four stages of a disruptive event described by the NAS. Other researchers and practitioners have organized metrics in terms of system categories (infrastructure, economic, social, environmental, community, political, hydrological, institutional, engineering, etc.) (Cutter et al. 2014; Frazier et al. 2010; Karamouz et al. 2014; Longstaff et al. 2010) or in terms of resilience characteristics (robustness, rapidity,

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resourcefulness, redundancy, restorative, adaptive, absorptive) (Bruneau et al. 2003; Francis and Bekera 2014; Longstaff et al. 2010) or both. The RM does not define specific metrics, but provides a framework to identify the relevant metrics to assess performance from a wider system perspective.

The RM framework diverges from the work of other community resilience methods (Cutter et al. 2014; Sempier et al. 2010; Karamouz et al. 2014) by utilizing a stakeholder-driven approach to identify indicators and thresholds of system performance specific to the community under consideration. In this way, the performance is defined relative to local needs rather than against performance of neighboring communities or national metrics, which may or may not be appropriate in the local context. Cutter et al. (2014) note that it is difficult to specify metrics of community resilience that are nationally applicable and at this time there is no clear method for external validation of metrics of community resilience. Consequently, the appropriateness and utility of any resilience assessment can only be judged by the community to which it is applied. Better yet, stakeholders are encouraged to select metrics from among those identified in other methods as significant indicators where possible, thereby integrating the RM with other methods to leverage the strength of both approaches.

The RM's generalized framework confers other strengths as well. Whereas interconnections are pervasive in all systems, urbanization, globalization, and technological advances make this especially true for communities. However, it is generally time and cost-prohibitive to investigate and model all of these interactions. The operational principle of the matrix is that to develop resilience, performance in all components of the system must be addressed. This differs from the past approach of engineered solutions, which have optimized individual components of system, but the failures of communities in the face of disasters are often due to cascading failures due to unidentified dependencies within the system. To be resilient to any scale of event, individual time stages or domains cannot be assumed to provide compensatory performance. Although the true relationship between system components may not be known, by improving resilience across all the breadth of the system, functionality can be maintained or quickly recovered.

The RM is a general framework for systems resilience assessment that has been previously developed and proposed in application to cyber, energy, engineering, and ecological systems (Eisenberg et al. 2014; Linkov et al. 2013a, b; Roege et al. 2014). This work is the first to present a specific method for completing a resilience assessment and applies it in limited form to a coastal community system.

## 2 Methods

The RM is a framework for the performance assessment of integrated complex systems. The framework consists of a 4 × 4 matrix where one axis contains the major subcomponents of any system and the other axis lists the stages of a disruptive event (Fig. 1). The rows describe the four general management domains of any complex system (physical, information, cognitive, social) as described in the US Army's Network-Centric Warfare doctrine (Alberts and Hayes 2003). The columns describe the four stages of disaster management (plan/prepare, absorb/withstand, recover, adapt) as defined by the NAS in their definition of resilience (Committee on Increasing National Resilience to Hazards and Disasters 2012).

Collectively, these sixteen cells provide a general description of the functionality of the system through an adverse event. Resilience is assessed by assigning a score to each cell that reports the capacity of the system to perform in that domain and time. For example, the Information-Recover cell is assigned a rating according to the ability of the system to collect (monitor) and share (analyze and disseminate) data that will aid in recovery. The Social-Adapt cell is assigned a rating according to the capacity of the system users to modify behavior and sustain changes beyond the immediate incident response. The matrix of scores can be aggregated to represent a snapshot of overall system resilience, which can be monitored over time, used for comparison with similar systems, or examined more closely to illuminate gaps in system capacity (Eisenberg et al. 2014).

