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Recent responses to hurricanes, while never seamless, have been very successful. Even more important than the success of a given response is the validation of processes and relationships. Disaster response planning and exercises are well informed by real world event after action reviews (AARs). Updated information products, such as the Federal Emergency Management Agency's (FEMA) Incident Annexes, have improved awareness and increased fidelity across a wider range of government levels than ever before.

However, it must be noted that the disaster response community's vast amount of recent experience has been across a narrow range of disasters. The "right" response for a hurricane may be inappropriate for another type of disaster. Hurricanes, tornadoes, floods and most of the other types of disasters we have experienced in recent years share a trait—the disasters themselves are relatively short in duration. There is another class of disaster that threatens our homeland which we have not experienced recently—an enduring disaster.

What is an Enduring Disaster?

Enduring disasters are those in which an initial event continues to generate new casualties and new damage weeks and months into the response. They are not necessarily more catastrophic than acute or discrete disasters, but enduring disasters may break current operational phase planning models and introduce new complicating factors and demands not experienced during shorter duration events. Enduring disasters do not have traditional signposts for transition into sustained operations or the recovery phase.

Lasting minutes, hours, or days, recent and typical meteorological events have allowed for a relatively quick and clean transition between operational phases. Whether employing FEMA's three-phase model [1] (see Figure 1) or the Department of Defense's (DoD) Operation Phases of Defense Support of Civil Authorities (DSCA) six-phase model (shape, anticipate, respond, operate, stabilize, and transition) [2], achieving a quick transition is essential for planning and anticipating needs. Considerations, priorities, and even planning personnel may change between phases.

Enduring disasters do not allow for a quick or clean transition between phases. A lengthy disaster event—lasting weeks or months—mires responders in prolonged Phase 2 operations while simultaneously requiring actions normally associated under Phases 1 and 3. While it is normal to have some phase overlap for a limited period of time during transition, the requirement to simultaneously execute tasks associated with all three phases in the long term is new.

