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Environmental Resilience:
Exploring Scientific Concepts for Strengthening Community Resilience to Disasters

Office of Research and Development
National Homeland Security Research Center

Disclaimer

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List of Acronyms & Abbreviations

AAAS	American Association for the Advancement of Science
CBRN	Chemical, Biological, Radiological, and Nuclear
CBWR	Community-Based Water Resiliency (Tool)
CERI	Community Environmental Resiliency Index
CHNS	Coupled Human-Natural System
CREAT	Climate Resilience Evaluation & Awareness Tool
DOI	Department of the Interior
DOSII	Database of Sustainability Indicators and Indices
EJ	Environmental Justice
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPI	Environmental Performance Index
FEMA	Federal Emergency Management Agency
HSRP	Homeland Security Research Program
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air Conditioning
I-WASTE	Incident Waste Assessment & Tonnage Estimator
NCEA	National Center for Environmental Assessment
NEJAC	National Environmental Justice Advisory Council
NERL	National Exposure Research Laboratory
NHSRC	National Homeland Security Research Center
NIST	National Institute of Standards and Technology
NRC	National Research Council
NRMRL	National Risk Management Research Laboratory
ORCR	Office of Resource Conservation and Recovery
ORD	Office of Research and Development
OSC	On-Scene Coordinator
OSP	Office of Science Policy
OSWER	Office of Solid Waste and Emergency Response
OW	Office of Water
PPD	Presidential Policy Directive
ROE	Report on the Environment
SDWA	Safe Drinking Water Act
TEVA-SPOT	Threat Ensemble Vulnerability Assessment–Sensor Placement Optimization Tool
US	United States
USGS	U.S. Geological Survey
USPS	U.S. Postal Service
WARN	Water/Wastewater Agency Response Networks
WEST	Waste Estimation Support Tool

Table of Contents

List of Acronyms & Abbreviations ii
Executive Summary 1
Key Workshop Themes 7
Resilience and environmental resilience concepts 7
Resilience, sustainability, and environmental justice 7
Resilience indicators 8
Index development and CERI products 9
Workshop I Highlights 10
Workshop II Highlights 14
CERI Workshop Outcomes 18
Next Steps 19
Afterword 20
Appendix A: Participants in the CERI Workshops 21
Appendix B: Agendas for CERI Workshops 24
Appendix C: Definitions and Descriptions of Resilience 28
Appendix D: CERI Breakout Discussion Questions 30
Appendix E: Community Environmental Resilience Indicators 31
Appendix F: CERI Workshop I Technical Brief 32
Appendix G: Project Resources & References 36

List of Figures

Figure 1: Definition of Resilience in Recent Federal Policy 4
Figure 2: Timeline of Federal Policies and Guidelines Addressing Resilience 5
Figure 3: Stages in the Cycle of Resilience 5
Figure 4: Benefits of Constructing an Index 6
Figure 5: CERI Team Definition of Environmental Resilience 7
Figure 6: Resilience as a Foundation for Achieving Sustainability 8
Figure 7: Key Design Considerations for Constructing an Index 9
Figure 8: Process for Improving Flood Resilience 12
Figure 9: Resilience & Sustainability, Distinct System Capacities 13
Figure 10: All-Hazard Threats to Health & Environment 14
Figure 11: EPI Index Development 16

List of Tables

Table 1: Available EPA Resilience Tools 11

Executive Summary

The U.S. Environmental Protection Agency (EPA) protects human health and the environment. The agency has responsibilities in emergency and disaster preparedness, response, and recovery. This work involves actions such as protecting water infrastructure, cleaning up contaminated sites, and promoting sustainable and resilient rebuilding. EPA's Office of Research and Development (ORD) Homeland Security Research Program (HSRP) conducts scientific research to improve the effectiveness and efficiency of EPA's response and remediation efforts. EPA's work in disasters helps communities build resilience. Presidential Policy Directive (PPD)-21 and Executive Order (EO) 13653 define resilience as "…the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions." Having a scientific means of measuring resilience would allow EPA, states, and local stakeholders to identify vulnerabilities, assess environmental and health risks of disasters, establish benchmarks, and track progress in improving recovery capacity.

In an effort to measure resilience, an HSRP team launched an innovative research project in late 2013 to conceptualize a framework for developing a Community Environmental Resilience Index (CERI). It followed a National Research Council (NRC) report on disaster resilience and interagency efforts in response to Hurricane Sandy. The CERI team used the five-step index development process used by the Yale Center for Environmental Law and Policy for its global *Environmental Performance Index* (EPI). It adapted the principles and criteria that the EPA's *Report on the Environment* (ROE) used to develop environmental indicators.

The first project goal was to define community environmental resilience and describe EPA's role in supporting it. The second was to establish how indicators could measure the resilience of environmental systems upon which communities depend. The third was to identify new opportunities to provide communities with tools and expertise to enhance their resilience to disasters. The fourth goal was to develop a network of collaborators for exploring CERI applications, indicators, and indices. This report summarizes the outputs of two workshops conducted by the CERI team involving 120 participants from across EPA, the federal government, academia, and other organizations.

The HSRP team convened a workshop in May, 2014, attended by 63 experts from EPA. Participants gained a better understanding of EPA's role in disaster recovery. They explored scientific concepts regarding environmental resilience. The EPA Office of Solid Waste and Emergency Response (OSWER) and Office of Water (OW) reported on how they build resilience through water security, waste management, and cleanup programs using utility-specific tools and indicators. EPA Region 2 briefed participants on how EPA and other federal partners assisted environmental response, recovery, and rebuilding after Hurricane Sandy. Participants from other EPA programs shared how they applied community resilience concepts to their work. Workshop participants recognized the value of pursuing a systems approach to resilience science. They identified the need for further research to address the relationship between resilience, sustainability, and environmental justice (EJ), key elements of EPA's mission and most recent Strategic Plan.[i]

Based on workshop discussions, the CERI team proposed a working definition of community environmental resilience: *Minimizing environmental risks associated with disasters, quickly returning critical environmental and ecological services to functionality after a disaster while applying this learning process to reduce vulnerabilities and risks to future incidents.*

Another outcome was a call to identify and inventory tools EPA has already produced to help communities assess their environmental vulnerabilities to disasters, health and environmental risks of disasters, and environmental recovery capacity. These tools address water security, contaminant detection, flood resilience, decontamination, emergency water supply, waste management, environmental justice, and other issues. As a result of this workshop, a report on EPA's resiliency tools will soon be published.

Communities can use indicators to monitor and measure progress in improving their resilience to disasters and other shocks to their social, environmental, and ecological systems. These indicators should be relevant, compelling to local stakeholders, and easily measured. Participants proposed an initial list of community environmental resilience indicators such as: percent municipal budget in reserve, number of environmental stakeholders involved in disaster preparedness exercises, ratio of green to gray infrastructure, landfill capacity, wetlands loss in last decade, and number of local environmental organizations per capita. They identified potential sources of indicators such as EPA's ROE, Database of Sustainability Indicators and Indices (DOSII), and framework and indicators of urban resilience to climate change. The workshop fostered an emerging community of interest in resilience across the agency.

The second workshop in July, 2014, was attended by 68 experts from EPA, ten other federal agencies, universities, and other organizations. One goal was to develop a common understanding of the importance of community environmental resilience to disaster preparedness, response, recovery, and mitigation. Another goal was to refine the initial list of indicators and build a roadmap for how to structure a CERI to support disaster decision-making.

One outcome of the July workshop was further refinement of proposed resilience indicators. Indicators for environmental health and environmental justice, the water-energy nexus, the waste-energy nexus, and ecological systems and services were discussed. Qualitative and quantitative indicators were suggested.

A second outcome was a better sense of how to structure a CERI to maximize its utility. Participants learned how the Yale EPI has become useful to environmental policy across the globe and how EPA's ROE uses indicators to measure national progress toward human health and environmental goals. They saw how strategic science has become part of disaster response at the U.S. Department of the Interior (DOI). Participants identified environmental information needs of disaster decision-makers including community planners, emergency management departments, public works and utilities, and state and federal agencies. They suggested developing a flexible framework for a CERI to apply it to a variety of communities and disaster situations. Communication and collaboration with stakeholders throughout the index development process was also emphasized. CERI products might be a full-fledged index, a self-assessment checklist, or a series of benchmarks.

The third outcome of the workshop was to identify potential purposes, audiences, and uses for a CERI. Audiences could include EPA, other federal agencies, state and local officials, and others involved in disaster and land use planning in urban or rural communities. It could be used by:

- Researchers, to identify thresholds above or below which systems gain or lose resilience;
- Communities, states, and tribes, to conduct self-assessments that benchmark vulnerabilities, capabilities, and needs;
- Communities, states, and tribes, to track improvements following preparedness and mitigation actions;
- Federal program managers, to guide resource allocations and measure policy outcomes.

A final outcome was that the workshop further expanded the network of collaborators interested in community environmental resilience research, indicator development, and CERI applications.