To perform a resilience assessment using the matrix approach: (1) define the system boundary and range of threat scenarios under consideration; (2) identify the critical functions of the system to be maintained; (3) for each critical function, select indicators and generate scores for system performance in each cell; (4) aggregate the matrices to create an overall resilience rating. The following section

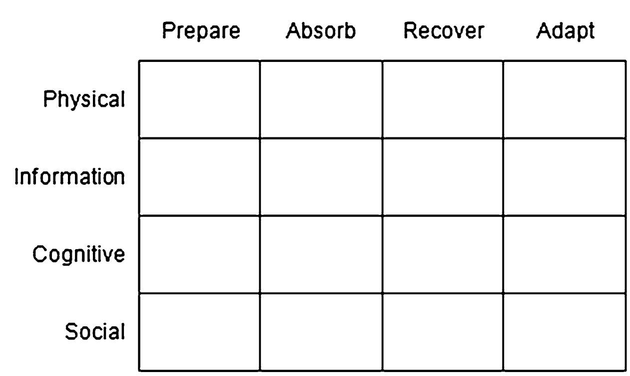


**Fig. 1** RM framework of Linkov et al. (2013a, b)

describes these steps in further detail with a focus on how to conduct an assessment at the community scale.

### 2.1 Define system boundary and threats

The RM approach is scalable to any size system. The system can be defined as a home and family, a neighborhood, a city, or a region. The system boundary should be defined geographically, and the scale will subsequently dictate the specificity of indicators. In addition, the range of threats under consideration should be established. These could include natural disasters, man-made disasters (cyber attack, terrorist attack, chemical spill, widespread power outage), or societal disasters (disease outbreak, economic recession).

### 2.2 Identify critical functions

To weather an extreme event, it is not always crucial to have every activity within a region continue uninterrupted. Critical functions are those that must be maintained at close to full capacity in order to continue providing the essential services of the system through the event and to support the resumption of other functions after the event. Most functions of interest will fall into categories related to residents, economy, or ecosystem. Possible critical functions for communities are: housing/shelter, food and clean water, medical services, transportation, electricity, sewage, industry/commerce, ecosystem services, education, and recreation. In the RM approach, each critical function of the system is individually assessed using the matrix. By performing an assessment at this level, the results may show that the system is highly resilient for one function but less resilient for others, thus providing more useful information to guide improvement than a generalized community resilience score. The number of critical functions chosen by the users should be limited to 3–5 to keep the inquiry to a reasonable scope. Critical functions will differ based on the location, scale, history, and values of the community.

### 2.3 Select indicators and generate scores

The RM uses a citizen- or local expert-informed approach. Best practice is to convene a panel of community representatives to perform the assessment. Such a panel should include experts knowledgeable about the context, i.e., at the community scale, this would include professionals or representatives of municipal government, municipal services, public utilities, transportation, medical services, emergency management, community development, commercial interests and needs, environmental and ecosystem sensitivity, locality-specific threats, and vulnerable populations, as well as citizens at large. Each cell of the matrix acts as an indicator of how well the system performs the given critical function. Rather than presume a set of comprehensive and universally appropriate metrics, the RM relies on local expertise to select indicators that pertain to the local context. These indicators should be selected keeping in mind some of the key properties of resilient systems that have been identified by others—modularity, dispersion, redundancy, flexibility, adaptability, resourcefulness, robustness, diversity, anticipation, and feedback response (Frazier et al. 2010; Park et al. 2013)—and acknowledging where each characteristic is most appropriate within the system of interest.

To support the role of a screening tool, the RM accommodates the use of the best available or most accessible data, whether qualitative of quantitative. Consequently, indicators and scores for each cell can be developed in a number of ways:

*Single metric* A single measurable quantity may be appropriate when it is a factor that drives or is largely indicative of the performance of the targeted section of the system. To determine how this measure affects the resilience score, the metric must be put in context; upper and lower bounds must be selected to identify optimal, or "good enough," performance and unacceptable performance. These two points define a linear utility function (unless sufficient information is available to suggest a nonlinear function), and the metric score is calculated as (metric value − lower bound)/(upper bound − lower bound), which results in a score between 0 and 1 (Linkov and Moberg 2011).

*Combined metric* When multiple factors are strong contributors to the functioning of the system but have differing performance, another option is to take an average or weighted sum of these multiple metrics. The weighted sum should be performed after the individual metrics have been contextualized with a linear utility function.

*Checklist* Where aspects of the system are not fully understood and an appropriate indicator of the degree or level of performance cannot be found, a simple checklist approach can be used to develop a score. Out of a comprehensive list of necessary components for functioning, the number of items checked is a possible metric. This approach is useful in the cognitive domain where the number of plans or extent of planning activities can be determined, but the sufficiency of the plans is difficult to assess. The matrix can be iteratively improved as more specific metrics are identified.