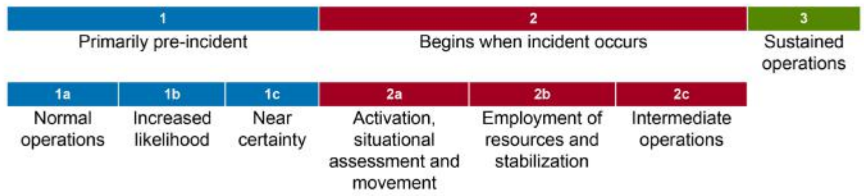
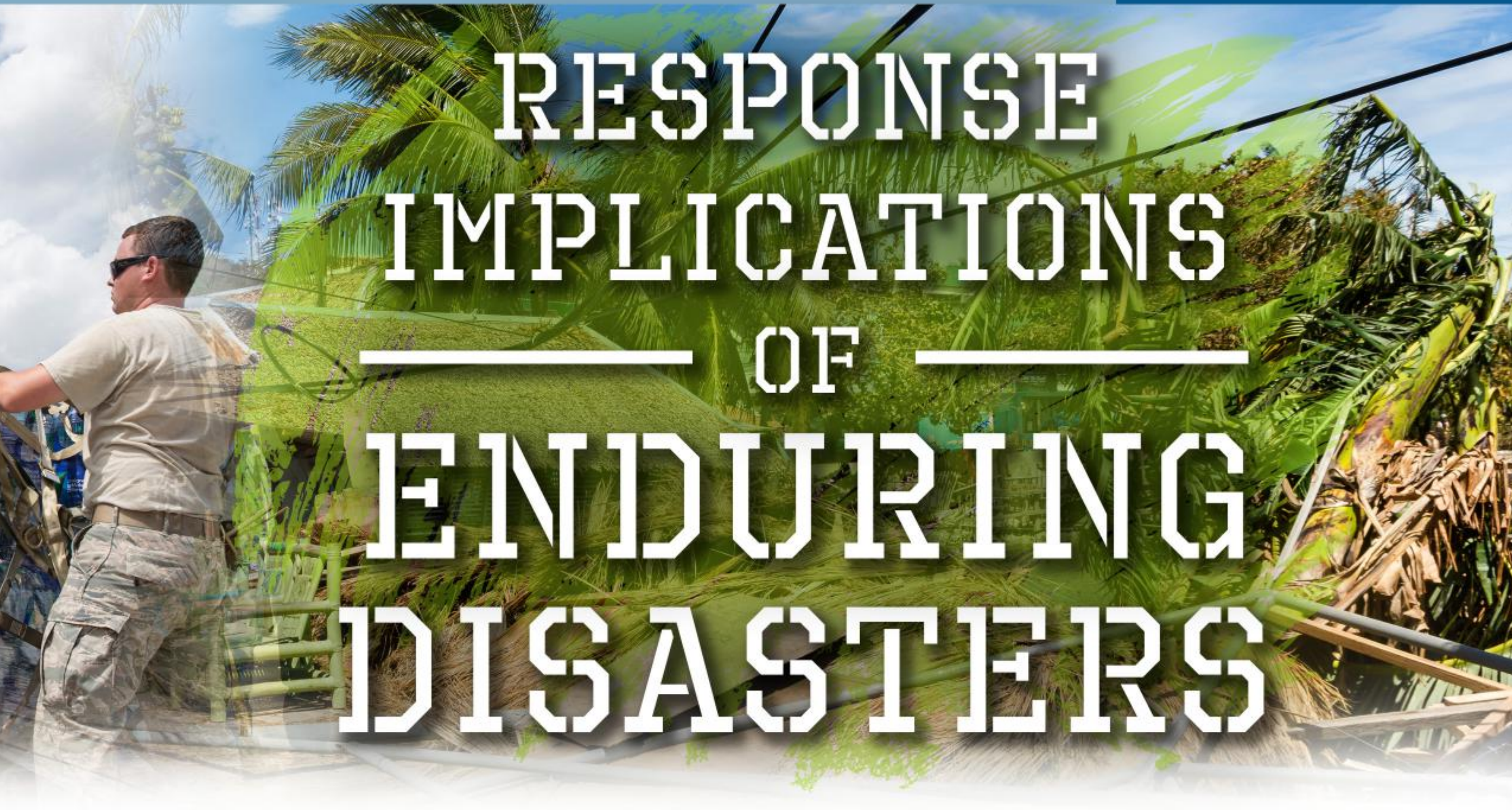


Figure 1. FEMA Common Operational Phases [1]. DoD is considering transitioning to a FEMA-based three phase model for DSCA operations: (1a) normal operations, (1b/1c) elevated/creditable threat (for a notice event), (2a) immediate response, (2b) deployment of resources and personnel, (2c) sustained response, and (3) recovery/transition in the next edition of JP 3-28 Defense Support of Civil Authorities.

Image Credit | *Photo Illustration created by HDIAC. Adapted from Marine Corps photo by Lance Cpl. Alexis C. Schneider (Available for viewing at http://www.jcs.mil/Media/News/cle/1320454/jbsa-volunteers-aid-in-hurricane-maria-relief-efforts/), and Adobe Stock.*



RESPONSE IMPLICATIONS OF ENDURING DISASTERS

Enduring disasters outlast local and personal on-hand resources (such as prescription medication refills), compelling responders to perform life-sustaining operations to prevent new secondary casualties while lifesaving operations in response to the original event continue. New considerations for planning and exercises must be implemented to ensure our community can respond to enduring disasters effectively.

An example of an enduring disaster is FEMA's response to Puerto Rico (DR 4339). Hurricane Irma's landfall set the conditions for Hurricane Maria, which resulted in enduring disaster conditions. As the local and state response culminated for Irma, Maria brought additional systemic requirements not normally seen in typical landfall. Destruction of the power grid, widespread debris management, and destruction of the commercial communication system significantly degraded Puerto Rico's ability to transition out of Phase 2. Combined with the logistical challenges of responding to an event outside the continental United States, Phase 2 actions for Puerto Rico went well into 60 days post landfall [3].

Disaster duration was proposed as one of five factors for the typology of disasters by Michael Berren in 1980 [4]. Berren hypothesized that using a five factor typology (natural vs. manmade, duration, degree of personal impact, potential for occurrence/recurrence and control over future impact), planners could better predict the psychological impact of a disaster and more effectively target intervention. Applying this same concept beyond just the psychological response to disasters provides an alternative way to improve our planning and response to disasters, which occur infrequently and are not supported by AARs, lessons learned, and responder experience.

