FEMA

Modeling and Data Working Group

Role of Data and Models in Supporting Planning and Response to an Improvised Nuclear Device (IND) Detonation

FINAL REPORT: IND Data and Modeling Resources for Emergency Management

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Executive Summary

Introduction

During management of any large-scale emergency, whether an improvised nuclear device or a hurricane, federal, state and local entities must effectively leverage information from a wide range of sources to answer the fundamental questions of “What happened?”; “Who or what was affected?”; and “What needs to be done?” To address these three foundational questions and the corresponding data requirements, the information resources available to the federal interagency must be identified, collated, and made available so they can be effectively used during all phases of emergency management to inform decision-making, either at the level of senior leadership or for on-the-ground operations.

This report presents a resource inventory of the datasets and models used to support operational decision making in the context of federal emergency management for nuclear detonation scenarios. This inventory was generated on the basis of nearly 200 interviews with emergency managers, subject matter experts, and high level decision. Nearly 500 data and modeling resources were identified and characterized, of which 114 are included in the final inventory to those resources currently used by the federal interagency in the context of emergency management for nuclear detonation scenario planning and are included in the inventory presented here. Each resource is characterized by a series of metadata tags that describe its function, use, and availability. The list of the IND resources and the associated metadata can be found in Appendix 8. The methods and findings from network and metadata analyses of the nuclear detonation resource inventory are described in brief below and in depth in this report.

Developing preparedness and response plans to a nuclear detonation scenario (also described as an improvised nuclear device, or IND, scenario) presents a unique challenge due to the absence of prior experience. Therefore, the first sections of this report outline the timeline of a nuclear detonation event and the corresponding emergency response activities that would be required. Such timelines can help guide the development of operational plans and ensure that the time critical information requirements for each stage of emergency management are available. This linkage between the event timeline and the data required for the corollary response efforts is particularly critical when developing plans that rely heavily on the outputs of predictive models. If an event were to occur, the reliance on the outputs of predictive models would quickly transition to a focus on the collection and analysis of assessment data to provide decision support information.

Results

In order to capture the breadth of data, analysis tools, and models used by those involved in federal emergency management, a conceptual framework was developed to categorize the information resources in the inventory by their utility. This framework describes the iterative process of data collection, processing, and analysis that produces the operationally relevant information that informs decision making across a wide range of missions. The categorization system contains seven basic types of resources: raw data, event characterization models and analysis tools, situational awareness data, consequence models, impact estimates, decision support tools, and mission specific requirements. These categories of data and models provide context for the widely varied utility of the information resources in the inventory and provide a framework that can be used to describe the flow of information between resource types relative to how and when each resource is used for emergency management.

The resources within the IND inventory have been analyzed to reveal trends in how information is processed and used by the federal interagency. Two types of analyses have been performed: network and metadata analysis. The network analysis was a systems-level analysis to evaluate the robustness and interconnectedness of the IND network that considered the number of users and resource categories, as well as the linkages between each resource. Metadata analysis characterized the types of resources used and identified the major users and producers of data and modeling resources. In addition, a preliminary mapping of resources in the inventory to response actions and associated information requirements was performed to illustrate how the resource inventory can be used and integrated into emergency preparedness and response plans. The major results from the analyses specific to those resources associated with emergency management for nuclear detonation scenarios are summarized below:

- Those information resources used are generally well-connected within the network, though some resources, termed orphans, have no upstream or downstream connections.
- Although many data and modeling resources are used by one or a few agencies at the federal level, only a few resources stand out as being widely used across the interagency.
- A qualitative analysis of the flow of information within the resource network shows a relatively clear progression from raw data to event characterization to consequence models. However, more operations-focused resources, including decision support tools and mission specific requirements, are not clearly organized within the network and are not well connected to upstream resources.
- The bulk flow of information shows that there is limited information passed from consequence models to downstream resources and little flow of information into mission-specific requirements.
- Some resources are more highly linked to other resources in the network and are important information conduits within the network. These resources are central to the flow of information and play a key role in providing hazard- and mission-specific information to support operational decision making.
- The few impact estimates, decision support tools, and mission-specific requirements available to the federal interagency only support a narrow range of emergency management missions.
- Few redundancies exist within the network, with most resources serving a unique function. Only two areas appear to have redundant resources – dispersion modeling and situational awareness viewers.
- FEMA, followed by DHS, DoD, and DOE, leads the federal interagency in using the available data and modeling resources to support operational decision making during all phases of emergency management. Generally, agencies tend to use a few widely-used resources that describe or characterize the event in addition to a few additional data and modeling resources that support their specific mission.

Discussion and gap analysis

The network and metadata analysis of the IND resource inventory, combined with information from interviews with subject matter experts, emergency managers, and senior level decision makers, have revealed three major gaps in how the interagency uses information resources to support decision making during emergency management. Each of the three gaps speaks to an overarching need to translate and link the outputs from existing data and modeling resources to response activities in order to support data-driven decision making across emergency management missions.

1) Lack of operations-focused information resources (e.g. impact estimate libraries, decision support tools, and sources of mission specific requirements)
2) Lack of robust connections between event characterization and existing operations-focused resources
3) Lack of cross-sector consequence and response models

Courses of action

Courses of action (COAs) are outlined to address these gaps. These COAs are based on the in-depth analysis provided in this report, as well as previous efforts across the interagency. They are focused on those efforts needed to maintain the existing resources and the networks between them and to build a more robust and well-connected network of resources that will help ensure that the necessary information is available to those who need it when they need it for emergency management in the context of nuclear detonation scenarios.

- Perform in-depth analysis and mapping of resources to mission-specific data requirements to determine how the resources in the inventory can inform response actions, and, by extension, the development of preparedness plans
- Develop cross sector impact estimate libraries to develop a well-connected and well-functioning network of resources relevant to INDs
- Develop decision support tools and mission specific requirements to ensure that a robust IND network of data and modeling resources are available to support operational decision making
- Develop a Concept of Operations to outline how the resource inventory can be used and to develop a maintenance strategy to ensure that this information is kept up-to-date and accessible to the emergency management community
- Expand the resource inventory to include additional scenarios, like biological and cybersecurity, to create a robust resource inventory, extend our understanding of how the different resources interact with each other, and highlight potential hazard-specific and mission specific gaps.

The inventory of resources used to inform nuclear detonation emergency management, as developed through this project, will enable the entire emergency management community to identify and use the resources available to support operational decision making during all phases of emergency management.

Introduction

A nuclear terrorism incident, such as the detonation of an improvised nuclear device (IND), will have devastating large-scale consequences to public health and safety. At ground zero, the blast will cause mass casualties, destroy infrastructure, damage utilities systems, stall immediate emergency response activities, and will continue to present a challenge during all phases of response and recovery. The immediate emergency management challenges will be determining how to save the most lives and minimize the impact of the disaster, which will require that critical decisions be made quickly. These decisions cannot be made without timely, accurate, and well-coordinated information, which must be collected and analyzed rapidly and then disseminated to relevant stakeholders at all levels.

Data and models have been used for many years to support operational decision-making. The advent of readily-available, high capacity, mobile computing systems have enabled the federal interagency to collect and access an unprecedented amount of incident-relevant information from data, models, and analysis tools. This expansion of data and modeling resources provide a wealth of information that needs to be organized and made accessible to the emergency management community, not just during a response, but during all phases of emergency management. An IND detonation, having no historical precedent, presents a unique challenge because effective strategies to respond and recover from such a scenario must rely heavily on predictive modeling and extrapolation from first principles. The roles and responsibilities for data collection and modeling to characterize the event in the early phases of a response have largely been codified for nuclear detonations through ongoing interagency efforts. However, in the absence of experience, many of the data and modeling resources needed to inform response and recovery operations are less well-defined.

In recognition that informed decision-making is key to successful emergency management, the Emergency Support Function Leadership Group (ESFLG) established the Modeling and Data Working Group (MDWG) in August of 2012 to promote better collaboration between stakeholders across the interagency to identify and characterize the data and models used to support emergency management. The membership of the working group is chosen by the ESFLG and expanded upon request by current ESFLG or MDWG members. Current members include a wide range of emergency managers and subject matter experts from across the interagency, including members from each of the federal Emergency Support Functions as identified by PPD-8. The primary goal of the working group, as defined by the charter, is to identify and characterize the data and modeling resources available to support federal decision-makers during all phases of emergency management, particularly during the time-sensitive period of emergency response. The data collected were analyzed to determine when and how those resources are used in the context of emergency management. The resulting information has been collated into an inventory of the currently utilized resources. The resulting web-based tool will help ensure that decision makers have access to the information they need when they need it to support operational decision making for emergency management.

Timeline of events after an IND detonation

A clear understanding of the expected effects and timeline of a nuclear detonation is critical for developing effective plans for emergency management and to understand the data and data processing tools that will be required to inform decisions related to the event. The timeline of events following a nuclear detonation are described below.

Detonation of a 10-kiloton (kT) IND in a major US city, as described in the National Planning Scenarios,[1] would cause large-scale and long-lasting damage, severely stressing national capabilities and requiring a concerted, time-critical, whole-community response to mitigate the disaster. In the immediate area, there would be few survivors and buildings would be leveled. The nuclear explosion can also produce fallout, which is generated when dust and debris created by the explosion are combined with radioactive fission products. This material can be drawn several miles upward into the atmosphere; as the cloud cools, highly radioactive particles fall creating dangerous radiation levels for up to 20 miles and detectable contamination for a hundred or more miles downwind of the explosion. A more detailed description of an IND detonation and expected outcomes can be found in the referenced reports.[2,3] The overview provided here describes the expected timeline of events following an IND detonation to outline the information required to support operationally-relevant decision making for emergency management across the interagency.

Figure 1 depicts the expected timeline of events that would occur after a ground detonation of a 10kT nuclear explosive in a densely populated city in the U.S. For the purposes of this report, these events have been categorized into prompt, delayed, and health effects.

1 DHS (Department of Homeland Security) (March 2006) National Planning Scenarios.
2 NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.
3 Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

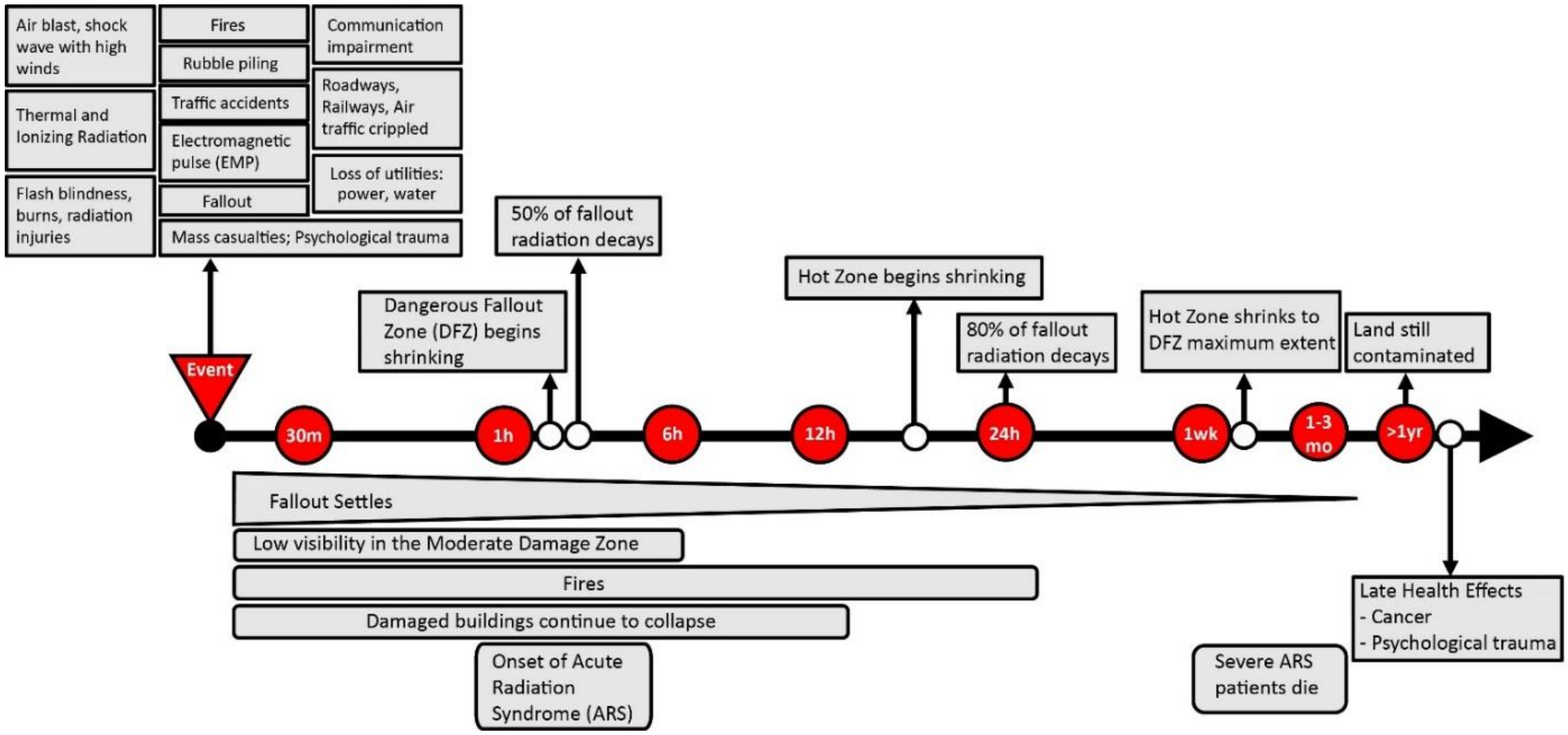

Figure 1. Expected timeline of events after a 10kT IND detonation.

Prompt effects

The prompt effects of an IND detonation consist of physical phenomena produced by the detonation usually within the first minute including an intense flash of light, a blast wave, heat, radiation, fires, and an electromagnetic pulse. The immediate consequences of prompt effects include rubble piling, traffic accidents, fires, communication impairment, infrastructure and utility damage and mass casualties. An overview of these effects in the context of how this information can be used in operational decision making is described below.

Blast effects

An IND blast is measured by the overpressure expanding in all directions from the detonation and the dynamic pressure related to the wind generated by the passing pressure wave. The combination of these two forces produces extensive physical damage to structures.[4] The amount of damage caused by the blast wave after an IND explosion can be described in zones, as shown in Figure 2, defined by the amount of observable damage (severe, moderate or light) that are used for planning and prioritizing response actions.[5] Within the severe damage zone (SDZ) most buildings will be destroyed and few survivors will be expected. In the Moderate Damage zone (MDZ), many buildings will be severely damaged or destroyed. The MDZ is expected to have the greatest number of "At-Risk" individuals, defined as that population at risk for injuries with a mortality rate between 5 and 95 percent.[6] This population will benefit most from medical intervention, and it is recommended that rescue efforts initially concentrate on the MDZ.5 Damage in light damage zone (LDZ) is caused by shock waves, and windows may be blown in up to 10 miles away.6 The majority of injuries in the LDZ are expected to be relatively minor, caused by projectile glass, with high survivability even without immediate medical care.

4 Samuel Glasstone, Philip J. Dolan (1977) The Effects of Nuclear Weapons, 3rd edn. Lexington, KY: Knowledge Publications.

5 NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.

6 Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

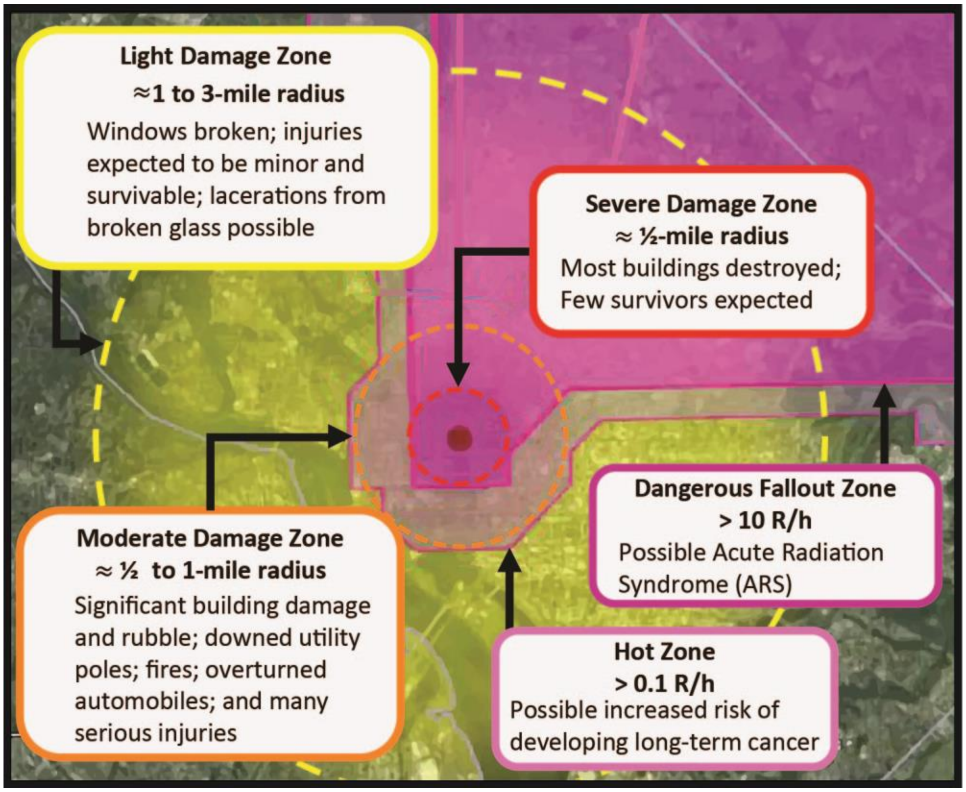

Figure 2. Depiction of blast and fallout zones after a 10-kT IND detonation. [7]

A clear understanding of the basic differences in scope of impact between these zones can significantly increase the ability of emergency managers and first responders to effectively prioritize response activities, whether during planning for or responding to the event. Models can be used to estimate the approximate area and size of the different blast zones, which can be used to inform early response activities. The data generated can help define anticipated fallout deposition patterns, identify the regions most likely to be affected by fires, predict degrees of building damage and the amount of rubble from damaged and collapsed structures in each blast zone. These data in turn can be used to inform and prioritize response activities such as identifying available evacuation routes, medical centers, and shelter facilities.

Thermal radiation effects

In contrast to more traditional explosives, an IND detonation releases significant thermal radiation. Approximately 35% of the energy released upon detonation will be thermal, resulting in a rapidly expanding fireball.[8] The fireball is created by the release of energy by the fission fragments, x-rays, and beta particles into the immediate vicinity of the explosion. Temperatures within the fireball are in the range of tens of millions of degrees Celsius with pressure many orders of magnitude greater than atmospheric pressure.[9] The intensity of the thermal pulse depends on distance from ground zero, the height of burst, and the urban environment, all of which affect the degree of shielding from the radiation.

7 Figure adapted from Buddemeier B et al, November 2011.
8 NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.
9 Samuel Glasstone, Philip J. Dolan (1977) The Effects of Nuclear Weapons, 3rd edn. Lexington, KY: Knowledge Publications.

A dense urban environment will most likely mitigate the effects of prompt thermal radiation from a ground level detonation, and is expected to result in a "starburst" effect as radiation moves down streets with a clear line of sight.[10, 11] Victims within a direct line of sight of the burst are subject to burn injuries up to two miles away from ground zero, with severity directly related to distance and available shielding. Models can help predict what types of burn injuries will be most common in the blast zones surrounding the blast and help inform medical triage plans and the development or purchasing of medical countermeasures to help treat the expected injuries. Those who have the detonation in their field of view may receive retinal burns that impair vision 10 or more miles away.

In addition to causing burns, thermal radiation will ignite material within the radius of the fireball.[12] While an urban environment is predicted to reduce the area subjected to thermal radiation, [13] flammables inside buildings destroyed by the blast are likely to cause additional fires, and new fires will appear as damaged buildings collapse. Fires are expected to spread unless extinguished by first responders. While a firestorm like those caused during previous nuclear detonations are unlikely given the shift in building materials from wood to less flammable materials (concrete, metal, and glass), models can be used to predict the relative likelihood of fires in specific areas, particularly as they relate to building collapse.

Prompt radiation effects

Prompt or ionizing radiation, also released during a nuclear detonation, is a direct result of the nuclear fission process. Like thermal radiation, ionizing radiation poses a significant risk to anyone close to the burst site. The spectrum and flux of ionizing radiation at any given point is dependent on the bomb design, distance from ground zero, and atmospheric conditions. Victims located outside in the SDZ at the time of the blast are expected to receive a lethal dose of prompt radiation. Shielding from a dense urban environment can substantially reduce the number of expected radiation-related casualties in the MDZ. Models that predict the area of prompt radiation would allow identification of populations that will likely exhibit radiation exposure symptoms and help determine the supplies required to treat them.

Flash blindness

Prompt effects of an IND detonation include a brilliant flash of light that can cause up to a minute of temporary blindness, often 10 or more miles from the detonation.[14] Poor atmospheric visibility can reduce the range of this effect; however reflection off clouds and buildings can create indirect exposures that do not require the victim to be looking in the direction of the detonation to be flash blinded. This sudden loss of vision for drivers could cause traffic accidents in a large radius surrounding the detonation, blocking roads and causing serious injuries. Recognizing the effect of flash blindness on roadways and estimating the resulting traffic accidents could assist in planning alternate evacuation routes out of the affected region and alternate access routes into the blast zones for emergency responders and supplies.

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10 Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

11 Marrs R *et al* (June 2007) Thermal Radiation from Nuclear Detonations in Urban Environments. Lawrence Livermore National Laboratory.

12 National Academies (2005) Nuclear Attack. Factsheet created for News and Terrorism: Communicating in a Crisis.

13 Marrs R *et al* (June 2007) Thermal Radiation from Nuclear Detonations in Urban Environments. Lawrence Livermore National Laboratory.

14 NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.

Electromagnetic pulse (EMP)

An IND explosion also releases a short electromagnetic pulse (EMP) of energy, which has the potential to damage electronic equipment.[15] EMP is primarily a concern for high-altitude, high yield detonations. While there is some disagreement regarding how significantly EMP would affect the communications and electrical infrastructure,[16] for a 10kT, ground-level detonation, disruption of electronics can be expected as far as five miles from the detonation. It is reasonable to assume that electricity and land-line communication would be disabled within this region, which suggests that response plans should include alternate means of communications after an IND detonation.

Damage to infrastructure and utilities

A wide range of critical infrastructure and utilities in the area surrounding the IND detonation will likely be damaged or destroyed by the prompt effects of an IND detonation, including the blast wave and thermal radiation. The loss of these assets will influence the allocation of disaster relief supplies and the suitability of locations to be designated as shelters or medical centers. For example, communications infrastructure in the severe and moderate damage zones will likely be damaged or destroyed. Cellular networks may be overwhelmed as tens of thousands attempt to locate loved ones. EMP could limit or disable electronic communications devices. Roadways, railways and air traffic will likely be crippled. Roadways situated closer to ground zero will be blocked by increasingly large amounts of rubble and traffic accidents caused by flash blindness. Many railways and other public transportation infrastructure will be disabled as stations and tracks are obstructed or destroyed, communications are disrupted, and electricity fails. Security concerns, lack of visibility, and communications failure will potentially ground aircraft. The explosion is likely to damage or destroy power lines, water pipes, and other types of utility infrastructure.[17] It may take several weeks to restore electricity to SDZ and MDZ. In total, the wide-spread impacts to critical infrastructure will limit effective communication with the public, the distribution of disaster relief supplies, and access to shelters and medical providers, among others. These impacts could be mitigated by effective pre-event planning driven and informed by supply-chain modeling, critical infrastructure contingency planning, and mechanisms to ensure that information regarding the immediate impacts to critical infrastructure will be readily available and widely-shared following an event.

Delayed effects

In addition to prompt effects, a nuclear blast will generate delayed effects, most generally caused by fallout. Fallout is produced when radioactive particles adhere to dust and debris as part of the initial explosion and are drawn up several miles into the atmosphere as part of the fireball. These particles, which emit radiation, will begin to fall out of the cloud and settle on horizontal surfaces. Unlike prompt effects, which occur too rapidly to avoid, health effects from fallout can be mitigated by taking shelter. Sheltering in place to avoid exposure is recommended for the first 12 to 24 hours after the plume extends into a given area.[18, 19]

The region affected by fallout is divided into two categories based on the danger of radiation exposure as measured by dose rates. These categories are the dangerous fallout zone (DFZ) and hot zone (HZ),

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15 ibid.

16 Casagrande R (2011) Brief: Possible Causes for Divergent Estimates of EMP Consequences.

17 National Academies (2005) Nuclear Attack. Factsheet created for News and Terrorism: Communicating in a Crisis.

18 Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory

19 NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.

illustrated in Figure 2. The fallout pattern is determined in good part by local meteorological conditions, including the prevailing winds that determine the direction the plume will travel and precipitation, which directly affects the rate and pattern of the fallout deposition. Precipitation can cause "hot spots," where higher rates of fallout accumulate; radiation may be further concentrated in gutters or sewers by continued precipitation or spread further by deposition in streams or other bodies of water. The fallout zones are also directly affected by the decay rate of the radioactive material itself, as described in Figure 3. Ongoing modeling of the radioactive plume, measurements of radioactive material, and calculations indicating decay rates for the types of radioactivity released can all be used to directly inform planning and response activities.

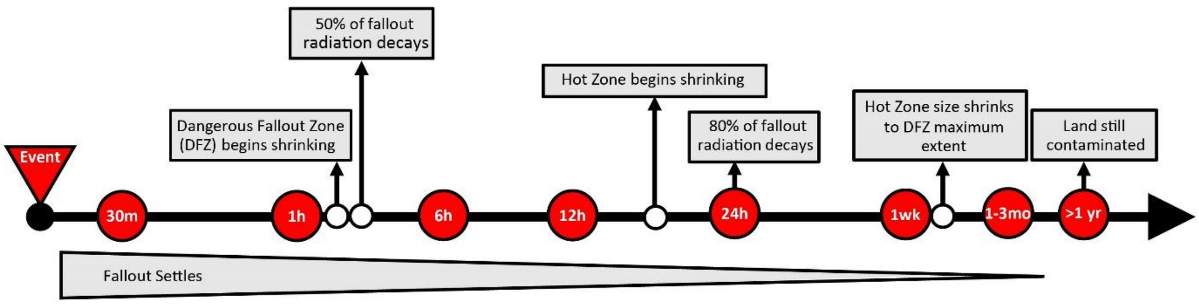

Figure 3. Expected timeline for decay of fallout after a 10-kT IND detonation.

Although the high radiation levels that present an immediate danger will rapidly decrease after the first few days, long term, low-level radiation will persist in the area for years. Land is expected to remain contaminated at least one year after the event.[18] Even though the long-term risk posed by such radiation levels is believed to be limited, it is likely that people will continue to avoid the affected areas. In addition, the public may lose confidence in agricultural products originating from these areas. Data and modeling resources that can accurately map this area will inform appropriate public messaging and long-term recovery efforts.

Health effects

Prompt and Delayed effects most commonly describe the physical effects of an IND detonation. The human health effects associated with such an event are described in Figure 4. The immediate health effects include those caused by the thermal and ionizing radiation and by secondary health effects, such as trauma from car accidents caused by flash blindness, building collapse, or burns from fires ignited by the blast, and psychological trauma. Many patients, particularly those in the MDZ, are likely to present with complex injuries caused by a combination of radiation exposure, burns, and injuries due to trauma. Populations within the fallout zones are expected to have an increased risk for radiation injury. For those outside of a robust shelter, acute radiation injury is highly likely in the DFZ. Therefore, modeling and data resources that can predict the number of individuals exposed to acute radiation will be necessary to determine the medical facilities and supplies required for treatment. Acute radiation effects are unlikely in the HZ, but minimizing exposure will reduce long-term cancer risks. Data and modeling resources that map the HZ will also be important to determine the number of individuals at risk for developing cancer in the long term, such that these populations can be monitored in the recovery phase and receive appropriate treatment.

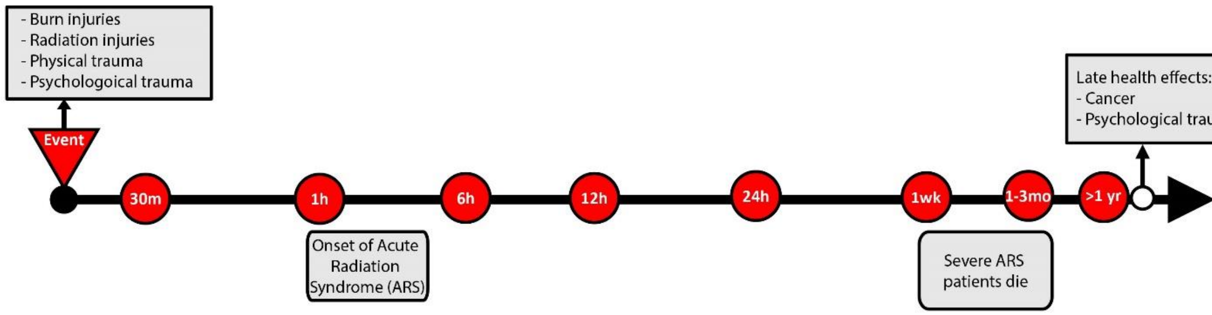

Figure 4. Timeline of expected health effects after an IND detonation.

Health effects can continue to manifest over the days and weeks following the event. High doses of full-body exposure to ionizing radiation causes acute radiation syndrome (ARS), which manifests over a period of hours to weeks with the rate of onset proportional to the amount of acute radiation exposure. Most ARS victims will experience nausea and vomiting within 24 hours of radiation exposure, although symptoms of ARS may continue for months. Depending on the amount of radiation exposure, patients with severe ARS will die starting at one week post-exposure.[20] This delay in ARS symptoms can cause confusion because those with significant exposure may initially appear to recover, only to present with more severe symptoms at a later date.[21] Deaths usually result from hemorrhage, cardiovascular system failure, infection, dehydration, or electrolyte imbalance. Supportive care, including blood transfusions and antibiotics, is usually indicated.[20] Modeling can help identify the approximate number of potential ARS victims, an important factor in determining the quantity and types of medical supplies and the number of medical facilities that will be required throughout the response and recovery phases.

Long-term health effects are predominantly radiation-induced carcinogenesis, which takes years to develop,[22] and psychological conditions, including posttraumatic stress disorder, generalized anxiety, panic, depression, and others, which could persist for several years.[23] The on-going response and recovery phases should include continued medical surveillance of individuals to manage long-term psychological trauma and to detect cancer.[24] Therefore, resources that can identify and track potential victims can facilitate the recovery process.

Timeline of response activities after an IND detonation

Detonation of an IND would require an immediate large-scale emergency response and recovery effort to save lives, stabilize the affected area, limit extended impacts, and return the region to normalcy. This section outlines the timeline of anticipated response activities corresponding to the event timeline described in the previous section. To put these activities in the context of response and recovery operations, the timeline depicted in Figure 5 is described on the basis of the phased approach to how

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20 CDC (Centers for Disease Control and Prevention). CDC Radiation Emergencies | Acute Radiation Syndrome: A Fact Sheet for Physicians. http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp. Last Update March 18, 2005. Accessed October 11.

21 Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

22 Tenforde TS *et al* (Summer 2010) Health Aspects of a Nuclear or Radiological Attack. *The Bridge* 40
Institute of Medicine (2009). Board on Health Sciences Policy. Assessing Medical Preparedness to Respond to a Terrorist Nuclear Event.

24 National Academies (2005) Nuclear Attack. Factsheet created for News and Terrorism: Communicating in a Crisis.

federal response operations are organized as described in the Response Federal Interagency Operational Plan (FIOP), which is currently being updated.[25]

The discussion in this section describes the response activities required following an event. This focus on response is specifically designed to guide planning activities: a clear description of the necessary response activities provides an outline of the information required to perform those activities efficiently and effectively and provides a guide for planning that would directly support response and recovery activities. The data, models, and analysis tools available to inform response activities must be identified and incorporated into interagency emergency management plans and Concept of Operations (CONOPS). Only if these resources are made readily available, exercised, and incorporated into the experience of emergency managers will the information they provide be successfully leveraged during an event.