*Expert judgment* As an alternative to identifying specific metrics that are indicative of overall performance, knowledgeable local experts can generate scores based on their experience and history of the system. In this case, the experts are implicitly considering multiple factors and putting the score in the context of the values and preferences of the system of interest. Scores can be reported on a generalized none–low–medium–high (NLMH) scale, on a relative numeric scale such as 1-to-5 or 1-to-10, or in some cases the expert(s) can estimate a value for an identified but immeasurable or unreported metric.

As each metric is a specific measure but is utilized as an indicator of the functionality across the entire cell (system component), reporting the actual scores in the final output may suggest undue precision for the RM as a screening tool. Instead, the results are classified into quintiles and presented as a color-coded heat map of relative system resilience. In this way, the matrix results will focus on discussions about resilience improvement on what features of the system can achieve capacity targets rather than attempt to narrowly improve only the indicator selected for the screening assessment.

### 2.4 Aggregate matrices

For most systems and most stakeholders, there will be multiple critical functions of interest. In a full assessment, the same approach is used to identify indicators and generate scores in a matrix for each critical function. To assess the overall resilience of the system, the scores for each sector can be averaged across the critical functions to create a single matrix reporting general resilience. However, in many cases the management agency or stakeholder group completing the assessment will be able to ascribe different levels of relative importance to the different functions. The relative importance of each can be denoted as weights that are included in the process for aggregating similar cells across the critical functions, thereby generating a resilience score that can be used to inform mission-specific management goals. The raw assessment data are preserved for use by neutral parties.

## 3 Results: case study for community resilience at Rockaway Peninsula

In September 2013, the USACE Coastal Engineering Research Board (CERB) was charged with developing a methodology to assess resilience for coastal regions to aid district offices in planning, design, and operations (Rosati et al. 2015). The matrix approach was identified as a possible initial resilience screening and stakeholder engagement tool, to be utilized as Tier 1 in a three-tier assessment framework to assess overall coastal resilience. The subsequent tiers will focus more on evaluating the Corps of Engineers coastal assets and modeling performance of the system under simulated conditions. The Jamaica Bay area of Queens, New York, was identified by the CERB as a demonstration location of the proposed methodology as the area includes important components of three USACE civil works missions—flood risk management, navigation, and ecological restoration—in addition to being an area of interest following Hurricane Sandy and with significant existing data (Rosati et al. 2015). The following case study describes a partial application of the RM to the Rockaway Peninsula region of Jamaica Bay.

The Rockaway Peninsula is a seven square-mile strip of land in Queens, NY, that lies between the Atlantic Ocean and Jamaica Bay (Fig. 2). The area is mostly residential, with 115,000 residents from across the economic spectrum. On the southwest tip lies the gated community of Breezy Point with private beaches; the central peninsula contains neighborhoods of single-family bungalow communities of renovated early 1900s summer houses and areas with median household incomes of up to $118,000; the northwest end is dominated by multistory brick and concrete public housing developments built in the 1950s to 1970s, some with median incomes of only $17,000; and a close-knit working class neighborhood has existed for generations on Broad Channel, an island in Jamaica Bay itself (NY Rising Community Redevelopment Plans 2014a, b, c, d). Besides homes, the land area is approximately 50 % open and vacant space, and only 5 % is industrial and commercial property (NYC DCP 2012). The economy is local to serve largely the needs of the residents. Rockaway Beach is a popular weekend destination for the rest of New York City, but a strong tourism-related economy has not developed.