The next steps for the CERI research team are to continue inventorying relevant indicators and seeking ways to apply EPA's resiliency tools. Following the conclusion of the workshops, the HSRP team has reached out to other ongoing resilience efforts including EPA's *Making a Visible Difference in Communities* initiative, interagency working groups and projects, and non-federal organizations that have Memoranda of Understanding with the EPA. The research team is working to leverage EPA's environmental indicators and collaborate with OSWER, OW, and other EPA Programs and Regions to further refine and test community environmental resilience indicators. They plan to adapt the Yale EPI index development process and begin by more clearly articulating the audience, principles, and goals of a CERI. As a result of the workshop, an ongoing exchange of information on emerging issues in resilience science and practice continues with an expanding network of collaborators.

Background to Workshops

Across the United States (US), communities experience extreme weather events, technological accidents, and other disruptive incidents. Since 2000, US Presidents have issued between 45 and 99 major disaster declarations annually.[ii] In 2014, eight weather and climate disaster events in the US caused losses exceeding $1 billion each.[iii] Disasters such as these impact communities in many ways. They destroy critical infrastructure and natural resources, damage human health and the local economy, displace human populations, and disrupt environmental services. One way for communities to improve their capacity to cope with disasters is to enhance their resilience (Appendix C).

Presidential Policy Directive (PPD)-21 and Executive Order (EO) 13653 define resilience as "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions" (Figure 1).[iv,v] Resilience helps communities mitigate risks disasters pose and facilitate recovery after an incident. Actions to build resilience may take place during any stage of disaster mitigation, preparedness, response, recovery, and rebuilding. In his introduction to the 2013 *Hurricane Sandy Rebuilding Strategy Report*, Hurricane Sandy Task Force Chair and former Secretary of Housing and Urban Development Shaun Donovan recognized that *"[resilience] work will help protect communities in the region when future disasters take place. It will also make a positive impact on budgets… We know that every dollar we spend today on hazard mitigation saves us at least $4 in avoided costs if a disaster strikes again. By building more resilient regions, we can save billions in taxpayer dollars."*[vi]

> ***'Resilience' means the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.***

FIGURE 1: DEFINITION OF RESILIENCE IN RECENT FEDERAL POLICY

The U.S. Environmental Protection Agency (EPA) has worked extensively with states, utilities, and other community stakeholders in disaster preparedness, emergency response, and recovery. After a devastating tornado struck Joplin, Mo., in 2011, EPA provided $5.4 million from the Superfund program to sample and remediate lead- and cadmium-contaminated soils to facilitate community rebuilding. In 2013, EPA provided $340 million to New York and $229 million to New Jersey to improve wastewater and drinking water treatment facilities impacted by Hurricane Sandy. Such water and storm protection improvements incorporate green infrastructure that can improve sustainability and resiliency by reducing stormwater runoff, lowering energy usage, and protecting floodplains. Efforts like these that build community resilience have been guided by federal policies that address disasters, homeland security, and climate change (Figure 2).[vii] These policies have begun to use resilience as a guiding principle and call on federal agencies to integrate resilience into their core programs.

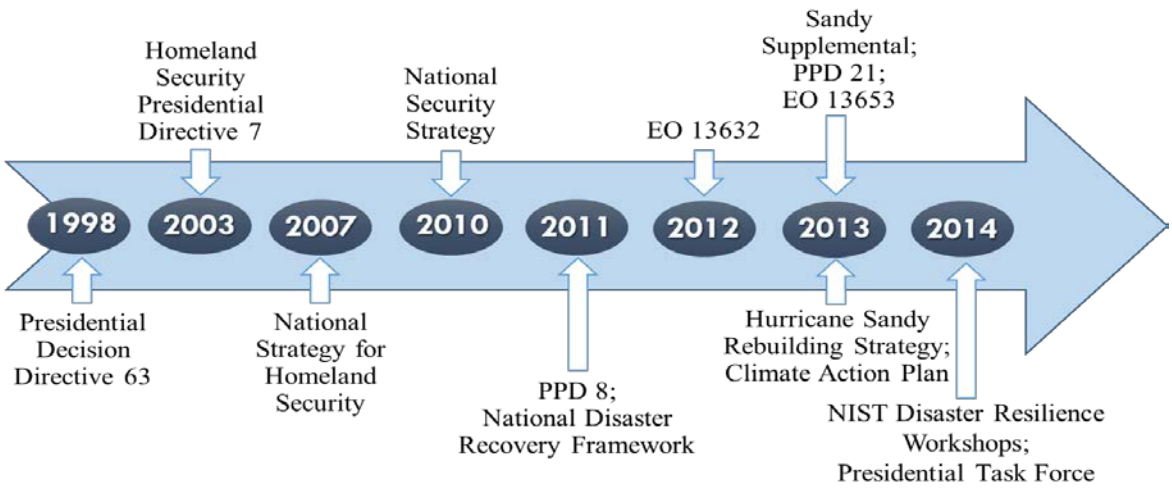

FIGURE 2: TIMELINE OF FEDERAL POLICIES AND GUIDELINES ADDRESSING RESILIENCE

The Homeland Security Research Program (HSRP) supports EPA's work in disaster preparedness, response, and recovery (Figure 3). It conducts research in two key areas: protection of water and wastewater systems and decontamination following a disaster. Its water security research addresses water system resilience. HSRP recently expanded its research focus to include "all-hazard" disasters, that is, natural hazards as well as chemical, biological, radiological, and nuclear (CBRN) incidents. As part of this shift, its research in resilience measurements and indicators has expanded, as well.

FIGURE 3: STAGES IN THE CYCLE OF RESILIENCE
Adapted from U.S. EPA. 2015. Systems Measures of Water Distribution System Resilience

The ability to use indicators to measure resilience would allow EPA, states, and local stakeholders to identify vulnerabilities, establish benchmarks, and track progress in reducing vulnerability and improving recovery capacity. The 2012 National Research Council (NRC) report on resilience calls for improved ways to assess community resilience, but also reveals a gap in scientific measurements of the resilience of environmental systems upon which communities depend (Appendix G). The EPA offers a number of scientifically based environmental indicators such as those in the Report on the Environment (ROE), but these do not

include resiliency indicators. To begin to fill this gap, the research team decided to explore scientific concepts for developing a Community Environmental Resilience Index (CERI).

An index is a collection of weighted indicators. It provides scientific measurements relevant to decision-making. The index development process laid out by the Yale Environmental Performance Index (EPI) was used as a guide for creating a CERI. The EPI itself does not measure resilience but does offer a refined methodology for creating an environmental index to be used in decision-making (Figure 4). The CERI team adapted the principles and criteria for establishing environmental indicators used by the ROE. A CERI could be used by the Federal Emergency Management Agency (FEMA) to establish priorities for preparedness or mitigation grants, by the U.S. Department of Housing and Urban Development (HUD) to measure success of its National Disaster Resilience Competition, or by EPA's Water Infrastructure and Resiliency Finance Center to evaluate community risks and vulnerabilities. Communities could develop self-assessment checklists to track their own progress in building resilience.

An environmental index can be used to "Distill complex information, allowing decision makers and key audiences to efficiently spot critical areas of concern, support policy development and target setting, and measure impacts of policy responses" (Hsu et al 2013 p. 5)

FIGURE 4: BENEFITS OF CONSTRUCTING AN INDEX

The CERI team hosted two workshops to explore scientific concepts, information needs, and strategies for developing a CERI (Appendix B). The first workshop was held May 6-7, 2014, concurrently in EPA facilities in Cincinnati, Ohio, Research Triangle Park, N.C., Washington, D.C., and via webinar. The workshop was attended by 63 participants from EPA's Office of Research and Development (ORD), Programs, and Regions. The workshop was organized around three questions:

- Would a CERI be relevant to EPA's work in disasters?
- What building blocks are already in place in terms of indicators, science, and tools?
- Who wants to be involved from across the agency?

The second workshop was held July 22-23, 2014, in Arlington, Va., and via webinar. The workshop was attended by 68 participants from EPA, ten other federal agencies, and scientific experts from academia and other organizations (Appendix A). The workshop was organized around four questions:

- What is environmental resilience?
- What indicators should we include in a CERI?
- How do we build a scientifically valid and usable index?
- Who will use a CERI, and in what form?

Key Workshop Themes

Plenary and breakout discussions at the workshops coalesced around four key themes: resilience and environmental resilience concepts; resilience, sustainability, and environmental justice; resilience indicators; index development process and CERI products (Appendix D, Appendix F). A few key takeaways for each theme follow.

Resilience and environmental resilience concepts

The workshops explored resilience concepts by examining how established definitions relate to EPA's mission and its work in emergency response, environmental justice, water, waste, and sustainable communities. Participants concurred that resilience is a systems concept with social and environmental components. They deliberated whether it applies to different types of disasters: slow-moving events as well as acute shocks, economic disruptions as well as environmental disasters. One lingering uncertainty is how resilience relates to other concepts such as vulnerability, resistance, and risk management. Another point of debate was what the end goal of resilience is: a return to normal or adapting to a new normal.

Participants suggested several ways EPA could engage with communities on resilience. One was to establish a common language to aid communication between EPA and local stakeholders. Another was to test technologies before an incident. Helping communities understand and apply EPA tools was mentioned. EPA research could help communities assess vulnerabilities, assets, and potential impacts of disasters. Challenges to engaging communities on resilience were also noted. Federal agencies play limited roles after disasters. Organizational structure and statutory mandates can impede collaboration within and between agencies.

