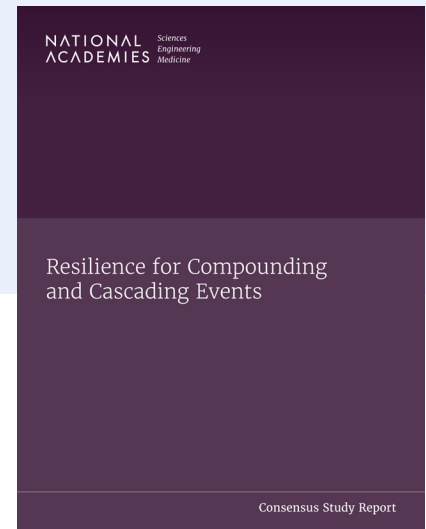


Resilience for Compounding and Cascading Events

There was a time not long ago when disasters would strike one at a time, and communities would have time to recover and rebuild. Today, however, there is a new normal regarding disasters, one in which most do not occur as isolated events and instead seem to pile on one another, often unleashing new devastation on a community before it has had a chance to recover from the prior disaster. Furthermore, chronic deteriorating conditions can compound acute events, as when extreme and prolonged drought can lead to mudslides and flash flooding when an acute, intense rain event occurs.

When two or more extreme events occur simultaneously, often with different causes, that is called a compound disaster. Compound disasters typically result from multiple causes, can generate multiplicative damage and losses, and are increasing in likelihood as the earth's climate changes. Examples are concurrent heatwaves and droughts, compound flooding when a storm surge combines with extreme rainfall and river flow), and any disaster taking place during a long-term pandemic, such as COVID-19. A cascading event refers to a primary event, such as heavy rainfall, seismic activity or rapid snowmelt, followed by a chain of consequences that may range from modest and whose damage and losses may be more severe than if they had occurred separately. A classic example is the tsunami triggered by the major earthquake that struck Japan in 2011, with one ensuing consequence being the Fukushima nuclear reactor failure. More recently, the war in Ukraine occurring during the COVID-19 pandemic highlighted the importance of supply chain problems, which are by their very nature cascading, as they represent the ripple effects of an initial bottleneck across sectors and regions over time.



As noted at the National Academies of Sciences, Engineering, and Medicine (the National Academies) May 31, 2022, workshop, there is an urgent need to disrupt the status quo and change and rethink how the nation thinks about disaster preparedness, emergency response, and recovery actions in the face of compounding and cascading events becoming more common.¹ In this new era, recovery requires more than just getting back to normal, especially when “normal” may be a major contributor to a community’s vulnerability to compounding and cascading disasters. Recovery also requires acknowledging a changing climate, shifting economic and cultural expectations for social equity, the imperative for climate-smart economic development, and the possibility that the way communities have designed and built their infrastructure, created their building codes, and implemented land use regulations contributes or even amplifies the effects compounding and cascading disasters have on those communities.

The Resilient America Program of the National Academies convened two committees on applied research topics for hazard mitigation and resilience to assist the Federal Emergency Management Agency (FEMA) in reducing the immense human and financial toll of disasters caused by natural hazards and other large-scale emergencies. FEMA asked the National Academies committees to identify applied research topics, information, and expertise that can inform action and collaborative priorities within the natural hazard mitigation and resilience fields.

APPLIED RESEARCH TOPICS FOR HAZARD MITIGATION AND RESILIENCE

The 2021–2022 committee, convened by the Resilient America Program, selected two large-scale themes within which to identify applied research topics. This year’s themes are Equitable and Resilient Infrastructure Investments, and Compounding and Cascading Events. Two workshops were planned for these two themes to gather information for identifying priority applied research topics.

¹ For further information about the workshop see: <https://www.nationalacademies.org/event/05-31-2022/hazard-mitigation-and-resilience-applied-research-topics-workshop-2-compounding-and-cascading-events>

On the theme of compounding and cascading events, the committee chose three applied research approaches as being particularly important for natural hazard mitigation and resilience, especially in motivating local action to address climate impacts and build resilience:

1. Defining the problem—drivers, systems, and relationships that impact our understanding of compounding and cascading disasters.
2. Mitigating impacts—developing solutions and avoiding unintended consequences.
3. Effectively implementing solutions and strategies and governance of those solutions and strategies.