Notably, this timeline does not include the period prior to the detonation, such as any activities undertaken by federal authorities if a credible, imminent threat of an IND were identified or predicted. These activities, typically referred to as consequence management, are covered in a series of ongoing efforts within the federal interagency. The data and models used to help guide the emergency management aspects of consequence management are expected to be largely similar to those used during planning efforts and during response to an event. Certainly, much of the information required would be similar: information identifying which populations and infrastructure could be affected; the degree of expected damage; and what actions could and should be prioritized to most effectively and efficiently provide support to those impacted.

The timeline of a response is shown in Figure 5. The section below describes these response activities as they relate to the event timeline described previously in this document and as they can be used to define the corresponding information required to support data driven, operationally-relevant decision making.

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25 DHS (June 2013) Response Federal Interagency Operational Plan - Draft for Approval.

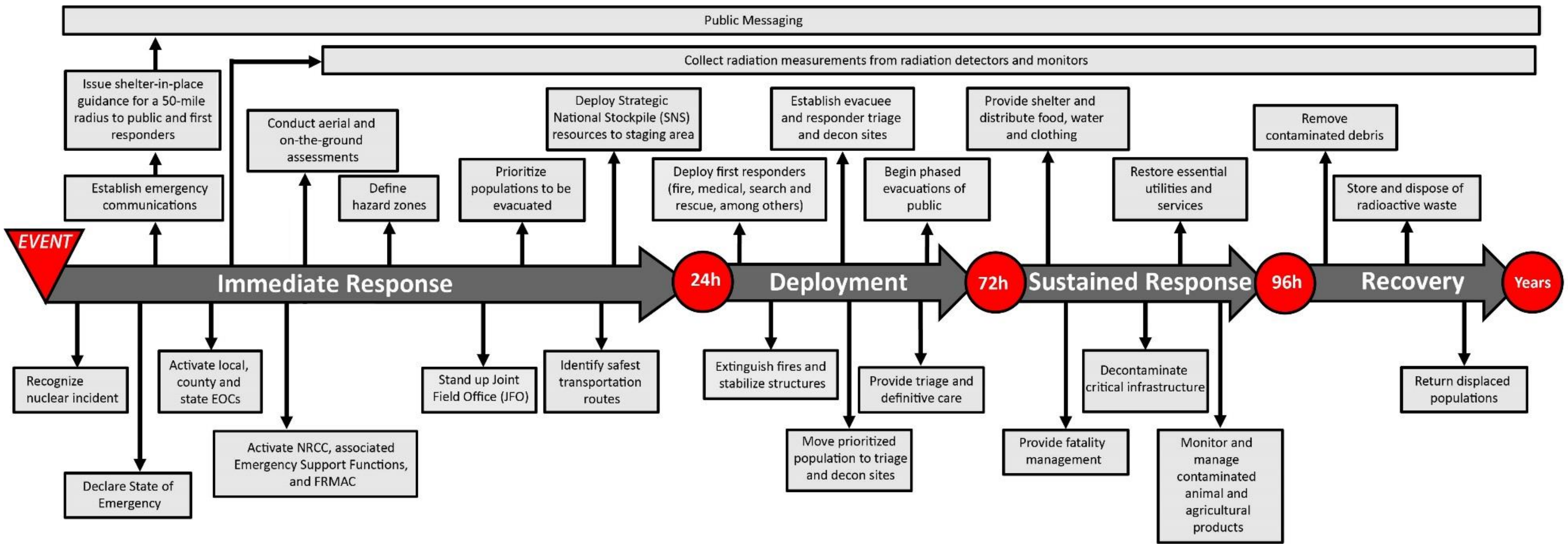

Figure 5. Timeline of response activities after an IND detonation.

Immediate response: 0 to 24 hours

A review of planning and policy documents suggests that most on-the-ground federal response activities are unlikely to occur within the first 24 hours after an IND detonation.[26, 27] However, this period will be critical for federal activities related to evaluating the situation, gathering information about the event, and preparing to deploy all available assets to the affected area once it is reasonably safe to do so. Figure 6 illustrates the activities expected to occur during this period. These proactive efforts will ensure that resources reach the impacted area in time to provide assistance.

Although federal assets will take time to arrive on the scene, state and local responders, such as fire and emergency medical services, are likely to attempt rescue operations immediately. Data and modeling resources that can provide information to these first responders about blast zones, fallout zones and protection factor of buildings will help to identify areas where response efforts can proceed with minimal risk to responders.

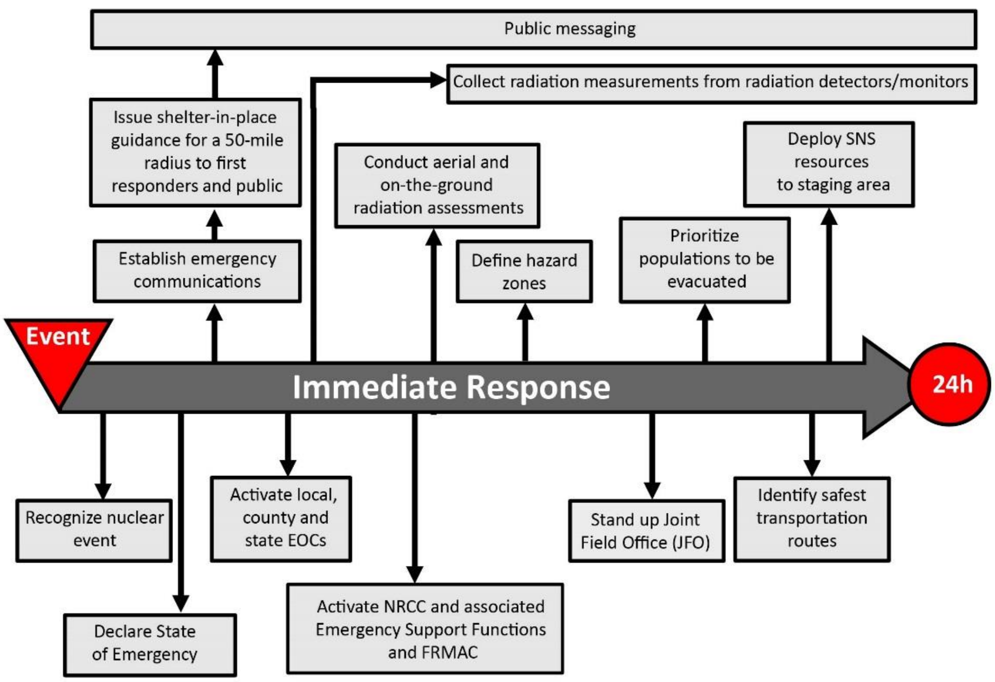

Figure 6. Response activities that will likely take place during the immediate response phase.

Event recognition

The radiation generated by a nuclear explosion demands a specialized response approach. The majority of response efforts, such as a phased evacuation or medical treatment, cannot proceed without first recognizing the nuclear nature of the incident. Widespread destruction, the flash of light, and the subsequent fallout cloud, among other indicators, will indicate that a nuclear detonation has occurred. Concurrently, fixed or portable radiation monitors will provide an indication of radiation contamination.[27] Resources, such as Rad Responder,[28] that collate, transmit and map radiation levels will be essential in

26 Garwin RL (Summer 2010) A Nuclear Explosion in a City or an Attack on a Nuclear Reactor. *The Bridge* 40

27 NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.

28 RadResponder Network. https://www.radresponder.net/ Accessed 11 November 2013

providing ongoing information such as the deposition of fallout, which can be used to estimate the relative health effects expected in affected areas and track radiation exposure to first responders and others. All these data can be used to directly support decision-making for emergency managers, but can also be used to update the parameters of models used for ongoing predictions regarding the scope and scale of the event.

Emergency communications

Current policy and planning documents advise that first responders and the public shelter-in-place for a 50-mile radius from ground zero until more information is obtained about the extent of the blast and fallout hazards.[29] However, this guidance is expected to be refined based on a combination of atmospheric dispersion modeling and radiation assessment data, such as data collected by real-time monitoring, which, taken together, will allow identification of areas where response activities can commence in the blast zones that are not contaminated with radiation. As the weather changes, aerial and on-the-ground assessment data, updated predictions regarding the trajectory of the radioactive plume, and information about the decay rates of the material released will be combined to refine the shelter-in-place guidance and provide estimates about the number of people affected and the types of medical care they will require once shelter-in-place guidance has been lifted.

Although shelter-in-place is advised within a 50-mile radius of ground zero, first responders outside of this area will mobilize and deploy to the affected area immediately. Therefore, it is crucial that data and modeling resources that provide information regarding contaminated areas also be disseminated to these groups as early as possible after an IND detonation. This information will help guide activities outside the immediate impact area toward those regions that will require the greatest support, while protecting the responders themselves.

Emergency communications post-event are necessary to effectively provide health and safety instructions to the public and first responders and are a critical factor in building trust, comforting the nation, saving lives, and minimizing injury.[30] The information must be disseminated broadly, providing guidance on protective activities such as shelter-in-place as well as information regarding where to seek medical care and longer term shelter. While there are systems in place to provide emergency communications, including the Emergency Alert System (EAS) and the Integrated Public Alert and Warning System (IPAWS),[31] the real challenge will lie in determining what information to provide to whom, when, and where. "Improvised Nuclear Device Response and Recovery: Communicating in the Immediate Aftermath" is one resource that can be used for emergency communications, providing key messages and anticipated questions and answers to be used during the initial 72-hour period after an IND detonation. The document is housed in the National Preparedness Resource Library[32] and is available for use by all emergency responders and federal, state, local, tribal and territorial officials communicating with the public.

Notably, compromised communications infrastructure is likely to complicate emergency communications efforts. While messaging by radio, television, and text messaging through cellular systems may be optimal, alternative messaging methods should also be considered. On-going assessments or estimates of

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[29] Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

[30] NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.

[31] Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

[32] Federal Emergency Management Agency. National Preparedness Resource Library. http://www.fema.gov/national-preparedness-resource-library. Last Update 2013. Accessed 2013.

the impacts to communications infrastructure will be required to inform these activities, ensuring that all available communications methods are leveraged to disseminate information to the public throughout the event.

Coordination of response activities: government emergency operations

An efficient and effective response will rely heavily on successful coordination. Immediately following an IND detonation, all affected local, county and state Emergency Operating Centers (EOCs) are expected to be activated immediately. Federal emergency assets will be leveraged once the affected states declare a state of emergency. Once a federal emergency is declared, the National Response Coordination Center (NRCC) will be activated and a Joint Field Office will be established as close to the detonation as possible within a safe area.[33] As described in the National Response Framework (NRF), the Emergency Support Functions (ESFs) will be coordinated through the NRCC to provide support for anticipated and identified response and recovery activities.

Coordination of efforts and initial events, including the declaration of a federal emergency and establishing a safe location for the Joint Field Office to stand-up, will rely heavily on the sharing and dissemination of information regarding the anticipated and assessed impacts of the event. This information is likely to be provided by a combination of assessment data collected post event with ongoing predictive modeling used to refine initial estimates of the event and its impacts. The Federal Radiological Monitoring and Assessment Center (FRMAC) and the Interagency Modeling and Atmospheric Assessment Center (IMAAC) will provide radiological assessments and modeling information to predict the trajectory of the plume and monitor radiation upon activation. As organized and coordinated by FRMAC, resources such as fire stations, aerial measurements taken by aircraft, on-the-ground radiation assessment teams, and first responders equipped with dosimeters will likely be reporting continuous time-stamped and geo-tagged dose rate measurements. These data could be collated and used to inform and refine modeling efforts to demarcate the blast and fallout zones. Such measurements allow fallout zones to be charted, providing a comprehensive situational awareness to emergency managers. Optimally, this information would be coordinated through the NRCC, shared with the state and local EOCs, and distributed to each of the ESFs to ensure that all these groups are operating under the same assumptions regarding the situation on the ground.

To facilitate response operations, blast and fallout zones will need to be characterized within a few hours of the explosion, so that responders on the ground can know which areas to avoid and on which areas to focus their response efforts. The blast zones can be recognized by visual inspection, but they tend not to have distinct boundaries (see Figure 2). Geo-tagged aerial imagery and reports from responders should serve as the basis for blast zone identification. The fallout zones may be recognized by a combination of aerial measurements, on-the-ground measurements, and modeling information. The shelter-in-place guidance up to a 50-mile radius is a blanket guidance in the early hours that is designed to prevent additional casualties due to radiation exposure. However, identifying the hazard zones within the 50-mile radius not contaminated by radioactive fallout would allow first responders to continue search and rescue operations outside the DFZ in the early hours after an IND detonation. Although most life-saving response missions are unlikely to begin in the DFZ for at least 24 hours post-event, identifying these hazard zones will be crucial as the greatest fraction of injured people whose lives can be saved by medical care will be in the moderate damage zone.[34] Demarcating this zone early will save time and lives by allowing relief assets to be pre-staged for deployment. In addition, actual dose rate measurements from

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33 DHS (Department of Homeland Security) (April 2006) Joint Field Office Activation and Operations.

34 Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

assessment data can be used to refine modeling parameters that predict the path of the fallout cloud. Such information will be vital to the planning of evacuation routes and location of triage centers.

Evacuation

While plans suggest that the public will be advised to shelter-in-place for 12 to 24 hours following detonation of an IND, extensive planning to guide evacuation efforts will be required during this time. Timely and organized evacuation is one of the most complex issues associated with a large-scale emergency and requires the merging of a large amount of information from a wide range of sources. Population, infrastructure, and event characterization information (e.g. type of blast, sources and types of contamination) will need to be collated and overlaid to understand the likely impacts of the event even before assessment data collected on the group are available. For example, impacts to transportation infrastructure such as bridge stability, traffic flow through streets or freeways blocked by traffic accidents, and debris-filled roads must all be considered.[35] Evacuation of the affected populations must be coordinated with the influx of emergency response vehicles, and those evacuating must have information regarding their final destination and whether that location can provide medical care, long term shelter, or both. Only once the blast and fallout zones have been identified can emergency managers prioritize the populations within the zones for evacuation based on the number of people estimated to be in each zone and the risk of radiation exposure and secondary hazards (i.e. fire, chemical release) in the zone.[36] Notably, all these activities rely heavily on the information about the event and its impacts. Without shared situational awareness, effective coordination of these activities would be impossible.

Medical supplies and services

Local and regional medical providers and supplies are likely to be immediately overwhelmed in the aftermath of an IND. Deployment of medical supplies from the Strategic National Stockpile (SNS) and the establishment of the onsite medical triage centers will be required to provide medical care and supplies to the affected populations and to support the response efforts. As these resources can require 24 hours to arrive, decisions regarding the extent to which they will need to be leveraged must be determined nearly immediately after the event.[37] This information, like that required to define the evacuation plan, will require the rapid collation of both predictive modeling results and aerial and on-the-ground assessment data collected immediately after the event to ensure a rapid and appropriate response. Notably, dose rate data collected by radiation detectors and monitors near the event can inform the quantity of supportive care products (e.g. antibiotics and neutropenia treatments) needed to combat ARS.[38]

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[35] Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

[36] NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.

[37] Benjamin GC (Summer 2010) Medical Preparedness and Response to Nuclear Terrorism. *The Bridge* 40

[38] CDC (Centers for Disease Control and Prevention). CDC Radiation Emergencies | Acute Radiation Syndrome: A Fact Sheet for Physicians. http://www.bt.cdc.gov/radiation/arsphysicianfactsheet.asp. Last Update March 18, 2005. Accessed October 11.

Deployment: 24 to 72 hours

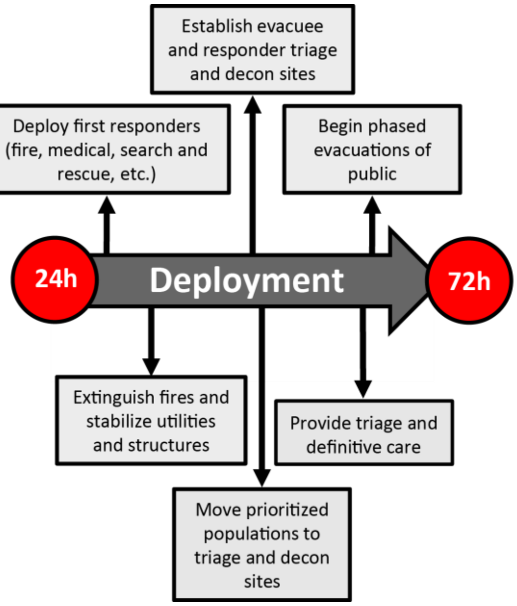

Figure 7. Response activities during the deployment phase.

After detonation of an IND, current plans suggest that shelter-in-place guidance for the general public would be lifted after 24 hours. At that point, more regional and federal assets would arrive and response and recovery activities would accelerate, as shown in Figure 7. As fire, medical, search and rescue, and other response activities escalate safe triage and decontamination sites must be chosen and outfitted to provide care for victims. While triage and medical care would ideally be provided at hospitals, resource constraints are likely to require expanding beyond traditional care providers to allow the largest numbers of casualties to be treated as rapidly as possible. Patient care is likely to be complicated by contamination issues: decontamination including guidance as simple as brushing fallout particles off clothing and removing and/or replacing clothing will need to be accomplished in addition to eventually washing.[39,40] The care of medical patients would need to be prioritized and triage hierarchies implemented. Disaster relief supplies such as food, water, and clothing would be distributed to evacuees as they assemble at shelter sites. Phased evacuations would commence as fires are extinguished, roads are cleared, and utilities and structures are stabilized.

All the activities implemented in the deployment period are time-sensitive and interdependent, requiring a great deal of coordination and the dissemination of clear information to guide prioritization, ensure safety, and save as many lives as possible. Large volumes of data are likely to be collected as first responders enter the affected regions, federal resources arrive onsite, and at least some communications infrastructure are restored or emergency communications systems are deployed. Whereas many of the decisions in the first 24 hours after the event are likely to rely heavily on information provided by predictive modeling, decision making during the deployment activity will shift to relying more on assessment data. In order for the assessment data to be used effectively to guide response activities, they must be collated, validated, processed, and made readily accessible to those on the ground. This process is a challenge even during much smaller events and highlights the need to incorporate detailed guidance for data and information

39 Benjamin GC (Summer 2010) Medical Preparedness and Response to Nuclear Terrorism. *The Bridge* 40

40 National Academies (2005) Nuclear Attack. Factsheet created for News and Terrorism: Communicating in a Crisis.

management into emergency response plans, so these activities can be validated and practiced along with the response and recovery activities they inform.

Sustained response: 72 hours to 30 days

The federal emergency management community aims to stabilize any major disaster by 72 hours after the event, at which point the response enters the Sustained Response phase (see Figure 8). Stabilization marks a transition from life-saving activities to life-sustaining activities and a shift of focus toward the sustained response and, eventually, to recovery.

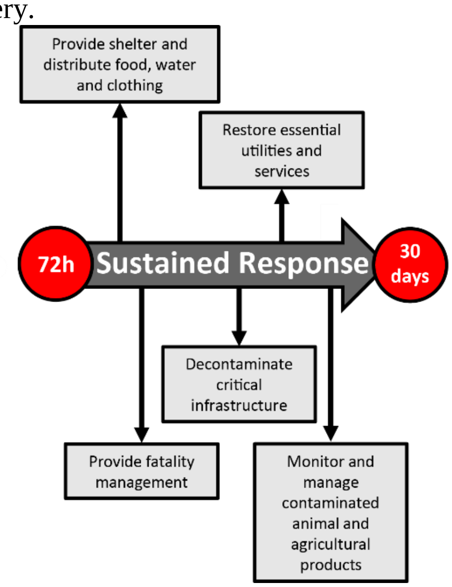

Figure 8. Response activities in the sustained response phase.

Mass care

The transition into sustained response includes a focus on mass care. Long term shelter facilities for displaced populations will need to be established, along with the food and medical services required for those populations. Due to the expected extended length of the recovery period, issues such as long term schooling solutions will need to be reached early in the sustained response phase so as to disrupt the lives of the displaced populations as little as possible. The long term solutions for displaced populations will need to be developed on the basis of information about the specific populations affected, their needs, and their levels of resilience.

Human health

As the situation on the ground is stabilized, medical providers will transition from triage into longer term life-support and ongoing treatment of patients suffering from radiation exposure (most notably ARS), all of which will require individual dose reconstruction. Determining the radiation dose received by victims will require biodosimetry tools and models, contamination maps, and reconstruction of victim location and movement patterns. Burn patients will require long term treatment, often requiring extended intensive care. Fatality management will need to be initiated, including the recovery, decontamination, identification, and interment of remains.[41] Information regarding treatment regimens, hospital bed space, available health care and supportive care providers, and necessary supplies to support long term medical

[41] NSS (National Security Staff) Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (June 2010) Planning Guidance for Response to a Nuclear Detonation.

care will all be critical to ensure that this care can be provided. In addition, medical providers will need to be ready to diagnose and treat the psychological impacts of a nuclear attack, which could range from posttraumatic stress disorder to generalized anxiety, and could continue for a protracted period.

Environmental contamination

For an event the magnitude of an IND detonation, decontamination and restoration efforts are projected to cost billions of dollars and will last years, but planning for these activities must be initiated during the first week following the event.[42, 43] Critical infrastructure and utilities will need to be restored as well as the decontamination of land and buildings before displaced populations are permitted to return home. Transportation infrastructure, including roads and bridges, are required to support restoration activities. These activities will rely heavily on data indicating when and where workers can safely re-enter to begin restoring services. Furthermore, any materials or rubble produced by the explosion must be cleared before reconstruction of the blast zones can begin, as proper disposal of these contaminated debris is essential to prevent recontamination of people and resources.[44] The ongoing collection and analysis of data will be critical to informing these efforts.

In addition to the effects of the blast and radiation contamination to the area immediately surrounding the explosion, fallout could settle on farmland as far as 100 miles downwind of ground zero.[45] Animal and agricultural products in the path of the fallout plume may be unfit for consumption. As illustrated by the public response to the Fukushima Daiichi nuclear release, public confidence in these agricultural and animal products may take longer to reinstate. It will be critical to continue appropriate public messaging as information becomes available regarding these products. Such messaging and the development of appropriate guidelines will, again, rely heavily on ongoing monitoring and assessments.

Recovery: 30 days to years

The recovery phase for an IND is likely to last years or decades (see Figure 9). As critical infrastructure and utilities are restored, much of the effort will need to focus on cleanup and restoration of contaminated sites. Models that predict occupational exposure and the fate and transport of radioactive material in the environment will be important recovery planning tools. Contaminated debris cleared from the fallout region will need to be safely managed, overwhelming existing radioactive waste removal protocols.[44,45] Once the blast zones are rebuilt and contamination is either removed or falls to safe levels, displaced populations may begin to return home, if they have not already permanently relocated. Ongoing data collection, analysis, and publication will be critical to support these efforts and restore public confidence in their safety.

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42 DHS (Department of Homeland Security) (March 2006) National Planning Scenarios.

43 National Academies (2005) Nuclear Attack. Factsheet created for News and Terrorism: Communicating in a Crisis.

44 Benjamin GC (Summer 2010) Medical Preparedness and Response to Nuclear Terrorism. *The Bridge* 40

45 Buddemeier B *et al* (November 2011) National Capital Region Key Response Planning Factors for the Aftermath of Nuclear Terrorism. Lawrence Livermore National Laboratory.

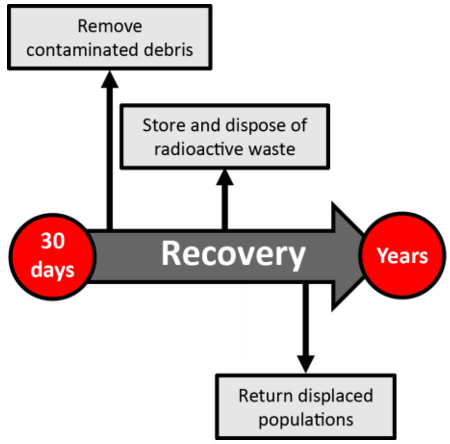

Figure 9. Response activities during the recovery phase.

Information requirements

Experience from past emergencies shows that the influx of information during an emergency is massive, ranging from social media information to data from weather satellites. Information, regardless of the source, can be organized into categories that describe how it is used during all phases of emergency management, from preparedness and planning to recovery. This section discusses the fundamental questions related to emergency management, outlines the ways modeling and data resources are able to answer those questions, and introduces a framework to elucidate the use of these resources in the context of IND detonation scenarios.

The big questions

An emergency response to any disaster, whether a hurricane or an IND detonation, will require the answers to three fundamental questions, "What happened?"; "Who and what was affected to what degree?" and "What needs to be done?" Figure 1 depicts the evolution of these critical information requirements as different phases of an emergency begin and end.

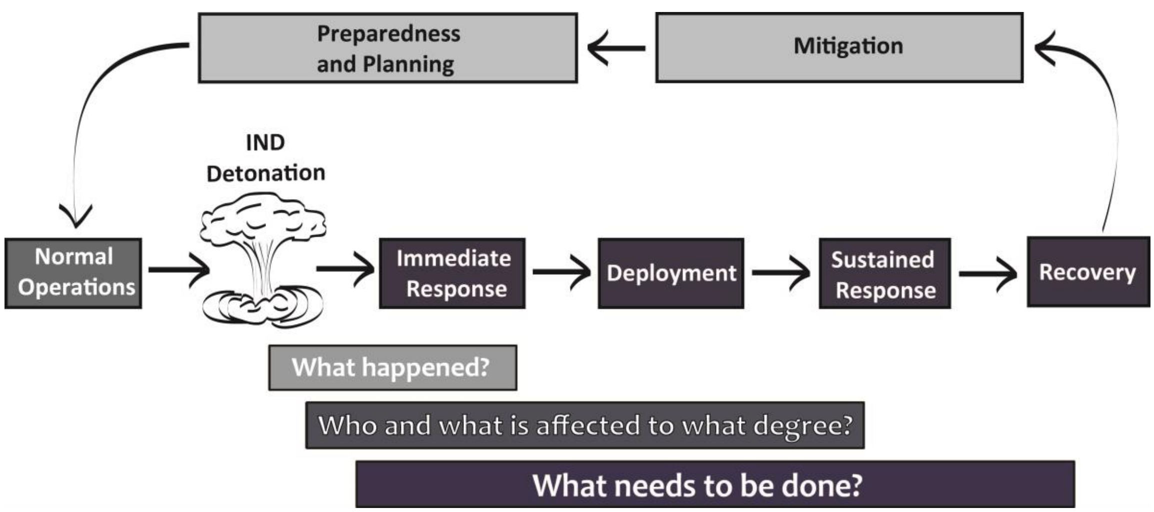

Figure 10. Critical information requirements and the phases of emergency management. The phases of emergency management are depicted along with the three fundamental questions.

The answer to "What happened?" provides information concerning the size, location, timing, and severity of an event. Knowing the details of the event itself will inform the question "Who and what was affected to what degree," which provides information about the severity and consequences of the incident on human health, infrastructure, economy, and the environment, and others. Knowing the consequences of the event will help to answer, "What needs to be done," to determine the number of assets and the types of actions that will be required to carry out a specific mission in response to an event.

Response activities and associated information requirements after an IND detonation

An emergency response viewed through the lens of these three big questions allows information to be parsed and organized into categories that can be useful for emergency managers to determine how and when the information can be used to assist in operational decision-making. Clarifying the information requirements that need to be fulfilled will ensure that emergency managers are aware of what information is available, which resources can provide it, and how and when it should be used to support decision-making.

In order to determine how data and modeling resources can inform response activities, the critical information requirements associated with the response activity must be identified. An overview of the timeline of the timeline of IND detonation and the stages of the emergency response is shown in Figure 2. The response activities associated with the event can be mapped to the three fundamental questions along with the specific information required to conduct those response actions. Table 1 outlines the response activities expected after an IND detonation and associated information requirements, phrased as questions to be addressed.

Table 1. Expected response activities after an IND detonation and associated information requirements mapped to the three fundamental questions				
Response action	**Information from previous response actions**	**What happened?**	**Who and what are affected to what degree?**	**What must be done?**
Recognize a nuclear incident		- Was it a nuclear bomb? - Was it a dirty bomb? - How big was the bomb? - Was it uranium or plutonium? - Is there a credible threat for a second detonation?		
Declare a State of Emergency	- *Recognize a nuclear incident*			
Establish emergency communications	- *Recognize a nuclear incident*	- What is the physical damage to communications infrastructure? - Was there an EMP?	- How many people are affected by the communication outage? - Which lines of communications are down?	- Can communication lines be restored? - What temporary measures are necessary (dropping leaflets, portable cell towers, and other measures)?
Issue shelter-in-place guidance for a 50-mile radius to public and first responders	- *Establish emergency communications*			
Activate local, county, and state EOCs	- *Recognize a nuclear incident*			
Activate NRCC, associated Emergency Support Functions, and FRMAC	- *Recognize a nuclear incident*			
Collect radiation measurements from radiation detectors and monitors	- *Declare a State of Emergency*			- Where are the functional nearby radiation measuring stations? - What aerial or other radiation measuring systems are available? - How long before radiation measurements will become available?
Conduct aerial and on-the-ground assessments	- *Declare a State of Emergency*			

Define Hazard Zones	- *Activate NRCC, associated Emergency Support Functions, and FRMAC* - *Collect radiation measurements from radiation detectors and monitors* - *Conduct aerial and on-the-ground assessments*	- Where is the radiation plume? - Which direction is the plume spreading? - Where will the plume be in the future (hours, days)? - Where is the hot zone? - Where are the damaged areas? - What is the general extent of the damage?		
Stand up the Joint Field Office	- *Recognize a nuclear incident*			
Prioritize populations to be evacuated	- *Define Hazard Zones*		- How many people are immediately affected by the radiation? - Who is at the most risk from radiation? - How many people were affected by the blast?	- What are the guidelines for prioritizing populations to be evacuated? - Where are medical centers to which radiation victims can be evacuated?
Identify safest transportation routes	- *Define Hazard Zones*		- Which transportation networks (rail, road and air) have been affected by the blast or radiation? - Will the plume move over any major transportation networks in the future?	
Deploy Strategic National Stockpile (SNS) resources to staging area	- *Recognize a nuclear incident*		- How many people were affected by radiation and blast?	- What SNS resources are available? - Where are the nearest functional staging areas?
Deploy first responders (fire, medical, search and rescue, among others)	- *Identify safest transportation routes* - *Prioritize populations to be evacuated* - *Establish emergency communications*			- How many first responders are available for deployment? - Which areas should first responders avoid? - How long can first responders stay out in hazard zones? - What is the coordination strategy?
Extinguish fires and stabilize structures	- *Deploy first responders (fire, medical, search and rescue, among others)*		- Where are the fires? - Which areas require immediate support?	

Establish evacuee and responder triage and decon sites	- *Identify safest transportation routes* - *Deploy first responders (fire, medical, search and rescue, among others)*		- Where are potential evacuation and decontamination centers? - How many people would require triage and decon?	- What are the capabilities/capacities of available centers? - Who is available to staff and run the centers? - Are there adequate supplies for the centers?
Move prioritized population to triage and decon sites	- *Establish evacuee and responder triage and decon sites* - *Deploy first responders (fire, medical, search and rescue, among others)*			- How can the victims be moved to the sites? - How can special populations be moved and cared for?
Begin phased evacuation of public	- *Move prioritized population to triage and decon sites*			- How is the public going to leave the hazard zones (walking, driving, etc)? - Is the public going to be decontaminated when leaving the hazard zones?
Provide triage and definitive care	- *Establish evacuee and responder triage and decon sites*			- Are additional resources/people required to take care of the victims?
Provide shelter and distribute food, water and clothing	- *Deploy Strategic National Stockpile (SNS) resources to staging area* - *Begin phased evacuation of public*		- How many people need shelter, food, water, and clothing? - How long do the refugees need housing, food and water?	- Where are the refugees going to be sheltered? - How will the weather affect the refugees? - Are additional supplies needed? - Is there staff to help distribute the supplies?
Provide fatality management	- *Deploy first responders (fire, medical, search and rescue, among others)*		- How many people are dead?	- Are the human remains contaminated? - Can the human remains be identified? - How will the human remains be taken care of? - Can families of the deceased be notified?