Likely Enduring Disasters

Certain disasters clearly have the potential to become enduring disasters. Epidemics, earthquake series, or major power outages may last weeks, months, or years.

America has not had a major epidemic in 100 years. The 1918 Great Flu Epidemic killed half a million Americans, roughly 0.5 percent of the population. Lasting from January 1918 to December 1920, this enduring disaster has largely been relegated to the history books, as it occurred in an America that bears little resemblance to our own [5]. However, there is a more recent epidemic worthy of discussion. The Ebola epidemic in Africa involved a significant U.S. response and qualifies as an enduring disaster. From December 2013 to March 2016, the Ebola epidemic took an especially heavy toll on native health care personnel [6, 7].The Centers for Disease Control and Prevention (CDC) enduring response lasted two and a half years.

After multiple American health care personnel contracted Ebola in the response, researchers expressed a renewed interest in developing Biosafety Level 4 (BSL-4) biocontainment technologies. While BSL-4 environments have been proven successful in preventing the infection and spread of pathogens in laboratory-based research and development (R&D), these biocontainment standards are all but impossible to meet in a dynamic (and often mobile) response environment [8]. Moreover, the infection pathways of the virus are poorly understood. Some persons closely involved with infected patients do not get sick, while others with only brief and tangential interaction to a patient can contract the virus.

Critically, recent research has established test protocols for chemical deactivation of BSL-4 level pathogens, including Ebola [9]. In July 2016, a team at the U.S. National Institutes of Health evaluated the efficacy of chemical inactivation techniques for Ebola specimen destruction, with an eye toward verifying their use for multiple specimen types in the lab. Although this effort focused on lab environments, its review of the efficacy of other methods of inactivation may prove invaluable in scenarios of high-level biocontainment for Tier-1 pathogens. Such technologies could aid first responders

News-Display/Article/1329638/dod-continues-support-in-hurricane-ravaged-areas/), *photo by Ismael Ortega (Available for viewing at* http://www.jbsa.mil/News/News/Arti-

Figure 1. U.S. Marines with SPMAGTF Crisis Response - Africa load bags of concrete, that will be used by local and international health organizations to build Ebola Treatment Units, into an MV-22B Osprey during Operation United Assistance in Monrovia, Liberia, Nov. 21, 2014. U.S. Marine Corps photo by Lance Cpl. Andre Dakis/ SPMAGTF-CR-AF Combat Camera/Released

in the early stages of response to a disaster, but cannot alone mitigate pathogenicity risks during an enduring disaster.

The New Madrid Earthquake Sequence started on December 16, 1811, and concluded on March 15th, 1812. The region experienced three earthquakes greater than magnitude 7, 10 greater than magnitude 6, and approximately 100 greater than magnitude 5. In total, more than 1,800 earthquakes above magnitude 3 struck during that three month period. Surprisingly, the earthquake epicenter also shifted steadily northward about 55 miles from the initial event. While the 1811-12 earthquake sequence long pre-dates our response procedures, if it were to occur today, this event would qualify as an enduring disaster.

The New Madrid Seismic Zone (NMSZ) underlies the engine of the United States' domestic and international commerce: the Mississippi River Valley. Major means of transport (e.g., major commercial air terminals, including FedEx headquarters in Memphis, Tennessee) are vulnerable to such a seismic threat, including an extended seismic sequence as the one witnessed in 1811/1812.

Apposite to its role in managing inland hydrological flows along major population areas, the U.S. Army Corps of Engineers (USACE) has been an active participant in researching ways to continuously monitor the status and structural resistive strength of civil flood control infrastructure [10]. USACE recognizes the importance of deploying advanced sensor technologies (attached to real-time communication devices) to critical flood-control structures to allow for effective control of area-wide flood events.

USACE studies conducted in 2016 and 2017 looked at means of improving flood-control monitoring beyond traditional airborne surveys. While remote, satellite-based sensing remains a distinct option for future use, it is likely to be prohibitively expensive even in the mid-term. Unmanned Aerial Vehicle (UAV) use in conjunction with thermal imaging cameras is a more likely candidate for the detection of behind-berm seepage and sand boil locations, especially with the rapid decrease in small-scale “drone”-type UAVs.