The committee selected these approaches based on information gained from the 1-day public workshop that took place on March 17, 2022, as well as the committee members’ backgrounds and experience with hazard mitigation and resilience. In organizing the report, the committee also identified four foundational themes to consider throughout research efforts: (1) compounding and cascading disasters are the new normal, (2) legacy conditions need to be assessed, evaluated, and addressed, (3) the importance of engaging in co-design with communities that starts with pain points and impacts and works backward to solutions, and (4) the importance of relentless resilience, or the ability to function throughout a series of disruptive events.

I. Defining the Problem: Drivers, Systems, and Relationships that Impact our Understanding of Compounding and Cascading Disasters

Creating appropriate solutions for the challenges linked to compounding and cascading disasters requires diagnosing the drivers, systems, and relationships that underlie the vulnerabilities and impacts on lives, livelihoods, and ecosystems. The workshop panelists and participants highlighted the need to identify possible distinctive signatures to recurring acute disasters and their impacts upon human use systems as well as ecosystems, as well as the importance of analyzing past events and their impact on current and future preparedness, response, and recovery. Other research

needs include exploring if and when future disasters will be compound as a result of climate change and identifying approaches for preparedness and mitigation that account for legacy stressors such as those related to economic characteristics and social marginalization.

Based on these needs, the committee identified the following applied research questions that would help define the drivers, systems, and relationships that affect our understanding of compounding and cascading events:

- Are there distinct signatures left by recurring acute disasters and their impact on human ecosystems?
- What additional knowledge would we gain by switching from an event-specific research approach to an impact-specific research approach?
- How can better identification and characterization of cascading events contribute to more effective design of solutions?
- How have smaller historic disasters contributed to subsequent events?
- How do global mitigating events or cascading events create supply chain disruptions that impact oil and gas, food supply, and computer chip shortages, which ultimately impact rural communities in terms of food insecurity and expensive fuel and power costs?
- What long-term resilience problems do ongoing cascading events generate?
- How can we evaluate the tradeoffs between exposure thresholds, such as extreme heat versus poor air quality exposure?
- What information is needed to evaluate the tradeoffs between preparation and response?
- How can long-term observation of disaster hot spots provide empirically based evidence that can help develop lessons learned and unlearned?

II. Mitigating Impacts: Developing Solutions and Avoiding Unintended Consequences

Current infrastructure design typically incorporates mitigation and resilience needs based on historical event probabilities and impacts and considers all potential natural hazards based on design requirements in codes and standards. However, buildings, bridges, roads, and other infrastructure design rarely accounts for multiple compounding hazards or future climate effects. In addition, there is a lack of understanding about the interconnectedness of various systems and impacts of multiple events on different components of a system. Moreover, while individuals and businesses can be counted on to make decisions that are consistent with both their best interests and the sound allocation of resources, disasters are major exceptions for reasons that include their infrequency and uncertainty, misperceptions of vulnerability and lack of access to information, inability or unwillingness to take a proper long-term perspective, and the divergence of objectives between parties of interest. Under-resourced populations and communities may also lack access to capital to support resilience investments

During the process of reaching consensus, the committee identified three topics for applied research that would inform efforts to mitigate the impacts of compounding and cascading events:

1. The built environment

Under this research topic, the committee identified the following applied research questions:

- How do we better model the impacts of compounding and cascading events on infrastructure, and how can we increase infrastructure resilience by incorporating these models into engineering and design?
- How do human-infrastructure interactions and decision-making affect outcomes in the face of compounding and cascading events?
- How do land use and population growth assumptions influence resilient infrastructure planning decisions to address compounding and cascading events?

- How can we design solutions knowing that all the future disasters may be compound due to climate change?

2. Systems and populations

Under this research topic, the committee identified the following applied research questions:

- How can compounding and cascading community infrastructure stakeholders mitigate hazards and attract investment?
- How can readiness strategies adapt to a new normal of multiple compounding hazards?
- How can business continuity and general recovery strategies be improved to cope with this new normal?
- How can we improve inventory strategies (e.g., “just-in-time”) to better smooth out supply chain bottlenecks?
- How do we create a more coherent and collectively agreed-upon understanding of human adaptive capacity and incorporate this into planning?
- What are the tools needed to provide ground truth screening that better characterizes risks and vulnerabilities (inclusive of identifying data and indicators) to evaluate disproportionate impacts and disproportionate recovery for under-resourced communities?
- What tools most effectively map the interdependency of institutions, infrastructure, and systems, and integrate this interdependency into approaches to hazard response (e.g., inclusion in standard Enterprise Asset Management practice)?
- How effective are early warning systems and other communication strategies for reducing injuries and loss of life in the face of multiple hazards?
- What are the unintended consequences of mitigation and adaptation decisions, such as managed retreat,

including in an equity context such as where trust in institutions is low because of historic inequities, where family wealth is low due to systemic lack of economic opportunity and educations, and where physical vulnerabilities are hard-wired into some communities located in marginal development areas most impacted by extreme events?