The peninsula forms the southern border of Jamaica Bay, a large saltwater marsh, part of which is a national wildlife refuge managed by the National Park Service. The Bay is both an important migratory bird habitat and an education

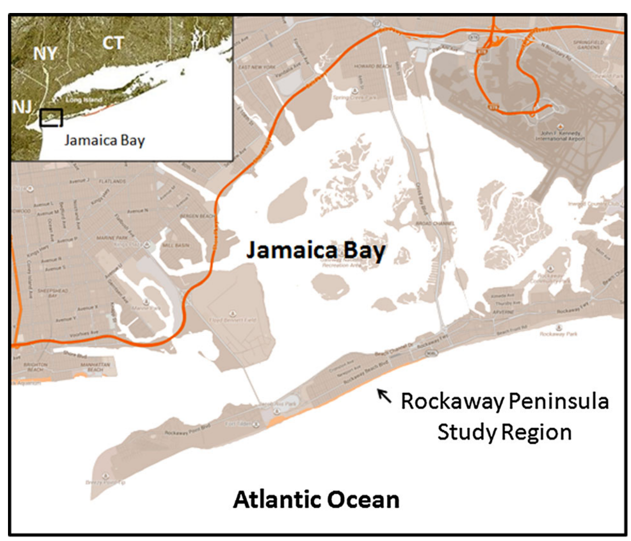


**Fig. 2** Rockaway Peninsula in Queens, New York, lies between Jamaica Bay and the Atlantic Ocean (Google Maps Base)

and recreation area. The health of the bay is fragile; over the past century, shipping activities, other industrial development, and sanitation works have released contaminants into the bay and dredging and development along the coastline have reduced the natural water circulation. The marshlands have lost the ability to regenerate themselves as the streams and rivers that feed new sediment to the bay have been paved over (National Park Service 2003).

Rockaway Peninsula is geomorphologically a low-lying barrier island with shorelines subject to daily tidal fluctuations and interior sections vulnerable to overtopping in severe storm events. Storms of the 1950s and 1960s inundated sections of the Peninsula with one to two feet of flood waters (FEMA 2013). More recently, the Rockaway Peninsula withstood flooding from Hurricane Irene in 2011 and suffered a direct hit from the storm surge generated by Hurricane Sandy (Fig. 3) in 2012. During Sandy, the beaches were almost entirely washed away and the boardwalk destroyed. In Fig. 3, it can be seen that much of the flooding is on the Bay side of the peninsula. Homes were destroyed, both washing debris into the Bay and littering the roadways, so that once the water receded, impassable roads became an impediment to restoring power. Although in retrospect, residents report that Irene was very manageable compared to Sandy, both events seriously disrupted the community, requiring long-term and costly evacuation and rebuilding activities for many residents and businesses (NYC OEM 2015).

### 3.1 System boundary and threats

The selected system includes the Rockaway Peninsula as a geographically isolated and demographically diverse section of Queens, along with Broad Channel, the only inhabited island within Jamaica Bay. The resilience assessment focuses on coastal storm threats, including hurricanes and nor'easters. The Rockaway beach has been termed "the most expensive beach in America" due to the large investments by the USACE to nourish the area for storm surge protection (Nessen 2013).

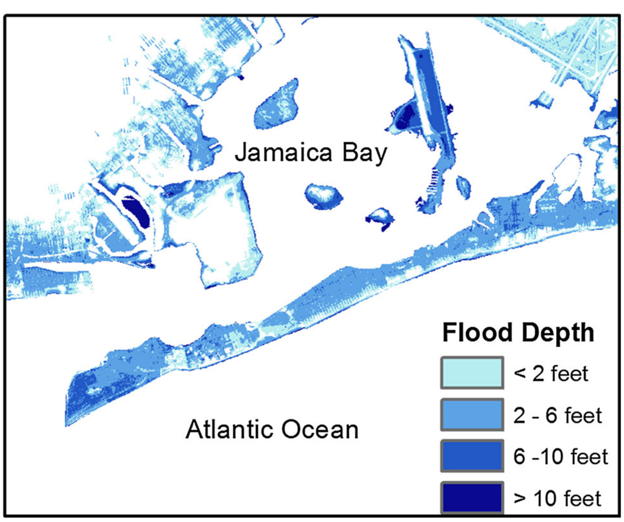


**Fig. 3** Flood depths on the Rockaway Peninsula during Hurricane Sandy (FEMA Final 3 m Surge Data 2014)

### 3.2 Critical functions

The Rockaway Peninsula of Queens, New York City, is largely residential. For the demonstration of the RM in this case study, the housing/shelter function is selected as the most critical function.