A proposed definition of environmental resilience emerged from the first workshop and was received positively at the second workshop (Figure 5). This proposed definition builds on other established definitions and provides a more specific focus on what resilience means for protecting human health and the environment.

Environmental resilience:
Minimizing environmental risks associated with disasters, quickly returning critical environmental and ecological services to functionality after a disaster while applying this learning process to reduce vulnerabilities and risks to future incidents.

FIGURE 5: CERI TEAM DEFINITION OF ENVIRONMENTAL RESILIENCE

Resilience, sustainability, and environmental justice

The workshops explored how resilience relates to EPA's priorities in sustainability and environmental justice. Participants discussed how environmental justice considerations are important to resilience and how resilience is relevant to EPA's ongoing work in Environmental Justice (EJ). The environment can present a threat during disasters. Floodwaters and tornado debris can create new exposure routes for environmental contaminants, for example. There was recognition that communities overburdened by environmental harms and underrepresented in

decision-making processes may be particularly vulnerable to the environmental impacts of disasters. Participants wondered whether affluent communities are more resilient and expressed interest in building resilience in ways that empower communities.

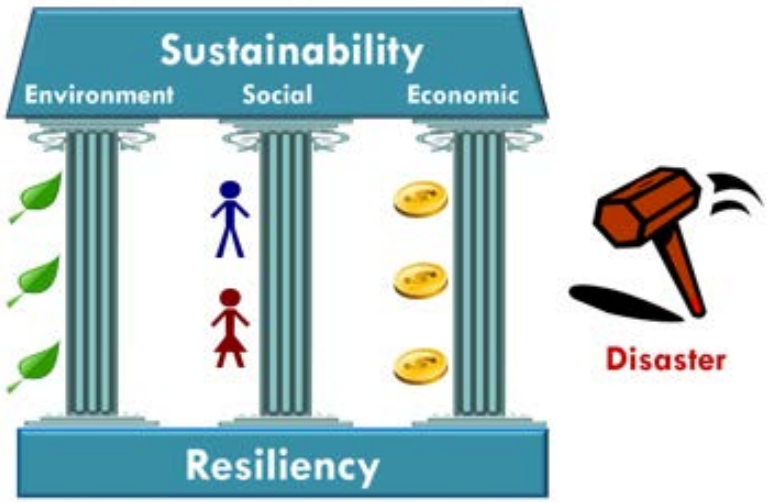

FIGURE 6: RESILIENCE AS A FOUNDATION FOR ACHIEVING SUSTAINABILITY

Working towards a sustainable future is one of seven EPA themes, a cross-agency strategy, and a principle underlying ORD research. Participants recognized that resilience to shocks and disasters is necessary for communities to achieve environmental, social, and economic sustainability (Figure 6). They acknowledged that there may be tradeoffs, as well. Resiliency may involve raising a short term environmental footprint to support long term sustainability.

Resilience indicators

A number of suggestions were made for developing community environmental resilience indicators. The first suggestion was to leverage existing EPA work in indicators and indices. Other environmental data sources such as urban tree inventories were mentioned, as well. Second, the team should finalize its criteria for what makes a good indicator. Scientific validity, routinely collected data, baseline data availability, and usability were mentioned as desirable qualities. Indicators should be evaluated periodically and deselected if no longer applicable.

There was general agreement that a systems approach should be used to measure resilience. Water, energy and transportation systems are all interdependent, for example. Upstream and downstream effects must be taken into account. There was not complete agreement over whether a community- or a sector-based approach was preferable to developing indicators. Participants noted that recovery speed and quality are integral to resilience and should both be measured.

Several challenges to measuring resilience were recognized. One is integrating measurements and data across systems. Another is that many aspects of disaster vulnerability and recovery are not easily measurable. Particular attention must be paid to the spatial scale of the measurement. Waste management jurisdictions or hospital visits for asthma attacks may not directly correspond with community boundaries. Time scales are also important. Lease lengths may affect residents' decisions to return after a disaster, and contaminants have varying persistence times in the environment. Forward-looking and scalable indicators were mentioned as desirable.

A number of potential indicators for a CERI were suggested, including several that are not routinely included in current resilience assessments (Appendix E). Suggested indicators spanned socioeconomic and environmental systems. Indicators of water resilience should address water systems serving the largest populations, those with most damage to drinking water systems, and

the ecosystem functions that support water supplies. Measurements should capture the functionality of the entire system, including drinking water, wastewater containment, secured reservoirs and surface impoundments, pumping stations, backup energy supplies, source water and aquifer recharge zones. Indicators of waste resilience could include landfill capacity, age of infrastructure, planning and field exercises conducted, affected populations in disaster and disposal sites, and maturity of curbside recycling programs.

Index development and CERI products

The value of developing a CERI was recognized. A CERI could help EPA, other federal agencies, states, tribes, urban and land use planners, non-governmental organizations, emergency responders, and community decision-makers prioritize issues, make decisions, and allocate resources to achieve resilience goals and objectives.

There was general consensus that the Yale EPI index development process was appropriate to follow because of its clear focus on identifying the audience and articulating the principles and goals of an index (Figure 7). Participants noted that a communications plan and community engagement are necessary from the onset to develop common language and understanding. The CERI development process should be transparent and incorporate feedback from community stakeholders. Following this method should result in a framework that is relevant to local values and flexible enough to accommodate local needs.

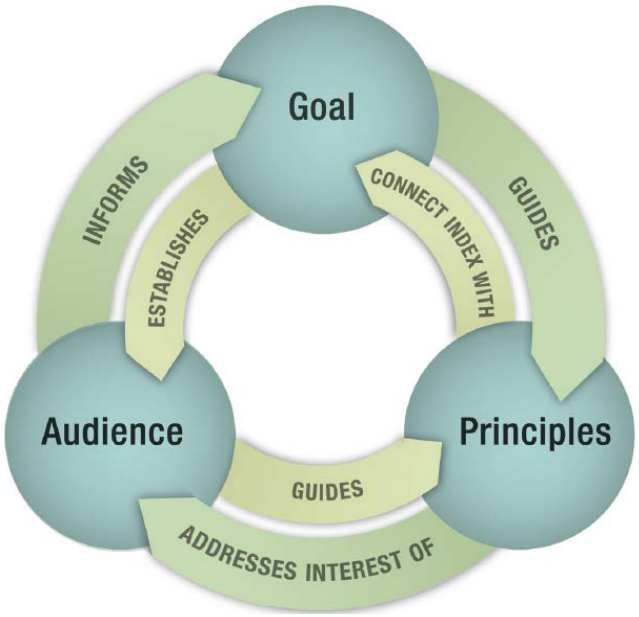

FIGURE 7: KEY DESIGN CONSIDERATIONS FOR CONSTRUCTING AN INDEX
Adapted from Hsu et al 2013

Building an index involves selecting, normalizing, and weighing indicators. Indicators should be selected based on relevance and importance. One way of prioritizing indicators would be making those that reflect critical functionality of basic life systems such as energy, water, food, mobility, and healthcare the highest priority. The possibility of creating a computational model was raised. An index should show a range of values, not a dichotomy, and could be semi-quantitative. Participants pondered whether different types of incidents or different places would require different indices. A one-size-fits-all set of indicators might not be relevant for all communities. An alternative is to develop a flexible framework. Communities themselves could tailor an index based on their values, vulnerabilities, and hazard threats. Data collection could be done in conjunction with communities.

There was not complete agreement on what CERI products might be. Some participants advocated for a scientifically vetted and validated index. Others proposed establishing a set of community benchmarks in lieu of an index. For example, the top three benchmarks for water

infrastructure protection could be availability, reliability, and upstream/ downstream dependencies. A number of participants thought that a community self-assessment checklist or dashboard might be of greater use to decision-makers at the state or local level. Still others recommended adding a CERI to existing EPA platforms. There was agreement that end-product should be useful to and easy to use by community stakeholders.

Workshop I Highlights

The first workshop was organized to identify EPA's assets, research needs, and opportunities in the realm of community resilience. By identifying potential uses of a CERI to support resilience and sustainability research, the goal was to generate interest throughout the agency. In his opening remarks, Dr. Gregory Sayles, the Acting Director of EPA ORD's National Homeland Security Research Center (NHSRC) and the National Program Director of the HSRP, outlined the vision of this initiative. It provides an opportunity for EPA and other federal partners to collaborate on exploring a CERI as an analytical and research planning tool to identify ways to strengthen communities' resilience to natural and anthropogenic disasters.

Brendan Doyle, Senior Advisor to EPA ORD NHSRC, outlined the concepts and development of a CERI. He shared the Yale EPI as a model for index development. The workshops are designed to help the CERI team advance through the first three steps of the index development process. He then gave examples of how a CERI would be helpful in communities.

Dr. Keely Maxwell, then an American Association for the Advancement of Science (AAAS) Fellow in EPA ORD NHSRC, discussed *Community Resilience Science: Definitions & Systems Model*. Dr. Maxwell was joined by Doug Pabst, the Chief of Region 2's Sandy Recovery Green Team. Mr. Pabst presented a case study of *Community Resilience in Action @ EPA: Disaster Response*. Dr. Maxwell described scientific resiliency models, including a coupled human-natural systems (CHNS) model of resilient systems.