- How do we account for personal and community crises, such as mental health crises during the pandemic, to better design solutions?
- What tools can be used to better measure how quickly people could recover from disasters and how long it takes?
- How are under-resourced communities that have not fully recovered from previous events able to prepare for or recover from successive events, not just from infrastructure damage, socially and emotionally?
- How do we understand unintentional consequences of mitigation, adaptation, and managed retreat? An example here is the relocation of Indigenous communities that resist relocation because it obliterates historical legacies?
- What are the impacts of land use and population growth on compounding and cascading event preparation and response?

3. Benefit-cost analysis, other assessment methods, incentives, metrics, and equity

Under this research topic, the committee identified the following applied research questions:

- What methods could most efficiently improve or replace benefit-cost analysis, which currently is biased toward evaluating impacts on aggregate property values, to put equity at the forefront by focusing on the distribution of benefits and costs and protecting people in addition to property and income?
- To what extent can we and should we measure the impacts of prior policy decisions and such areas as

home values as a means of accounting for systemic racism?

- To what extent do various market failures take place in the context of disasters, what are the inequitable outcomes of market operation, and how do we design strategies to close the gap between typical outcomes and those in the best interest of a climate-resilient society?
- To what extent does government policy promote or interfere with private sector initiatives?
- How do we reach consensus on key metrics, supported by sensitivity and validation studies, to better understand and articulate how to better reduce loss of lives and livelihoods, and how can these metrics be used to better inform government spending, planning, and philanthropy?
- What are the tradeoffs that communities face when preparing for and responding to hazards?
 - How do communities perceive tradeoffs and how does that affect adaptation pathways (e.g., sea walls or beach access)?
 - What are the tradeoffs between exposure thresholds (e.g., extreme heat v. poor air quality exposure)?
- How do we apply measurement systems that may be able to weigh decisions regarding specific solutions and their tradeoffs, such as building storm walls versus allowing unfettered beach access?

III. Effective Implementation of and Governance for Solutions and Strategies

Great relationships are the foundation for successful interactions in emergency response situations, where there is a sudden need resulting from an unexpected event to interact with many partners that are not part of daily operations. As such, it would likely improve a community's response to an emergency if procedures for

collaboration were in place prior to the emergency. The challenge, then, is to develop mechanisms for efficient coordination between government entities, public utilities, private stakeholders, and nongovernmental organizations that improves communication and minimizes barriers to coordination. One of the most important elements of effective recovery after a disaster is the availability to access funding to support recovery and to advance resilience, and effective implementation of both disaster recovery and resilience measures will require coordination among available sources of funding.

During the process of reaching consensus, the committee identified four topics for applied research that would inform efforts to implement and govern solutions and strategies for mitigating the impacts of compounding and cascading events and designing for resilience:

1. Improving institutional operations

Under this research topic, the committee identified the following applied research questions:

- How can coordination for mitigation, planning, and recovery from cascading events be streamlined for timely, effective operations between government entities, public utilities, private stakeholders, and NGOs?
- How can communications between agencies and community members, both urban and rural, be improved for clarity, timeliness, and understanding, both in terms of providing early warnings and that can function under emergency conditions?
- What is the minimum capacity (staffing, funding, etc.) needed at the local and state level to appropriately plan for resilience and effectively coordinate disaster recovery (e.g., improve governance)?