Decontaminate critical infrastructure	- *Collect radiation measurements from radiation detectors and monitors* - *Conduct aerial and on-the-ground assessments* - *Extinguish fires and stabilize structures*		- What critical infrastructure was contaminated?	- Which critical infrastructure is most important? - What resources are needed/available to decontaminate the infrastructure?
Restore essential utilities and services	- *Decontaminate critical infrastructure*			- Can the existing infrastructure be repaired/ decontaminated? - What resources are needed/available to restore the essential utilities and services?
Monitor and manage contaminated animal and agricultural products	- *Collect radiation measurements from radiation detectors and monitors*			
Remove contaminated debris	- *Collect radiation measurements from radiation detectors and monitors* - *Extinguish fires and stabilize structures*		- How much contaminated debris is there?	- How can the debris be moved safely?
Store and dispose of radioactive waste	- *Remove contaminated debris*		- How long will the waste be radioactive?	- Where can radioactive waste be stored?
Return displaced populations	- *Provide shelter and distribute food, water and clothing* - *Restore essential utilities and services*		- How many people want to return?	- What resources do displaced persons need to return?

Interdependence of information requirements

Emergency support functions were created with the recognition that response activities are inherently connected across mission spaces. Identifying the linkages and associated information requirements that span mission areas is critical to mounting a robust response to mitigate the effects of a disaster. On the basis of the critical information requirements in Table 1, a response action tree, shown here for a single set of time-dependent questions, can be used to illustrate linkages to upstream response activities and associated information requirements (see Figure 11). These linkages show that each response activity cannot occur in a vacuum and, in fact, depends upon knowing key critical information from upstream response activities.

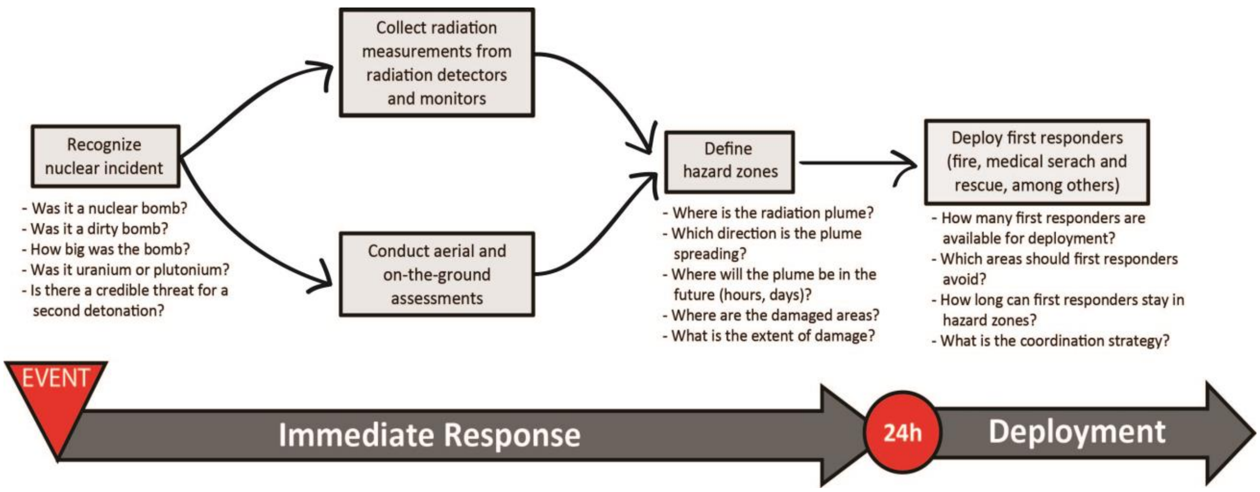

Figure 11. Example of how each response activity is dependent on critical information requirements from upstream response actions. The response action "Deploy first responders" requires that the hazard zones are defined. Defining the hazard zones requires the assessment and collection of radiation measurements, which in turn relies upon recognizing the type of event that has occurred.

Time-dependent information requirements

Not only are critical information requirements interdependent, they are also time-dependent, and vary depending on the phase of the emergency. During normal operations, data and modeling resources are used to help emergency managers and those agencies involved position themselves to be more effective once the event occurs. During this phase, the questions that will need to be addressed during future events are defined, the specific information resources available are identified, and the personnel who will need to use them are trained. As the event is predicted or begins to unfold, the data and models identified during planning and preparedness are used to address questions about the specific, impending threat. Early in the response phase, the big question of "What happened?" will need to be addressed. Data and modeling resources that characterize the event can help to answer this question. Once the location, time and severity of the event have been characterized, the next big question of "Who and what was affected to what degree?" will need to be addressed. Again, data and modeling resources that provide information on the severity and impact to human health, infrastructure and economy, and others will be valuable. During the remaining period of the response and into the recovery phase, data and models that can assist in answering the question "What needs to be done?" will be instrumental in providing assistance to immediately save lives and property and, ultimately return the affected population and area to normalcy.

Methods

The workflow of analysis performed for this project is divided into three parts: data collection, data processing, and analysis; this workflow is depicted in Figure 12 and described in brief in this section. See Appendix 4 for a complete description of the methods.

Data collection was performed through interviews with members of the MDWG, other emergency managers, and subject matter experts. In brief, the interviewees were asked how they use data and models to answer questions relevant to their emergency management mission, what data they use to address those questions, and what models or analysis tools they use to process those data. Based on the data collected during interviews, a systems-level analysis of the information requirements was conducted and an ontology, or categorization system, was developed to capture the flow of information between the resource types. The information ontology is described in detail in subsequent sections. Metadata about the specific resources identified during interviews as both operational and used by the federal emergency management community were compiled in an inventory. Metadata characteristics about each resource were defined both through interviews and through additional background research.

Each resource in the inventory is characterized by over twenty metadata tags, including information about the owners and federal users of the resource and the connections between resources. These metadata characteristics provided the basis for two types of analyses: a network analysis based on the upstream and downstream connections of each resource and a statistical analysis of the types of resources. The network analysis is based on network maps, visualizations of the resources and the flow of information between them. Analysis of the metadata characteristics of the resources was used to calculate the types and number of resources in the inventory. The Methods are described in detail in Appendix 4.

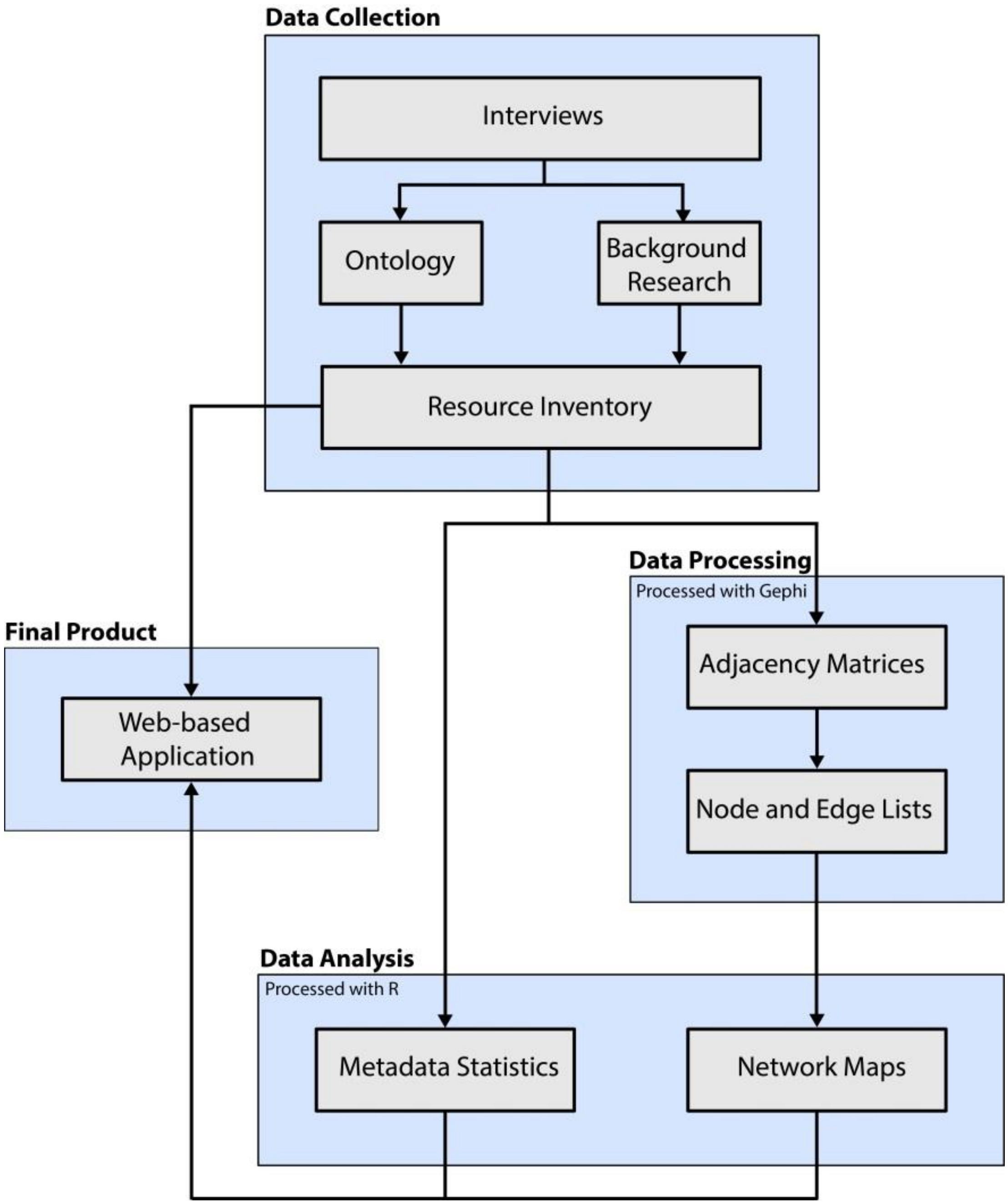

Figure 12. Analysis workflow. A depiction of the sequence of work involved in producing quantitative analysis of the resource inventory.

An information ontology

Data and models are used extensively in emergency management across the interagency and through every phase of an emergency. Notably, these data and models are not monolithic: there is a cascade of information that flows through iterative steps of data collection and data processing. At each step, raw observational data and outputs from earlier iterations of modeling are aggregated. These data are then processed using analysis tools of varying sophistication, ranging from computationally intensive predictive weather forecast models, to simple, computationally-conservative tools that produce the information required to inform more narrowly-defined mission-specific decisions.

The data and modeling resources can be organized into categories based on the type of information generated and how and when they are used during emergency management, and can be used to answer the three big questions of "What happened;" "Who and what is affected;" and "What needs to be done." A categorization scheme capturing the key relationships between models and data and the flow of information between them was developed based on a systems level analysis of information requirements identified through interviews and is presented in Figure 13. The flow of information categories and their interconnections constitute an ontological framework through which the iterative collection and processing of information can be understood and translated into operational decisions.

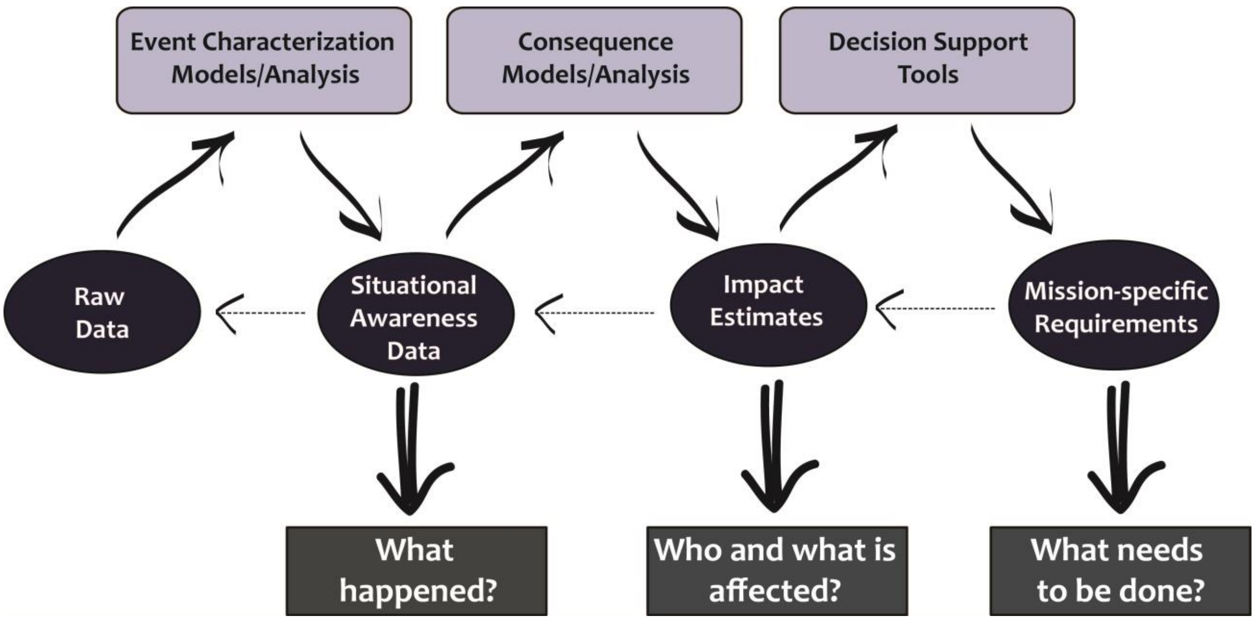

Figure 13. Framework describing the flow of information through iterative rounds of data and modeling. Information flows through modeling and data resource categories to produce answers to the fundamental questions of emergency management.

Defining data and models

Data, models, and analysis tools play a critical role in parsing the enormous stream of information to inform operational decision-making and enhance response, recovery, mitigation and preparedness and planning activities. These resources are extensively employed across the interagency throughout all phases of emergency management. The flow of information in emergency management follows iterative rounds of data collection (e.g. instrument readings, impact maps, damage estimates) and modeling or data analysis (e.g. weather projections, damage calculations, decision trees). Given the breadth of information resources used and included in the inventory, the terms ‘model’ and ‘data’ are defined below, as used in the context of this work.

Data are defined as repositories of information used for emergency management. This definition of data encompasses tools that assist in the presentation or visualization of data without transforming the data itself (e.g., FEMA GeoPlatform, see Appendix 5). Data are classified as raw data, situational awareness data, impact estimates, or mission specific requirements. The data within these categories may be steady-state data describing features of the environment during normal operations. Alternatively, they may be event-specific assessment data collected as an event unfolds. Notably, the data categories in the flow of information are not necessarily model outputs. The National Shelter System, for example, provides the locations and capabilities of open shelters in the United States. These situational awareness data are collected by the American Red Cross, not produced by a model. Thus, the framework captures data sources that enter the flow of information externally.

Models are defined as any program, algorithm, or computational tool that transforms or processes data to produce new information. Models are classified as event characterization models and analysis tools, consequence models, and decision support tools. Models accept, as inputs, data that are transformed to provide a new type of information (e.g., NARAC Modeling System, HPAC, NUEVAC, see Appendix 5).

Flow of information

For all phases of emergency management, the primary flow of information begins with the collection of scientific raw data and culminates in the estimation of mission-specific requirements that guide operational activities related to all phases of emergency management (Figure 12). Raw data describing the event are processed by event characterization models or analysis, which estimate the timing, scope, and severity of the threat, and define what happened or is expected to happen. The situational awareness data produced by those models serve as inputs to consequence models, which quantify the impacts of the event on human lives and infrastructure and provide information as to who and what is affected and to what degree. Finally, these impact estimates, processed by decision-support tools, are translated into the amount and type of assets needed to mount a comprehensive event-specific response – the mission specific requirements that answer the question of “what needs to be done.”

The flow of information between these categories is not unidirectional. For example, the outputs of event characterization produce post-event situational awareness data, which can in turn guide the collection and assessment of additional raw data. In the context of nuclear detonations, FRMAC coordinates the collection of radiation assessment data by aircraft, on-the-ground radiation assessment teams, and first responders equipped with dosimeters that report continuous time-stamped and geo-tagged dose rate measurements. These raw data are used to refine the inputs for updated runs of the event characterization models managed by IMAAC, such as the NARAC Modeling System. These modeling runs produce updated situational awareness data and can be used by FRMAC to refine the collection of additional radiation measurements.

All categories of data, with the exception of raw data, can be directly used to inform decision-making. For instance, the situational awareness data found in post-IND detonation briefing products generated by the NARAC modeling system would greatly influence initial shelter-in-place and evacuation decisions. As another example, FEMA Individual Assistance consults Preliminary Damage Assessment data (an impact estimate) collected during and after an event to determine the potential size of its recovery programs.

The data and modeling resources that provide raw data, event characterization, consequence assessment, and impact estimates tend to be hazard-specific. These resources are designed to provide an understanding of the specific event to determine what happened and who and what was affected to what degree. The decision-support tools and mission-specific requirements, on the other hand, tend to vary more by mission areas, rather than by hazards. In-depth descriptions of the resource types within each category in the flow of information framework are described in the follow sections.

Raw data

Raw data are used to describe the environment and can include static look-up tables, on-the-ground assessment data, steady-state information (e.g., bridge databases), or real-time data (e.g., observational weather data). Raw data may be collected using instruments such as weather stations that collect a variety of raw data related to local meteorological conditions. Raw data may also be collected by reporting methods, such as Census data which describe the size and demographics of various populations. Unprocessed social media and crowd-sourced data are also considered raw data. Raw data are not directly consulted to inform decision-making; they must first be converted into situational awareness data by computational or analytical means.

After an IND detonation, a significant amount of raw data will likely be gathered by specialized teams and equipment which are activated in response to radiological incidents, including data from aerial instrumentation assets, radiation detectors, aerial photography, and observational weather data, among others. Aerial instrumentation assets are expected to be deployed to sample fallout dose rates in the impacted area. Radiation measurements collected by first responders outfitted with radiation detectors would provide similar raw data on the ground. Geo-tagged and time-stamped aerial photography is an example of raw data that would later be collated to provide visual situational awareness. Observational weather data will provide real-time weather information. All of these raw data would serve as input to refine event characterization modeling or analysis prior to being useful to support decision makers.

Examples of raw data applicable to IND detonation scenarios are included in Table 2. These examples are illustrative and not all-inclusive. See Appendix 6 for a full list of resources.

Table 2. Raw data. Examples applicable to IND scenarios.

Example	**Function**	**Owner**
RadNet	Radiation measurements	EPA
RAMS		DOE
Observational Weather Data	Weather measurements	NOAA
US Census Data	Population demographics	US Census Bureau
NAVTEQ/HERE	Road networks and maps	NAVTEQ/HERE
HSIP	Infrastructure data	NGA, HIFLD

Event characterization models and analysis

Event characterization models and analysis tools characterize or predict the location, time, and severity of an event. These models are used to consider specific characteristics of past, current, or impending hazards and compile raw data to identify patterns that define an event or identify the characteristics of a developing event. These models and tools provide the means for emergency managers to transform raw data into situational awareness data that can be used to support decision-making.

Event characterization models include those developed to inform planning for IND detonation scenarios, as well as those hosted by groups who perform the modeling and analysis post-event. In the early hours after an IND detonation, emergency managers will rely upon the analysis performed by these centers to provide an initial assessment of the event. Coordination and communication between these analysis centers and emergency managers will be critical to inform operational decision-making during response and recovery. For example, atmospheric dispersion models accept raw data inputs (such as weather data) and estimate the trajectory and relative density of a fallout cloud. Other models determine the expected decay characteristics of the fallout cloud based on the radionuclides released or characterize the blast based on pressure generated by the explosion. The situational awareness data produced by these models will influence many decisions on the ground, including where to locate triage centers and to map out safest evacuation routes.

Table 3 provides examples of event characterization models. These examples are illustrative and are not all inclusive. See Appendix 6 for a full list of resources.

Table 3. Event characterization models and analysis tools. Examples applicable to IND scenarios.

Example	**Function**	**Owner**
HPAC	Dispersion characterization	DoD
HYSPLIT		NOAA
NARAC Modeling System		DOE
NucFast	Blast characterization	DoD
SHAMRC		

Situational awareness data

Situational awareness data are used to characterize an event. These data are typically produced through the extraction, transformation, or analysis of raw data. Situational awareness data address the question of "what happened?"

Situational awareness data can be the outputs of event characterization models which process raw data or may be obtained through the extraction, transformation or analysis of raw data such that they can be used to describe or characterize the event. For example, after a nuclear detonation, situational awareness data could consist of maps showing the time- and location-dependent levels of radioactivity. Although a single radiation measurement does not provide actionable information, aggregated and geo-tagged measurements can show emergency responders the boundaries of high-risk radiation zones that should be avoided. This information can also be used to validate the output of event characterization models that estimate the plume trajectory and radioactivity levels.

Situational awareness data include collated raw data, if it has been processed or validated. For example, the RadResponder network is a source of collated, validated radiation measurement data uploaded and shared during response to a radiological event

Examples of situational awareness data applicable to IND detonation scenarios are provided in Table 4. These examples are illustrative and are not all inclusive. See Appendix 6 for a full list of resources.

Table 4. Situational awareness data. Examples applicable to IND scenarios		
Example	**Function**	**Owner**
RadResponder	Radiation monitoring	FEMA
Local National Weather Service (NWS) Forecasts	Weather forecasts	NOAA
OnTheMap for Emergency Management	Worker demographics	US Census Bureau
FEMA GeoPlatform	Situational Awareness Data Viewer	FEMA

Consequence models

Consequence models predict the impacts of a potential or impending hazard, including, but not limited to, economic consequences, infrastructure damage, health effects, or impacts to the supply chain. For example, these models can be used to estimate economic loss and infrastructure damage to help characterize the affected populations impacted by a specific hazard. These models are typically hazard-specific, though some support loss predictions for multiple hazards. The outputs of these models do not determine the number and types of resources required to address consequences.

Although hazard-specific consequence models, like those for earthquakes or hurricanes, estimate impacts differently from IND consequence models, these consequence estimates could be tailored to source terms specific to INDs and use similar algorithms to calculate the impacts.

The most effective and widely-used consequence models, such as those used for natural disaster scenarios including hurricanes and earthquakes, are those that span a wide mission space and allow for the analysis of a wide range of possible scenarios within a single hazard type. In the context of IND-relevant consequence modeling, effective consequence models would be able to predict a wide range of impacts, including loss estimates of local hospital resources due to destruction or contamination, the extent of environmental contamination, health effects, infrastructure damage, and others. In addition, such a model would be able to predict the impacts of both relatively small and large detonation events either with or without advanced notice. Versatile IND consequence models would help emergency managers overcome the lack of historical experience and data, increasing the quality of planning guidance.

Most IND-relevant consequence models that have been identified so far have a relatively narrow scope and focus on one mission space, such as health consequences. Although mission-specific consequence models are useful for the specific purpose for which they are designed, a coordinated emergency response depends on consistency in the planning and response assumptions that are embedded in and produced by these consequence models. For example, a health-effects-focused consequence model and an infrastructure-damage-focused consequence model must assume the same initial conditions if they are to be used to estimate impacts for the same event.

Examples of consequence models applicable to IND detonation scenarios are provided in Table 5. These examples are illustrative and are not all inclusive. See Appendix 6 for a full list of resources.

Table 5. Consequence models. Examples applicable to IND scenarios		
Example	**Function**	**Resource Provider**
RESRAD	Residual radiation	Argonne National Laboratory
BT-GAM	Human health, radiation consequences	HHS ASPR
HPAC		DoD
NARAC Modeling System		DOE
Turbo FRMAC		
EMPREP	EMP consequences	DoD, DHS

Impact estimates

Impact estimates define the consequences of an event, answering the question "who and what is affected and to what degree?" These estimates include the outputs of predictive consequence models or post-event assessment data that has been collected and processed to provide an analysis of the event impacts. These data can be used to inform activities from the stockpiling of the type and amount of medical countermeasures pre-event to targeting of response missions to damaged areas and the distribution of disaster relief supplies to populations displaced by radiological hazards post-event.

The most effective impact estimate resources provide access to a compilation of archival outputs of consequence models run or libraries of historical post-event assessment data. Such repositories are critical to support decision-making immediately following an IND detonation event, prior to the completion of event-specific consequence modeling or the acquisition of assessment data.

For INDs, outputs of consequence models could generate impact estimates that will inform operational decision-making during all phases of emergency management. For example, the number and type of anticipated casualties as predicted by impact estimates will directly influence the strictness of triage guidelines for first responders. Also, damage estimates to critical infrastructure could be used to anticipate which populations are most likely to be threatened by dangerous secondary hazards and would therefore benefit from earlier evacuation.

Examples of impact estimates applicable to IND detonation scenarios are provided in Table 6. These examples are illustrative and are not all inclusive. See Appendix 6 for a full list of resources.

Table 6. Impact estimates. Examples applicable to IND scenarios		
Example	**Function**	**Resource Provider**
DSARS	Infrastructure impact estimates	Red Cross
PDA Data	Infrastructure, population impact estimates	FEMA
NARAC Modeling System	Human health, radiation impact estimates	DOE
FEMA GeoPlatform	Impact estimate data viewer	FEMA

Decision support tools

Decision support tools are those that define the amount and type of resources, including materials and personnel, necessary to support mission-specific activities. These tools are typically used by responders on the ground or by emergency managers responsible for coordinating missions.

The most effective decision support tools process impact estimate data to determine specific actions required for response and recovery missions. Examples specific to IND detonation scenarios would include tools that recommend evacuation routes and departure times, the medical resources required to treat casualties (e.g., numbers of beds, equipment, blood and other material, personnel by occupational specialty, and transportation requirements), and the resources required for clean-up, including debris clearing and fatality management. These tools may use the outputs of consequence models or assessment data collected post-event as inputs. For example, radiation dosages for patients exposed to fallout from an IND may be processed by a decision support tool to produce triage recommendations for medical technicians in local hospitals.

High-resolution decision support tools are required across all emergency support functions to inform decision-making during emergency management. Because these tools are more tailored to the specific mission of the operational practitioner, tools that are used in the context of natural disasters could be adapted for emergency response to nuclear detonation events. For example, tools developed to estimate required response and recovery assets, such as the number of dump trucks needed to clear debris, would be equally useful across a wide range of hazards. Effective adaptation of such tools would require harmonization between the outputs of nuclear detonation-specific impact estimates and existing decision support tools.

Examples of decision support tools applicable to IND detonation scenarios are provided in Table 7. These examples are illustrative and are not all inclusive. See Appendix 6 for a full list of resources.

Table 7. Decision support tools. Examples applicable to IND scenarios

Example	**Function**	**Resource Provider**
Turbo FRMAC	Radiation response decision support	DOE
NUEVAC	Evacuation decision support	Sandia National Laboratories
USACE Debris Estimating Model	Debris estimation and clearing requirements	USACE
Temporary Housing Model	Housing requirements	USACE
ODA Scalability Model	Surge personnel required to respond to loan applications	SBA

Mission-specific requirements

Mission-specific requirements define the amounts and types of material and personnel resources necessary to support each missions, answering the question “what needs to be done?” These requirements may be derived from the outputs of predictive models or from post-event assessment data and are typically produced by decision support tools. They provide a concrete description of the assets needed to support missions ranging from the distribution of general disaster relief supplies, the long-term sheltering of displaced populations, and the removal of debris from the impacted area to informing decontamination efforts.

Mission-specific requirements tend not to be hazard specific; instead they vary more by mission areas or emergency support functions. For instance, the resources required to repair the structural damage to a building depend more on the amount of damage it has sustained and less on the cause of the damage. Many of the mission-specific requirements that are useful for IND scenarios are currently used during natural disasters, such as the outputs of the debris estimating model or the temporary housing model developed by the US Army Corps of Engineers.

Examples of mission-specific requirements applicable to IND detonation scenarios are provided in Table 8. These examples are illustrative and are not all inclusive. See Appendix 6 for a full list of resources.

Table 8. Mission-specific requirements. Examples applicable to IND scenarios

Example	**Function**	**Resource Provider**
DSARS	Logistics requirements	Red Cross
LCMIS	Managing supplies and logistics requirements	FEMA
DRC Locator	Logistics and public information requirements	FEMA

Information challenges for IND scenarios

Nuclear detonation scenarios present a unique set of challenges for the emergency management community. While nuclear explosions of varying magnitudes have been analyzed in both combat and testing scenarios, no historical examples of an urban, ground level IND detonation exist. These data have been used to develop powerful event characterization models and are being used to inform consequence models such events. However, the challenge is to translate these data for use in operations post-event for mission-specific activities. This key difference profoundly affects the planning and response approaches as a large number of time-sensitive decisions will need to be made on the basis of limited post-event assessment data immediately following the event.

Reliance on predictive modeling

All IND planning scenarios are based upon predictive models as there are no empirical data available for an urban, ground-level IND detonation. The prompt effects, delayed effects, health effects, and subsequent impacts of an IND detonation have been predicted through models and extrapolation of existing data. For example, it is understood that the extent of the blast, thermal radiation, and other prompt effects will likely be reduced by the structures found in urban environments. However, the degree to which such urban shielding will occur has only been modeled on reasonable assumptions and never empirically measured. Models used to predict the fallout hazard in an urban setting are subject to similar uncertainty.

In addition, emergency managers will have to consider the potential error in both the anticipated physical characteristics of the event and the outputs of models used during the response to the event. Throughout pre-event preparedness efforts, the range of expected error in modeling results will have to be considered and incorporated into response planning operations. “Best case” and “worst case” scenarios may need to be considered in the planning process so as to account for the range of error in modeling results.

Rapid collection of assessment data post-event

Most predictive modeling relies heavily on assessment data collected during previous events to refine the modeling parameters and validate the outputs. These data include situational awareness data, impact estimates, and mission-specific requirements derived from observations of the real event. For example, in hurricane scenarios, assessment data is collected both during and after the response in the form of maps showing actual hurricane paths, storm wind speed measurements, and high water marks denoting maximum surge heights. The performance of the hurricane models used prior to landfall is improved by adjusting model parameters and assumptions to fit the predictions to the available data. However, only very limited historical assessment data are available for nuclear detonations, which significantly hinders this process of model refinement.

Given this uncertainty in the available modeling, the collection of assessment data will need to be prioritized during response to a nuclear detonation to provide an accurate assessment of the event as it occurs and to allow the real-time refinement and updating of on-going modeling efforts. Given that the physical characteristics of a detonation are uncertain and the impact estimates guiding the IND emergency response have not been validated, situational awareness generated by modeling efforts should be confirmed by actual measurements and observations of the hazard. Predictions of the fallout plume trajectory produced by models must be substantiated by on-the-ground data. These data will ensure that life-saving decisions, such as evacuation routing and timing, are supported by accurate information. Moreover, assessment data will be invaluable for the verification and validation of models after the incident. Once the situation has been stabilized and long-term recovery begins, there will be an opportunity for reflection and the documentation of lessons learned. During this time, models can be verified and validated with assessment data from the response to the IND detonation. This process will increase their fidelity and utility for future events.

Because an IND detonation has no historical precedent, all plans for IND response operations have been developed on the basis of predictive event characterization modeling that relies heavily on parameters extrapolated from existing data on combat and nuclear testing. Although post-event assessment data will be crucial to refine modeling parameters and to accurately characterize the event, such assessment data will be unavailable immediately after an IND detonation. Emergency managers will have to rely on data and models developed during preparedness and planning to provide an initial assessment of the event in the early hours. Once the acute emergency has passed, there is an opportunity to reflect on lessons learned, as well as a chance to consider assessment data collected during and after the event. These assessment data may be used to verify, validate, and evaluate the models, data assessment tools, and specific actions taken during the event to improve the efficiency and effectiveness of emergency management efforts for future events.

No-notice vs. advanced-notice

Similar to earthquakes, an IND detonation will likely be a no-notice event in which there will be no pre-event warning period to prepare for the imminent threat. Information about the details of the event, including the detonation site and bomb yield, will likely not be known in advance. Therefore, clear plans for the coordination of information sharing will have to be established and exercised to ensure that critical information is obtained quickly enough to answer time-sensitive questions during an actual event. These plans should specify what resolution of data will be required at each point and for whom, how often certain kinds of data will need to be gathered, who will process or interpret the data, and finally how and to whom the resulting useful information will be disseminated. As part of these plans, the modeling and data resources that will be used to satisfy critical information requirements at every phase should be identified in advance. This is especially crucial given that the majority of data applicable to IND detonation scenarios are not publically available. Preparedness plans that identify restricted data sets and the owners of that information ahead of time will prove useful during the response to an IND detonation.