Mr. Pabst shared the case study of Hurricane Sandy. On October 29, 2012, Hurricane Sandy hit the Mid-Atlantic coast. EPA Region 2 offered immediate technical assistance to wastewater and drinking water facilities by providing On-Scene Coordinators (OSCs) and site assessments. Mr. Pabst highlighted the rebuilding strategy that was developed after the incident and described the structure of the Sandy Regional Infrastructure Resilience Coordination Group. He also noted that Group members were beginning to assess impacts of Hurricane Sandy on environmental and natural resources in the Region.

The participants broke into small workgroups to discuss definitions of community resilience and how EPA could apply the concept of resilience to its work on different types of disasters. The workgroups identified what information, resources, and collaborative efforts would be required, and what EPA tools are available to on-scene coordinators, water utilities, and other stakeholders involved in disaster planning and response (Table 1). Restoring estuaries and wetlands, proactively managing debris and waste and addressing interdependencies between water and energy systems are all steps communities can take to strengthen their environmental resilience.

Dr. Alan Hecht, Director of Sustainable Development, ORD and Dr. Peter Jutro, former Acting Associate Administrator for Homeland Security, engaged in a discussion on the differences and

the similarities between *Sustainability and Resiliency*. Dr. Hecht noted that sustainability is one of the cross cutting goals of EPA. People depend on environmental, social, and economic systems that are more and more tightly coupled. Because of these system linkages, resilience is a key element to achieving sustainability. From the Homeland Security perspective, resilience is the ability to bounce back as quickly as possible after a natural disaster or homeland security incident. Recent examples include the World Trade Center attack and Hurricane Sandy. These incidents can be statistically predictable like a hurricane or tornado or unpredictable like a terrorist attack. Differentiating between rapid disasters and slow moving changes such as climate change is also necessary for building resilience. EPA has a role in enhancing resilience and in interagency response and recovery. Dr. Hecht called for a comprehensive inventory of EPA tools that aid the agency's resilience efforts.

TABLE 1: EPA RESILIENCE TOOLS DISCUSSED AT FIRST CERI WORKSHOP

Resilience Tool	Purpose
Climate Resilience Evaluation and Awareness Tool[1]	Water utilities explore climate change impacts & adaptation strategies
CANARY & TEVA-SPOT[2]	Detection & early warning for contaminants & service disruption in drinking water distribution systems
Community-Based Water Resiliency Tool[1]	Water utilities gauge current preparedness efforts. Promote community awareness of need to include the water sector in emergency planning.
Emergency Water Supply planning guidance[1]	Guidance on how to plan for disruptions in drinking water services
Flood Resilience: A Basic Guide for Water & Wastewater Utilities[1]	Understand flooding threats, identify vulnerable assets, evaluate mitigation options
Water Security Toolkit[2]	Evaluate & design rapid responses to water contamination incidents
Water Resiliency Action Planner Kit[1]	Convene meetings with key players in water utility planning to discuss roles & responsibilities during water service interruptions
Water/Wastewater Agency Response Networks (WARN)[1]	Intra-state network of utilities for effective sharing of local water sector resources during disasters or service disruptions
My Environment[1]	Integrate community environmental & health data with maps based on a user's location; "Shout out" to report on local environmental efforts
I-WASTE[3]	Estimate types of debris, select appropriate waste management after a disaster
Waste Estimation Support tool (WEST)[1]	Estimate waste from a wide-area radiological incident as a function of selected decontamination approaches
Municipal Solid Waste Decision Support Tool[4]	Solid waste planners evaluate environmental aspects & cost of integrated waste management strategies
Integrated Climate & Land Use Scenarios[1]	Estimate housing density, population, impervious surfaces for climate scenarios
Environmental Justice View[1]	Create online maps to view factors affecting community environmental health
[1]Via search on http://www.epa.gov [2]https://software.sandia.gov//trac [3]http://www2.ergweb.com/bdrtool/login.asp [4]https://mswdst.rti.org/ Tools may require permission to access and training to use.	

Brian Pickard from EPA's Office of Water, Water Security Division, gave a presentation on strategies and tools EPA's Office of Water (OW) has produced to help water utilities increase resilience. He described how utilities had taken steps to prevent damage from natural disasters and other hazards through mitigation and training. One tool to aid them in doing so is OW's Flood Resilience Guide that walks them through steps to achieve resilience (Figure 8). Other OW tools include the Community-Based Water Resiliency Tool (CBWR) and Climate Resilience Evaluation & Awareness Tool (CREAT). Steve Clark from EPA ORD NHSRC presented the American Water Works Association approach to risk and resilience management of water and wastewater systems with a focus on proposed resilience standards.

FIGURE 8: PROCESS FOR IMPROVING FLOOD RESILIENCE

A joint presentation on decontamination, cleanup, and waste management entitled *Preparedness & Resiliency in an "All-Hazards" Environment* was given by Dr. Paul Lemieux, HSRP, Susan Thorneloe, EPA ORD's National Risk Management Research Laboratory (NRMRL), and Mario Ierardi, Office of Solid Waste and Emergency Response (OSWER) Office of Resource Conservation and Recovery (ORCR). Waste management is an important part of resilience that involves integrating many processes and stakeholders. Pre-disaster waste management planning can facilitate post-incident recovery. Tools such as the Incident Waste Assessment & Tonnage Estimator (I-WASTE) can aid disaster debris management efforts. Areas for waste resilience indicators to be developed may include community preparedness, contamination detection and spread, decontamination, and waste management.

Dr. Roy Sidle, then at the EPA ORD National Exposure Research Laboratory (NERL) in Athens, Ga., gave a presentation on *Ecosystem Sustainability and Resilience in the Context of Natural Disasters.* Resilience addresses the ability of ecosystems to absorb change and disturbance and adapt to small-scale perturbations. Ecosystem resilience accommodates a range of natural and anthropogenic stressors and needs to be considered to frame sustainability assessments. Chronic anthropogenic pressures (air pollution, climate change, soil degradation) can push resilient systems to tipping points. It is a challenge to assess sustainability in ecosystems that are predisposed to episodic natural disasters that can reset landscapes in the long-term. To be effective, sustainability assessments must embrace the dynamic nature of the environment.

Gelena Constantine, EPA ORD's Office of Science Policy, reported on *NEJAC Community Resiliency in EJ Industrial Waterfront Communities Work Group.* Industrial waterfront communities face environmental justice issues as a result of climate change. They already face risks from hazardous waste sites and environmental contaminants. Flooding and sea level rise may increase environmental risks to vulnerable populations. Best practices can be identified and

carried out to promote community resiliency and environmental justice in industrial waterfront communities.

In an afternoon discussion, workshop participants identified several potential purposes and audiences for a CERI. Communities could conduct self-assessments to benchmark conditions and track improvements. Researchers could identify tipping points where environmental systems lose resilience. Federal stakeholders could identify funding targets and measure policy outcomes.

Dr. Keely Maxwell gave a presentation on *The Science of Resilience Indicators*. An index can be built to measure the attributes of a resilient system. Social and environmental indicators can be used to measure resilience. Challenges include identifying appropriate metrics and data.

Susan Julius, EPA ORD's National Center for Environmental Assessment (NCEA), discussed *Urban Resilience to Climate Change: Framework and Indicators.* The Urban Climate Resilience Assessment Framework was created as a tool that uses indicators to evaluate urban resilience. This tool was piloted in two communities, Worcester, Mass., and Washington, D.C. Qualitative and quantitative indicators were tested with community leaders. The qualitative indicators provided the richest source of information on resilience. The findings from the pilots will be used to refine the tool and methodology for national application.

Dr. Joseph Fiksel, Executive Director, Center for Resilience at Ohio State University and at the time a special advisor for Sustainability in EPA's ORD, presented *A Systems Approach to Sustainability and Resilience.* Dr. Fiksel discussed how resilience and sustainability are distinct system capacities (Figure 9). He demonstrated the application of the *Triple Value Model*, a systems approach, to the Narragansett Bay Pilot Project.

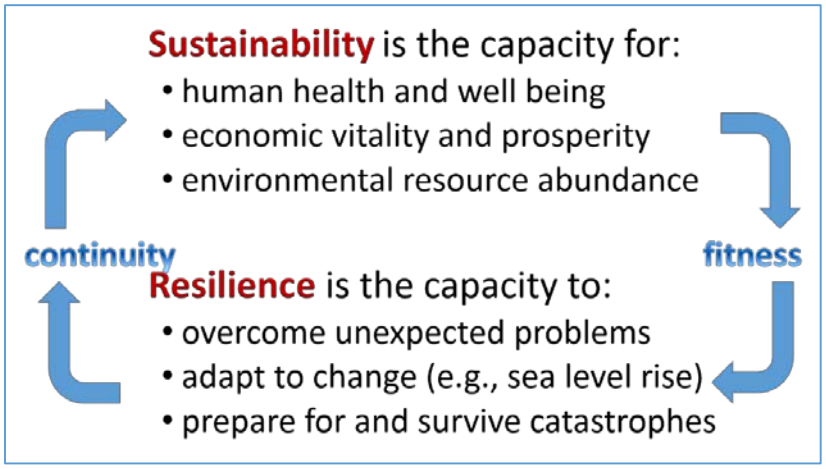

FIGURE 9: RESILIENCE & SUSTAINABILITY, DISTINCT SYSTEM CAPACITIES

Dr. Tarsha Eason from EPA ORD NRMRL finished the session by presenting on *Sustainability Indicators.* Sustainability indicators provide a means of tracking the social, economic and environmental condition of a system. Indicators are critical to sustainability decision making, monitoring and management. Dr. Eason highlighted the Database of Sustainability Indicators and Indices (DOSII), a database of sustainability indicators and indices from a variety of sources.