### 3.3 Metrics and scores

In lieu of an expert panel, this case study leverages extensive data from community workshops and federal and city task forces collected following Hurricane Sandy (Assistant Secretary of the Army for Civil Works 2013; NY Rising Community Reconstruction Plans 2014a, b, c, d; Gibbs and Holloway 2013; Redlener and Abramson 2013; NYC SIRR 2013) in order to demonstrate the RM. Informational interviews with several residents of the Peninsula and staff of the US Army Corps of Engineers and newspaper articles were used to provide further historical insights and nuance for the authors to identify indicators and benchmark utility.

Table 1 shows the identified indicators and values for each matrix cell along with the selected upper and lower bounds of utility functions to provide the context for the values. For the purposes of demonstrating the methodology, these indicators and bounding conditions were identified by the authors rather than an expert group. The indicator for Adapt-Social shows the Single Metric approach, the Physical-Prepare indicator demonstrates the Combined Metric process with each metric assigned a 50 % weight, and Prepare-Social utilizes Expert Judgment scoring. The final column reports the calculated score for each cell on a scale of 0 (low) to 1 (high). The scores were calculated using linear utility functions, giving the position of the metric value on a scale between the upper and lower bounds. For example, in the Physical-Recover cell, the upper bound (best potential performance) for beach rebuilding time is 2 months and the lower bound (minimal acceptable performance) is 12 months. The actual rebuilding time after Sandy was 10 months; thus, using the linear utility function, the final score is calculated as $(10-12)/(2-12)=0.2$. The exception to this method is the Prepare-Cognitive cell, where the common logs of the value and the upper and lower bounds are used in the calculation due to the approximately log-linear nature of storm return periods.

**Table 1** Selected indicators and scores for resilience assessment of the housing function at Rockaway Peninsula

| Matrix position | Metric selected | Value | Source | Upper bound (acceptable performance) | Lower bound (poor performance) | Score |
|---|---|---|---|---|---|---|
| Prepare-Physical | Average of two metrics: | | | | | |
| | Percent of coastline protected by dune or berm | 34 % | NY Rising Community Reconstruction Plans (2014a, b, c, d); Google Earth ruler tool | 100 %—entire region is <15′ above sea level | 0 % | 0.47 |
| | Height of dune relative to storm surge protection needs | 8.9′ | Assistant Secretary of the Army for Civil Works (2013) | 15′—approximate target height of new NY coastal projects | 0′ | |
| Prepare-Information | Weather forecasting and communication | High | *Personal communication with Rockaway Peninsula residents* | Qualitative Scale: none–low–medium–high | | High |
| Prepare-Cognitive | Storm level design | 30 years | Assistant Secretary of the Army for Civil Works (2013) | 200 years (log scale) | 1 year (log scale) | 0.64 |
| Prepare-Social | Coastal storm risk education | Medium | *Personal communication with Rockaway Peninsula residents* | Qualitative Scale: none–low–medium–high | | Medium |
| Absorb-Physical | Percent of coastline infrastructure with erosion protection (bulkheads, setbacks) | 75 % | NY Rising Community Reconstruction Plans (2014a, b, c, d); Google Earth ruler tool | 100 % | 0 % | 0.75 |
| Absorb-Information | Number of users of notify NYC emergency alert system | 200,000 | Silvestri (2014) | 3 million—target population is the 36 % of 8.4 million city residents that live in cell phone-only households | 0 | 0.07 |
| Absorb-Cognitive | Percent of evacuated population that can be housed in emergency shelters | 20 % | Gibbs and Holloway (2013) | 20 % | 0 % | 1 |
| Absorb-Social | Percent of residents that report likely to evacuate *before* the storm | 68 % | Gibbs and Holloway (2013) | 100 % | 0 % | 0.68 |
| Recover-Physical | Actually time to rebuild beaches and dunes | 10 months | Lau (2013) | 2 months—time required to physically place new sediment | 12 months—time to next hurricane season | 0.20 |
| Recover-Information | Communicate rebuilding guidance to residents via inspection tag system | Med | Harris (2012); *Personal communication with Rockaway Peninsula residents* | Qualitative Scale: none–low–medium–high | | Medium |
| Recover-Cognitive | Percent of rebuilding money dispersed at 1 year | 11 % | Redlener and Abramson (2013) | 75 % | 0 % | 0.15 |