Alternatively, it is possible that the intelligence or law enforcement community may be aware of an imminent threat of a nuclear detonation. In such a scenario, just like hurricanes, response assets may be able to be pre-positioned to relevant locations. During this period, the emergency management community can rely heavily upon existing predictive modeling to determine evacuation routes, medical and triage requirements, what type, and how many resources to move, among others, in order to mitigate the damage to human life and property. Although the majority of decision support tools are used during response and recovery, there are a few tools that are available that can be used to inform the movement of people and response assets to enhance safety and security prior to the event, in the elevated or credible threat phase.

Results

The MDWG was tasked with identifying and characterizing the data and modeling resources used by the federal interagency to inform operational decision making for emergency management. The goal was not only to develop an inventory of those resources, but to better understand how those resources are used, how they are connected, and how they function together to provide the information needed during all phases of emergency management. Using a combination of metadata and network analysis, the results that follow describe the characteristics of the resource network based on an in-depth analysis of the resources in the inventory known to be used in the context of emergency management for nuclear detonation scenarios.

To perform the analysis, the metadata characteristics of each resource, including owner and user data and resource type, were collated, quantified, and analyzed. Metadata analysis was used to determine the types of resources used, the total number of linkages between each resource, and to identify the major users and producers of the information that supports decision making within the federal emergency management community. The metadata describing the linkages between the resources were used to build network maps and perform network analysis. Network analysis is a systems-level analysis that was used to evaluate the robustness and interconnectedness of the resource network. The network analysis provides a method to simultaneously visualize the flow of information through all resources based on their resource type, their upstream and downstream connections, and the users and owners of the resources. A detailed description of the methods can be found in Appendix 4. The results of these analyses are described below.

Flow of information within the network

Resource network by resource type

A network map of the resources in the inventory used for nuclear detonation emergency management is shown in Figure 14. The map shows the flow of information between resources, providing a framework to understand how the system functions as a whole. Upstream resources provide data that are ingested by downstream resources, as shown by curved arrows connecting the resources, with each resource color coded by its resource type in the flow of information framework. Each resource is sized by the total number of federal-level users. Mapping how the resources are connected and how they are categorized provides context for how the resources work together to generate the information needed for emergency management.

A qualitative analysis of the network indicates that the resources used by the emergency management community are generally well-connected, with information flowing throughout the network. Disparate resource types, including weather, infrastructure, and population data, are interconnected, and the majority of resources are well-integrated into the network. However, a few groups are clearly outliers. For example, the cluster around EAGLE-I, the energy model owned by the Department of Energy, is only linked to the rest of the network through a single resource, MedMap (Department of Health and Human Services). A subset of resources (bottom right) is entirely unconnected to other resources in the network (see discussion under “Orphan resources”).

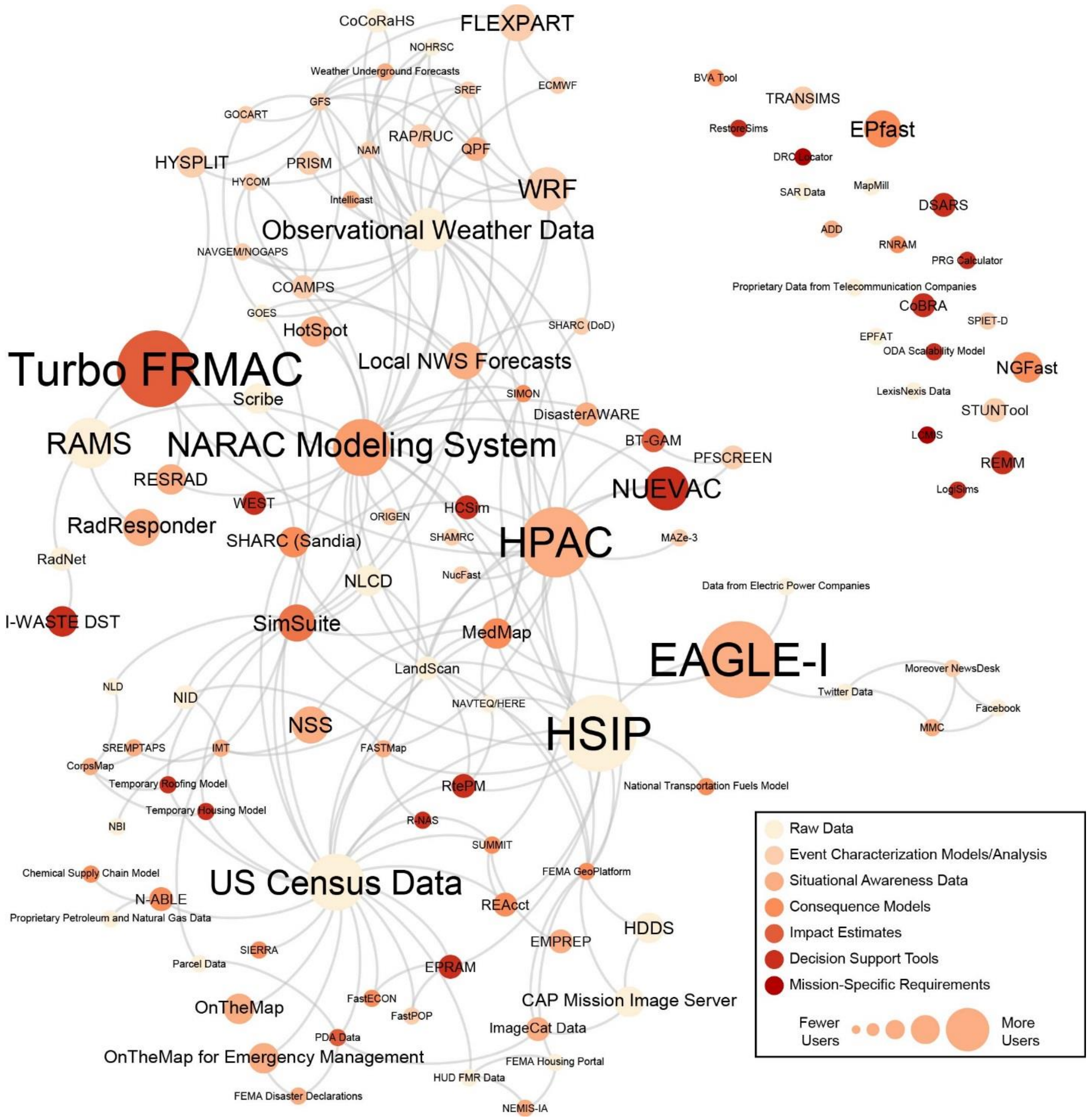

Figure 14. IND resource network colored by resource type. In this network, each node (circle on the graph) represents a resource in the inventory and is sized proportionally to the number of organizations that use that resource across the federal interagency. Edges, the curved lines connecting two nodes, represent information passing from one resource to another. The edges curve in a clockwise fashion, distinguishing which resource is the source and which is the target of the information.

There is a relatively clear flow of information from weather-related resources (raw data and event characterization) and to atmospheric dispersion modeling (event characterization and situational awareness data) to consequence modeling. However, this trend is less apparent beyond consequence models. As shown in Figure 14, the darker colored resources, the decision support tools and mission specific requirements, are randomly distributed throughout the network, suggesting that there is a breakdown in the flow of information from consequence models to downstream resources (see additional analysis in Figure 16). In addition, a large number of decision support and mission-specific resources are unlinked to the rest of the network. This lack of resource integration in the network suggests a breakdown in the sharing of information from consequence models to the more operationally-focused resources that would be used by operations personnel prior to or during an event.

Not surprisingly, just as weather features prominently in the most used resources for hurricanes and earthquake scenarios, so is it widely used for nuclear detonation scenarios.[46] Weather conditions have a large effect on the direction of the radioactive plume and deposition pattern of the radiation. This information is critical when planning for and performing response activities from decisions to deploy first responders to determining safe evacuation routes. This finding highlights and reinforces the role and impact of weather across hazards and the importance of maintaining a robust weather forecasting infrastructure to support all-hazards emergency management, not just hazardous weather events, like hurricanes.

Most heavily-used resources

As shown in Figure 14 and listed in Table 9, there are a relatively small number of heavily used resources (as indicated by the size of the node) within the resource network. These resources are relied upon by a large number of federal agencies, which suggests that it is important to maintain support for these resources and ensure that they are well-integrated into the network of resources. Of these resources, half are tagged with more than one resource type, suggesting that they have broad utility. Four of six include some consequence modeling capability. These widely-used resources demonstrate that the information used most in the context of emergency management describes the event and the damage that event causes.

The most heavily used resource is EAGLE-I, a relatively new situational awareness viewer developed by the Department of Energy that provides real time information about electricity outages. EAGLE-I is heavily used in part because it provides information that was not previously available about the stability of a sector with consequences that have a large impact on all other sectors. However, this model is notably separated from the rest of the network (see Figure 14), and, while the majority of other resources on these lists are also highly central (see Figure 17), EAGLE-I is not yet well integrated into the interagency information networks. By contrast to most of the other heavily-used resources, EAGLE-I is a relatively young resource for which technical solutions to link to other resources have not yet been developed. This lack of integration suggests an area that may warrant further investment by the interagency.

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[46] Graeden E (January 2014) MDWG Phase III Report Draft: Data and Models for Hurricanes and Earthquakes

Table 9. IND resources with the most federal agency users. Resources with at least 7 federal agency users are listed in decreasing order of number of users. There are no resources with 6 users and many with 5. Resources with the same number of users are listed alphabetically.

Resources	Users	Hazards	Resource Types	**Descriptions**
EAGLE-I	10	All-Hazards	consequence model	Models and monitors electric grid impacts
HSIP	10	All-Hazards	raw data	Critical infrastructure and key resource data
Turbo FRMAC	10	IND	consequence model; decision support tool	CBRNE assessment data analysis
HPAC	9	IND	event characterization models/analysis; consequence model	Models CBRNE atmospheric dispersion and impacts
NARAC Modeling System	7	IND	event characterization models/analysis; consequence model	Models CBRNE atmospheric dispersion and impacts
US Census Data	7	All-Hazards	raw data	Regional populations, demographics, and survey items

Orphan resources

Within the inventory of nuclear detonation resources, there is a subset of resources that are not linked to any other resources (as shown in Figure 14 and listed in Table 10). While these resources are all used by the federal interagency, none share information with any other resources: they do not pull in data from other resources, including hazard specific information processed by upstream resources within the inventory, nor do they produce data that are ingested by any other resources in the inventory.

Interestingly, the majority of the orphan resources fall at either end of the flow of information: they are either tagged as raw data or as decision support tools or mission specific requirements. Most likely, the raw data resources are those that have not yet been incorporated into event characterization or consequence models. These datasets, if linked to relevant downstream resources, may be useful to refine and improve the parameters of existing models.

The lack of linkages to the downstream resources, tagged as decision support tools and mission specific requirements, is of concern, as these resources must be linked to upstream event characterization and consequence analyses in order to ensure that the calculations are based on the best available real-time data about the event. Effective decision-support tools and mission-specific requirements should be linked to upstream resources to ensure that the information provided is based on event-specific empirical data.

Of the 25 orphaned resources (see Table 10), over half are owned or housed by industry or the national laboratories, suggesting that when these resources are shared with the federal interagency, additional investment by the federal client could help improve their integration with the larger information sharing network. All the orphan resources specific to nuclear detonations (6 of the 25) are models or analysis tools (event characterization models, consequence models, and decision support tools). These resources need to be linked to the rest of the network to ensure that their outputs are shared and used effectively and that their inputs are informed by event-specific data.

Table 10. Orphaned resources. These resources do not have any upstream or downstream linkages within the inventory network. Resources are ordered by where they fall in the flow of information alphabetically. (See Appendix 8 for details on each resource.)

Resources	**Hazards**	**Resource Types**	**Descriptions**
EPFAT	All-Hazards	raw data	Dataset of facility emergency power requirements
LexisNexis Data	All-Hazards	raw data	Census block-level insurance information from LexisNexis
MapMill	All-Hazards	raw data	Aerial imagery converted to maps by crowdsourcing
Proprietary Data from Telecommunication Companies	All-Hazards	raw data	Selectively shared, proprietary telecommunication data
SAR Data	All-Hazards	raw data	Synthetic Aperture Radar data describing the Earth's surface
SPIET-D	IND	event characterization models/analysis	Post-IND charged particle formation model
STUNTool	IND	event characterization models/analysis	Tunnel explosion effects model
TRANSIMS	All-Hazards	event characterization models/analysis	Transportation Analysis and Simulation System for regional transportation modeling
ADD	All-Hazards	situational awareness data	Federal Emergency Management Agency automated database for personnel tracking
BVA Tool	IND	consequence model	Blast vulnerability analysis for water infrastructure
EPfast	All-Hazards	consequence model	Consequence model for large-scale electrical power systems
NGFast	All-Hazards	consequence model	Natural gas simulation tool to estimate impacts of pipeline breaks
RNRAM	IND	consequence model	Radiological/nuclear threat risk assessment model
DSARS	All-Hazards	impact estimates; mission-specific requirements	Automated reporting system for Federal Emergency Management Agency disaster services
CoBRA	IND	decision support tool	Decision support and hazard identification for law enforcement response to CBRNE events
I-WASTE DST	All-Hazards	decision support tool	Planning information on handling, transportation, treatment, and disposal of contaminated waste and debris
LogiSims	All-Hazards	decision support tool	Resource allocation decision support software
ODA Scalability Model	All-Hazards	decision support tool	Small Business Administration loan application volume model

PRG Calculator	IND	decision support tool	Preliminary Remediation Guides calculator for radiation clean-up
REMM	IND	decision support tool	Radiation dose calculation and medical decision support for emergency responders
RestoreSims	All-Hazards	decision support tool	Resource allocation decision support software
DRC Locator	All-Hazards	mission-specific requirements	Locations and statuses of Disaster Recovery Centers
LCMIS	All-Hazards	mission-specific requirements	Federal Emergency Management Agency database for disaster relief supplies tracking

Number of resources based on the flow of information

Network maps are designed to provide a broad, systems-level view of the resources and the connections between them. Quantifying the number of resources that are available within each resource type can reveal where the bulk of information resides with respect to the categories within the flow of information. Such an analysis can be used to assess the relative robustness of the network and identify gaps in the flow of information. Figure 15 shows an uneven distribution of resource types within the inventory.

For nuclear detonation scenarios, there are many more resources tagged early in the flow of information (raw data, event characterization, situational awareness, and consequence models), as there are later. To some degree, this trend is not surprising. Raw data from a wide range of sources are necessary to feed effective event characterization models. For example, many weather models and observational weather data feed into IND-specific event characterization models, such as the NARAC Modeling System and HPAC. Both of these event characterization models can also provide estimates of consequences, such as casualties and building damage. As such, these resources pull from raw data sources that provide infrastructure (e.g., HSIP) and population statistics (e.g., US Census Data). However, there is a marked lack of resources that function as sources for impact estimate data or mission-specific requirements data. This trend is discussed in more detail later, but this result highlights a need for repositories or libraries of the data produced by consequence models and decision support tools.

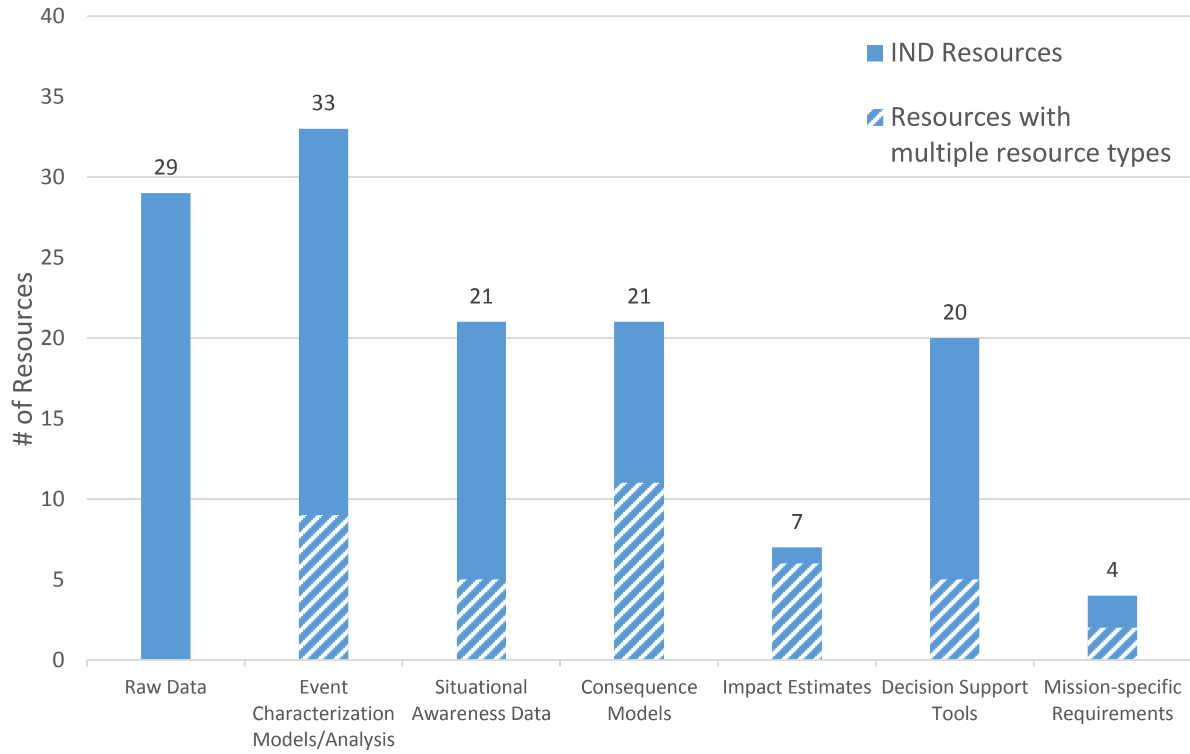

Figure 15. Number of resources by type. The number of used resources are shown for each resource type from the Flow of Information. Resources only relevant to INDs are shown in dark blue. The number of resources tagged as more than one resource type is displayed as white hatch marks. All the resources shown are either tagged as All-Hazards or at least one of the IND hazards (Nuclear Detonation, Industrial Radiological Release, and Explosion).

Resources tagged as multiple resource types

The vast majority of the resources in the IND inventory are tagged by a single resource type. However, a small subset of the resources provides data or performs modeling or analysis that is more accurately described by more than one category (see Figure 15 and Table 11).

Table 11. Resources with multiple resource types. Resources applicable to all-hazards are listed with boldface names. IND-specific resources are listed without boldface names.

Resources	**Raw Data**	**Event Characterization Models/Analysis**	**Situational Awareness Data**	**Consequence Models**	**Impact Estimates**	**Decision Support Tools**	**Mission-Specific Requirements**
DSARS					X		X
FEMA GeoPlatform			X		X		
MedMap			X		X		
SIMON			X		X		
SimSuite		X	X	X	X	X	X
SUMMIT		X		X		X	
BT-GAM				X		X	
EMPREP		X		X			
HotSpot		X		X			
HPAC		X		X			
NARAC Modeling System		X	X	X	X		
RESRAD		X		X			
SHARC (Sandia)		X		X		X	
SREMPTAPS		X		X			
Turbo FRMAC				X		X	

Of the resources tagged by multiple hazard types, four are agency-specific situational awareness viewers that provide visualization of the outputs of consequence models; these resources are tagged as both situational awareness data and impact estimates and include FEMA GeoPlatform (FEMA), MedMap (HHS), SIMON (State), and SimSuite (USACE). SUMMIT (DHS/FEMA) is a tool designed to combine multiple model types to generate comprehensive modeling outputs with code that calculates results related to each category. DSARS (Red Cross) serves as both a source of impact estimate data as well as mission specific requirement as it is used to track damage assessments, supply needs, and staffing needs for the American Red Cross.

Seven of the nine IND-specific resources with multiple resource types are tagged as both event characterization and consequence models. These models not only characterize the event itself, but also estimate the consequences of the event on human health or infrastructure. For example, BT-GAM (HHS) predicts the health impacts to the population following a nuclear detonation, though it is used primarily as a decision support tool to define the amount and type of medical resources needed to respond to the event. Turbo FRMAC (DOE) is tagged as both a consequence model and a decision support tool as it maps radiation data collected post-event to determine the deposition pattern following a radiological release.

The tool then processes those data to address specific emergency management questions regarding whether radiation doses exceed city, state, or federal limits; whether crops are safe for consumption or should be destroyed; and whether residents should be evacuated, among others.

Additionally, two resources, the NARAC Modeling System and USACE’s SimSuite provide utility across nearly the entire flow of information from event characterization modeling to providing impact estimates, with SimSuite acting as a decision support tool and mission-specific requirement as well. These resources wrap both models and datasets into one large resource that transforms hazard-specific raw data into situational awareness, consequences, and in SimSuite’s case, mission-specific requirements for USACE as well.

Bulk flow of information

In order to analyze how information moves through the network at the systems level, the bulk flow of information from raw data to mission-specific requirements was visualized (see Figure 16). Each category was weighted by the total number of resources and the linkages between each category were mapped. Resources tagged as multiple resource types were duplicated and separated into each of those resource types to more accurately represent how data is processed, even within a single resource.

This analysis provides a broad overview of which resource types produce and consume information and highlight the non-linear aspects of the flow of information. As shown in Figure 16, raw data resources provide the majority of information. However, while some raw data resources feed event characterization models directly downstream, some also or additionally feed resources in every other category. Likewise, the outputs of event characterization models produce situational awareness data, but these outputs also serve as inputs for consequence models and decision support tools. In addition, feedback loops in the system can be seen as retrograde flow. Notably, self-loops (e.g., an event characterization model such as a weather model that feeds another event characterization model such as an atmospheric dispersion model) are not shown in this figure, though they are an integral part of the network. Such self-loops are a further example of the non-linearity of the system and are evidence of the multiple tiers of data processing required for accurate event characterization.

This visualization highlights a major gap in the flow of information: there is limited information passed from consequence models to downstream resources and very little flow of information into mission-specific requirements. This lack of connectedness suggests that these resources fail to use data from upstream resources that provide real-time information. This resource isolation also suggests a lack of communication between those producing real-time event characterization and consequence modeling and those in the emergency management community tasked with performing mission-specific operations.

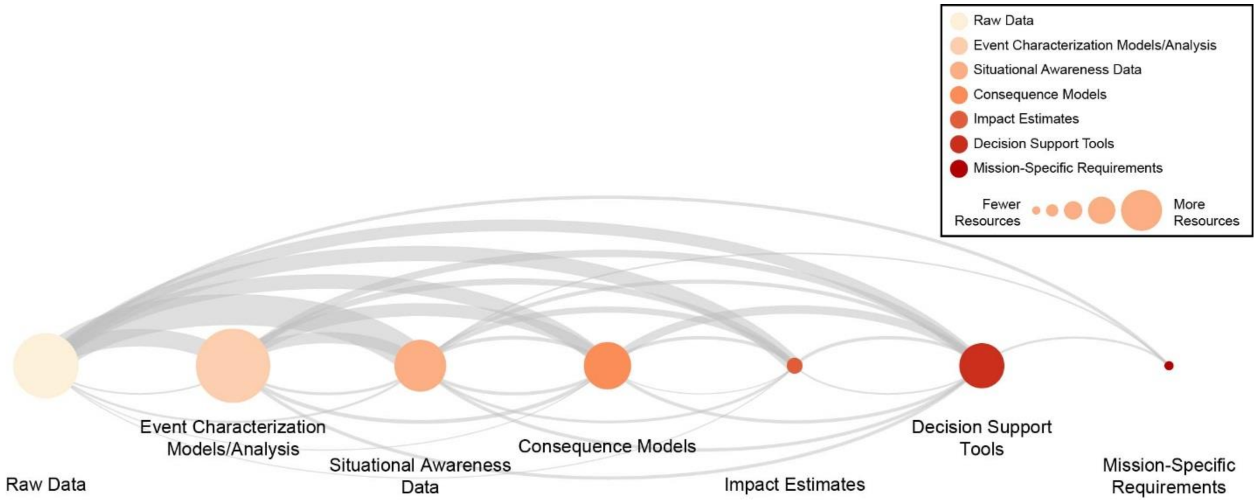

Figure 16. Bulk flow of information. In this figure, nodes represent each Flow of Information category and edges represent the flow of information from a resource in one category to a resource in another. The size of the nodes is proportional to how many resources there of that type. The color of the nodes is a gradient from Raw Data (light beige) to Mission-Specific Requirements (darker red) along the Flow of Information. The width of the edge is proportional to the number of connections between the two resource types. The edges curve in a clockwise fashion, distinguishing which resource type is the source and which is the target of the information. All self-loops (resource connections between two resources of a single type) were not considered when making this graph.

Resource centrality

Centrality of individual resources

Knowing where information resides within the network and the bulk flow of information provides a systems level view of how information moves through the resource network, but it does not provide information about which resources are central and act as information bridges to contribute to the overall functionality of the network. One measure of how integral a resource is to the network is its "centrality" (see detailed description of betweenness centrality in Appendix 4). [47] In brief, centrality is as the number of times a resource appears on the shortest path between two other resources in the network. Though not an indicator of the only critical resources within the network, particularly when considering a specific mission, the most central resources in the network are those that are most critical for efficient flow of information and without which the most resources would be left without sources of critical information.

As shown in the network map in Figure 17 coded by degree of centrality, of the resources in the IND network, five stand out as highly central and highly used: NARAC Modeling System, Turbo FRMAC, HPAC, HSIP, and RAMS (see Appendix 8 for a description of resources). These five resources serve as critical "bridges" of information between other resources and their presence is critical to the functionality of the rest of the network. Notably, four of the five are also on the list of most widely used resources in the network (see Table 9).

Centrality is largely determined by the number and diversity of upstream and downstream resources in the network. The NARAC Modeling System is the most central in the IND network in part because it pulls

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[47] As described in Appendix 4, the degree of integration of each resource within the network can be quantified by betweenness centrality, a common centrality measure that characterizes how often a node is found between other nodes in the network.[47,47]

from resources including observational weather data, the outputs of weather forecasting models, population datasets, infrastructure data, and radiation measurements. The outputs are used just as broadly, from dispersion forecasts to consequence projections for human health, which are critical inputs for a wide range of downstream resources from additional consequence models to decision support tools used across the interagency.

Both the NARAC Modeling System and HPAC (another highly central model) play similar roles in the processing of information, as both are capable of generating dispersion forecasts and consequence projections. The presence of two such highly central models suggest that the IND emergency management community relies heavily on projections to develop preparedness plans. Without any prior incidents on which to base planning decisions, it is not surprising that the emergency management community relies heavily on models that are able to simulate an IND and project environmental and human health consequences.

Not all highly central resources are widely used. For example, the Global Forecasting System (GFS) and the Quantitative Precipitation Forecast (QPF) are two highly central weather forecasting systems that are used only by NOAA and FEMA, respectively. Both resources transform observational weather data into weather forecasts essential for dispersion modeling and other rounds of event characterization. Despite having few users, the high centrality of these GFS and QPF indicate their importance as bridges within the network.

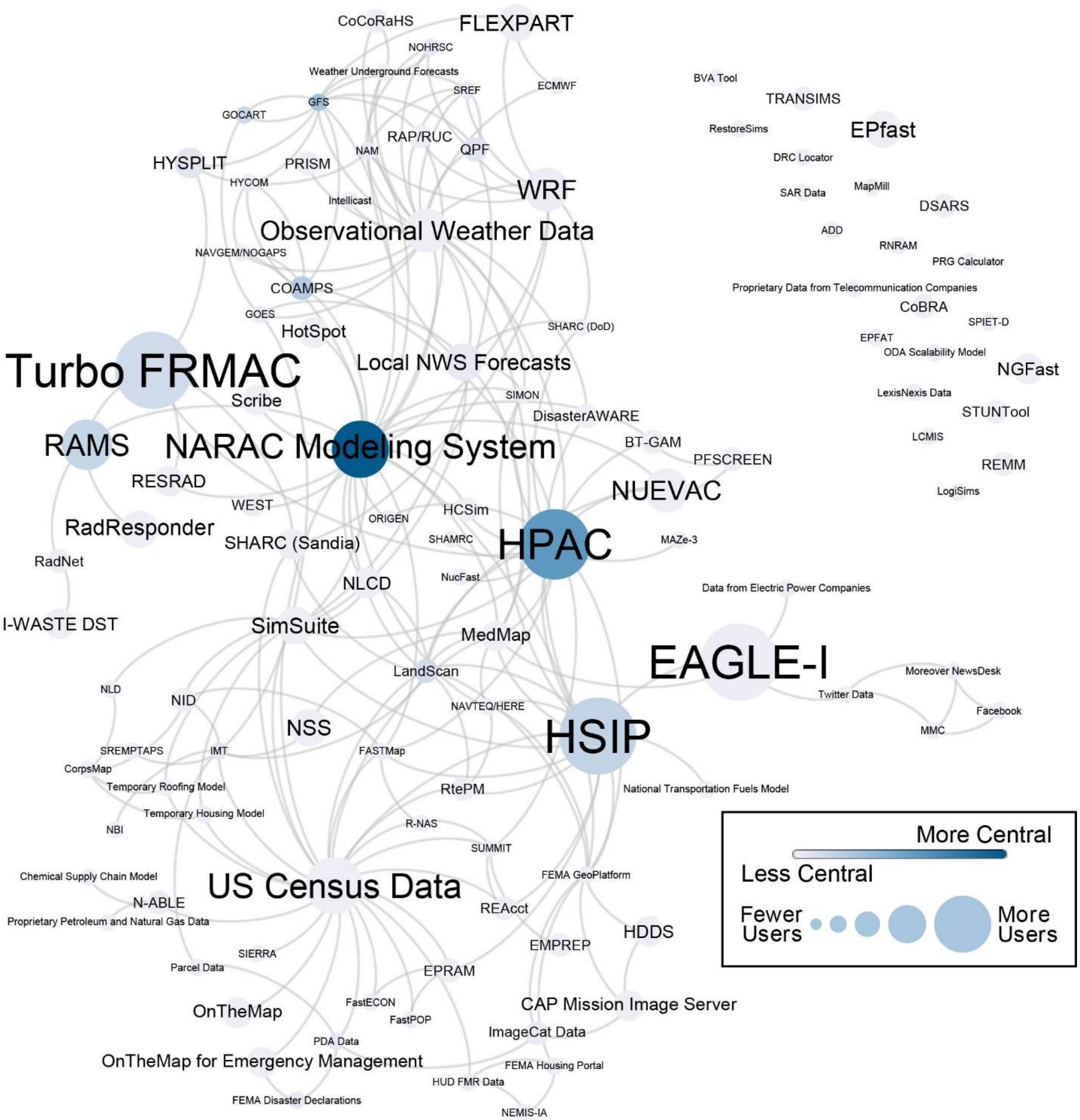

Figure 17. IND resource network colored by betweenness centrality. In this network, each node (circle on the graph) represents a resource in the inventory and is sized proportionally to the number of organizations that use that resource across the federal interagency. Darker blue represents more central resources, while lighter blue represents less central resources. Edges, the curved lines connecting two nodes, represent information passing from one resource to another. The edges curve in a clockwise fashion, distinguishing which resource is the source and which is the target of the information.

Centrality of resource types

In addition to identifying individual resources that are integral to the network, each category of resources can be characterized by centrality. As the centrality measure of a single resource represents the number of times it appears on the shortest path between two other resources in the network, the centrality measure of the resource type represents the number of times a resource of that type functions as an "information bridge." The centrality of resource types would be expected to correlate to the categories within the flow of information. For example, raw data and mission specific requirements have either no upstream or no downstream connections, respectively, and, therefore, neither would be characterized as central. By contrast, resources in the middle of the flow of information, such as consequence models, would be expected to have high centrality measures as they act as conduits of information with a large number of both upstream and downstream connections with in the network.