2. Leveraging funds and creating incentives through financial instruments

Under this research topic, the committee identified the following applied research questions:

- There is a significant gap between available federal funds and local capacity to apply, manage, and implement multiple funding streams with varying requirements. How can mitigation and recovery programs be made less complex and cumbersome? How can local/state agencies get the capacity (staffing and funds) needed to navigate the complex system of federal and state funding streams?
- What incentives and metrics can be used to improve coordination at the interagency and public/private levels?
- How effective are federal and state mandates and incentives for encouraging hazard mitigation and response planning?
- How should different funds be used to effectively coordinate between different actors? If the funding comes from one source, how should it be distributed?
- How can communities better leverage federal funding more effectively (e.g., through bond issuances, to securitize private investment, etc.)?
- How can we better integrate resilience into solutions that are driven by funds, service, and connections provided by industry, government, and civil society?
- What do social and behavioral sciences provide as evidentiary basis for improving implementation of disaster mitigation and resilience policies and strategies?
- How can consensus on adaptive capacities, especially in the context of compound and cascading disasters, be developed to inform resilience solutions and strategies?
- How do we balance acute hazard events and chronic conditions, such as drought, from a governance perspective?
- How can governance roles and authorities be more effectively assigned between entities (federal, state, local, public-private)?
- How can government staff be trained to obtain new capabilities for future event resilience planning, response, and recovery?
- What does the governance transition look like when hazard events become so frequent that they have to be managed as status quo? Perhaps these are no longer “emergency” appropriations?

3. Expanding governance perspectives and strategies

Under this research topic, the committee identified the following applied research questions:

- How can the federal and state mindset for acute events and emergency management be shifted to include long-term planning for compounding and cascading events?
- Should there be Chief Resilience Officers for every state to help coordinate at the local and federal levels?
- How can innovation be introduced and incorporated into risk-averse institutions?

4. Obtaining governance knowledge and tools for implementing solutions and strategies

Under this research topic, the committee identified the following applied research questions:

- What knowledge (data/information) is needed by decision makers and those that implement resilience solutions and strategies?
- How can this knowledge about implementation status (progress/vulnerabilities) be provided through current data/information and tools (assessments, indexes, indicators/metrics, etc.)?
- In particular, what knowledge and tools are available or needed to address equitable solutions?

CONCLUSION

The consensus study report *Resilience for Compounding and Cascading Events* identifies three applied research approaches that would provide important insights that would help communities become more resilient to compounding and cascading events. The report includes specific questions to consider when taking these approaches to applied research. The Committee on Hazard Mitigation and Resilience Applied Research Topics took a broad view of applied research and those involved in that research, ranging from researchers in academia to small community groups exploring and testing approaches for addressing resilience in the face of climate impacts. In proposing these three approaches and the associated applied research questions, this report

challenges the applied research community and the disaster response professionals to apply their analytical skills to begin to address the challenges that maintains the status quo and perpetuates the suffering that individuals, families, and communities are facing at a time when extreme events and the disasters they produce are becoming the norm.

With this report, the committee hopes to inspire researchers and communities. Research findings from these approaches should bolster and extend attention and activities that strengthen capacities for community resilience through inclusive work at the local, regional, national, and global levels for robust and equitable action.

COMMITTEE ON HAZARD MITIGATION AND RESILIENCE APPLIED RESEARCH TOPICS **STEVE MODDEMEYER** (*Chair*), Principal for Planning, Sustainability and Resilience, CollinsWoerman Architects; **CHRISTOPHER EMRICH**, Boardman Endowed Associate Professor of Environmental Science and Public Administration, School of Public Administration, University of Central Florida; **ERICK C. JONES, SR.**, Dean, College of Engineering, University of Nevada, Reno; and Jefferson Science Fellow, Office of the Chief Economist, U.S. Department of State; **ELENA KRIEGER**, Director of Research, Physicians, Scientists, and Engineers for Healthy Energy; **THERESE McALLISTER**, Community Resilience Group Leader and Program Manager, National Institute of Standards and Technology; **ADAM ROSE**, Research Professor, Department of Public Policy, and Senior Research Fellow, Center for Risk and Economic Analysis of Threats and Emergencies, University of Southern California; **STACY SWANN**, Chief Executive Officer, Climate Finance Advisors, BLLC

PROJECT STAFF **NEGIN SOBHANI**, Study Director; **DANIELLE GOLDSMITH**, Senior Program Assistant; **HOPE HARE**, Administrative Assistant (*until March 2022*); **BERNA OZTEKIN-GUNAYDIN**, Program Officer (*since April 2022*); **OLIVIA TORBERT**, Senior Program Assistant (*until March 2022*)

CONSULTANT **JOE ALPER**, Consultant Writer

FOR MORE INFORMATION

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The full Consensus Study Report is available from the National Academies Press | (800) 624-6242 | <http://www.nap.edu> | <http://www.nationalacademies.org>

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