Both seepage and sand boils are flood symptoms likely to present in the wake of seismic-induced damage or terrain-shift along the USACE-administered Lower Mississippi Levee System. One of the studies recommended that researchers consider fiber-optic-based monitoring of seepage as an early-warning system for earthen dam failures. Fiber-optic-based monitoring may also be suitable for flood-control and other infrastructural-based applications, as fiber-optic-based sensors have demonstrated their capability to act as permanent receivers over distances of 12 miles or more via a single optical fiber line [11].

The second USACE study investigated the use of structural infrasound signals to monitor urban environments [12]. The effort demonstrated that infrasound arrays, which consist of a network of sensors capable of detecting acoustic signals below 20 hertz (monitorable at distances well beyond 8,000 miles), can successfully detect structural sources of wave propagation in an urban environment. Such infrasound sensors and algorithms have already been useful in detecting events likely to occur along the Mississippi in the wake of an earthquake, including barge–bridge allisions. Extended deployment of infrasound array-based monitoring can offer true real-time and remote monitoring and rapid assessment of structural changes in flood-control structures and areas.

The U.S. has not experienced a widespread, extended power outage. Such an outage could be generated by a stand-alone event, such as a cyberattack, a space weather event (solar flare), or even a weaponized electromagnetic pulse. Alternatively, such an outage could also result from a cascade effect of other disasters. For example, 8.5 million people lost power during Hurricane Sandy in 2012 [13]. And in 2017, after 136 days of response to Hurricanes Irma and Maria, only 70 percent of Puerto Rico's residents regained power [14].

Domestic DoD installations are major consumers of electrical energy, accounting for more than 1 percent of total United States consumption in FY 2015 [15]. The vast majority of these rely on the commercial grid for the provision of power—a key point of vulnerability in any electrical blackout scenario, and especially so in an enduring disaster. DoD's traditional approach to mitigating an extended blackout period relies almost entirely on the use of diesel-fired standalone generators, which are energy inefficient [15].

A study commissioned by the Pew Charitable Trusts suggested that a unique form of hybrid microgrid may be especially well suited to DoD's need to remain resilient in the face of an enduring disaster. Combining natural gas-fired generators with standalone diesel generators would alleviate the disruption caused by an interruption in supply of one fuel type [16]. Indeed, DoD recently installed at least two such hybrid microgrids—one at the Marine Corps Air Ground Combat Center at Twentynine Palms, and the other at the Marine Corps Air Station Miramar [15]. However, this is not a long term solution, as it won't eliminate the problem entirely. Even the most efficient hybrid microgrid of this type can only extend the energy self-sufficiency of a base for a finite period of time.

FEMA has developed a new Power Outage Incident Annex to the Response and Recovery FIOPs, which addresses the response and recovery to a mass or long-term power outage, regardless of cause. FEMA Regions I, II, III, V, VIII, and X developed regional power outage plans that address power outage risks and impacts. The Incident Annex also specifically highlights the development or addition of microgrids as a key preparedness activity, whether operated by DoD, federal entities, or commercial interests [17].

Recommendations for Current Plans and Exercises for Enduring Disasters

Minor changes and low-cost additions to select plans and exercises involving enduring disasters could save lives, increase efficiency, and reduce overall response costs.

Extended and Robust Planning Staff

Perhaps the biggest challenge of an enduring disaster is the establishment and long-term operation of an integrated, strategic-minded planning staff with prevention, response, and recovery phase expertise.

For instance, a 2006 federal lessons learned report on the response to Hurricane Katrina concluded that

"Federal, state, and local officials responded to Hurricane Katrina without a comprehensive understanding of the interdependencies of the critical infrastructure sectors in each geographic area and the potential national impact of their decisions. For example, an energy company arranged to have generators shipped to facilities where they were needed to restore the flow of oil to the entire mid-Atlantic United States. However, FEMA regional representatives diverted these generators to hospitals. While lifesaving efforts are always the first priority, there was no overall awareness of the competing important needs of the two requests [18]."