In order to test the relative centrality of the flow of information categories, the aggregate centrality measure of each category was calculated and graphed, as shown in Figure 18. The overall trend for centrality of the seven resource types generally increases from raw data to the more central categories in the middle of the flow of information and decreases again to mission specific requirements. As expected, event characterization models and consequence models have very high centrality measures. These high values reinforce the importance of these kinds of models for the rest of the network as they function as important conduits of information. Mission specific requirements have a combined centrality of zero, as none of the resources have downstream connections. Raw data, on the other hand, has a relatively low aggregate centrality value, but is not zero. This finding reflects feedback loops within the flow of information in which raw data resources feed each other and some downstream resources feed assessment data into resources most accurately characterized as raw data resources. For example, the raw data resource, RAMS, receives inputs from other RadNet (raw data) and RadResponder (situational awareness data). These inputs contribute to the centrality score.

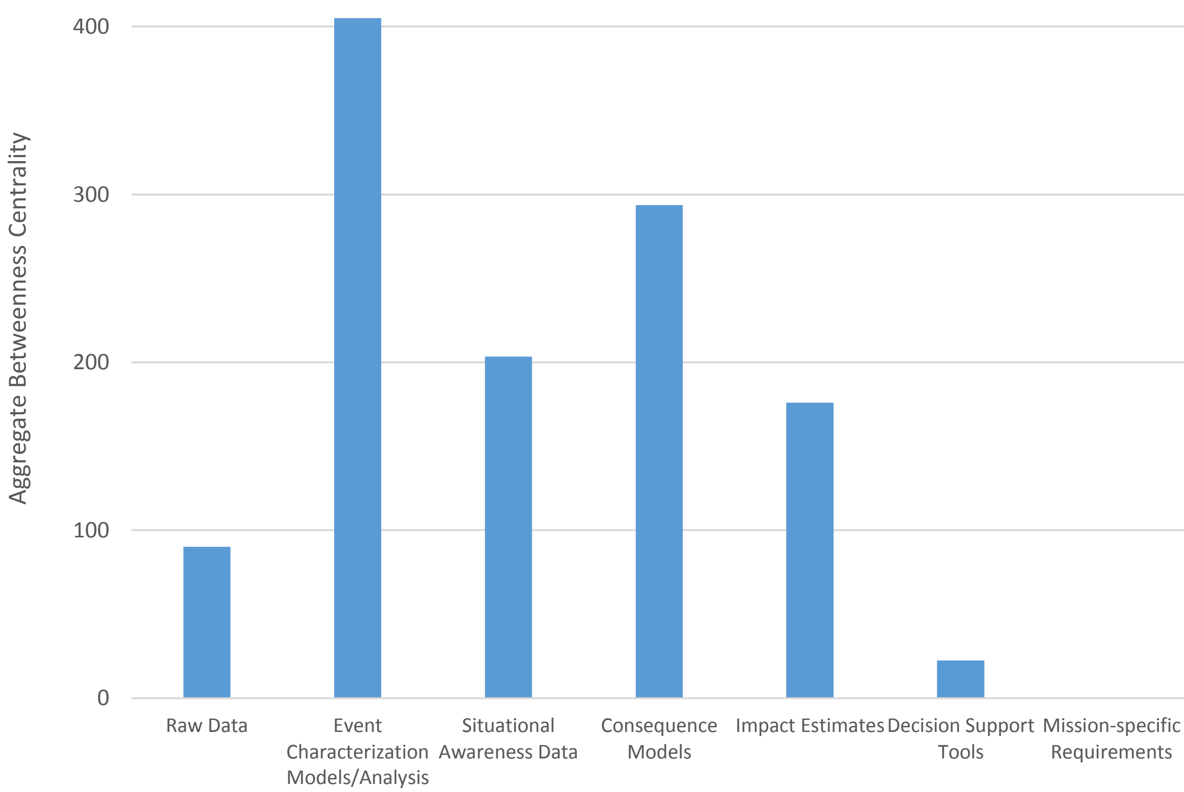

Figure 18. Centrality measures by resource type. The sum of the betweenness centrality measures for each resource category in the flow of information. This sum represents the total number of times a resource tagged as each resource type lies on the

shortest path between any other two resources. Resources tagged as multiple resource types contribute to the averages of each resource type they are tagged as.

Heavily-used resources with low centrality scores

While centrality is a useful indicator of resources critical to the integrity of the network, it is not the only indicator of resource value within the network. Low centrality measures do not necessarily indicate a lack of importance of the resource within the network. For example, Figure 17 shows that a number of heavily used raw data resources within the network, like Observational Weather Data or US Census Data, have low centrality measures. Resources at the beginning (raw data) or end (mission specific requirements) of the flow of information are rarely information bridges and generally have low centrality values because they fall at either end of the flow of information. Nonetheless, these resources are widely used and serve as important sources of data or mission-specific information.

However, low centrality values for widely-used resources, particularly for resources that fall in the middle of the flow of information, can indicate network components that could be better integrated and linked. For example, the situational awareness data resource, EAGLE-I, has the largest number of users (see Table 9), but a very low centrality value. As situational awareness data, EAGLE-I would be expected to connect upstream to event characterization models and downstream to consequence models and would be expected to be an important information bridge. EPFast is another example of a relatively heavily-used consequence model with low centrality measures. This lack of centrality for resources like EAGLE-I and EPFast indicate that heavily-used resources towards the middle of the flow of information could be better integrated into how information is processed, analyzed, or used by the interagency.

Owners and users of data and modeling resources

Number of resources owned and used

Lists of available data and modeling resources within the federal emergency management community have been generated previously; to our knowledge, none of these, have identified which of those resources are used and by whom. To address that gap, interviewees across the federal interagency were asked not only which resources that they have developed or produced, but which resources they use in the context of their mission in emergency management. Those resources identified as being used directly to support emergency management by at least one federal agency were included in the inventory.[48] Each resource was tagged by the agency or agencies using the resource directly.[49] The results of this analysis are shown in Figure 19. Note that a resource is defined as used by an agency only if they use the resource directly; upstream resources or feeds of used resources are not included.

The Federal Emergency Management Agency (FEMA) is the largest user of interagency resources, closely followed by the Department of Homeland Security (DHS, excluding FEMA), the Department of Defense (DoD, including DTRA and NORTHCOM), and the Department of Energy (DOE). Because FEMA is tasked with coordinating efforts between all other agencies involved in emergency management, it is not surprising that they are heavy users of these resources from across the interagency and of every resource type. Other organizations have more specific missions and therefore use only a subset of resources relevant to that mission. For example, National Oceanic and Atmospheric Agency (NOAA) and the Department of Transportation (DOT) only use resources towards the beginning of the flow of

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[48] See the Methods section, described in detail in Appendix 4 for a complete description of guidelines for including resources in the inventory.

[49] For the purposes of our analysis, users are defined as federal government agencies or organizations explicitly included in the Emergency Support Functions, as described in the National Response Framework. Users can also be calculated by including not only the number of direct users, but also those users of all resources that provide inputs for a given resources. We refer to this latter method as calculating "cumulative users."

information, like raw data and event characterization models. The US Coast Guard (USCG), US Army Corps of Engineers (USACE), and Health and Human Services Office of the Assistant Secretary for Preparedness and Response (HHS ASPR) all are proportionally larger users of more processed information like consequence models and decision support tools.

While FEMA is the largest user of resources, the largest owners of resources are private companies or corporations (labelled Industry). This result reflects the reliance of the federal government on industry to develop and maintain the resources upon which it relies heavily. In addition to industry, the largest producers of the resource types early in the flow of information are the DoD, NOAA, and the US Geological Survey (USGS). Conversely, the production of consequence models and decision support tools is largely dispersed amongst government organizations including FEMA, DHS, the EPA, HHS ASPR, and USACE. These resources are designed to answer specific questions and are often created by the organizations that need them to address information requirements that are specific to each agency's emergency management missions.

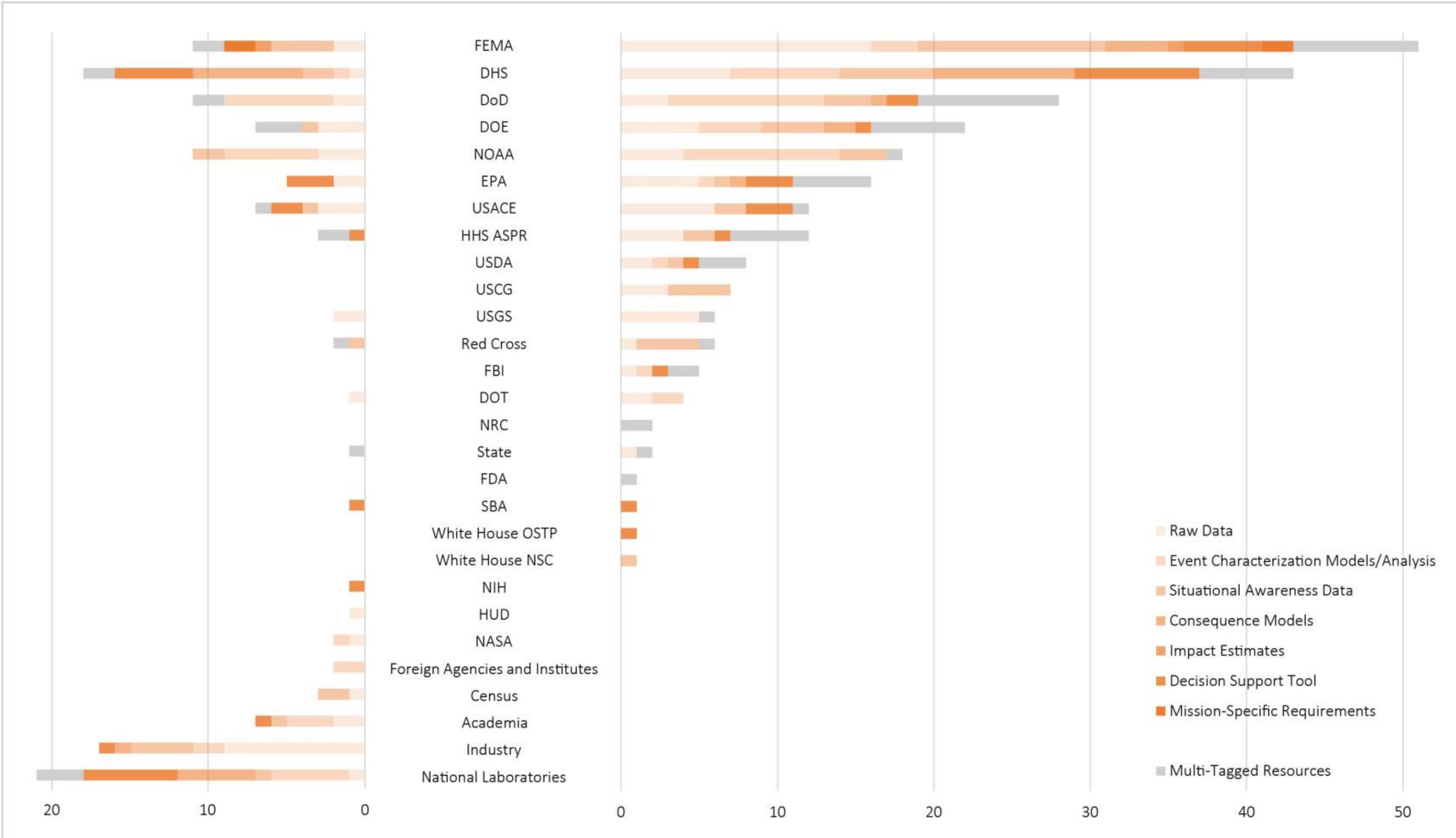

Figure 19. Number of resources owned and used by organization. The number of resources both used and owned by organization. Used resources are shown on the right side of the graph and owned resources are shown on the left. Resources are shaded based on resource type. Resources tagged as multiple resource types are counted once for each resource type they are tagged as. Therefore, the bars do not represent the absolute number of resource used and owned, rather the individual colors represent the number of resource used or owned of that resource type.

Federal users and resource types

In considering how data and models are used to inform emergency management decisions, it is useful to know what types of resources are being used by whom. Figure 20 shows a systems level view of the federal-level users and the resource types they use, which shows that, for most agencies, the types of resources they use generally aligns with their primary missions in emergency management. For example, NOAA is positioned toward the top of the vertical axis, indicating that the agency uses primarily raw data and event characterization resources. This finding corresponds to the NOAA mission of providing data about the changing environment and, particularly, the weather. Similarly, HHS ASPR is positioned toward the bottom of the image, indicating that is a heavier user of resources that provide consequence modeling, impact estimates, decision support tools, and mission specific requirements relative to other agencies. This finding corresponds to the HHS mission focused on providing the specific medical supplies and countermeasures required to effectively respond to nuclear detonation scenarios. Agencies positioned in the middle of the flow of information, such as FEMA, tend to be heavy users of information from across all resource types, not surprising, especially for agencies such as FEMA tasked with coordinating efforts across all emergency management missions.

Notably, only a handful of agencies use information from resources positioned near the end of the flow of information. Partially, this lack of connectivity reflects a lack of resources in those categories, but this finding also reflects the fact that most agencies use data earlier in the flow of information and the relatively few decision support tools and mission specific requirements are not widely used. If agencies, especially ones tasked with identifying what must be done after an event, were to use more operationally relevant data, this would be reflected as a more even distribution of the agencies down the vertical axis.

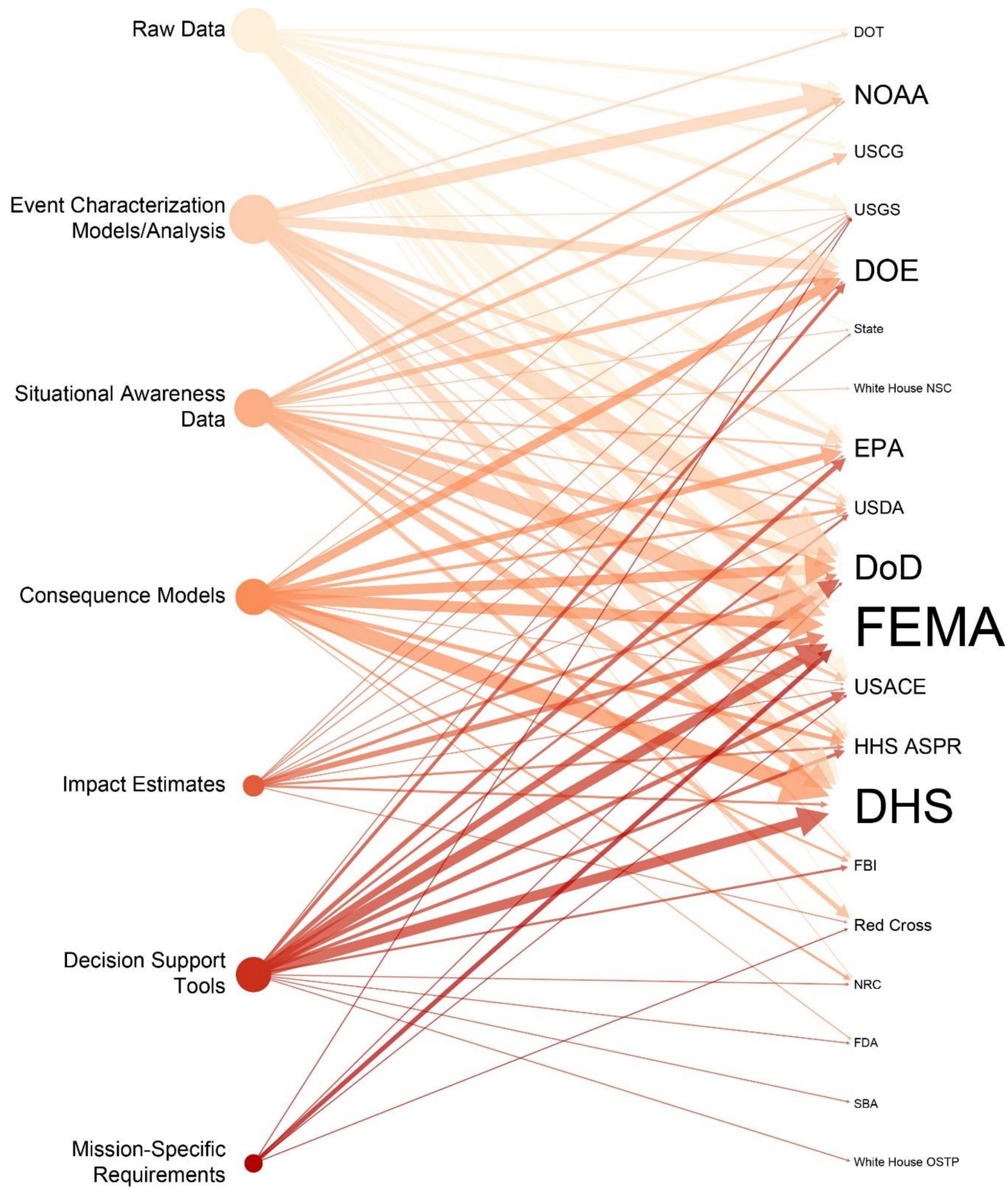

Figure 20. Bulk resources used by organization. In this figure, the left column represents all the resources in the inventory grouped by resource type. The color of the nodes is a gradient from Raw Data (light beige) to Mission-Specific Requirements (darker red) along the Flow of Information. The resource type nodes are sized proportionally to the number of resources in that resource type. The right column represents organizations that act as federal level users of the resources contained in the inventory. The names of the users are sized proportionally to the number of resources they use. An edge (arrow) from a resource type node to a federal user, indicates that the agency/department uses a resource within that resource type. The width if the edge is proportional to the number of resources the organization uses of that resource type. The users are also arranged vertically based on which types of resource they use more, e.g., an organization that uses more Raw Data than the other organizations are placed near the top of the diagram while an organization that uses mostly Decision Support Tools or Mission-Specific Requirements are placed near the bottom.

Resource connectivity

Individual resource connections

Centrality, discussed above, is a measure of the degree to which a given resource or resource type functions as a bridge between resources in the network (see Figures 17 and 18). This centrality value is closely correlated to the total number of upstream and downstream resources to which a resource is connected and can be analyzed together with the category of each resource in the flow of information to visualize the role of each resource relative to the flow of information within the network. As shown in Figure 21, the cumulative connections (direct and in-direct) between resources in the network is shown on axes based on whether those connections are with resources downstream in the flow of information or upstream.

Based on this analysis, the network segregates into four discrete groups: resources with many downstream connections, those with many upstream connections, those with a large number of upstream and downstream connections (highly central), and those with a very few connections either upstream or downstream. As expected, the flow of information is fairly well-correlated to the number of cumulative downstream and upstream resources within the IND network. The resources with the most downstream connections are resources categorized towards the beginning of the flow of information (lightly colored nodes). For example, Observational Weather Data, supports 50 other resources in the network, almost half of the inventory. The resources with the most upstream connections are resources categorized towards the end of the flow of information (darker colored nodes). For example, SimSuite, is supported by 38 other resources, well over a third of the total number of resources in the inventory. Additionally, intermediary resources with a large number of upstream and downstream connections are all resources that have event characterization or consequence modeling capabilities. The final group includes resources with very few upstream or downstream connections. Though most of the resources in this group tend to have few or no users, this group includes EAGLE-I, the most widely used resource in the inventory. In order to create a well-functioning network of resources, these resources need to be further integrated into the rest of the network to increase their usefulness to the federal emergency management community and to better support the functionality of the network as a whole.

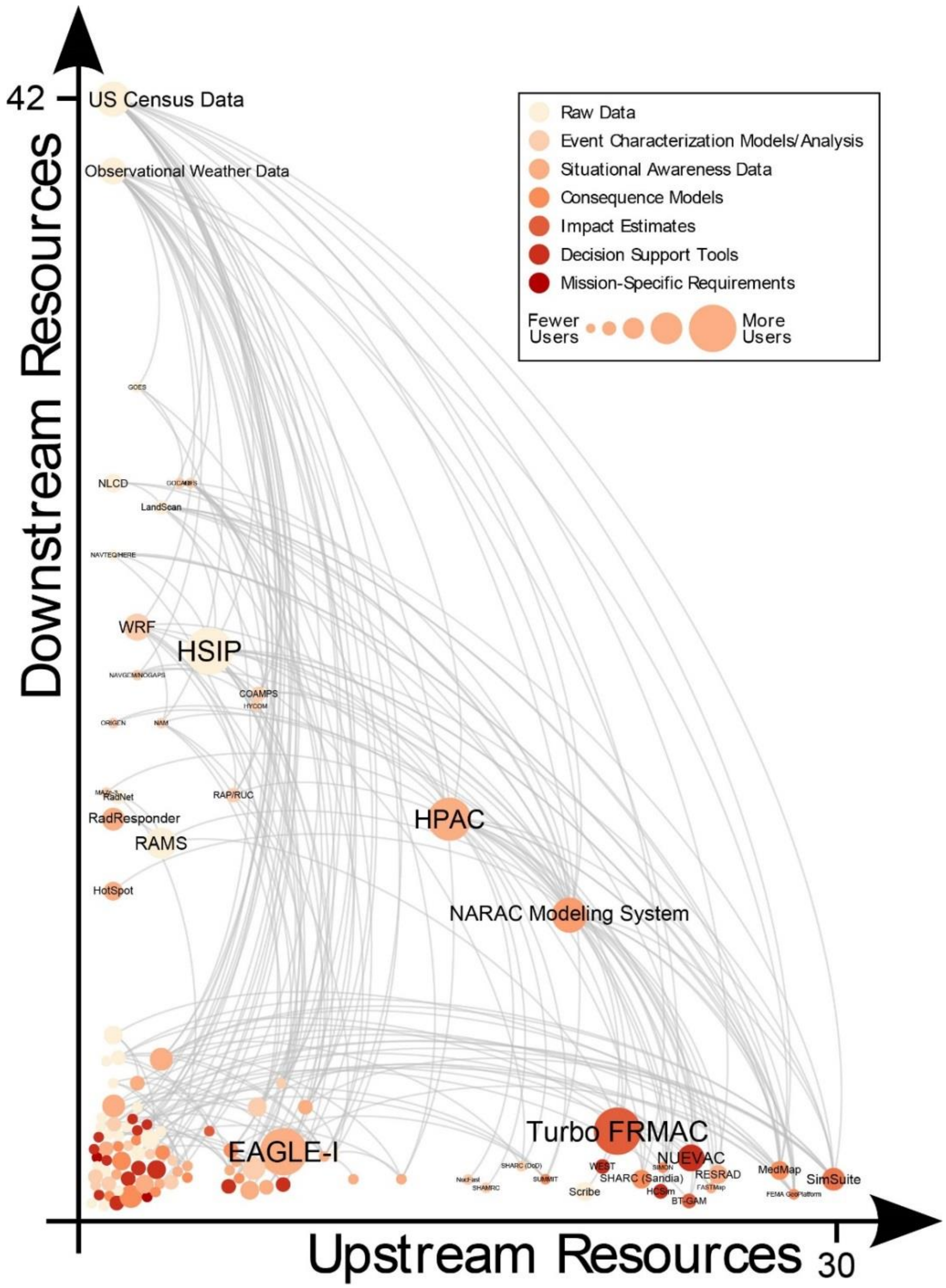

Figure 21. Cumulative upstream and downstream connections of individual resources. In this figure, each node (circle on the graph) represents a resource in the inventory and is sized proportionally to the number of organizations that use that resource across the federal interagency. Nodes are colored based on their resource type within the Flow of Information. The resources are graphed according to the total number of resources upstream of them (both directly and indirectly connected) and the total number of resource downstream of them. Node locations were adjusted slightly in order to display all resources in the network, and should not be interpreted absolutely but rather only relative to other nodes. Edges, the curved lines connecting two nodes, represent information passing from one resource to another. The edges curve in a clockwise fashion, distinguishing which resource is the source and which is the target of the information. The greatest number of cumulative upstream and downstream connections for any organization in the network is displayed on the respective axes.

Flow of information by owners of resources

Understanding the way information is used by the agencies in the emergency management community is important for ensuring that those who need it have access to it in a useful format. Equally useful is understanding who provides what types of information to the community. To better understand the flow of information within the network at the agency level, the cumulative upstream and downstream connections for all resources owned by each agency can be graphed and coded by the types of resources owned by the agency (see Figure 22).

The results highlight the patterns in resource ownership across the interagency. Not surprisingly, NOAA and DoD are major producers of raw data and event characterization models, corresponding to their role in producing, respectively, weather forecasts and developing the physics models necessary for robust characterization of nuclear detonation events. The national laboratories immediately stand out as the group with the most upstream and downstream linkages. This result corresponds with their role in linking raw data and event characterization modeling to robust consequence modeling and the production of impact estimates for nuclear detonation events. Interestingly, FEMA, HHS, and DHS all have a much larger number of upstream resources, suggesting that their primary role is ingesting data, not producing it. However, because the analysis is relative, this result may also simply reflect the lack of decision support tools and mission specific requirements linked to upstream resources, as already described.

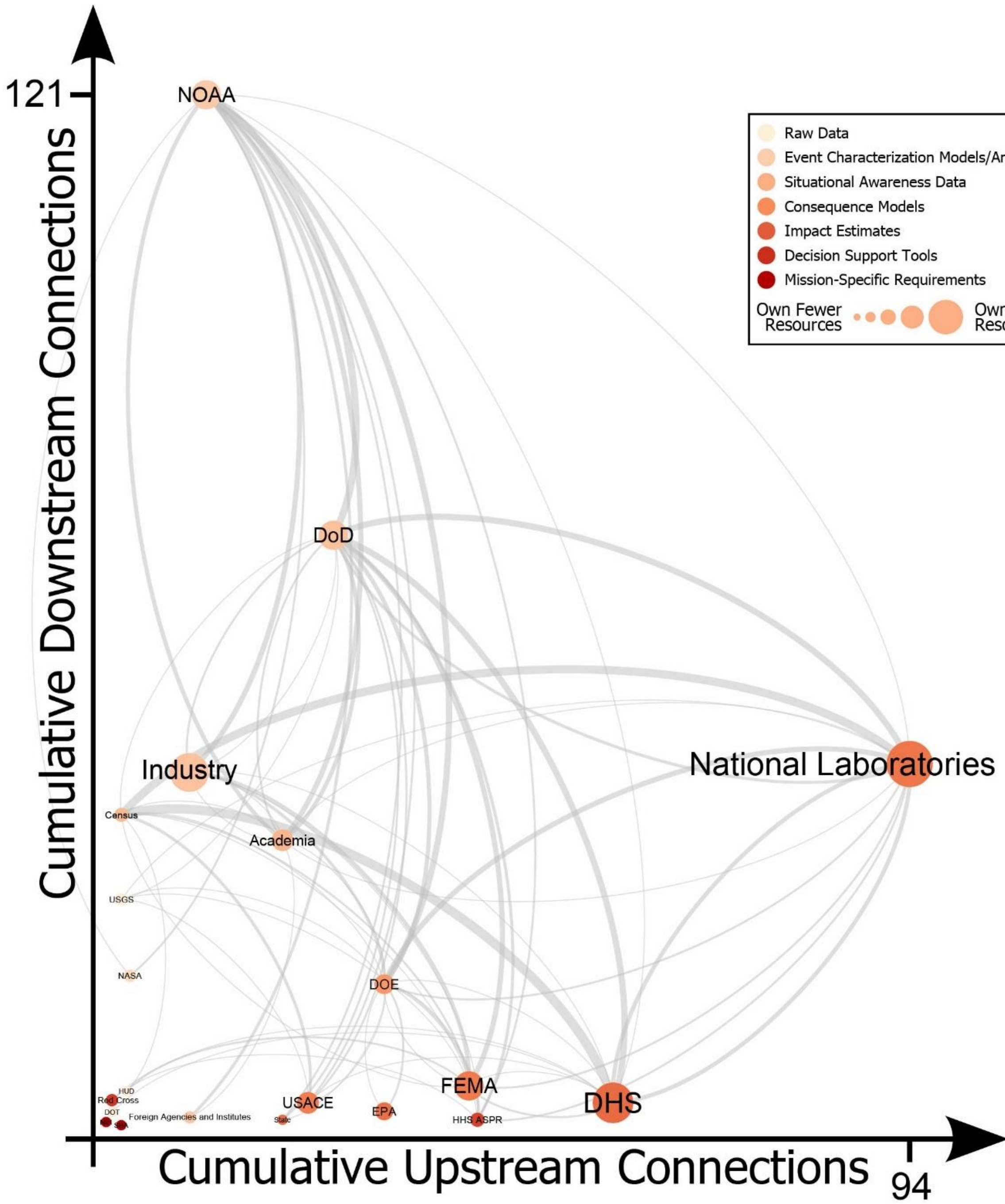

Figure 22. Organizational upstream and downstream resource connections. In this figure, each node (circle on the graph) represents an owner and is sized proportionally to the number of resources they own in the inventory. Nodes are colored based on the average resource type of the resources owned by that organization. The organizations are graphed according to the total number of upstream connections and the total number of downstream connections for all of the resources they own. Both direct and indirect connections were counted. Node locations were adjusted slightly in order to clearly display all organizations, and should not be interpreted absolutely but rather only relative to other nodes. Edges, the curved lines connecting two nodes, represent information passing from a resource owned by one organization to a resource owned by a different organization. The edges curve in a clockwise fashion, distinguishing which resource is the source and which is the target of the information. All self-loops (resource connections between two resources both owned by one organization) were not considered when making this graph. The greatest number of cumulative upstream and downstream connections for any organization in the network is displayed on the respective axes.

Connections by resource type

As previously described, resources that fall early in the flow of information would be expected to have a large number of resources downstream; resources that fall late in the flow of information would be expected to have a large number of resources upstream. While network maps allow this hypothesis to be analyzed qualitatively, Figure 23 provides a quantitative analysis.

As expected, a general trend of decreasing number of downstream connections is seen across the flow of information, with raw data resources having the most number of downstream connections, and mission specific requirements having the least (Figure 23; lighter color). This observation is expected as resources early in the flow of information provide information to the rest of the resources in the network.

By contrast, the trend for upstream connections (Figure 23; darker color) suggests that impact estimates, decision support tools, and mission specific requirements do not pull from hazard- and scenario-specific information provided by upstream resources, including either event characterization or consequence models. In order to provide accurate, real-time data to inform decisions regarding resource and personnel requirements, as is the goal of effective decision support tools and mission specific requirements, these resources must be linked to the hazard characterizations and forecasts, consequence projections, and post-event assessment data available by upstream data collection and processing.

Interestingly, the number of upstream resources peak at situational awareness data. This is surprising given that situational awareness data have a smaller centrality measure than both event characterization models and consequence models (see Figure 18). This juxtaposition of a high number of upstream resources, but relatively low centrality indicates that information does not generally flow out of situational awareness data. The most prominent situational awareness data are the situational awareness views like FEMA GeoPlatform and MedMap that compile a large amount of data, but feed few downstream resources. These viewers present and visualize the data to federal emergency managers, but are not generally processed by other resource types.