Workshop participants compiled a preliminary list of qualitative and quantitative resilience indicators. These indicators address social and environmental trends and conditions. There was

convergence around using a systems approach to resilience indicators research. For example, waste resilience indicators could help identify the socioeconomic and environmental challenges of handling disaster debris and waste. Water resilience indicators could measure trends across the production and distribution system. Participants agreed that indicators should be compelling to community stakeholders, lead to action, and be easily measured. They advocated building a CERI on existing EPA science, including many of the resilience tools that have been developed for homeland security, climate change adaptation or disaster recovery. Workshop participants also identified an emerging need for research that addresses environmental justice and resilience.

Achieving resilience will require long-term planning and implementation. A CERI can support research and planning to help communities to achieve environmental resilience and sustain critical community values after a disaster.

Workshop II Highlights

The vision of the second workshop was to explore how EPA and other federal partners could use a CERI as an analytical and research planning tool to identify ways to strengthen the resilience of communities to natural and anthropogenic disasters. The goals for the second CERI Workshop were to build on the enthusiasm of Workshop I, expand the network of experts, share expertise and identify assets, needs, and opportunities for CERI research and products.

Community environmental resilience involves minimizing and mitigating the environmental and human health risks associated with disasters, quickly returning critical environmental and ecological services to functionality after a disaster, and applying this learning process to reduce vulnerabilities and risks to future incidents. It supports the local economy, well-being, and quality of life. Dr. Greg Sayles, the Acting Director, EPA ORD NHSRC and HSRP National Program Director, noted during his welcome that environmental resilience has been a theme running through HSRP's work for the last several years. The HSRP is exploring new ways to apply the latest science and research on resilience to CBRN incidents to "all-hazard" threats (Figure 10), which can aid communities at risk from natural disasters.

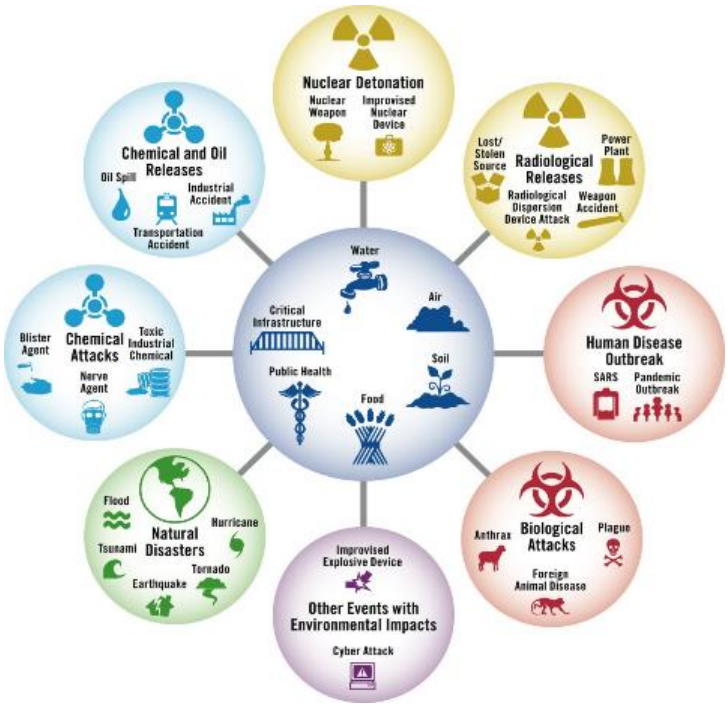

FIGURE 10: ALL-HAZARD THREATS TO HEALTH & ENVIRONMENT

Adapted from U.S. EPA. 2011. Refining EPA's Strategic Approach to Homeland Security.

Brendan Doyle provided a common framework by outlining the need for a CERI and how federal, state, and

community stakeholders could utilize the CERI. It could be used to aid decision making about how to prioritize issues and allocate resources effectively to achieve resilience goals.

In the following session, Dr. Peter Jutro presented *Exploring the environmental "e" in resilience*. He discussed environmental issues that arose in recent disasters. Disasters can increase exposure to existing and new environmental contaminants. They require management of waste and debris and raise environmental justice concerns. They disrupt critical services such as water and wastewater treatment and impact ecological systems such as wetlands and streams that provide ecological services and amenities. Federal agencies can use comprehensive, forward-looking, and science-based analysis to improve resilience of environmental and ecological systems.

Dr. Kris Ludwig, Natural Hazards Mission Area, US Geological Survey (USGS) presented *Developing disaster scenarios using the coupled human-natural system*. She introduced the coupled human-natural systems (CHNS) framework used by the Strategic Sciences Group at the U.S. Department of the Interior (DOI) to develop scenarios of the cascading effects of Hurricane Sandy on coastal communities. First-tier consequences included increased voluntary activity, altered risk perception, and ecological change. Resilience is best applied at the full system level.

Dr. Keely Maxwell presented *What is community environmental resilience? EPA workshop results*. She summarized the outcomes of the May workshop and raised questions for the participants in this workshop. What is environmental resilience? What indicators should be included in a CERI? How do we build a scientifically valid, usable index? Who will use a CERI and in what form? Dr. Maxwell emphasized the point that each organization represented addresses some part of environmental resilience now, and her hope was that by working together, the team could build a CERI that would be useful and valuable to communities.

With Dr. Maxwell's charge to collaborate on building a CERI, the participants broke into small groups to discuss how to improve collaboration across agencies and organizations to achieve environmental resilience. Legislation, regulations, and organizational structures are among some of the challenges agencies face in doing so. Convening workshops, exercises, and other face-to-face meetings is one way to improve collaboration. Workshops such as this one highlight opportunities among agencies and encourage potential partnerships and linkages.

Dr. Angel Hsu, Director, Environmental Performance Measurement Program, Yale Center for Environmental Law and Policy, talked about *Environmental index development for policy and planning*. She introduced the Yale EPI as a global scorecard that provides insight into the world's collective impacts on the major environmental issues of our time. The EPI measures how well countries perform on high priority environmental issues in two broad policy areas: protection of human health from environmental harm and protection of ecosystems. EPI indicators can be used to measure how close countries are to meeting internationally established targets or how they compare relative to the best performers. The EPI gives access to important environmental data organized in a way that is easily understandable, useful to policymakers, and drives productive competition.

Dr. Hsu walked participants through the phases of index development (Figure 11) and gave several recommendations for developing a CERI. The team should identify, and continuously revisit, the audience, purpose, and goals of a CERI. It should inspire communities to collect data. A communications plan should be developed from the outset. Communication about environmental indicators is a long term process. A primary focus should be to develop common language with other stakeholders.

Index Development Process

1. Define Objectives & Principles
2. Prepare the Process
3. Design a Framework
4. Evaluate Data Quality
5. Construct an Index

FIGURE 11: EPI INDEX DEVELOPMENT

Dr. Seema Schappelle, EPA ORD NCEA, presented a brief overview of the *Report on the Environment*. The ROE is EPA's comprehensive source of national-level scientific indicators that describe the condition of and trends in the nation's environment and human health. ROE indicators help answer questions of critical importance to EPA's mission to protect human health and the environment. The 86 indicators show observed trends in five areas – air, water, land, human health, and ecological condition. Sustainability indicators in the ROE measure trends in consumption of natural resources, i.e., energy use, freshwater withdrawals, hazardous waste, and municipal solid waste.

The participants broke into thematic groups to identify which indicators EPA might include in a CERI. The small groups were waste/energy, water/energy, environmental health/environmental justice and ecological systems. The goal of the discussion was to collaborate on the scientific process to establish indicators most appropriate for developing a CERI. All the groups underlined the importance of working with communities while developing resilience indicators.

Dr. Gavin Smith, Executive Director, University of North Carolina at Chapel Hill's Center for the Study of Hazards and Disasters, and Executive Director of the Department of Homeland Security's Coastal Hazards Center of Excellence, presented *Disaster planning and decision-making*. He talked about challenges, opportunities, and strategies to link natural hazards risk management and climate change adaptation through planning. Dr. Smith echoed the advice from workgroups to join forces with communities. He said the importance of collaborative governance cannot be stressed enough. Governmental, non-governmental, and private sector organizations all need to be prepared with up-to-date information about hazard vulnerability and disaster resources, to be linked with effective communication networks, and to be experienced in working together. Good vertical connectivity needs to be established between national policy and local plans. While higher level goals are important, empowering people and supporting flexibility at the local level is crucial.