Therefore, it is imperative that balancing the competing needs of immediate live-saving relief efforts and critical infrastructure restoration activities be part of a strategic plan.

The potential damage to energy infrastructure caused by an NMSZ earthquake provides a ready example. The East Coast relies on gasoline and heating oil, but pipelines in the Mississippi Valley will likely be damaged during a New Madrid earthquake sequence. If the next major NMSZ event occurs in the winter, as it did in 1811, pipeline repair and operation will be a national priority, competing for resources against immediate local needs. All pipelines along the Mississippi Valley may have to be inspected and repaired after each earthquake greater than magnitude 3 for months. Such an extended earthquake sequence could shut down the majority of crude oil, natural gas, and refined liquid petroleum product-bearing pipelines that emanate from the Gulf Coast.

International oil and gas firms and midstream corporations have invested significant R&D dollars in pipeline monitoring and inspection technologies at a slow, but steady, rate since the construction and installation of the 800-mile-long Trans-Alaskan Pipeline System. The surge in crude oil prices between 2004 and 2008 served to supercharge pipeline protection-related R&D investments. However, apart from the addition of wireless connectivity and by-now-common optical ranging capabilities to standard oil field "pig" (Pipeline Inspection Gadget) designs, pipeline-monitoring technology has lagged behind the need for continual inspection necessitated by aging pipe ages. The threat of a major seismic area in the Lower Mississippi River Valley area stands as a notable threat to both below- and aboveground petroleum pipeline integrity.

Since 2015, multiple methods of improving pipeline status and performance monitoring have been introduced in the petroleum engineering community [19]. However, the majority of these advances assume a stable base pipeline (and seismic) environment for the operation of their inspection or monitoring technologies. In March 2018, engineers at Mississippi State University (MSU) revealed the results of research conducted on a bacteria-based sensor network designed to alert pipeline managers to even the smallest leaks in real time [20].

Unlike traditional pig-based inspection techniques, this material would be applied to the full outer diameter surface of each pipeline segment, which would also provide supplementary information on the basic structural integrity of the pipes. The MSU team has proven the versatility of their bacteria-based coating. Future research efforts will seek to identify and test suspending materials for the durable application of the bio-based film to pipelines at full scale.

Operations planning for an enduring disaster will be more complex, covering all the opera-

Figure 2. Loadmasters from Dover Air Force Base, Del. work with Aerial Port personnel to unload a Transport Isolation System on Joint Base Charleston, S.C. during Exercise Mobility Solace Aug. 17, 2016. Exercise Mobility Solace provides AMC, working with joint partners, the opportunity to evaluate the protocols and operational sequences of moving multiple patients exposed or infected with Ebola using the TIS while testing its capabilities and working in concert with various military units, first responders and local government agencies. (U.S. Air Force Photo by Tech. Sgt. Gregory Brook)

tional phases simultaneously, and will have to be maintained over a prolonged period of time versus that of a typical hurricane response. Plans and exercises for enduring disasters must reflect the need for a larger planning staff and the need to rotate both individual staff members and staff teams.

Integration of Non-traditional Aid

Disaster response work has inherent hazards. Search and recovery teams may be caught in significant earthquake aftershocks. Medical providers may become infected during an epidemic. Enduring disaster response may take a heavy toll on equipment. Long-term operations can require responders to service equipment and rotate personnel. It is likely that a prolonged response to an enduring disaster will deplete existing domestic resources, which may be offset by the integration of foreign response teams and resources.

Interest in employing these resources is a recurring theme in AARs from recent operations. For example, the 2017 Joint Task Force Texas Hurricane Harvey AAR stated "there were a number of foreign governments who sought to lend support to Texas during this response [21]."

Additionally, the NMSZ 2011 National Level Exercise AAR indicated "Sweden was unwilling to deploy their medical team without the [United States Government] assuming medical liability. Other international offers—such as those to supply field hospitals, medical teams, HazMat (Hazardous Material) teams, and water purification resources—had not been accepted by the end of the exercise and were therefore still pending [22]."

Pre-planning for the use of foreign response teams and their inclusion in enduring disaster response exercises provides the opportunity to exercise individual international support agreements with key partner nations. Processes for quickly employing unanticipated partners as well as establishing pre-incident agreements with traditional international partners for selected enduring disasters may prove beneficial.