**Table 1** continued

| Matrix position | Metric selected | Value | Source | Upper bound (acceptable performance) | Lower bound (poor performance) | Score |
|---|---|---|---|---|---|---|
| Recover-Social | Approximate percent of population still displaced at 1 year | 20 % | Redlener and Abramson (2013) | 0 % | 50 % | 0.60 |
| Adapt-Physical | Adaptability of protective infrastructure | Medium | *Personal communication with USACE planning staff* | Qualitative Scale: none–low–medium–high | | Medium |
| Adapt-Information | Community participation in city recovery planning meetings | 1000 | NYC SIRR (2013) | 13,000<br>~1/10 of Rockaway population | 0 | 0.08 |
| Adapt-Cognitive | Years for USACE to perform feasibility study, design, appropriate funding, and construction. (0 if no authority or guidance to consider climate change) | 10 | *Personal communication with USACE planning staff* | 1 (inverse of years) | 0 (inverse of years) | 0.10 |
| Adapt-Social | Median household income | $54,000 | US Census Bureau (2013) | $120,000—highest average income for neighborhoods in Queens County | $20,000—household poverty threshold for 2 person home | 0.34 |

### 3.4 Aggregate matrices

Figure 4 shows a way to summarize and communicate the performance scores from Table 1. The figure shows the relative results from the RM assessment of residential housing resilience to coastal storms on the Rockaway Peninsula in New York using a five-level color scale. Qualitative scores of high, medium, and low were converted to 1, 0.5, and 0 for this purpose. As only one critical function assessment is developed here, no aggregation is necessary. However, this study was motivated by the needs of the US Army Corps of Engineers' Coastal Engineering Resilience Board, and the USACE has civil works and environmental missions related to the protection of life and property, as well as navigation and estuary restoration (US Army Corps of Engineers). If other assessments of relevant critical functions for coastal communities completed, they might be weighted as such: housing (40 %), water transportation (20 %), wildlife habitat (30 %), and recreation (10 %). The equivalent cells of each critical function matrix could be aggregated using these weights to develop an overall community RM. The results would be appropriate to inform USACE management decisions and would aid in identifying gaps and prioritizing projects that align with agency missions.

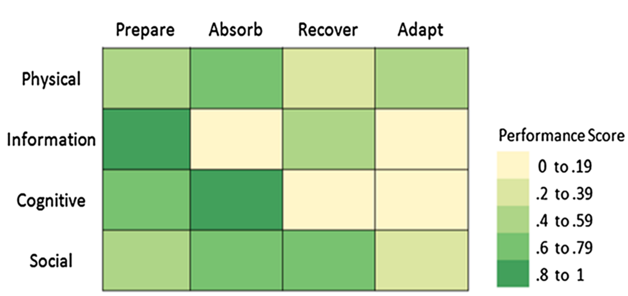


**Fig. 4** Performance scores (from Table 1) for the critical function of housing at Rockaway Peninsula presented in summary using a five-level color scale to aid in communication

## 4 Discussion

In this demonstration, we see that housing/shelter in the community has greater capacity to prepare for and absorb coastal storm events than to recover from them and adapt accordingly. Similarly, it has somewhat greater capacity across the social and physical domains compared to the information and cognitive domains. Low scores are largely due to the inadequately long time period to perform tasks, rather than an outright lack of resources. This pattern is expected in many coastal environments. Although state and federal recovery funding often becomes available to communities immediately following a damaging storm, the system is too disrupted to devote it to building new capacities, and instead, the money is used to return the system to its previous state. Resources for improvement available at other times are more limited and—before resilience became part of the national disaster management discussion—were used to reduce risk through physical disaster preparation and vulnerability reduction. These actions, while helpful, do not actively develop the capacity of the system to recover and adapt when it becomes impaired. The immediate utility of the matrix approach, given the infancy of the resilience industry, is to identify gaps in the capacities of the system to support the successful management of adverse events (i.e., resilience). Such information can guide the prioritization of ongoing community activities to ensure that the lowest performing components of the system are addressed in a timely manner.