Planning for climate change adaptation and natural hazards risk management can lead to improved use of existing planning tools and processes and scenario-based planning as also mentioned by Dr. Ludwig. Planners can act as coalition builders integrating risk reduction, sustainable development, resilience and adaptation. Dr. Smith cautioned not to discount the influence of pre-event conditions such as culture, wealth/poverty, policy frameworks and institutions as well as some of the broad issues underpinning disasters.

The participants used two different scenarios, Tornado Alley and Hurricane Sandy, as hypothetical situations to build a CERI for disaster decision making. Several themes emerged to assist the CERI team as it moves forward in developing an index. First and foremost was the need to finalize and communicate the definition of community environmental resilience, including input from communities. The CERI team should implement a communications strategy that clearly defines the goals and the boundaries of its resiliency work. For specific indicators, participants' advice was to select those that are forward looking yet flexible enough to meet the individual needs of different communities and to assure critical functionality.

CERI Workshop Outcomes

1. ENVIRONMENTAL RESILIENCE: Environmental resilience concepts and proposed definition gained support from participants. Established its relevance to EPA's Mission, Programs, Regions, and communities served by the Agency.

2. RESILIENCE SCIENCE: Recognized the utility of a systems approach to researching environmental resilience. Acknowledged the need to expand understanding of how resilience relates to EPA's mission and strategic plan, in particular to sustainability and environmental justice. Identified need to inventory EPA resilience tools.

3. RESILIENCE INDICATORS: Produced preliminary list of environmental resilience indicators. Refined criteria for developing resilience indicators that will be of utility to communities and based on sound science and best available data.

4. INDEX DEVELOPMENT: Advanced through the first three stages of index development. Refined ideas for index format, CERI products and potential applications.

5. ENVIRONMENTAL RESILIENCE NETWORK: Emergence of a collaborative and enthusiastic network across EPA, other federal agencies, universities, and other stakeholder organizations.

Next Steps

1. RESILIENCE TOOLS: Conduct inventory of EPA resiliency tools. Test application of HSRP resiliency tools in all-hazards contexts. Participate in tech transfer opportunities afforded by EPA and other ongoing resilience efforts (e.g., EPA's *Making a Visible Difference in Communities* initiative, National Institute of Standards and Technology's (NIST) *Community Resilience Planning Guide*, HUD's *National Disaster Resilience Competition*, Rockefeller Foundation's *100 Resilient Cities* program, United Nations Office for Disaster Risk Reduction's *R!SE Initiative*).

2. RESILIENCE INDICATORS: Leverage EPA's sustainability, environmental justice, human health, and other environmental indicators and performance measures (e.g. DOSII, Human Well-Being Index). Evaluate social, economic, and environmental metrics and data sources for measuring resilience qualitatively and quantitatively. Test indicators in communities with Regional and Program partners. Discuss potential for incorporating resilience indicators into other EPA platforms (e.g., *Report on the Environment*), climate change adaptation plans, and interagency collaborations.

3. INDEX DEVELOPMENT: Continue to follow the index development process laid out by the Yale EPI. Identify CERI audience, principles, and goals. Establish a communications strategy. Work with community stakeholders to determine relevance of a checklist or dashboard that communities could tailor to their particular environmental and hazard risk vulnerabilities, community composition, and values. Engage communities in developing self-assessment tools to benchmark conditions and measure progress in strengthening environmental resilience. Integrate tools into other EPA platforms and resilience projects. Establish procedures for updating a CERI as necessary.

4. ENVIRONMENTAL RESILIENCE NETWORK: Expand and maintain the network of collaborators who participated in the workshops. Clarify roles, responsibilities, and contributions to EPA and interagency resilience efforts. Revisit and refine the definition of community environmental resilience. Share experiences applying environmental resilience concepts such as conducting emergency response exercises for natural disasters and homeland security incidents. Continue to exchange information, best practices, and new ideas.

Afterword

Since the workshops, EPA and other public and private organizations have undertaken new resilience initiatives. NIST has drafted a *Community Resilience Planning Guide*. The State of Colorado now has the *Colorado Resiliency Framework.* EPA's Office of Research and Development has several ongoing resilience projects. The CERI project is now part of HSRP's research action plan. EPA will soon publish its resiliency tools report. The CERI team is inventorying resilience indicators from the disaster literature and environmental indicators from EPA and other sources to establish a short list of community environmental resilience indictors. It is continuing to refine the audience, principles, and goals of a CERI. Tools based on resilience science can help EPA, federal program partners, states, local governments, and civic organizations address the environmental aspects of community disaster preparedness, response, and recovery.

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[vii] Report figures were adapted from workshop slides shared by presenters unless otherwise noted.

Appendix A: Participants in the CERI Workshops

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Appendix B: Agendas for CERI Workshops

Community Environmental Resilience Index Workshop I Agenda

Vision: EPA and other federal partners use a Community Environmental Resilience Index (CERI) as an analytical and research planning tool to identify ways to strengthen communities' resilience to natural and anthropogenic disasters.

Goal: Share expertise and work underway to identify EPA's assets, research needs, and opportunities in the realm of community resilience. Explore CERI development concepts.

Outcomes:

- Participants will be able to apply community resilience science to their work and gain a better understanding of the relationship between sustainability and resilience.
- Establish agency interest in and potential uses of a CERI to support resilience and sustainability research and EPA's work in community disaster preparedness and recovery.
- Produce a conceptual framework of CERI purposes, objectives, audiences, scope, scale, & potential indicators to present to external scientific experts & other federal stakeholders.

Tuesday, May 6, 2014

8:30 – 9:00 **Welcome:** Dr. Gregory Sayles, Acting Director, ORD NHSRC
- Introductions and Workshop Orientation
  - Elaine Wright, Facilitator
- CERI concepts & development
  - Brendan Doyle, Senior Advisor, ORD NHSRC

9:00 – 10:00 **Session I: Community resilience science & disaster response**
- Community resilience science: definitions & systems model
  - Dr. Keely Maxwell, AAAS Fellow, ORD NHSRC
- Community resilience in action @EPA: Disaster response
  - Doug Pabst, Chief of EPA Region 2 Sandy Recovery Green Team

Q&A; Plenary discussion on community resilience, EPA mission & values

10:00 –10:15 BREAK

10:15 – 11:30 **Breakout Discussion I: Community resilience to disasters**
- What aspects of community resilience resonate best with your work?
- How might EPA apply the concept to different types of disasters?

11:30 – 11:45 **Report out**

11:45 – 12:45 LUNCH

12:45 – 1:15 pm **Sustainability and Resiliency:** Dr. Peter Jutro, Acting Associate Administrator for Homeland Security; Dr. Alan Hecht, Director of Sustainable Development, ORD
Q&A; Plenary discussion on synergies and trade-offs.

1:15-3:15 pm **Session II: Community environmental resilience**

- Water
  - Brian Pickard, OW WSD
  - Stephen Clark, ORD NHSRC
- Decontamination, clean-up, waste management
  - Dr. Paul Lemieux, ORD NHSRC; Susan Thorneloe, ORD NRMRL; Mario Ierardi, OSWER ORCR

BREAK

- Disasters and environmental resilience
  - Dr. Roy Sidle, ORD NERL
- Resilience in EJ industrial waterfront communities
  - Gelena Constantine, ORD OSP

Q&A; Plenary discussion on community environmental resilience.

3:15 – 4:30 pm **Breakout Discussion II: CERI**

- Purposes, objectives, audiences, scope, scale for a CERI

4:30 – 5:00pm **Report-out & Wrap-up**

Wednesday, May 7, 2014

8:30 – 9:45 **Session III: Indicators for Sustainability & Resiliency**

- The science of resilience indicators
  - Dr. Keely Maxwell, AAAS Fellow, EPA in ORD NHSRC
- Indicators of urban resilience to climate change
  - Susan Julius, ORD NCEA
- Sustainability & resilience indicators
  - Dr. Joseph Fiksel, ORD NRMRL
  - Dr. Tarsha Eason, ORD NRMRL

Q&A; Plenary discussion on indicators.

9:45 – 10:00 BREAK

10:00 – 11:15 **Session III Breakout Discussion**

1. Which indicators seem most relevant for a CERI?
2. What should criteria be for selecting indicators?
3. How do sustainability and resilience indicators overlap?

11:15 – 12:00 **Workshop Summary**

- Report-out, Next Steps
  - Brendan Doyle, Sr. Advisor, ORD NHSRC; Elaine Wright, Facilitator
- Closing Remarks
  - Dr. Gregory Sayles, Acting Director, ORD NHSRC

Community Environmental Resilience Index Workshop II Agenda

Vision: EPA and other federal partners use a Community Environmental Resilience Index (CERI) as an analytical and planning tool to identify ways to strengthen communities' resilience to environmental impacts and risks from natural and anthropogenic disasters.

Goal: Share expertise to identify assets, needs, and opportunities in community environmental resilience. Assess CERI development with scientific experts and other federal stakeholders. Build on EPA's recent workshop results to refine CERI indicators & CERI structure (purpose, audience, objectives, scale, scope).