Government agencies continue to benefit from collaboration with industry, representing enhanced capabilities in strategic crisis management planning. These partnerships will bring a quicker response and facilitate an efficient transition into community recovery following a crisis [23].

Collaboration with non-traditional disaster response groups can also be optimized to provide highly accurate data for the mapping of a disaster site. The last decade has seen a trend of online volunteers using satellite imagery to crowdsource an up-to-date map of an affected area. However, this data is typically produced in a random order, and not in line with responder needs or priorities. Research recently published by a team from the University of Tennessee, Knoxville, and the University of California, Santa Barbara, has demonstrated a digital triage method for prioritizing disaster mapping for volunteer efforts [24]. Such mapping data, when combined with on-the-ground reconnaissance, can aid in an effective response.

Increase Responder Resiliency Via Social Networks

CDC Deputy Team Lead and Senior Laboratory Advisor John Saindon worked in Liberia during the Ebola epidemic from November 2014 through March 2017. He made several observations and recommendations for improving the U.S. response that can easily be extrapolated to other enduring disasters, writing that "the focus of much of the existing published literature is on the disease outbreak itself but neglects the responder's own social and resilience considerations during a disease outbreak [25]."

Saindon had great concerns about the social and mental well-being of crisis responders in an environment where an increased distrust and fear of health workers and international support became inherent. This distrust and fear was due to the emphasis on stopping the disease at the expense of recognizing the community aspects of the response. He stated that remaining in contact with friends and family outside the crisis event is critical to long-term responder success [25]. "During any response, it is recommended that responders maintain communication with friends, family, and other responders to create a social network of support. It is also important that a responder consider participating in collective efficacy [25]."

Response to Vulnerable Populations

During an enduring disaster, citizens requiring access to prescription medication will turn to the disaster response community for assistance. While stockpiling a vast variety of medicines is expensive and seldom effective as a long-term solution, advanced planning on how to alternatively resource select drugs and obtaining advanced emergency-use waivers concerning manufacturing, importation, and inspection techniques may save significant and lifesaving time during an enduring disaster response. This consideration should be included in planning for disasters that may become enduring and exercised accordingly.

Effective responses to enduring disasters plan ahead for providing aid to vulnerable populations, such as the elderly and disabled. In the wake of Hurricane Sandy, New York City expanded its emergency response plan to address the evacuation of disabled citizens who live in high-rise apartments [26].

The revised plan includes a task force dedicated to addressing processes and methods for high-rise evacuation, bringing together governments, first responder agencies (New York City Fire Department, etc.), and technical standard-setting organizations like the National Institute of Standards and Technology and the National Fire Protection Association [27]. Planning for the evacuation of vulnerable populations must also account for the lengthy period of an enduring disaster, possibly resulting in multiple relocations.

Maintaining a Responder Reserve and Developing Responder Depth for Enduring Disasters

"Never be late to need" is a common mantra during response events and exercises. In an effort to meet the need, there is a tendency to maximize the use of personnel—sending all available responders on missions. However, holding a third of forces in reserve to enable later flexibility in response is a proven military tactic that assists in the recovery of initial responders. For example, in an earthquake sequence, where additional earthquakes are often incorrectly assumed to be significantly lower magnitude than the initiating event, responders and citizens can become trapped or injured as easily as in the initial event. Employing a reserve personnel in this scenario would greatly aid in response efforts.

Furthermore, a national-level cadre of properly trained reserve responders provides depth during an enduring disaster. After the 2017 Hurricane Season, FEMA's Planning Cadre integrated Incident Management (Field) and Incident Support (Regional and National) operational planning capabilities [28]. The responding operational planning cadre provides assumption-based forecasting and planning, which allows greater use of programmatic activities to support responder communities.

Furthermore, a national qualification system should be operationalized to provide the standardized structure for training, organizing, and equipping personnel.

Conclusion

Enduring disasters require different approaches and considerations than traditional duration disasters. The aforementioned recommendations are low-cost improvements to existing response plans and training exercise designs. Deliberate planning will address issues readily apparent in enduring disaster response and recovery.

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