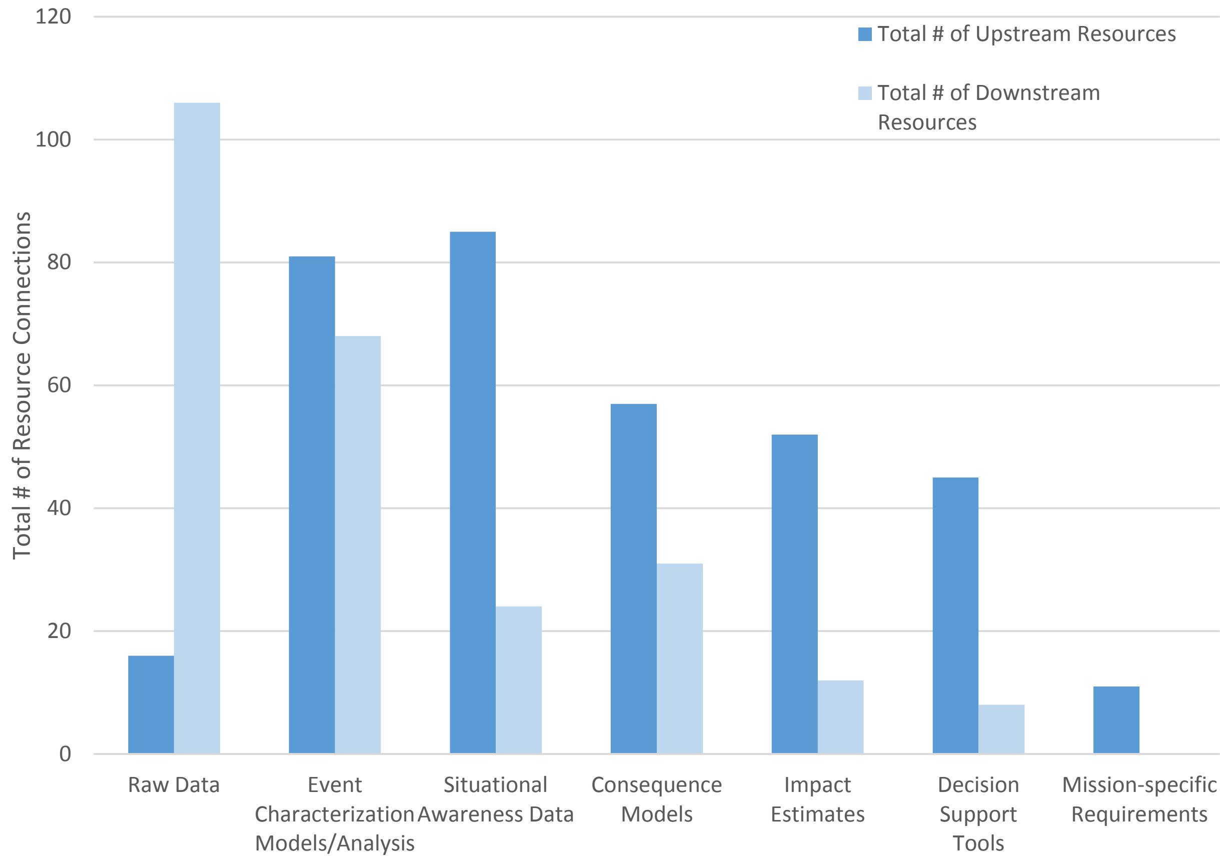

Figure 23. Total number of upstream and downstream resources by resource type. The total number of Upstream and Downstream Resources for each resource type. Resources tagged as multiple resource types contribute to the averages of each resource type they are tagged as.

Resources in the IND inventory mapped to response activities

The network and metadata analyses described in previous sections have highlighted salient features of the network and provided a systems level view of how information flows through the resources and the connections between them. Figure 5 and Table 1 have mapped out a timeline of response activities and corresponding critical information requirements after an IND detonation. Identifying which resources in the inventory are useful to address the critical information requirements is important to understand how the resources would be used during an event, as well as to identify gaps in availability of data and modeling resources.

Figure 24 maps the resources in the IND inventory that could be used to inform response activities and address the associated critical information requirements and is designed to highlight how the inventory can be used. Not all the resources in the inventory are shown; rather this preliminary analysis correlates the resources in the IND inventory to five examples of response activities and the corresponding critical information requirements, which have been distilled down to five keywords – weather, dispersion, radiation, human health, and energy.

As an IND response progresses from immediate to late response activities, a general trend is observed in the types of resources required. Response activities like “Define hazard zones,” are necessary to answer “What happened?” after an event and rely on critical information requirements relevant to the keywords weather, dispersion, and radiation. These keywords tend to utilize resources early in the flow of information, like raw data and event characterization models (Figure 24). As “Define hazard zones” leads into those response activities that deal with the question of “What must be done,” the associated radiation- and human health-related critical information requirements tend to use resources later in the flow of information, like impact estimates and decision support tools.

Of note, four of the five response activities shown in Figure 24 require radiation-related information. Together these response activities are also useful to answer all three fundamental questions of “What happened,” “Who and what was affected,” and “What must be done.” Not surprisingly, the resources mapped to radiation span the gamut of almost all the resources types depicted in the flow of information framework (Figure 12).

Interestingly, when considering the critical information requirements relevant to energy, the response activities, “Establish triage and definitive care strategy,” and “Restore utilities,” cross cut the different types of resources, and range from raw data to situational awareness data to decision support tools. This observation underscores the importance of energy during all phases of a response, be it early or late.

Some resources are tagged with multiple resource types, as well as multiple keywords. A general trend observed in these types of resources is that early in the timeline of an IND response, these resources tend to function early in the flow of information. As an IND response progresses, these resources tend to be used later in the flow of information. For example, the NARAC Modeling System is used more as an event characterization model when critical information relevant to early response activities such as “Define hazard zones” is needed. The resource is used more as a consequence model when radiation- and human health-related critical information is needed

Notably, of the 57 unique resources shown in Figure 24, none of them represent mission specific requirements. This is not surprising because only four resources are tagged as mission specific requirements in the IND inventory, and these four resources tend to be useful for the narrow mission space for which they were designed.

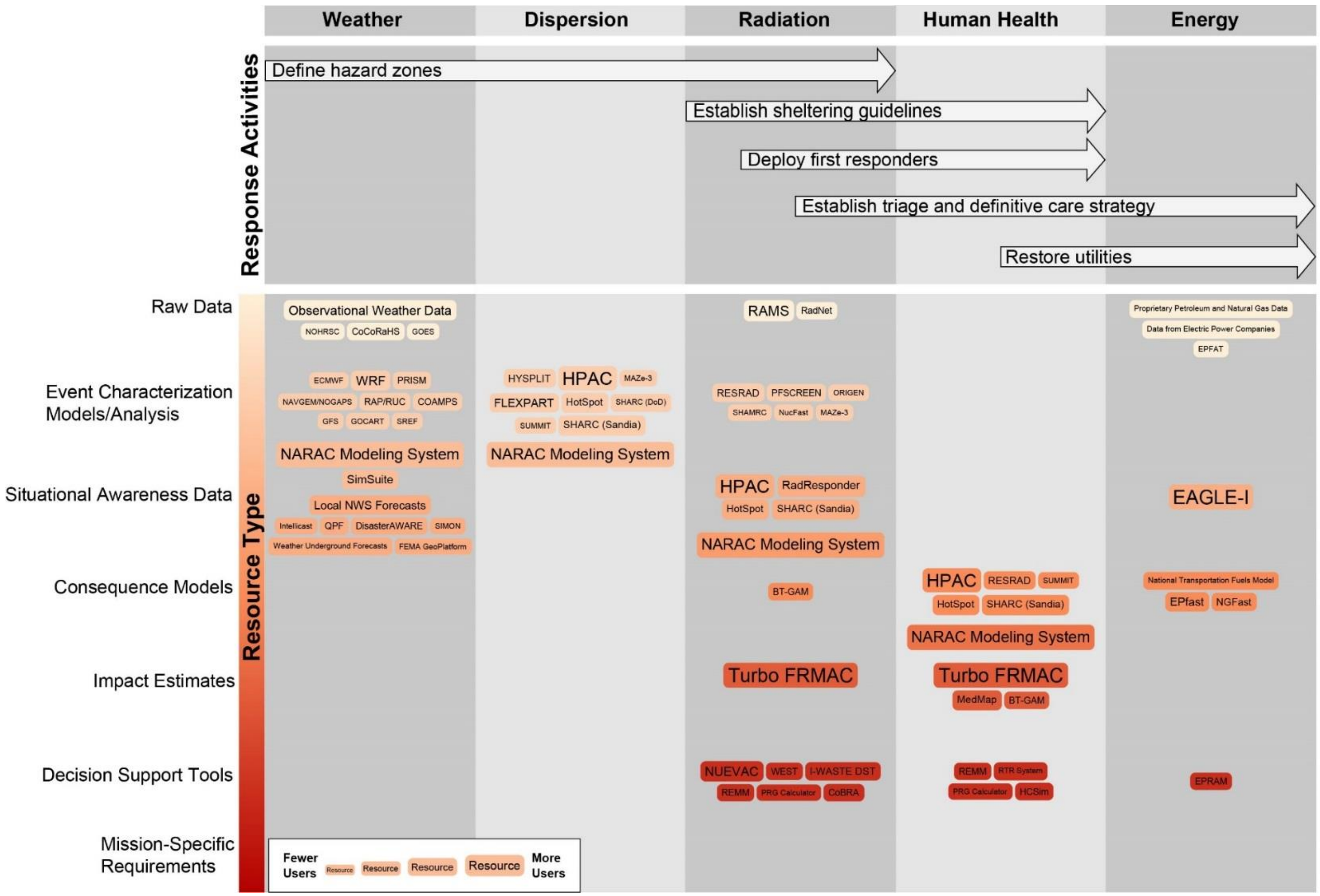

Figure 24. IND resources mapped to select response activities. Five examples of IND response activities were selected along with five keywords (Weather, Dispersion, Radiation, Human Health, and Energy), which describe the information requirements for each response activity. Inventory resources tagged with each of the keywords are displayed below the timeline, ordered by resource type. Each labeled box represents a resource in the inventory and is sized proportionally to the number of users that resource across the federal interagency. Lighter boxes represent resources tagged earlier in the flow of information, while darker boxes represent resources tagged later. If a resource was tagged with the same keyword, but with more than one resource type, its vertical position was determined by the average of those resource types. Box locations were adjusted slightly in order to display all relevant resources, and should not be interpreted absolutely. Only resources from the IND inventory with users and with at least one of the five keywords appear in the figure.

Discussion

The network and metadata analyses described in this report illustrate that the wide array of IND-relevant resources used by the emergency management community are generally well-connected and integrated. The results indicate that there is a relatively clear flow of information from weather-related resources to atmospheric dispersion models to consequence models, but the translation of these data into the operations-focused mission-specific information is incomplete. In nearly every analysis, whether a qualitative assessment of the flow of information through specific resources or the quantitative assessments of information transfer between specific resources and producers of those resources, the breakdown in the flow of information from consequence models to resources downstream is clear. In the following section, these results are addressed in the context of a discussion about the systems-level redundancies and gaps identified through the analysis, leading to courses of action for improving the utility of the available data and models for emergency management.

Networks rely on a few highly central resources

Although data and models are widely used by the federal interagency, only a few resources stand out as being heavily used. In most cases, these widely-used resources are also the most central (e.g., the NARAC Modeling System and HPAC (Figure 17). These resources not only have a large number of upstream and downstream resources, but are also linked to other highly central resources, such as Turbo FRMAC and HSIP, which make them important bridges for the flow of information within the network. This finding highlights the importance of investing in the maintenance and updating of these resources to ensure the long term viability of the information system.

The breadth of the user community across the federal interagency involved in emergency management also highlights the importance of interagency engagement in decisions regarding the continued maintenance, long-term development strategies, and access requirements. Unilateral decisions regarding upkeep and future investments for these widely-used and central resources by the owner or funding agency would put at risk the needs of the additional users and stakeholders. Conversely, a single owner or agency cannot be expected to single-handedly fund or maintain resources and capabilities needed by a broad user community without some financial and time investment from that group.

Interagency coordination specifically focused on developing and maintaining critical resources for the emergency management community writ large has been and still is successful in some well-established cases. The Homeland Security Infrastructure Program (HSIP) is one example of a productive resource developed and maintained by an interagency group specifically designed to address exactly this type of coordination challenge. The resource is managed by an interagency working group led by DHS and the NGA that collates a large number of datasets from a wide range of public and private sources (586 data layers at last count) into a single mapping platform and distributes the compiled product according to access requirements approved by the group. This coordination of efforts is time-intensive, but has generated one of the most widely used and frequently cited resources throughout the interagency. The success of HSIP and other resources managed and supported by interagency groups suggest that this mechanism could be a successful path forward to ensure the ongoing maintenance and stakeholder engagement with other critical resources within the information network.

Not all resources are well-connected

Network analyses of IND resources have identified a number of resources that are completely unlinked to the network. In addition, a few widely-used resources have only very limited connections to other resources, suggesting that the information from these resources could be more effectively integrated into the network. Better linkages between resources would ensure that the information generated is used by decision makers for emergency management.

Orphan resources

As shown in Figures 14 and listed in Table 10, over 10% of the total number of resources in the inventory exchange no information with any other resource in the inventory. These resources do not input real-time, event-specific data, nor are the outputs further processed or analyzed. If these resources remain unconnected to other resources, then the flow of information is severed, resulting in an incomplete picture of the event as a whole and what needs to be done to respond effectively. For example, LCMIS is a logistics decision support tool owned and used by FEMA to determine the resources required in the initial resource push to an affected region. However, LCMIS is an orphan resource, suggesting that the data it provides are based on a series of assumptions not aligned with the event-specific data provided by upstream event characterization or consequence models, despite their availability. The incorporation of these upstream data is particularly important when the decisions made need to be coordinated with other groups within the same agency, ESF, or between ESFs. This coordination is critical to prevent conflicts caused by competing assumptions inherent in resource requirements calculations. Incorporating validated hazard-specific inputs helps ensure that downstream resources are processing information based on the most accurate, up-to-date data.

Widely-used resources with limited connections

Widely-used resources are expected to be central and well-integrated into the network; however, the IND network contains resources that are widely-used, but poorly linked to the rest of the network. For example, EAGLE-I is one of the most widely-used resources in the inventory, yet has few upstream and downstream linkages and is not well-integrated into the network (Figure 14). When widely-used resources are not well-linked, this disrupts the flow of information, and results in the resource not being leveraged to its full potential. Therefore, just as improving linkages to orphan resources improves the function of the entire network, better integrating these widely-used resources helps prevent gaps in the flow of information and ensures maximum availability and usage of information produced by these resources.

Redundancies

Analysis of the resources in the network has revealed that, of those resources used by the interagency, there are few redundancies with most resources serving a unique function. This result most likely reflects a combination of centralized utility and previous coordination of efforts. Particularly based on the finding that there are only a relatively few widely-used resources, it is likely that there may be redundant resources available that are not captured in the inventory because they are no longer (or not yet) used. Moreover, previous efforts at reducing redundancies (e.g. IMAAC for dispersion models) have largely been successful, though, as in the case of IMAAC, multiple models that perform similar functions are still widely used.

Function versus utility

Although there are resources that appear to provide overlapping function, the utility of these resources is often very different. For example, while function is largely determined by general information about the types of information provided (e.g. plume maps), utility is based on a combination of factors, including function, but also when the data are available, to whom, and at what level of resolution. There is an obvious need for functional redundancy when the utility is broadly disparate. For example, in some cases one model can produce approximate results within five minutes that are critical to provide initial guidance. However, a second, functionally similar model, may take five hours to produce results, but is much more accurate and calculates a much broader array of effects that are needed to inform longer term decisions regarding on-going response and recovery activities. While the function of the models is similar, the utility is very different; access to and maintenance of both models is critical, despite the initial appearance of functional redundancy.

Functional redundancy can cause confusion when the results appear to conflict. This issue has been addressed for atmospheric dispersion modeling through an interagency effort that resulted in the formation of IMAAC, a partnership between eight federal agencies that have plume modeling capabilities or responsibilities. During an emergency, IMAAC can be activated to provide coordinated plume models of hazardous atmospheric releases. This structure provides a mechanism to provide the end user with the information that best meets their needs: rapid, low resolution results for quick-turnaround requests and more time-consuming, but complete analyses when more accurate and detailed results are required. Similar mechanisms may be required for other resources for which there is functional redundancy. Evacuation models and population datasets might both fall in the category of resources for which this kind of discussion would be useful.

Situational awareness viewers

The only resources identified in this analysis that are redundant both in function and utility and for which there is no current mechanism to deconflict efforts are situational awareness viewers. There are seven situational awareness viewers in the inventory that all serve the same function and are used for the same purpose (see Table 12 for a list of these resources). Each of the seven is owned by a different agency, of which three are only used by the agency that owns them.

Situational awareness viewers are typically map-based platforms that provide event-specific information overlaid with steady state data including infrastructure and population data. Excepting EAGLE-I, which is the most heavily used resource, the other six viewers have a limited number of federal users. With the exception of FEMA GeoPlatform and OnTheMap for Emergency Management, all the viewers limit access, either to their own employees (e.g. SIMON and SimSuite, which are only available to State and DoD, respectively) or to a limited subset of the emergency management community.

Situational awareness viewers are critical resources for emergency managers and are heavily used within each agency (many users within the agency, as contrasted to widely-used between different agencies). A robust situational awareness viewer would incorporate information from a common set of validated data layers and models and would be available not just to the decision makers within the agency, but also to the broader emergency community to inform operational decision making across and within all ESFs. Such sharing of information or validation of data layers used in multiple situational viewers is critical to provide a complete, shared understanding of the event upon which to make coordinated decisions regarding preparedness and response operations. For robust data sharing within and between ESFs, a comprehensive situational awareness platform that uses a common set of validated data layers and models and made available to the federal interagency would be invaluable to inform decision-making at all levels.

Table 12. Situational awareness viewers across the federal interagency. The situational awareness viewers are listed alphabetically, along with their owners, users and a short description.

Resources	Owners	Users	Description
EAGLE-I	DOE OE	DHS, DoD, DOE, FEMA, HHS ASPR, NOAA, USACE, USCG, USDA, White House NSC	Aggregates, processes, and displays near real-time feeds covering the nation's electric grid.
FASTMAP	DHS OCIA, Sandia	DHS OCIA	Browses and analyzes national infrastructure and emergency resource data.
FEMA GeoPlatform	FEMA	FEMA	Provides access to emergency management-relevant geospatial data.
MedMap	HHS ASPR	HHS ASPR, DHS NOC, NORTHCOM	Maps infrastructure locations and facility/demographic data against hazard imagery.
OnTheMap for Emergency Management	Census Bureau	FEMA, Red Cross, DOE	Summarizes worker data for reported disaster zones or user-defined areas.
SIMON	State	State	Maps critical infrastructure against hazard data for risk assessment.
SimSuite	USACE	USACE, FEMA, USGS, Army	Provides multi-hazards modeling and data viewing for planning, response, and recovery.

Gap analysis

Based on the results of the network and metadata analysis of the IND resource inventory and information from interviews with subject matter experts, emergency managers, and senior level decision makers, a series of gaps in how the interagency uses information resources to support decision making during emergency management have been identified. Importantly, these are broad systems-level gaps that impact the entire federal interagency and the emergency management community; addressing these systems-level gaps will improve the flow of information that supports operational decision making during emergency management.

Every gap described below speaks to an overarching need to translate and link the outputs from existing data and modeling resources to response activities in order to support data-driven decision making across emergency management missions. Although robust tools to characterize an IND event are widely available and used, it is less clear how the information from event characterization and consequence models will be used to inform operational decision-making, such as triage needs, mass care, and transportation, among others. For example, models that can predict evacuation routes that are based on the location of the fallout cloud are available, but emergency managers do not know how those evacuation routes will be impacted by traffic accidents, mass exodus of the public, and reverse flow traffic of resources being transported into the affected areas post-event.

In order to provide usable information, the scientific community that develops the models needs to be aware of the critical information needs of emergency managers. The outputs of predictive event characterization modeling need to be translated and linked to each ESF, so that emergency managers across all mission areas have access to and understand modeling outputs in order to inform decisions as to how and when to use this type of information to support planning, response, and recovery activities. This translation will require both understanding the outputs of the models themselves (the quantitative data and associated error) and understanding the time-sensitive and information-overloaded environment faced by operations leads in the field.

Analysis of the network and metadata characteristics has revealed three major gaps that impede the translation and linking of outputs from existing data and models to response activities. These gaps and Courses of Action to address them are described below.

Lack of operations-focused data, models, and analysis tools

As apparent in nearly every analysis performed and described in this report, there are few resources that provide operations-focused information. Moreoever, those resources that are used (including impact estimates, decision support tools, and mission specific requirements) are not sufficiently linked to upstream resources to ensure that the data provided are event-specific and coordinated with the event characterization and consequence modeling being performed by others within the community.

Lack of cross-sector impact estimates

A robust response to any event will require a comprehensive coordination across all mission areas. In order to ensure that this response is informed by the most accurate, up-to-date data available, impact estimate data must be made available rapidly and be readily accessible to emergency managers across all emergency support functions. Metadata analyses show that a total of eight impact estimate resources are used for IND scenarios, less than 5% of the total number of resources in the inventory (Figure 15). A closer analysis of these resources confirms that no single impact estimate resource is sufficiently cross-sector to provide the information needed by the complete breadth of downstream ESFs and associated missions. The available impact estimates support only relatively narrow mission spaces – for example, health, infrastructure, or housing. Without robust cross-sector analysis, it is impossible to assess how the consequences in each sector will impact other sectors, resulting in a lack of comprehensive assessments regarding the total consequences to which the emergency management community will need to respond.

Lack of impact estimate libraries

Impact estimates are defined as resources that provide data about the impacts of an event. They are either the outputs of predictive consequence models, historical consequence assessments, or real-time post-event assessment data. However, there are currently very few repositories for this type of data, and the existing repositories are not well-recognized as providing access to this type of data.

Impact estimate libraries are important tools for both planning and response efforts for senior level decision makers and those involved in operations. Immediately after an event, libraries containing the outputs from consequence models run previously, combined with historical data from similar events, providing information about the effects of a wide range of event scenarios can be used to inform early decisions when little or no assessment data are available. These data are particularly critical early in the response before the outputs of consequence models based on the current event have been produced or made available.

Optimally, impact estimate data feed decision-support tools that can be used to inform mission-specific activities and resource requirements to support response and recovery efforts. For example, the number and type of anticipated casualties as predicted by impact estimates would directly influence the strictness of triage guidelines for first responders. Damage estimates to critical infrastructure would be used to anticipate which populations are most likely to be threatened by secondary hazards and would therefore benefit from earlier evacuation. These data could also be used to inform decisions such as the type and amount of medical countermeasures stockpiled pre-event, targeting of response missions to damaged areas, and the distribution of disaster relief supplies to populations displaced by radiological hazards post-event.

Impact estimate libraries are the only mechanism for those who do not have the expertise or computing power to run the consequence models or analysis capabilities themselves to gain access to high resolution impact estimate data. Many of the most robust and widely-used consequence models, particularly for nuclear detonation consequence modeling, require subject matter expertise to run with appropriate parameter inputs and analyze the outputs. A library that contained outputs of runs performed and analyzed by these experts would provide these data in a format that could be much more readily accessed and used by a much broader community than are currently available.

Ideally, when consequence models, such as the NARAC Modeling System or HPAC, are run, the outputs of these runs should be collated into an easily-accessible library that can be referenced for future planning or response operations. A searchable library of impact estimates that collates information on damage assessments to all emergency support functions, including damage to human health, the economy, infrastructure, and the environment, among others, would provide decision makers a measure against which to compare consequences and inform critical early decisions to respond to an event and provide the data required to validate and verify data produced by consequence models.

Very limited decision support tools and mission specific requirements available

Effective decision support tools and mission specific requirements translate the consequences of an event into the concrete, quantitative personnel and material requirements needed to respond and recover. These types of resources can analyze shelter or evacuate strategies after an IND detonation (NUEVAC) or provide information on the handling, transportation, treatment, and disposal of contaminated waste and debris (I-WASTE). The most effective tools as described by interviewees use mobile applications for the ready input of assessment data collected by those on the ground in the affected regions. This information can be collated into a centralized database from which the data is analyzed and provided back to those making operationally-relevant decisions across all emergency support functions. However, there are relatively few resources available to support a limited number of emergency management missions.

Lack of connections to other resources in the network

Impact estimates and mission specific requirements datasets are poorly integrated in the network

Of the available impact estimates and mission specific requirements, only a few are sufficiently linked to other resources in the inventory. Connections to upstream resources are critical to ensure that the resource requirements calculated by the decision support tools are data-driven and based on the same event-specific consequence data informing decisions across the ESFs. Regardless of whether new resources are developed to address the needs of each specific mission or emergency support function (ESF) or whether the existing resources are expanded to provide information specific to a wider range of missions, all ESFs and missions should be supported by empirical data that is shared broadly within the interagency and available through effective decision support tools and mission specific requirements.

The lack of connections is particularly highlighted by resources that serve as sources of mission specific requirements. Of the four resources used, three have no upstream linkages. Resources at the end of the flow of information would be expected to have many upstream feeds, from raw data to consequence models and impact estimates to decision support tools. The lack of any upstream feeds for the majority of mission specific requirements is problematic as it underscores a lack of integration and cohesiveness within the network, regardless of the type of hazard.

All emergency support functions need mission specific information in order to leverage appropriate resources to respond effectively to any event. Therefore, mission specific requirements need to be linked to existing upstream resources to generate a robust and well-integrated network. In addition, when new resources are developed that support specific missions, these need to be connected to appropriate upstream resources to ensure that emergency management personnel have access to event-specific, empirical data upon which to make decisions for planning and response.

Lack of response-ready, cross-sector consequence models

Although robust event characterization models exist to describe nuclear detonations, the available consequence models for INDs are limited in scope or address only specific sectors. For example, the NARAC Modeling System and HPAC are both widely used consequence models, but the primary consequence outputs of both models are focused on relatively simple calculations for causalities and fatalities – a consequence output of limited scope; neither model provides these outputs at a level of resolution necessary for medical response planning. Sector-specific consequence models include ResRad, which is focused primarily on radiation contamination and clean-up requirements and FastECON, which addresses the economic consequences of the event. Effective cross-sector consequence models would be able to predict a wide range of impacts and the way in which impacts in one sector would affect other sectors, including, for example, estimating losses of local hospital resources due to destruction or contamination and the effect of those losses on the ability of those hospitals to respond to the specific types of casualties expected in specific areas around the blast.

Response dynamics not analyzed in currently available models

While there are a number of consequence models available to inform IND emergency management, there are no well-known or widely used models that incorporate the effect of response dynamics on those consequences. Incorporating response dynamics can significantly improve the value of the consequence models by identifying the key parameters of a response, such as the length of time it would take first responders to reach and treat their patients with the appropriate medications. This type of information is critical, for example, for reducing casualties: many radiation treatments are only effective if administered within the first few hours of exposure, but if the current shelter-in-place guidance is followed, most victims will not receive radiation treatment for at least 12 hours post-detonation. The guidance for development of new medical countermeasures, emergency medical service guidance, and shelter-in-place guidance could all be directly affected by analysis that incorporates these types of data.

Notably, response modeling requires data that are also not currently available. Particularly for events such as a nuclear detonation, there are no historical data on which to define likely response times, first responder or medical provider absenteeism, or traffic patterns. However, models that incorporate such parameters could be used to test assumptions and perform comparative analysis to evaluate which aspects of the response are most critical to reducing causalities or fatalities.

Courses of action

The gaps identified as part of this analysis reflect a functional system that could be significantly improved by a few coordinated, systems-level investments. While a few specific gaps were identified during interviews, they are not the consistently-described gaps that require interagency participation to address. The gap analysis, instead, identified areas within the network and the flow of information that could be better linked and integrated. In addition, network analysis has identified a few highly central and widely used resources for which the broader emergency management community would benefit from a more concerted interagency effort to provide ongoing updates and maintenance. The Courses of Action below are focused on building a robust and well-connected network of resources that will be useful in providing the necessary information to those who need it when they need it in the context of emergency management.

Increase support for highly central resources within the IND network

- Update and maintain highly central resources through interagency investment
- Ensure the long-term viability of these highly-central and widely-used resources

Improve network integration

- Link and integrate orphan resources into the rest of the network
- Ensure that widely-used resources are well connected to the network

Improve data sharing for situational awareness viewers

- Ensure that available situational awareness viewers pull from a common set of validated data layers and models
- Ensure that the emergency management community at all levels of the federal government has access to a common operating picture

Improve the flow of information within the network

- Ensure that the existing sources of impact estimates and mission specific requirements are integrated into the network
- Develop readily-accessible repositories of impact estimate data
- Identify the critical data requirements for all emergency support functions in order to develop relevant decision support tools and mission specific requirements that address these requirements
- Build decision support tools and mission specific requirements that support all emergency management missions

Next steps

The previous section outlines courses of action for the interagency to improve the utility and robustness of the network of resources. In this section, concrete next steps are described to help address the gaps within the network and ensure that the IND resource inventory is available and useful to the emergency management community

Develop a concept of operations for the resource inventory

The overall goal of this project has been to identify and collate a list of the data and models used to inform operational decision making for emergency management. However, applying this inventory to the mission of specific agencies or ESFs was outside the scope of the project. A concept of operations would ensure that the inventory is incorporated into the day-to-day emergency management operations of each agency and ESF. This CONOPS would, optimally, also include a maintenance strategy that determines how the inventory will be updated and hosted. Such a CONOPS will ensure that the inventory is used, maintained, updated, and included in planning documents so that the interagency can leverage the resources within it to support and inform decisions made during an emergency, whether during planning stages or during response and recovery activities.

Perform an in-depth analysis to map resources to mission-specific data requirements

One of the major challenges remaining in emergency management is how to use the available resources to better inform decision making. Building the resource inventory and a user interface to access that information was the first step forward. Figure 24 illustrates a few key examples for how the IND resource inventory can be used to inform response activities and corresponding information requirements. However, this analysis was limited. Such an analysis, performed in-depth for each ESF or emergency management mission would significantly improve the immediate utility of the inventory, and help ensure that the information available in the inventory is applied effectively to the missions for which it was designed. Such an in-depth analysis would also help identify the specific missions for which there are insufficient resources available, therefore, providing empirical evidence to support future investment decisions.

Develop impact estimate libraries

As identified in the gap analysis, very few repositories of impact estimate data are available to the emergency management community to support IND preparedness and response operations. A closer analysis of these few resources confirms that no single impact estimate resource covers a breadth of consequences, nor, when taken together, do they cover all mission spaces. A well-connected and well-functioning network of resources relevant to INDs relies on a robust flow of information through cross sector impact estimates. In order to ensure a robust, well-coordinated response, impact estimate libraries are needed to ensure that the outputs of the highly-central, widely-used consequence models are readily available to the broader emergency management community.

Develop decision support tools and mission specific requirements

Decision support tools and mission specific requirements serve the critical function of making event characterization and consequence data available to support operations-level decision making. Although several decision support tools and mission specific requirements are available to the federal interagency, these resources fulfill data requirements for only a narrow mission space. Developing tools to better support a broader range of emergency management missions would significantly improve the access of the operations community to the data they need to make informed decisions and ensure that those data are provided in a way that are immediately relevant and useful. Identifying and defining the data requirements from all ESFs would ensure that any new tools developed are meeting the needs of the operations community and ensure that those tools are effective and useful to the community for which they are designed.

Expand the inventory to additional hazards

The inventory presented in this report identifies data and modeling resources relevant to INDs. As of this report, resources relevant to hurricanes and earthquakes have been collated as well.[50] To build a comprehensive and cohesive network of data and modeling resources for emergency management, the effort would need to be expanded to additional scenarios. Of particular interest to those interviewed are biological and cybersecurity scenarios.

Biological scenarios, like cybersecurity scenarios, are likely to require fundamentally different response strategies than those scenarios addressed. Cybersecurity scenarios, like biological scenarios, are caused by a largely invisible hazard. Both events would be expected to be delayed-notice and require ongoing surveillance in order to identify and characterize the event, which fundamentally changes how information is used and when decisions need to be made on the basis of the available information. For both types of scenarios, it will be critical to determine what information is required, what resources are available, and how the existing resources will be used to ensure continuity of operations.

Expanding the resource inventory to include these additional scenarios would significantly expand the inventory, as there are few resources in the existing inventory that would be expected to directly support these other scenarios. This expansion would also help highlight hazard-specific gaps.

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[50] Graeden E (January 2014) MDWG Phase III Report Draft: Data and Models for Hurricanes and Earthquakes

Conclusions

Data and models are widely used across the federal interagency to support operational decision making for emergency management. The network of resources used for all phases of emergency management related to nuclear detonation scenarios is relatively mature and robust. While there are improvements to be made, from better integrating orphan and widely-used resources to developing a more complete toolkit of operations-focused decision support tools and sources of mission-specific requirements, all the agencies and ESFs are represented in the inventory and are involved in the process. Continued work to better integrate and coordinated sharing of the available data and outputs of the available computational models is critical to improve the effectiveness and efficiency of federal emergency response. Key investments leveraging the engagement of stakeholders from across the community could generate rapid and significant improvements, if based on the information now available about how the larger information system functions. The identification and characterization of the used resources, as well as the systems-level analysis of how these resources function together to generate useful information for the emergency management community, provides the information on which to found future conversations. The resulting web-based inventory provides unique access to this information and will help ensure that the resources are used ever more broadly to better inform emergency management decision across the federal interagency.