Outcomes:

- Participants will develop a common understanding of the importance of community environmental resilience to disaster preparedness, response, recovery, and mitigation.
- Participants will refine key indicators to use in a CERI.
- Participants will establish how to structure a CERI to maximize its utility for community planning, disaster decision-making, and associated research.

Tuesday, July 22, 2014

1:00 – 1:30 pm — **Welcome to EPA:** Dr. Gregory Sayles, Acting Director of the National Homeland Security Research Center, Office of Research & Development, EPA

- Introductions, workshop orientation
  - Elaine Wright, Facilitator
  - Brendan Doyle, EPA CERI team

1:30 – 2:30 pm — **Session 1: Exploring the environmental "e's" in resilience**

- Dr. Peter Jutro, Acting Associate Administrator for Homeland Security, EPA

Q&A; plenary discussion

2:30 – 2:45 pm — BREAK

2:45 – 3:15 pm — **Session 2: Developing disaster scenarios using the coupled human-natural system**

- Dr. Kris Ludwig, Staff Scientist, USGS

Q&A

3:15 – 3:45 pm — **Session 3: What is community environmental resilience? EPA workshop results**

- Dr. Keely Maxwell, AAAS Fellow, EPA CERI team

Q&A

3:45 – 4:45 p.m. — **Breakout discussion I**: **Community environmental resilience and your work**

4:45 – 5:00 — **Wrap-up**

Wednesday, July 23, 2014

8:30 – 8:45 **Recap from Day I**

- CERI team

8:45 – 9:45 **Environmental index development for policy and planning**

- Dr. Angel Hsu, Director, Environmental Performance Measurement Program, Yale Center for Environmental Law & Policy

Q&A, plenary discussion

9:45 – 11:30 am **Breakout discussion II: Environmental resilience indicators for a CERI**

- Test drive indicators

11:30– 12:00 p.m. **Report-out and expert commentary**

- Dr. Joseph Fiksel, Special Assistant for Sustainability, Office of Research and Development, EPA

12:00-1:15 pm LUNCH

1:15– 2:15 pm **Disaster planning and decision-making**

- Dr. Gavin Smith, Executive Director, Department of Homeland Security, Coastal Hazards Center of Excellence; Associate Research Professor, Department of City and Regional Planning, University of North Carolina at Chapel Hill

Q&A, plenary discussion

1:15-3:15 pm **Breakout discussion III: structuring a CERI for disaster decision-making**

- Test drive POSAS (purpose, objectives, scope, audience, scale)

3:15 – 3:45 pm **Report-out and expert reactions**

3:45 – 4:00 pm **Wrap-up**

- Next Steps
  - Brendan Doyle, EPA; Elaine Wright, Facilitator
- Closing Remarks
  - Dr. Alan Hecht, Director of Sustainable Development, Office of Research and Development, EPA

Appendix C: Definitions and Descriptions of Resilience

POLICY

- **Executive Order 13653: Preparing the United States for the Impacts of Climate Change:** The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

- **Presidential Policy Directive (PPD) / PPD-8: National Preparedness:** The ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies.

- **Presidential Policy Directive / PPD-21: Critical Infrastructure Security and Resilience:** The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.

- **National Environmental Justice Advisory Council (NEJAC):** The capacity for a community to work together to: prevent (protect), anticipate (plan), adapt (absorb), and recover (reorganize) from a physical, biological, chemical or natural hazardous threat. In addition a community must maintain basic functions (infrastructure), and structures, strengthen its interconnectedness and identity (culture), improve the health, social, political natural and economic quality of life (sustainability) and guarantee equal access to emergency assistance, technical and financial resources, and related information (transparency).

- **American Water Works Association J-100 working group:** The ability of an asset or system to withstand an attack or natural hazard without interruption of performing the asset or system's function or, if the function is interrupted, to restore the function rapidly.

- **Hurricane Sandy Rebuilding Task Force:** Ensuring a Regionally Coordinated, Resilient Approach to Infrastructure Investment Regional Resilience by:
    - Collaborative work with partners across all levels of governance and the private sector from neighboring communities and states
    - Promote regional and cross –jurisdictional approach to resilience
    - Identify interdependencies among and across geography and infrastructure systems
    - Compound individual investments towards shared goals; foster leadership
    - Build capacity
    - Share information and best practices on infrastructure resilience
    - Long-Term Efficacy and Fiscal Sustainability
    - Environmentally Sustainable and Innovative Solutions
    - Targeted Financial Incentives
    - Adherence to Resilience Performance Standards

SCIENCE

- **Pfefferbaum et al. 2007:** Community resilience entails the ability of community members to take deliberate, purposeful, and collective action to alleviate the detrimental effects of adverse events.

- **National Research Council 2012:** The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.

ENVIRONMENTAL

- **EPA Sustainability Research Program:** Resilience is the capacity to overcome unexpected problems, adapt to change (e.g., sea level rise), and prepare for and survive catastrophes.

- **EPA Ecosystems Research Program:** Resilience addresses the ability of ecosystems to absorb change and disturbance and adapt to small-scale perturbations. It can also be viewed as the time to recover from external stresses as well as the magnitude of stress a system can withstand without moving to a new 'stable' state.
- **EPA Air & Climate Research Program:** Urban resilience to climate change is the ability of a city or urban system, through its risk reduction and response capacity capabilities, to reduce exposure and sensitivity to, and recover and learn from gradual climatic changes or extreme climate events for the purpose of retaining or improving the integrity of its infrastructure and economic systems, vital environmental services and resources, the health and welfare of its populations and communities, and the flexibility and diversity of its institutional and governance structures.
- **CERI team:** Resilience entails minimizing environmental risks associated with disasters, quickly returning critical environmental and ecological services to functionality after an incident, and applying this learning to reduce exposure and sensitivity to future incidents, whether slow-moving or acute. Restoring estuaries and wetlands, proactively managing debris and waste, and addressing interdependencies between water and energy systems, are all steps that communities can take to strengthen their environmental resilience.

Appendix D: CERI Breakout Discussion Questions

WORKSHOP I

Breakout Session I: Community resilience definitions and systems model

Q1. *What aspects of the resilience definitions or model resonate best with your work?*

Breakout Discussion I: EPA application of resilience in disaster scenarios

Q2. *How might EPA apply the concept of community resilience to different types of disasters?*

Breakout Discussion II: purpose objective scope audience scale of a CERI

Q1. What should the *purpose(s)* and *objective(s)* of a CERI be?

Q2. What should the *scale* of a CERI be?

Q3. Who should the *audience(s)* of a CERI be?

Q4. What should the *scope* of a CERI be?

Breakout Discussion III: Resilience and Sustainability Indicators

Q1. *Which indicators seem most relevant for a CERI?* Are there other indicators that should be included? Who should be involved in this process?

Q2. *What should criteria for selecting indicators be?*

WORKSHOP II

Breakout Discussion I: Environmental Resilience

Q1. What aspects of environmental resilience do you address in your work?

Q2. How can we improve collaboration across agencies & organizations to achieve environmental resilience?

Breakout Discussion II: CERI Indicators

Q1. *Which indicators should we include in a CERI? How might we rank them in order of importance?*

Q2. *What other indicators should we add to the list?*

Q3. W*hat social indicators should be included in a CERI?*

Breakout discussion III: Structuring a CERI for disaster decision-making

Q1. Read through your scenario on how you might apply a CERI. *How would you begin to combine indicators to build a CERI?*

Q2. What other purposes and objectives would a CERI meet? Or not meet?

Q3. How could a CERI aid disaster decision-making & planning situations you encounter in your work?

Appendix E: Community Environmental Resilience Indicators

Preliminary list of proposed indicators of community environmental indicators discussed at the workshops.

- Inclusion of environmental stakeholders in preparedness tabletops or scenario exercises
- Pre-incident waste management plans in place
- Landfill capacity
- Tree canopy coverage
- Curbside recycling program
- Number of Safe Drinking Water Act (SDWA) violations
- Mutual aid agreements among utilities
- Water utilities' emergency response plan (scale of 1 to 5, from having no existing plan to having conducted extensive exercises)
- Percent wastewater infiltration and inflow
- Green infrastructure
- Age of infrastructure
- Average hours of energy outage in major storms
- Ease of egress from potentially contaminated areas
- Percent population below poverty level
- USPS vacancy rates
- Hazmat capability of local responders
- Local government debt to revenue ratio
- Household access to equity
- Environmental stressors present before a disaster
- Park visitation rates
- Urban gardens
- Populations affected by asthma, diabetes
- HVAC systems
- Construction capacity
- Collaborative governance
- Environmental knowledge and actions
- House ownership

Appendix F: CERI Workshop I Technical Brief

EPA PURSUES INTEREST IN DEVELOPING COMMUNITY ENVIRONMENTAL RESILIENCE INDICATORS AND INDICES

Introduction

Environmental resilience includes minimizing environmental hazards and public health risks from disasters, facilitating restoration of critical environmental services following a disaster, and building back in a way that mitigates future adverse impacts. Because local social networks, civic organizations, and municipal services play key roles, we approach environmental resilience at the community scale. Community resiliency supports long-term sustainability. Community environmental resilience indicators and indices can help communities conduct self-assessments, develop corrective actions, and measure progress towards attaining their environmental resilience goals.