In addition to the interpretation of the results, the RM approach provides the opportunity to open communication and establish relationships. First, the stakeholder engagement process generates conversation between residents and government agencies to help focus on the early development of improvement projects toward locally acceptable alternatives. Second, the process of completing the RM brings awareness to the full range of needs of the system and recognition to the fact that no one single government agency or community organization has the expertise, authority, or resources to manage the resilience of the entire system. For each critical function, the same framework can be useful to facilitate the development of partnerships among relevant management agencies by bridging responsibilities. For example, government agencies have traditionally focused on the plan and prepare temporal phase of resilience and tend to work in parallel only within their own agency mission (Larkin et al. 2015). Figure 5 displays a non-exhaustive list of the agencies and groups that may have responsibilities or capabilities related to supporting the function of the system components of a community. Establishing strategic partnerships may reduce costs by eliminating redundant efforts and enhance resilience by strengthening collaboration and lines of communication that can prove valuable in real-time disaster response. As an example, much of the flooding of Rockaway during Hurricane Sandy occurred from the Bay side of the peninsula. While the USACE can invest in building more robust coastal protections on the Atlantic side, without a partner to similarly increase protection on the Bay side (which is outside of the USACE authority and domain), any such project will have limited effectiveness.

Many methods exist for assessing community resilience, but not all provide a final output that is specifically designed to guide further action. The eventual use of resilience assessment tools such as this one will be to provide a baseline performance score on which the resilience improvement potential of proposed system changes can be evaluated.

| | Prepare | Absorb | Recover | Adapt |
|---|---|---|---|---|
| Physical | USACE, NYC Buildings, NPS | USACE, National Guard | USACE, FEMA, NPS | USACE, NPS |
| Information | NOAA, USACE | NYC Mayor's Office, FEMA | FEMA, NYC Buildings | NYC Planning |
| Cognitive | NYC Planning | NYC OEM, FEMA | FEMA, NYC | USACE, NYC |
| Social | NYC OEM | NYC OEM, FEMA, National Guard | NGOs, HUD | NGOs |

**Fig. 5** Agencies with expertise and/or authority to manage each component of the system. *USACE* US Army Corps of Engineers, *FEMA* Federal Emergency Management Agency, *NYC OEM* NYC Office of Emergency Management, *NYC Buildings* NYC Department of Buildings, *NYC Planning* NYC Department of City Planning, *National Guard* US Army National Guard, *NOAA* National Oceanic and Atmospheric Administration, *NGO* Non-Governmental Organizations, *HUD-US* Department of Housing and Urban Development, *NYC* many city departments within the City of New York, *NPS* National Park Service

At a minimum, the scores can be used to guide the selection of proposed projects to ensure that they are comprehensive in addressing the needs of the system pertinent to resilience, rather than investing in projects that are the easiest to accomplish or the most visible to the community. Although not demonstrated here, the matrix approach can be effectively used to this end via a qualitative approach. Proposed projects can be assessed by determining which indicators of which critical functions would be affected by implementing the project and recalculating the resilience scores to compare against the baseline. The methodology provides a process to document recognized reduction of performance in some system components in addition to improvement of performance in others. For example, mobile generator-run pumps may increase recovery for residents in the physical domain by providing a modular resource. On the other hand, unlike permanent stormwater pumps, mobile pumps discharge water untreated, which may reduce the recovery of ecosystem health. In documenting the impacts of proposed projects across multiple critical functions, the RM provides a structured basis for decision making.

## 5 Conclusion

This case study demonstrates the methodology of applying the RM to coastal community resilience assessment. The RM is a new community resilience assessment method with specific strengths over existing methods. The RM provides a framework that utilizes stakeholder-informed selection of metrics and critical functions, assesses resilience in terms of the stage of disruptive events that make up the resilience definition, and allows the use of both qualitative and quantitative data in the resilience scoring process. Furthermore, the RM can be combined with other methods by incorporating their identified metrics into the RM framework to utilize the strengths of both approaches. The process of completing the assessment with community professionals and experts can provide an important education and engagement tool. In addition, the final presentation of relative performance in different parts of the system via a color-coded visualization is useful for communication and project development. The RM is flexible enough to be used as a screening tool given any level of data availability, but detailed enough to support actionable decision making (Linkov et al. 2013a, b).

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