Appendix 1: The ESFLG Modeling and Data Working Group (MDWG) CHARTER

August 6, 2012

1. PURPOSE

This charter provides the framework for the establishment and structure of the Modeling and Data Working Group (MDWG). The MDWG is comprised of Emergency Support Function Leadership Group (ESFLG) members or designees and chaired by the Director of FEMA's Planning Division, Response Directorate. The MDWG will:

- Analyze the catastrophic scenarios to be addressed and prioritized;
- Define and assess information requirements for response planning and operational decision-making;
- Evaluate existing modeling resources to support the range of scenarios and determine modeling input and output requirements;
- Identify gaps and recommend solutions to meet the modeling input and output requirements.

2. MISSION

The MDWG mission is to identify consistent, reliable, authoritative models and data sets for response planning and operational decision making for catastrophic events.

3. BACKGROUND

Scientific based models and empirical information products and programs are increasingly used to predict the effects of and inform response planning and operations, particularly when faced with complex, cascading "maximum of maximums" threats and incidents. These models and programs enable decision makers with enhanced situational awareness and heightened visualization of the operational environment to prepare and assess the response to catastrophic events. For example, the benefits of prompt and accurate modeling include improved incident warning, reduction of public anxiety through effective risk communications, and delineation of hazard areas. Both real world events and exercises alike have highlighted a need to standardize these processes and products. However, currently no central mechanism exists to address the doctrine, organizational, training, materiel and leadership requirements necessary to exploit the effective use and coordination of such models and products.

The lack of a formal and standardized approach to integrating scientific modeling and coordinating related technical programs is a challenge to information sharing as well as to the development of effective preparedness plans and responses. The need to develop a standardized framework of modeling across the Emergency Support Function Leadership Group (ESFLG) structure is essential to closing core capability gaps, and improving the overall effectiveness of models for both planning and operations. The MDWG will address modeling and analysis requirements and the most effective ways to exploit emerging data generation products, to include scientific modeling and data sets to meet those requirements.

4. MEMBERSHIP

The Modeling and Data Working Group (MDWG) members were nominated by the Emergency Support Function Leadership Group (ESFLG) and will meet on a monthly basis. A list of the voting organizations of the MDWG is attached. The MDWG will address the most effective ways to exploit emerging data generation products, to include scientific modeling and data sets. The working group will determine the most effective programs to incorporate into the ESFLG structure as well as to evaluate implementation success.

5. ROLES AND RESPONSIBILITIES

- The MDWG voting members will provide primary and alternate representatives to contribute throughout the process.
- Each primary organization of the MDWG will have a voting responsibility when dealing with modeling and data issues that affect the interagency working group.
- The MDWG gathers and assesses modeling and information requirements for catastrophic scenarios and will provide regular updates to the ESFLG for evaluation.
- The ESFLG will then use the information compiled to work with the Office of Science and Technology Policy (OSTP) and the National Security Staff (NSS) to develop and formalize interagency modeling capability governance and coordination.

6. DELIVERABLES

The working group will provide an update status to the ESFLG on a monthly basis.
The working group will provide the following deliverables:

1. Identify and analyze the catastrophic scenarios to be addressed and prioritized;
2. Define and assess information requirements for response planning and operational decision-making;
3. Define information requirements for response planning and operational decision making.
4. Develop criteria to evaluate and determine modeling and data source that support requirements
5. Evaluate authoritative modeling and data sources to support catastrophic scenarios; and
6. Identify gaps and recommend solutions to solve the identified modeling and information requirements.
7. Utilize the results from each scenario to inform subsequent scenarios.

7. RESOLUTION OF ISSUES AT MDWG MEETINGS

- The working group will utilize the ESFLG structure to resolve interagency coordination issues.
- Any interagency issues that cannot be resolved at the ESFLG level will consult the National Security Staff (NSS) and the Office of Science and Technology Policy (OSTP) for resolution of policy issues.
- Finalize resolution of policy issues will be handled by the Domestic Readiness Group (DRG).

8. ESFLG WORKING GROUPS

The MDWG is an ESFLG working group, in accordance with the ESFLG Charter. ESFLG working groups will include appropriate expertise and representation to guide the development of the requisite procedures for response and recovery activities under the National Response Framework (NRF) and National Disaster Recovery Framework (NDRF), as well as Federal Interagency and National planning efforts. Representation on working groups will be open to selected departments and agencies and FEMA Regions as appropriate.

The working group's purpose is to:

- Convene on an ad-hoc basis as designated for specific issues, and disband upon completion of the specific assigned task;
- Address issues that require appropriate department/agency participation for researching and developing procedures to operationalize and execute policy decisions;
- Identify and suggest process improvements to the ESFLG for approval;
- Provide input from subject matter experts; and
- Provide expertise to the Federal response community to address tasks including the research and development of potential options/courses of action and drafting of documents, recommendations, and procedures to improve Federal interagency coordination, integration, and incident response.

9. MDWG Primary Voting Organizations

Department of Agriculture

Department of Agriculture/Forest Service

Department of Commerce

    National Oceanic and Atmospheric Administration

Department of Defense (OSD, Joint Staff)

Department of Defense/U.S. Army Corps of Engineers

Department of Energy

Department of Energy/National Nuclear Security Administration

Department of Health and Human Services

Department of Homeland Security

    Federal Emergency Management Agency

    U.S. Coast Guard

    Transportation Security Administration

    Immigration and Customs Enforcement

    Customs and Border Protection

    United States Secret Service

    Office of Science & Technology

    United States Citizenship & Immigration Services

Department of Housing and Urban Development
Department of the Interior
Department of the Interior/National Park Service
Department of Justice
Department of Transportation
Environmental Protection Agency
Small Business Administration

Appendix 2: The ESFLG Modeling and Data Working Group Project Plan

DHS/FEMA

The ESFLG Modeling and Data Working Group (MDWG)

Project Plan

Introduction

In July of 2012, both the Department of Homeland Security (DHS) and Federal Emergency Management Agency (FEMA) agreed that FEMA would coordinate the creation and implementation of an interagency Modeling and Scientific Workgroup (MDWG), with the full support and involvement of the Emergency Support Function Leadership Group (ESFLG). At the July 19, 2012 ESFLG meeting, there was concurrence by the ESFLG to form the Modeling and Data Working Group (MDWG) and designate a representative from their department/agency to participate on the MDWG. On July 31, 2012, the MDWG was formed from ESFLG nominations and the August 6th kickoff meeting was announced. The MDWG will assess the current state of modeling systems used, including their owners, requirements, consumers, production processes and means of public messaging. The working group will utilize the ESFLG structure to resolve routine interagency coordination issues. The working group will consult the National Security Staff (NSS) for resolution of policy issues. The purpose of the MDWG will be information gathering – regular updates will be provided to the ESFLG. The ESFLG will then use the information compiled to work with the NSS to develop and formalize interagency modeling capability governance and coordination.

Background

Scientific based models and data generation products and programs are increasingly used to predict the effects of and inform response planning and operations, particularly when faced with complex, cascading "maximum of maximums" threats and incidents. These models and programs enable decision makers with enhanced situational awareness and heightened visualization of the operational environment to prepare and assess the response to catastrophic events. For example, the benefits of prompt and accurate modeling include improved incident warning, reduction of public anxiety through effective risk communications, and delineation of hazard areas. Both real world events and exercises alike have highlighted a need to standardize these products, programs, and processes. A need exists to understand the strengths and constraints of each scientific model and related technical program; enabling the closing of core capability gaps, however, currently no central mechanism exists to address the doctrine, organizational, training, materiel and leadership requirements necessary to exploit the effective use and coordination of such models and products.

The lack of a formal and standardized approach to integrating scientific modeling and coordinating related technical programs is a challenge to information sharing as well as to the development of effective preparedness plans and responses. The need to develop a standardized framework of modeling across the Emergency Support Function Leadership Group (ESFLG) structure is essential to closing core capability gaps, and improving the overall effectiveness of their use in both planning and operations.

Project Plan

The MDWG will address the most effective ways to exploit emerging data generation products, to include scientific modeling, data requirements, and geospatial analysis for catastrophic scenarios. The working group will determine the most effective modeling and data products to incorporate into the ESFLG structure as well as to evaluate implementation success. Further, Presidential Policy Directive #8 (PPD-8), and specifically the response core capabilities, will inform this process and support this effort.
The MDWG will:

- Analyze catastrophic scenarios to be addressed;
- Assess data requirements for response planning and operational decision-making;
- Evaluate existing resources to support scenarios and address data requirements;

- Identify gaps and recommend solutions to solve the data requirements.

Roles/Responsibilities

- The MDWG voting members will provide primary and alternate representatives to contribute throughout the process.
- Each primary organization of the MDWG will have a voting responsibility when dealing with modeling and data issues that affect the interagency.
- The MDWG gathers and assesses modeling and data requirements for catastrophic scenarios and will provide regular updates to the ESFLG for evaluation.
- The ESFLG will then use the information compiled to work with the OSTP and NSS to develop and formalize interagency modeling capability governance and coordination.

Project Management

1. The membership group will establish a charter.
2. The membership group will establish a work plan.
3. The MDWG will meet monthly to discuss working issues.
4. The MDWG Chair will provide an update to the ESFLG on a monthly basis.
5. The MDWG will provide a formal status update to the ESFLG annually.
6. The MDWG voting members will provide primary and alternate representatives to contribute throughout the process.

Deliverables

The MDWG will provide an update status to the ESFLG on a monthly basis.
The MDWG will provide the following deliverables:

1. Identify and analyze the catastrophic scenarios to be addressed and prioritized
    a. Review the 15 National Planning Scenarios
    b. Review other catastrophic scenarios (i.e. flooding, tsunami, solar storms)
    c. Prioritize scenarios and choose pilot scenarios
    d. Establish process and rating scheme for prioritizing scenarios
2. Define and assess data requirements for response planning and operational decision-making
    a. Map the data requirements for the pilot scenarios
    b. Identify the response organizations for each pilot scenario
    c. Collect input from the response organizations on their current modeling and data requirements supporting these pilot scenarios
3. Evaluate authoritative modeling and data sources to support pilot catastrophic scenarios
    a. Review the modeling and data requirements of each response organization
    b. Define the lead agency responsible for the modeling and data products
    c. Identify the consumers of each modeling and data product
4. Identify gaps and recommend solutions to meet the identified modeling and data requirements

a. Determine if the existing modeling and data products are meeting the needs of the response organizations and stakeholder groups (e.g. White House, Public, etc.) in assisting them to make informed decisions.
b. Develop a matrix to determine gaps in modeling and data requirements for each pilot scenario
c. The MDWG will vote upon solution sets for each gap identified and recommend these solutions to the ESFLG for review and approval

5. Utilize the results from the pilot scenarios to inform subsequent catastrophic scenarios
6. Provide a formal briefing to the ESFLG annually on work accomplished during the fiscal year.

Appendix 3: Interviewees

NAME	AGENCY
Millage, Kyle	ARA
Nichols, James	ARA
Cragan, Jennifer	ASA
Ward, Matt	ASA
Buikema, Ed	Argonne National Laboratory
Folga, Steve	Argonne National Laboratory
Gunn, Julia	Boston Public Health Commission
Demarais, John	CAP
St. John, Courtney	Columbia University, Center for Research on Environmental Decisions
Alexander, David	DHS
Billado, William	DHS
Briggs, Kevin	DHS
Chacko, Betsie	DHS
Cole, Ray	DHS
Coller Monarez, Susan	DHS
Cotter, Dan	DHS
Danielson, Glen	DHS
Franco, Crystal	DHS
Klucking, Sara	DHS
Langhelm, Ron	DHS
MacIntyre, Anthony	DHS
Mapar, Jalal	DHS
Maycock, Brett	DHS
Moe, Mathew	DHS
Shepherd, Dave	DHS
Valentine Davis, Victor	DHS
DeCroix, Michele	DHS DNDO
Waters, Amy	DHS DNDO
Driggs, Kevin	DHS NCCIC
Berscheid, Alan	DHS NISAC/HITRAC
Chatfield, Catherine	DHS NISAC/HITRAC

Gordon, Craig	DHS NISAC/HITRAC
Norman, Mike	DHS NISAC/HITRAC
Stamber, Kevin	DHS NISAC/HITRAC
Aeschelman, Jeremiah	DoD DTRA
Basiaga, Dariusz	DoD DTRA
Blandford, Michael	DoD DTRA
Blandford, Mike	DoD DTRA
Cooper, Charles	DoD DTRA
Grouse, Andy	DoD DTRA
Kahn, Todd	DoD DTRA
Leong, Timothy	DoD DTRA
Lowenstein, Eric	DoD DTRA
Mazzola, Tom	DoD DTRA
Meris, Ron	DoD DTRA
Phillips, Michael	DoD DTRA
Baron, Thomas	DoD NORTHCOM/NORAD
Danaher, Leo	DoD NORTHCOM/NORAD
DeGoes, John	DoD NORTHCOM/NORAD
Friedman, Andy	DoD NORTHCOM/NORAD
Jackson, Mike	DoD NORTHCOM/NORAD
Wireman, Jody	DoD NORTHCOM/NORAD
Allen, Gary	DoD Office of the Secretary of Defense
Gerrig, Dan	DoD Office of the Secretary of Defense
Greenberg, Brandy	DoD Office of the Secretary of Defense
Miller, Brian	DoD Office of the Secretary of Defense
Mullen, Frank	DoD Office of the Secretary of Defense
Sorden, Caryn	DoD Office of the Secretary of Defense
Yu, Leigh	DoD Office of the Secretary of Defense
Blumenthal, Daniel	DOE
Cedres, Stewart	DOE
Clark, Jamie	DOE
Corredor, Carlos	DOE
Favret, Derek	DOE
Fernandez, Steve	DOE
Hsu, Simon	DOE

Lippert, Alice	DOE
Lucas, Anthony	DOE
Rollison, Eric	DOE
Scott, Margaret	DOE
Willging, Pat	DOE
Schilling, David	DoT
Stuckey, Bill	DoT
Vanness, Jeffrey	DoT
Howard, Jeffrey	Dun & Bradstreet
Clark, Steve	EPA
Haxton, Terra	EPA
Hudson, Scott	EPA
Irizarry, Gilberto	EPA
Lemieux, Paul	EPA
Magnuson, Matthew	EPA
Mosser, Jen	EPA
Snead, Kathryn	EPA
Woodyard, Josh	EPA
Almonor, Niclaos	FEMA
Anderson, Lindsey	FEMA
Bahamonde, Marty	FEMA
Bausch, Doug	FEMA
Bellamo, Doug	FEMA
Bennett, Gerilee	FEMA
Berman, Eric	FEMA
Bonifas, Michelle	FEMA
Boyce, Carla	FEMA
Brierly, Mick	FEMA
Brown, Cliff	FEMA
Crawford, Sean	FEMA
Daigler, Donald	FEMA
Decker, K.C.	FEMA
Demorat, David	FEMA
Ewing, Melvin	FEMA
Faison, Kendrick	FEMA

Farmer, Bob	FEMA
Gilmore, Lance	FEMA
Gorman, Chad	FEMA
Griffith, David	FEMA
Harned, Rebecca	FEMA
Hewgley, Carter	FEMA
Hinkson, Tasha	FEMA
Hodge, Craig	FEMA
Huyck, Charles	FEMA
Ingram, Deborah	FEMA
Jackson, Liz	FEMA
Jacques, Richard	FEMA
Juskie, John	FEMA
Kazil, Jacqueline	FEMA
Lawson, David	FEMA
Legary, Justin	FEMA
Longenecker, Gene	FEMA
Lumpkins, Donald	FEMA
McDonald, Blair	FEMA
Pollock, Marcus	FEMA
Preusse, Paul	FEMA
Rabin, John	FEMA
Ransom, Darrell	FEMA
Roberts, Nikki	FEMA
Rogers, James	FEMA
Rodgers, Nathan	FEMA
Rozelle, Jessee	FEMA
Sanderson, Bill	FEMA
Schlossman, Mikhail	FEMA
Scott, Kara	FEMA
Shaffer, Deb	FEMA
Sonhaus, Daniel	FEMA
Stanfill, Derek	FEMA
Stuart, James	FEMA
Truax, Wayne	FEMA

Vaughan, Chris	FEMA
Wilson, Preston	FEMA
Wolfgul, Gus	FEMA
Woodhams, Katrina	FEMA
Wright, Roy E.	FEMA
Wycoff, Kristen	FEMA
Zohn, Ashley	FEMA
Zuzak, Casey	FEMA
Butgereit, Richard	Florida Division on Emergency Management
Baker, Jay	Florida State University
Gabriel, Edward	HHS ASPR
Koerner, John	HHS ASPR
Lant, Tim	HHS ASPR
Lurie, Dr. Nicole	HHS ASPR
Olsen, Jennifer	HHS ASPR
Shankman, Robert	HHS ASPR
Wright, Sue	HHS ASPR
George, David	JHU APL
Taylor, Steven	JHU APL
Waddell, Richard	JHU APL
Alai, Maureen	Lawrence Livermore National Laboratory
Buddemeier, Brooke	Lawrence Livermore National Laboratory
Goforth, John	Lawrence Livermore National Laboratory
Glascoe, Lee	Lawrence Livermore National Laboratory/NARAC
Homann, Steve	Lawrence Livermore National Laboratory/NARAC
Nasstrom, John	Lawrence Livermore National Laboratory/NARAC
Pobanz, Brenda	Lawrence Livermore National Laboratory/NARAC
Simpson, Matthew	Lawrence Livermore National Laboratory/NARAC
Sugiyama, Gayle	Lawrence Livermore National Laboratory/NARAC
Tuttle, Benjamin	NGA
White, Greg	NGA
DiMego, Geoff	NOAA
Draxler, Roland	NOAA
Feyen, Jesse	NOAA
Heffernan, Robyn	NOAA

Knabb, Richard	NOAA
Lapenta, Bill	NOAA
McQueen, Jeff	NOAA
Mitchell, Daisy	NOAA
Mongeon, Albert	NOAA
Roohr, Peter	NOAA
Sokich, John	NOAA
Tallapragada, Vijay	NOAA
Tolman, Hendrik	NOAA
Collins, Andy	Old Dominion University
Jordan, Craig	Old Dominion University
Myer, David	Old Dominion University
Robinson, Mike	Old Dominion University
Tune, Greg	Red Cross
Bynum, Leo	Sandia National Laboratories
Fulton, John	Sandia National Laboratories
John, Charles	Sandia National Laboratories
Jones, Dean	Sandia National Laboratories
Kimura, Margot	Sandia National Laboratories
Knowlton, Robert	Sandia National Laboratories
Kraus, Terry	Sandia National Laboratories
Mahrous, Karim	Sandia National Laboratories
Miller, Trisha	Sandia National Laboratories
Pennington, Heather	Sandia National Laboratories
Pless, Daniel	Sandia National Laboratories
Teclemariam, Nerayo	Sandia National Laboratories
Vurin, Eric	Sandia National Laboratories
Dial, Patrick	SBA
Valliere, John	SBA
O'Neill, Ed	State
Dowell, Earlene	US Census
Pitts, Robert	US Census
Diaz, Steve	USACE
Harris, Dewey	USACE
Hendricks, Joel	USACE

Irwin, Bill	USACE
Keown, Patrick	USACE
Markin, Chad	USACE
Nye, Bill	USACE
Schargorodski, Spencer	USACE
Schuster, Michael	USACE
Town, Patrick	USACE
Butwid, Jerry	USCG
Gleason, Joe	USCG
Gunning, Jason	USCG
Hunt, Michael	USCG
Landry, Mary	USCG
Lundgren, Scott	USCG
McGlynn, Matt	USCG
Moore, Brian	USCG
Carpenter, Ryan	USDA
Li, Yun	USDA
Collins, Brian	USFS
Erickson, Rod	USFS
Hill, Laura	USFS
Triplett, Sean	USFS
Applegate, David	USGS
Blanpied, Michael	USGS
Gallagher, Kevin	USGS
Haines, John	USGS
Hammond, Steve	USGS
Ludwig, Kris	USGS
Lyttle, Peter	USGS
Mandeville, Charles	USGS
Mason, Robert	USGS
Perry, Sue	USGS
Driggers, Richard	White House NSS

Appendix 4: Methods

The workflow of analysis performed for this project is shown in Figure A1 and described briefly in the Methods section in the main text. Each step is described in detail below.

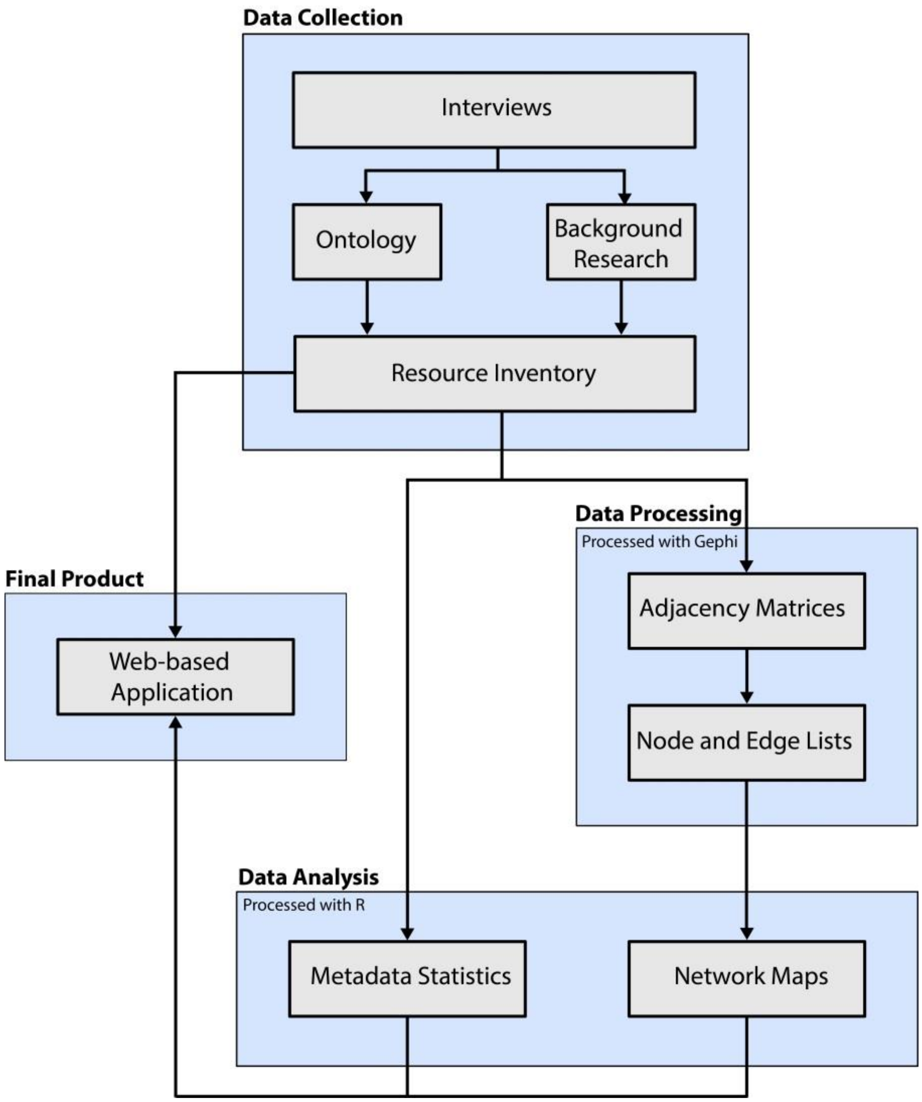

Figure A1. Analysis workflow. A depiction of the sequence of work involved in producing quantitative analysis of the resource inventory.

Data Processing

A network is defined as a system consisting of interconnected components where network analysis is the process of understanding the connections between those components. The individual components of the network are called nodes and the connections between them are called edges, with information moving through the network by a defined, or directed, flow. To build network maps describing the linkages between resources in the inventory, the metadata defining the upstream and downstream linkages for each resource was quantified in an adjacency matrix. An adjacency matrix is a mathematical method of representing a network that provides a simple way to calculate many network measures and statistics.[51] The adjacency matrix was then converted into separate node and edge lists. A node is a point on a network, and in this case, each node represents a single resource in the inventory. The nodes list contains the metadata of each node in the network, allowing that information to be visualized on the network map and analyzed in the context of the network. An edge is a line in the network that connects two nodes, and in this case, represents the transfer of information from one resource to another. The edge list contains a list of connections between nodes in the network. These node and edge lists were imported into Gephi,[52] an open source network visualization and analysis software, to create the network maps used in the analysis.

All data processing was performed using R, an open source, statistics-based programming language.[53] R was chosen because of its ease and efficiency in calculating basic and network-based statistics. An open source language, this coding language facilitates transfer of the analysis scripts to another party.

Data Analysis

Network Analysis

The analysis presented in this report describes the connections between the data and models used by the federal interagency in the context of emergency management. Two metadata categories (upstream and downstream resources) describe linkages between the resources based on the flow of information between those resources. These linkages were used to build a flow-based network of the datasets and models collated in the inventory. This dataset, including the resources and their associated metadata, and the network based on this dataset, was used to perform a preliminary analysis of the IND resource inventory, as described in the results section.

To visualize the data contained in the resource inventory, network maps were generated of the resources from their upstream and downstream metadata tags. In these networks, each dataset or model is a node in the network with each edge representing the flow of information and processing of data as it passes between those nodes. The size of a node and its label is directly proportional to the number of users of that resource, an indicator of the relative utility of each resource, which is defined by the number of federal agencies that directly use the resource in the context of their work.[54] The edges curve in a clockwise fashion, distinguishing which resource is the source and which is the target of the information. In this case, the source node is the upstream resource. A downstream resource is defined as the one that the source node feeds. Figure A2 illustrates an example of a simple network map. Both the inputs (upstream resources) and outputs (downstream resources) of each resource in the network were identified based on in-depth analysis of interview data and a review of the technical documentation of the resource, when available.

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51 A short, rigorous definition of an adjacency matrix: For a network of n nodes, the adjacency matrix A is an n x n matrix where the i,j^{th} entry in the matrix represents the number of connections from the i^{th} node in the network, to the j^{th} node in the network.

52 Bastian M., Heymann S., Jacomy M. (2009). ***Gephi: an open source software for exploring and manipulating networks***. International AAAI Conference on Weblogs and Social Media.

53 R Core Team (2013). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

54 Note that users could also be calculated by including not only the number of direct users, but also those users of all resources that provide inputs for a given resources. We refer to this latter method as calculating “cumulative users”, a method that significantly increases the number of users for resources that fall in the Raw Data and Event Characterization categories, for example.

Unless explicitly stated otherwise, the nodes in each network are arranged by a Force-Direction algorithm that groups closely linked nodes. This algorithm treats each node as a charged particle that repels all other nodes, and each edge as a spring, pulling the nodes back together.

Several network maps were generated to visualize the general flow of information between different resource types and what kinds of resources are owned or used by the federal government for emergency management. These network maps also explored two attributes of the network, betweenness centrality and resource connectivity.

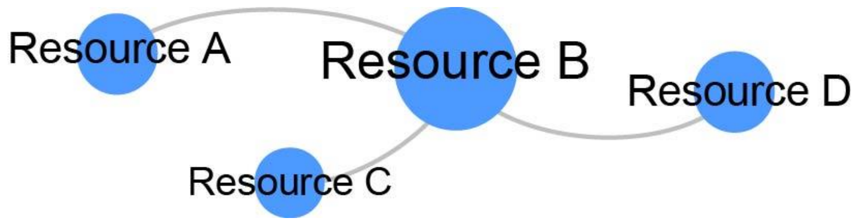

Figure A2. Example of a simple network map. Individual resources are represented by blue discs (nodes). Direct connections between resources are represented by gray curved lines (edges). The flow of information travels clockwise. In this example, information flows into Resource B from Resources A and D. Information from Resource B flows into Resource C. The size of each node can convey additional information; for the network maps presented in this report, nodes are sized relative to the number of users of that resource.

Resource Type

Each network map (see Figure A2 for example) depicts the flow of information, with the nodes representing the seven different resource types. Each node is sized based on how many resources in the inventory are of that resource type. Edges represent a connection between resources of different types and are sized proportionally to the number of those connections.

Betweenness Centrality

The importance of specific nodes was also investigated using the betweenness centrality measure, which is a common centrality measure that characterizes how often a node is between other nodes in the network.[55,56] Specifically, the betweenness centrality of a specific node is calculated as the number of times that node appears on the shortest path between any other two nodes in the network, measuring the degree to which a node acts as an intermediary between other nodes. With betweenness centrality, the most important nodes are those that act as “shortcuts” or “bridges” between different parts of the network. However, betweenness centrality only considers the shortest paths between nodes and therefore gives no weight to alternative paths over which information could be passed within a network. In the network diagrams, nodes were colored on a gradient such that more central nodes were darker and less central nodes were lighter.

Resource Connectivity

Nodes in directed networks can further be characterized by their in-degree (the number of incoming edges or upstream resources) and out-degree (the number of outgoing edges or downstream resources). According to these measures, the most important nodes in a network are those that are directly connected

[55] Freeman LC (1977) A set of measures of centrality based on betweenness. *Sociometry*: 35-41
[56] Freeman LC (1979) Centrality in Social Networks Conceptual Clarification. *Social Networks* 1: 215-239

to the largest number of other nodes, regardless of their position in context with the rest of the network. A node's in-degree is defined as the number of nodes feeding into it (in the resource network, the number of upstream resources) and a node's out-degree is the number of nodes it feeds into (the number of downstream resources). A node's degree is the sum of its in-degree and out-degree, signifying the total number of connections that node makes to another node.

As another way to quantify a node's relative importance, the nodes cumulative in-degree and cumulative out-degree are respectively defined as the number of nodes that lie upstream and downstream of it, whether directly connected or linked through intermediary nodes. These cumulative measures rank a nodes relative importance in the network based on its role as a source or sink of information. In the resource network, resources with high cumulative out-degree are sources or providers of information to a large number of other resources, while resources with high cumulative in-degree act as the sinks of information, relying on information from many supporting resources. For the network of owners, the cumulative in-degree and cumulative out-degree of owners are calculated as the sum of the cumulative in-degree and out-degree of the resources they own. This calculation helps characterize which organization are the sources and which are the sinks of information.

Data Collection

Interviews

The information required to analyze the available data and modeling resources was collected through a series of in-person and phone interviews with the members of the MDWG and the subject matter experts they recommended. During these interviews, the users and producers of each resource identified and characterized the ways in which each resource is used to support planning and operational decision making. In most cases, the MDWG members were interviewed initially. Interviews with additional subject matter experts or leadership were scheduled upon recommendation to provide further breadth or depth of information depending on the size of the agency or division represented and the expertise of each interviewee.

Interviews were opened with an introduction to the project. Throughout the project, interviewees have included those who are providers of data or are tool developers; those who are analysts and users of those data and tools; those who make operational decisions informed by data and modeling resources; and those who have roles that include a combination of tool-development, analysis, and decision making. Interviews are designed to capture an overview of the roles and responsibilities of each group and the ways in which data and data processing tools, including modeling, support those roles. The flow of the conversation varied widely based on the expertise of the interviewee and attempted to capture both the general and specific information requirements from each interviewee across the spectrum of emergency management missions and the phases of an emergency. A comprehensive list of the interviewees can be found in Appendix 3.

Develop Ontology

In the first phase of this project, interviewees were asked about the types of information they need to support their emergency management mission. Based on the responses, a systems level analysis of the information requirements was conducted and a framework to capture the flow of information between the different types of data and modeling resources was developed. This ontology describes how the information required is collected and processed over several iterations of collation and analysis. This analysis provides a framework to understand the role and value of both computationally intensive predictive modeling and the rapid calculations provided by simple algorithms to determine mission specific requirements. This information ontology or flow of information framework was vetted and validated by the working group and is described in detail in "An Information Ontology: The Categorization System" section of this report.

Resource Inventory

A comprehensive inventory of resources used across the federal interagency and the linkages between them was generated on the basis of the resources discussed during interviews, followed by background research to identify inputs and outputs of each resource. Only resources with federal users were included in the inventory. Resources under development or not currently used to support emergency management activities were identified, but not included in the inventory. Information about these resources and how they function within the flow of information has been retained in an archived library. This information allows for more a more detailed analysis and verification of the analyses. Additionally, these resources can be used in future iterations of the report to suggest mechanisms to fill gaps identified in the current inventory. The inclusion of only used and operational resources in the inventory enables an analysis of how information currently travels within the interagency and results in a streamlined resource inventory containing the information immediately useful for emergency managers.