Community Environmental Resiliency Index (CERI) Workshop I

Vision: EPA, federal, tribal, state & local partners develop indicators & indices as analytical & planning tools to help communities protect public health & the environment by identifying ways to strengthen their resilience to natural & human-made disasters.

Goal: Share expertise and work underway to identify EPA's assets, research needs, & opportunities to develop relevant, actionable, & useful indicators & indices.

EPA's Homeland Security Research Program (HSRP) is working with national experts to develop community environmental resilience indicators and indices to identify public health and environmental vulnerabilities and assess ways to mitigate future disaster risks. EPA held an internal workshop May 6-7, 2014, to pursue interest in developing such indicators and indices. Its aim was to identify assets, interests, and needs. The workshop was held concurrently in Cincinnati, Research Triangle Park, Washington, D.C., and via webinar. It was attended by EPA staff from the Office of Research and Development, Programs, and Regions. The results of that workshop are presented in this brief.

Why Community Environmental Resilience Indicators?

Community environmental resilience involves protecting public health and the environment by reducing vulnerabilities to disasters and developing the capacity to minimize health and environmental risks. By doing so, communities increase their potential to recover quickly from disasters, including homeland security incidents, and sustain resources they depend on for well-being. As climate change amplifies the risks of extreme weather events, community environmental resilience becomes a key component of climate change adaptation. The National Research Council (NRC) report *Disaster Resilience: A National Imperative* recognizes the need for improved ways to measure community resilience to disasters (NRC 2012). Researchers have proposed socioeconomic, demographic, and health indicators of community resilience, but there is no established, scientifically vetted and validated set of indicators. Also, none of these efforts has focused on community environmental resilience indicators. EPA's HSRP is addressing this gap.

EPA's HSRP primarily addresses two key areas: water and wastewater infrastructure protection, and community cleanup and recovery. EPA researchers and program managers have produced tools and technologies that communities can use to enhance their environmental resilience. EPA has also developed science-based, environmental and sustainability indicators in its *Report on the Environment* (EPA 2014). HSRP researchers are seeking ways to leverage this science to develop resiliency indicators. This work builds on efforts already underway across the federal government. It can feed into EPA resilience initiatives and support interagency efforts under Presidential Policy Directive (PPD)-8, PPD-21, the national climate action plan, and national response and disaster recovery frameworks. Community environmental resilience indicators can be incorporated into a self-assessment checklist or full-scale index. Decision-makers from the

public, private, and civic sectors could use these to identify areas of concern and allocate resources to strengthen resilience to natural disasters, technological accidents, and homeland security incidents.

What is Community Environmental Resilience?

Workshop participants defined community environmental resilience as minimizing environmental risks associated with disasters, quickly restoring critical environmental and ecological services after a disaster, and applying this learning process to reduce vulnerabilities and risks to future incidents. It includes reducing vulnerability to disasters, that is, minimizing exposure and sensitivity to disasters. It also includes increasing the capacity of environmental systems to return after an incident and building back in ways that mitigate future impacts. Community environmental resilience indicators and indices can help communities gauge their capacity to withstand disruption and reduce disaster impacts. Indicators of resilience might include the capacity of a wastewater treatment plant to process storm flow, the capacity of wetlands to provide natural flood protection, and knowledge of the environmental contaminants communities might be exposed to as the result of a disaster. Restoring estuaries and wetlands, proactively managing debris and waste, and addressing interdependencies between water and energy systems are all steps that communities can take to strengthen their environmental resilience.

Workshop Outcome: Environmental Resilience Science & Tools

Workshop participants proposed establishing a scientific basis for investigating environmental resilience by adapting a *coupled human-natural systems model*. They discussed how characteristics of resilient infrastructure such as redundancy, robustness, and connectivity apply to environmental systems. Participants examined how the index development process laid out by Yale's *Environmental Performance Index* might be adapted to create a resilience index. They advocated building on existing EPA resilience tools developed for homeland security, climate change adaptation and disaster recovery (Table 1). They recommended adapting EPA environmental and climate change resilience indicators for a CERI.

Sustainability is the capacity for:

- Human health and well-being
- Economic vitality and prosperity
- Resource abundance and quality

Resilience is the capacity to:

- Overcome unexpected problems
- Adapt to change
- Prepare for and survive catastrophe

EPA scientists posit that resilience to disasters is necessary for long term sustainability, and are investigating the relationship between resilience and sustainability. EPA's Database of Sustainability Indicators and Indices (DOSII) provides a tool for considering how sustainability and resilience indicators are interrelated.

Workshop participants also identified an emerging need for research that addresses environmental justice and resilience. Communities with economically disadvantaged or marginalized populations located in proximity to environmental hazards could be disproportionately affected by disasters. For example, disasters generate large volumes of waste and debris. Regional coordination is required to support communities' capacity to manage this waste, and that debris disposal does not affect already overburdened populations. Fully considering a disaster's environmental life cycle, that is, the environmental consequences of preparedness, mitigation, response, and recovery, is necessary when assessing resilience.

Table 2 EPA Resilience Tools Discussed at CERI Workshop

Resilience Tool	Purpose
Climate Resilience Evaluation and Awareness Tool (CREAT)[1]	Water utilities explore climate change impacts & adaptation strategies
CANARY & TEVA-SPOT[2]	Detection & early warning for contaminants & service disruption in drinking water distribution systems
Community-Based Water Resiliency Tool (CBWR)[1]	Water utilities gauge current preparedness efforts. Community awareness of including water sector in emergency planning.
Emergency Water Supply planning guidance[1]	Guidance on how to plan for disruptions in drinking water services
Flood Resilience: A Basic Guide for Water & Wastewater Utilities[1]	Understand flooding threats, identify vulnerable assets, evaluate mitigation options
Water Security Toolkit[2]	Evaluate & design rapid responses to water contamination incidents
Water Resiliency Action Planner Kit[1]	Convene meetings with key players in water utility planning to discuss roles & responsibilities during water service interruptions
Water/Wastewater Agency Response Networks (WARN)[1]	Intra-state network of utilities that share local water sector resources during disasters or service disruptions
My Environment[1]	Integrate community environmental & health data into maps; "Shout out" reports on local environmental efforts
I-WASTE[3]	Estimate types of debris, select appropriate waste management after a disaster
Waste Estimation Support tool (WEST)[1]	Estimate waste from a wide-area radiological incident as a function of selected decontamination approaches
Municipal Solid Waste Decision Support Tool (MSW-DST)[4]	Solid waste planners evaluate environmental aspects & cost of integrated waste management strategies
Integrated Climate & Land Use Scenarios[1]	Estimate housing density, population, impervious surfaces for climate scenarios
Environmental Justice (EJ) View[1]	Create online maps to view factors affecting community environmental health
[1]Via search on www.epa.gov [2]https://software.sandia.gov//trac [3]http://www2.ergweb.com/bdrtool/login.asp [4]https://mswdst.rti.org/. Tools may require permission to access and training to use.	

Workshop Outcome: Developing INDICATORS for an INDEX

After reviewing currently available resilience tools, workshop participants compiled a preliminary list of qualitative and quantitative environmental resilience indicators (Table 2). Participants also agreed that indicators should be compelling to community stakeholders, easily measured, and lead to action. Since resilience involves interactions across complex social, economic, and environmental systems, these indicators cover social and environmental trends and conditions. For example, environmental, economic, and demographic data together may highlight the challenges of handling wastes produced by a disaster.

Table 3 Community Environmental Resilience Indicators Proposed at the Workshop

Water resilience	Waste resilience
Practiced emergency response plans	Household recycling rates
Active watershed association	Percent population below poverty line
Access to emergency water supplies	Available landfill capacity
Ratio of municipal debt to revenue	Number of Superfund sites per square mile
Presence of mutual aid agreements with neighboring communities	Scenarios conducted with stakeholders to pre-plan waste & debris management
Contamination warning systems in place	Familiarity with debris disposal options

Workshop participants identified several potential purposes and audiences for developing community environmental resilience indicators and indices:

- Communities conduct self-assessments to benchmark current conditions, capabilities and needs.
- Communities take corrective action based on indicators and track improvements.
- Researchers identify thresholds where environmental and ecological systems gain or lose resilience.
- Federal program managers identify funding opportunities and measure policy outcomes.
- Audiences include federal, state, and local agencies, and stakeholders such as urban planners, businesses, and others involved in disaster planning, mitigation, response, and recovery.

Achieving community environmental resilience will require long-term planning and implementation. EPA's CERI project team aims to develop environmental indicators and contribute the best available science and research that can support community environmental resiliency. Its next step is to host a second workshop in July, 2014 to refine indicators and the purpose and scope of an index.

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For More Information

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U.S. EPA's Homeland Security Research Program (HSRP) develops products based on scientific research and technology evaluations. Our products and expertise are widely used in preventing, preparing for, and recovering from public health and environmental emergencies that arise from terrorist attacks or natural disasters. Our research and products address biological, radiological, or chemical contaminants that could affect indoor areas, outdoor areas, or water infrastructure. HSRP provides these products, technical assistance, and expertise to support EPA's roles and responsibilities under the National Response Framework, statutory requirements, and Homeland Security Presidential Directives.

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