Resource Inventory Metadata

The flow of information framework captures the functional, time-dependent, and mission-specific variation between resources used across the federal interagency. However, it does not describe other essential characteristics such as how those resources are accessed, used, and updated. These additional characteristics, or metadata, must also be collected to properly organize and analyze the resources to maximize effective usage during all phases of emergency management. These metadata will appear in the interactive inventory of resources upon completion of the project.

Metadata categories include: the resource's full name, abbreviation, model/data, owner, users, upstream resources, downstream resources, relevant hazards, core capabilities supported, emergency support functions (ESFs) supported, recovery support functions (RSFs) supported, key words, function tags, resource type, data collection method, phase specific utility, access information, access type, processing requirements, refresh rate, last known version, programming language, file type, contact information, contact during activation, website, and a brief summary of its function and use. Complete descriptions of each metadata tag are included in Appendix 5.

Metadata Analysis

In addition to network analysis, statistics of the inventory metadata were also analyzed to determine resources available to support operational decision making in the context of emergency management. These analyses include the number of used IND resources by resource type, the number of resources used and owned by organization, and the total number of upstream and downstream connections by resource type. Appendix 6 includes a series of analyses that show the number of resources organized by ESFs, the different phases of emergency management, resource function or keywords, and the number of internal and external resources used by each organization, agency, or department.

Appendix 5: Metadata tags

Resource

Resources are named. An abbreviation/acronym is used if one exists.

Model/Data

All resources are categorized as either models or data. Models are defined as programs, algorithms, or sets of calculations which may be used for emergency management. Many models accept as input a type of data which they transform into another type to provide new information. Other models collate individual data resources to yield a new dataset with enhanced utility. Data are defined as repositories of information that may be used for emergency management. This definition of data encompasses tools which assist in the presentation or visualization of data without transforming the data itself. Resources that have both modeling capabilities and a repository of their output, or some other data feed, are tagged as both a model and data.

Hazard

Resources are tagged based on the hazards during which they can be used to inform operational decision making. One or more hazards can be tagged for each resource. Resources can be tagged as: hurricane, earthquake, tsunami, flood, tornado, chemical release, contagious outbreak, non-contagious outbreak, nuclear detonation, explosion, fire, radiological dispersion device, and industrial radiological release. Resources may be tagged with a single hazard or multiple hazards. Additionally, resources that support emergency planning and response for any hazard type are tagged as All-Hazards.

Cascading effects were not considered when tagging hazards. Users interested in the cascading effects of a given hazard would instead search the inventory for the secondary hazard directly.

Supported Core Capabilities, ESFs, and RSFs

The Core Capabilities are designations that represent a list of critical elements within the five mission areas (Prevention, Protection, Mitigation, Response, and Recovery) necessary for Emergency Management.[57] The Core Capabilities are used to assess both the capabilities and gaps over the entire federal interagency emergency management community. In order to facilitate this effort, resources are tagged based on which Core Capabilities they support. Each resource may be tagged as supporting one, more than one, or no Core Capabilities. Each resource was tagged with Core Capabilities it directly supports, in addition to those supported by any downstream resources.

The Emergency Support Functions (ESFs) and Recovery Support Functions (RSFs) provide a coordinating structure for the key functional areas that are most frequently needed in response and recovery, respectively.[58, 59] Identifying the resources that directly support each ESF and RSF will allow emergency managers to ascertain which resources can be used to support their specific missions. Like the Core Capabilities, each resource may be tagged as supporting one, more than one, or no ESFs and RSFs. Resources were only tagged with RSFs if they were also tagged with the Recovery phase (see the 'Phase Specific Utility' subsection). Unlike the Core Capabilities, the ESFs and RSFs are directly used in coordination of federal disaster response and recovery. Therefore, it is only necessary to know which

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57 (2011a) National Preparedness Goal. Department of Homeland Security
58 (2008) National Response Framework. Federal Emergency Management Agency
59 (2011b) National Disaster Recovery Framework. Federal Emergency Management Agency

resources directly support each ESF and RSF, and these tags are not inherited from downstream resources as Core Capabilities tags are.

As described in their Framework documents, each ESF and RSF has one Coordinating Agency and one or more Primary Agencies chosen on the basis of authorities and resources. These agency assignments were used in ESF and RSF tagging to help users identify inventory resources useful for their missions. First, based on information from interviews and research, resources were tagged depending on whether those resources were expected to support ESF or RSF missions. In addition, resources were automatically tagged with the ESFs and RSFs for which their federal users were Coordinating and/or Primary Agencies. This approach ensured that the ESF and RSF tags were informed by both interview data and existing policies for emergency management.

Keywords and Resource Functions

In addition to the Core Capabilities, ESFs, and RSFs, resources are further characterized based on their function. Keywords are simple titles designed to describe the resources independently of the flow of information. Each resource may be tagged with one or more keywords. In order to provide a higher level of resolution for the functions of resources included in the inventory, the keywords are further split into categories based on the flow of information. Each resource may be tagged with one or more resource functions. These tags provide a succinct description of the utility of a resource, both with regards to situations for which the resource is relevant and how it is incorporated into the flow of information.

Resource Type

Resource types are directly drawn from the flow of information categories. As outlined in the Phase II report, data are categorized as raw data, situational awareness data, impact estimates, and/or mission specific requirements, while models are categorized as event characterization models/analysis, consequence models, and/or decision support tools. Each resource may be tagged as one or more resource types. Modeling resources that are useful as multiple resource types can also have multiple tags. Multi-tagged modeling resources represent models that perform multiple, successive steps of data processing. Similarly, data resources that are useful as multiple resource types can have multiple tags.

Data Collection Method

There are three primary methods of data collection: instrumentation, reporting, and the use of social media and crowd-sourced data. Data that are collected, aggregated, and processed directly (i.e., not generated as the output of models) fall into one or more of these three categories. It is important to specify the methods used to collect the data within a resource because collection methods can influence the availability, accessibility, and error associated with the resource.

Instrumentation data are obtained through the use of instruments that are capable of recording repeated observations. Often, data collected by instrumentation is raw data and requires processing by event characterization models or analysis tools before it can be used in support of decision making. Successful collection and aggregation of instrumentation data requires investment in a data collection infrastructure, which must be developed and deployed before an event occurs in order to collect and transmit the data in real time.

Data collected through human observation or non-automated data entry are considered reporting data. These data include damage assessments, hospital records, and critical infrastructure locations. While many types of instrumentation data can be continually collected without the need for large numbers of personnel during an event, reporting data generally take longer to collect and aggregate, and they demand larger personnel investments. Thus, reporting data are typically available at a lower resolution and after a longer delay than instrumentation data.

Social media data, including crowd-sourced data, are also used to inform and validate operational models and decision support tools, though much less frequently than the other two types. There is considerable interest across the interagency to develop methods to use social media data to support decision-making in a way that accounts for the data's inherent uncertainty. Particularly in instances where traditional data feeds are unable to address a question, social media has the potential to serve as a valuable resource.

Owner

The agency, division, or group responsible for updating, maintaining, and validating a given resource is identified. As specific contact information and organizational structures may change over time, specifying the entity in control of a given resource will ensure that it continues to be accessible, regardless of personnel changes or reorganization within agencies. If a resource has more than one organization that is in control of the resource, both organizations are listed as an owner.

Users (Agency-Level)

Resources are tagged with known members of their user communities. Here, users are defined as federal level organizations who directly apply information from the resource in order to answer a policy- or operations-related question in support of their missions for emergency management. Therefore, for the purposes of this project, state and local governments as well as private sector or academic organizations were not considered users (with the one exception of the Red Cross).

It is necessary to note that, while it is informative to tag resources with their known users, this is not the only way to judge the utility or reliability of a resource. New or recently updated resources may be underrepresented due to a lack of familiarity within the emergency management community. Similarly, it is also useful to consider the quality control methods used to verify and validate a given data resource. In any case, identifying the existing user communities who regularly use specific information resources in support of decision making allows both users and producers of these resources to work together in a process of ongoing development, evaluation, and maintenance.

Upstream and Downstream Inventory Resources

Based on the understanding that data collection, analysis, and modeling is an iterative process, the data and models that lie upstream of a given resource (i.e., those that serve as inputs for that resource) are defined. Complementary to the upstream resources category, downstream resources list the data and models that are fed by a given resource. This information indicates the datasets and models that use the resource as an input. It is important to identify the data and modeling resources that are interdependent, as validity of any model relies heavily on the accuracy of its inputs.

Phase Specific Utility

To assist users in determining which inventory resources are most relevant to their missions, the resources are tagged with the phases of emergency management for which they are useful. The phase tags are planning, pre-event preparedness (only for advance-notice events), immediate response (within approximately 36 hours following the event), deployment, sustained response, and recovery. Resources are phase-tagged based on their potential uses, not only their known ones. Thus, a resource which has been used for planning but which could likely be used in the immediate response phase would carry both tags. A resource may be tagged by one or more of the listed phases.

Full Name

The full name of the resource is provided.

Summary

A brief summary of each resource is provided to capture key usage and feature information.

Access

The procedures or credentials necessary to view, use, or update a resource are also defined. Resources can either be open access (immediately available to anyone or only requiring a free, automatic registration) or limited access (which can include proprietary data, classified data, or data that requires permission to access). Each resource may only be tagged as limited access or open access. These two tags are mutually exclusive.

Access Information

Detailed information regarding how to access the resource is provided.

Access Type

There are three primary ways a model can be run: standalone, through a reachback capability, or through interaction with a subject matter expert. Every model is tagged as one or more of these three access types. If a resource can be run through multiple sources, then it is tagged appropriately.

A model tagged as standalone describes any resource that can be run by any individual with access. Standalone access can include access through a web portal. A model tagged as a reachback capability is accessed through a reachback facility. This tag refers to resources run and managed by specific organizations and accessed through formal Requests for Information. A model tagged as subject matter expert is defined as any model that can only be accessed through personal interactions with the model developer or owner. Often, the outputs from these models can be accessed by the public online but the model itself is restricted for use by the subject matter expert. Models are also tagged as subject matter expert if they are run on a schedule based on computing limitations that precludes additional runs of the model outside the set schedule.

Processing Requirements

The processing requirements for viewing a data resource or running a model are defined as one or more of four categories: supercomputer, desktop/laptop, web-based application, and mobile device. Web-based applications are resources that can be accessed through a web portal. Resources are only tagged with ‘mobile device’ if they have a dedicated mobile application. Likewise, an Internet-based resource that could be accessed with a mobile browser is not tagged with ‘mobile device’ unless its website is optimized for mobile viewing. In certain cases, a resource may be tagged with two of the three processing requirements. For example, a weather model that can be run on a desktop computer but is often run on a supercomputer, would be tagged as both ‘desktop/laptop’ and ‘supercomputer.’ A supercomputer application accessed through a web portal would be tagged as both ‘supercomputer’ and ‘web-based application’. A resource run on a desktop application with the same capabilities would be tagged with both ‘mobile device’ and ‘desktop/laptop.’

Refresh Rate and Last Known Version

During all phases of emergency management, frequently updated resources are necessary to inform all levels of decision making. If the information is available, resources are tagged based on their refresh rate (how often they are updated). For data resources, this category specifies how often new information is uploaded into the dataset. For models, it indicates whether the model is routinely run, and if so, how frequently.

Not all data used to support decision making during emergency management can or should incorporate real-time data. While observational weather data must be updated every few minutes to reflect current conditions, data regarding the locations of critical infrastructure or residential building codes do not require the same update frequency to be operationally relevant. For datasets that do not consist of real-time data, the last known version of the dataset (often a release date) is indicated.

Similarly, not all models can or should be automatically run. While automatically refreshing weather forecasts are required for up-to-date situational awareness, many of NOAA's weather forecasting systems are run on a predetermined schedule because of the processing limitations of their supercomputers. This means that many of these models can only be run on their predetermined schedule and cannot be run more frequently during activation. As with datasets, the last known version of the model is indicated to ensure users are aware of the most recent release.

Programming Language

When possible, the programming language in which a resource is coded is given. This metadata category is not only important for developers interested in updating, modifying, or adapting a resource, but it may also provide essential compatibility information, indicating whether or not a resource can operate on a certain computer platform.

Output File Types

If relevant, the file type for a data resource or the file type for the output of a model is given. This information can be used by a model developer or analyst when determining data compatibility or other technical issues. It can also be used to indicate software requirements. If resources are capable of outputting multiple file types, then every file type it is capable of creating will be listed.

Technical Contact and Contact During Activation

The contact information for the group or individual responsible for updating, maintaining, or granting access to each resource is provided. When possible, coordinates for specific individuals are listed. Contact information always contains the organization or agency and, if applicable, the division of the contact in case of personnel changes. Where applicable, an additional contact is listed for use during activation.

Website

The resource's official website is provided where available.

Appendix 6: Additional analyses

Number of ESFs by organization, graded by resource type

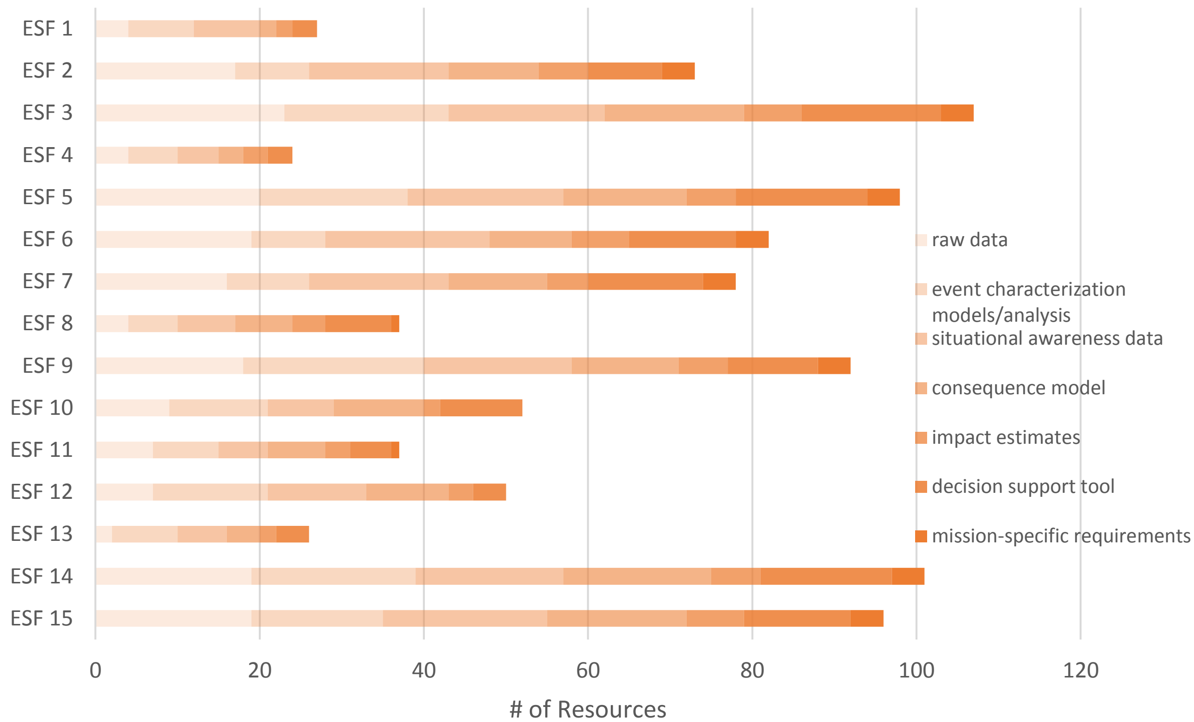

Figure A3. Number of ESFs by organization. The number of resources that support each Emergency Support Function. Resources tagged as multiple resource types are counted once for each resource type they are tagged as. Only used resources were counted.

Figure A3 describes the resources available that directly support each Emergency Support Function. ESF #3, Public Works and Engineering, has the most resources supporting it, closely followed by ESF #14 (Long-Term Community Recovery), ESF #5 (Emergency Management), and ESF #15 (External Affairs). ESF #1 (Transportation), ESF #4 (Firefighting), and ESF #13 (Public Safety and Security).

Phase specific utility by resource type

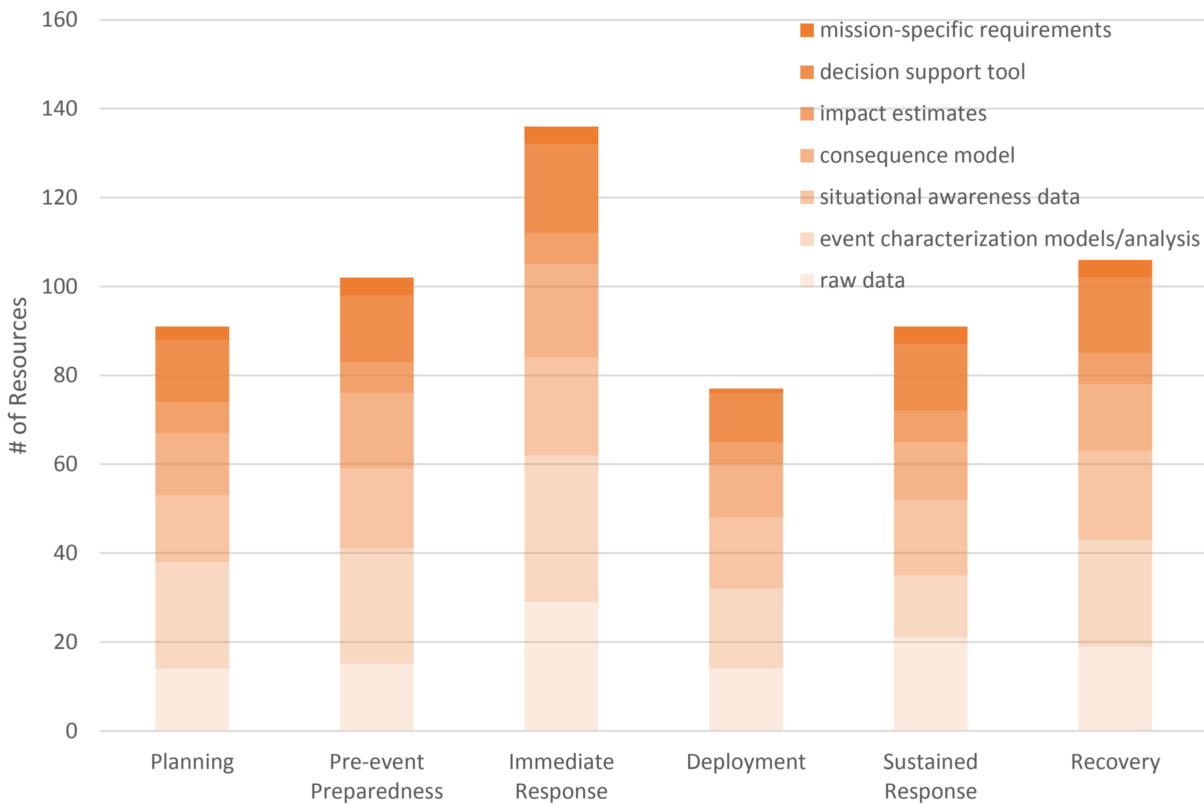

Figure A4. Phase specific utility by resource type. The number of resources that are relevant for each phase of emergency management. Resources tagged as multiple resource types are counted once for each resource type they are tagged as. Only used resources were counted.

Figure A4 describes the resources available during the phases of emergency management. Nearly every resource is available during the planning phase, while the least number of resources are available during pre-event preparedness.

Resource function (keywords) by resource type

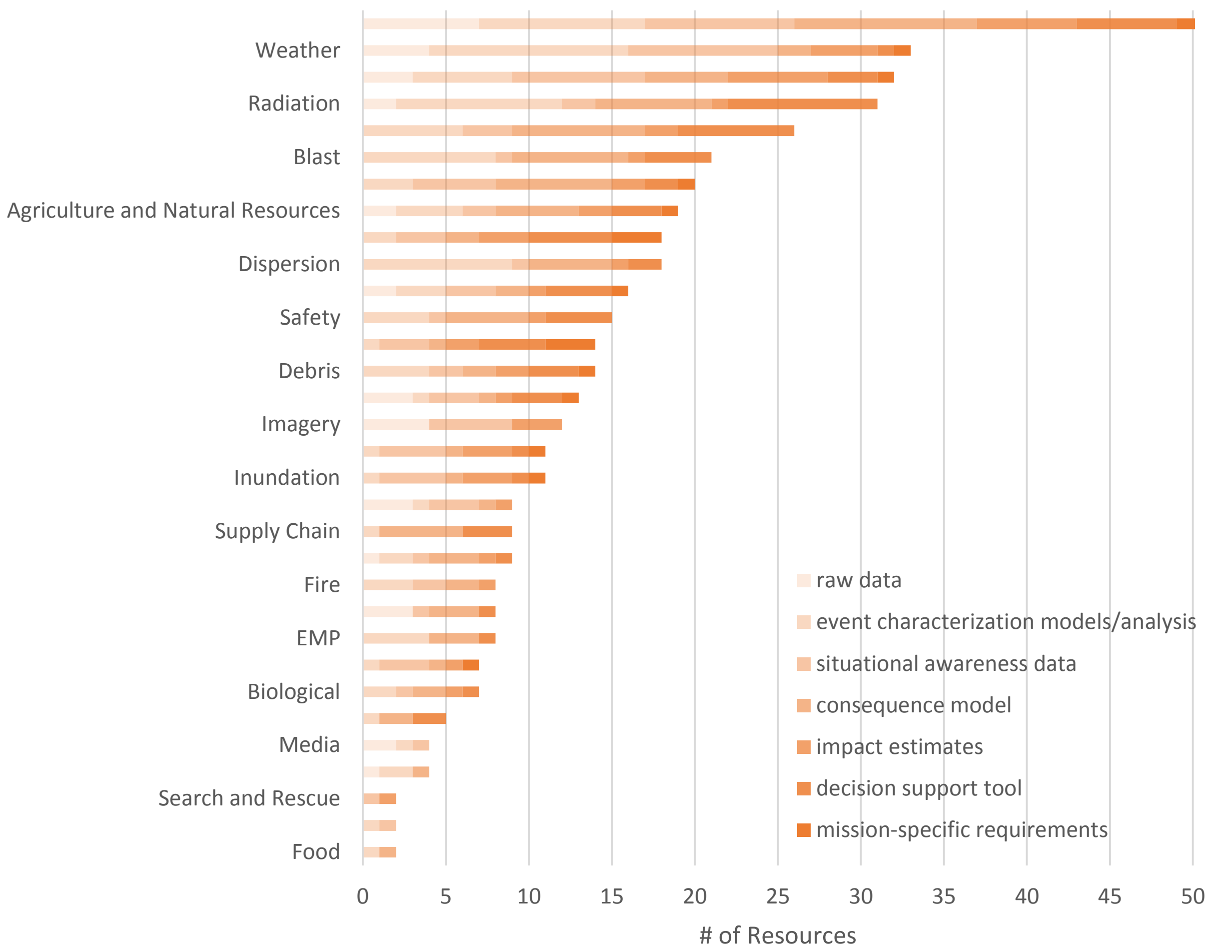

Figure A5. Resource function (keywords) by resource type. The number of resources that provide specific functions within emergency planning and response. Resources tagged as multiple resource types are counted once for each resource type they are tagged as. Only used resources were counted.

Figure A5 describes the resources available by resource function. There are by far more infrastructure resource than resources of any other function. This is largely due to the diversity of infrastructure resources as they include communication infrastructure, transportation infrastructure, and buildings, among others. Logistics and Mass Care resources are primarily consequence models and decision support tools. Most of the other resource functions have a larger diversity of resource types from across the flow of information.

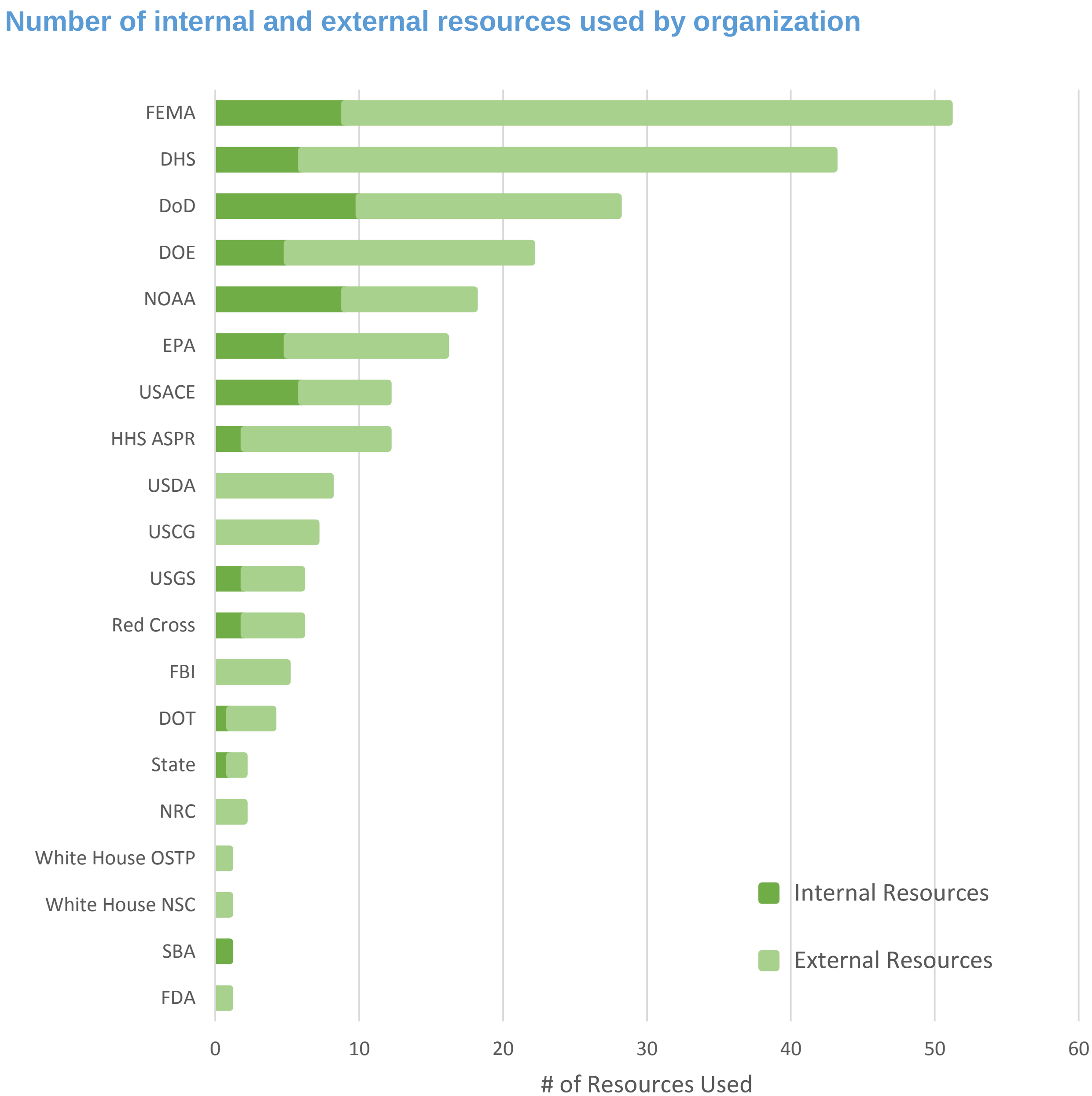

Figure A6. The number of internal and external resources used by organization. The number of resources used by each federal organization, agency or department uses is shown. The number of resources owned (internal) is shown in dark blue. The number of resources used, but not owned (external), is shown in light blue.

As shown in Figure A6, the Federal Emergency Management Agency (FEMA) is the largest user of interagency resources, followed by the Department of Homeland Security (excluding FEMA), the Department of Defense (including both the Defense Threat Reduction Agency and NORTHCOM), and the Department of Energy (including the National Laboratories). Because FEMA is tasked with coordinating efforts between all other agencies involved in emergency management, it is not surprising that they are heavy users of these resources from across the interagency. Other organizations have more specific missions and therefore use only a subset of resources relevant to that mission.

Almost all agencies use more resources owned by other organizations (external resources) than those they own themselves (internal resources). Most users use a mix of largely external resources and a smaller fraction of internal resources. Several agencies that use relatively few resources, like the Department of Justice (DOJ), use only external resources. The SBA is the only exception, as it uses only internal resources.

Appendix 7: List of abbreviations

ARS – Acute Radiation Syndrome
BT-GAM – Blood and Tissue Gap Analysis Model
CBRNE – Chemical, Biological, Radiological, Nuclear, and Explosive
CONOPS – Concept of Operations
DFZ – Dangerous Fallout Zone
DHS – Department of Homeland Security
DoC – Department of Commerce
DoD – Department of Defense
DOE – Department of Energy
DOJ – Department of Justice
DoT – Department of Transportation
DRC – Disaster Recovery Response Center
DRG – Domestic Readiness Group
DSARS – Disaster Services Automated Reporting System
DTED – Digital Elevation Terrain Data
DTRA – Defense Threat Reduction Agency
EAGLE-I – Environment for Analysis of Geo-Located Energy Information
EAS – Emergency Alert System
EMP – Electromagnetic Pulse
EMPREP – Electro-magnetic Pulse Response
EOCs – Emergency Operating Centers
EPA – Environmental Protection Agency
ESF – Emergency Support Function
ESFLG – Emergency Support Function Leadership Group
FBI – Federal Bureau of Investigation
FDA – Food and Drug Administration
FEMA – Federal Emergency Management Agency
FIOP – Federal Interagency Operational Plan
FRMAC – Federal Radiological Monitoring and Assessment Center
GFS – Global Forecasting System
HHS – Department of Health and Human Services
HHS ASPR – Department of Health and Human Service, Office of the Assistant Secretary for Preparedness and Response
HIFLD – Homeland Infrastructure Foundation-Level Data
HPAC – Hazard Prediction and Assessment Capability
HSIP – Homeland Security Infrastructure Program
HUD – Department of Housing and Urban Development
HYSPLIT – Hybrid Single-Particle Lagrangian Integrated Trajectory
HZ – Hot Zone
IMAAC – Interagency modeling and Atmospheric Center
IND – Improvised Nuclear Device
IPAWS – Integrated Public Alert and Warning System
I-WASTE – Incident Waste Decision Support Tool
LCMIS – Life Cycle Management of Information Systems
LDZ – Light Damage Zone
MDWG – Modeling and Data Working Group
MDZ – Moderate Damage Zone
NAM – North American Mesoscale Model

NARAC – National Atmospheric Release Advisory Center
NASA – National Aeronautics and Space Administration
NBI – National Bridge Inventory
NDRF – National Disaster Recovery Framework
NGA – National Geospatial-Intelligence Agency
NOAA – National Oceanic and Atmospheric Administration
NORTHCOM – US Northern Command
NRC – National Regulatory Commission
NRCC – National Response Coordination Center
NRF – National Response Framework
NSC – National Security Council
NUEVAC – NUclear EVacuation Analysis Code
NWS – National Weather Service
ODA – Office of Disaster Assistance Scalability Model
OSD – Office of the Secretary of Defence
OSTP – Office of Science and Technology Policy
PDA Data – Preliminary Damage Assessment Data
QPF – Quantitative Precipitation Forecast
RAMS – Radiological Assessment and Monitoring System
RESRAD – RESidual RADioactivity
RSF – Recovery Support Function
SBA – Small Business Administration
SCIPUFF – Second-order Closure Integrated Puff
SDZ – Severe Damage Zone
SHAMRC – Second-order Hydrodynamic Automatic Mesh Refinement Code
SHARC – Specialized Hazard Assessment Response Capability
SIMON – State Incident Management Operating Nexus
SNS – Strategic National Stockpile
SREMPTAPS – Source Region Electro-magnetic Pulse Targeting Applications
State – US Department of State
SUMMIT – Standard Unified Modeling, Mapping, and Integration Toolkit
USACE – US Army Corps of Engineers
USCG – US Coast Guard
USDA – US Department of Agriculture
USGS – US Geological Survey

Appendix 8: Data and models resource catalog

The IND resource inventory is electronically attached as an Excel file.