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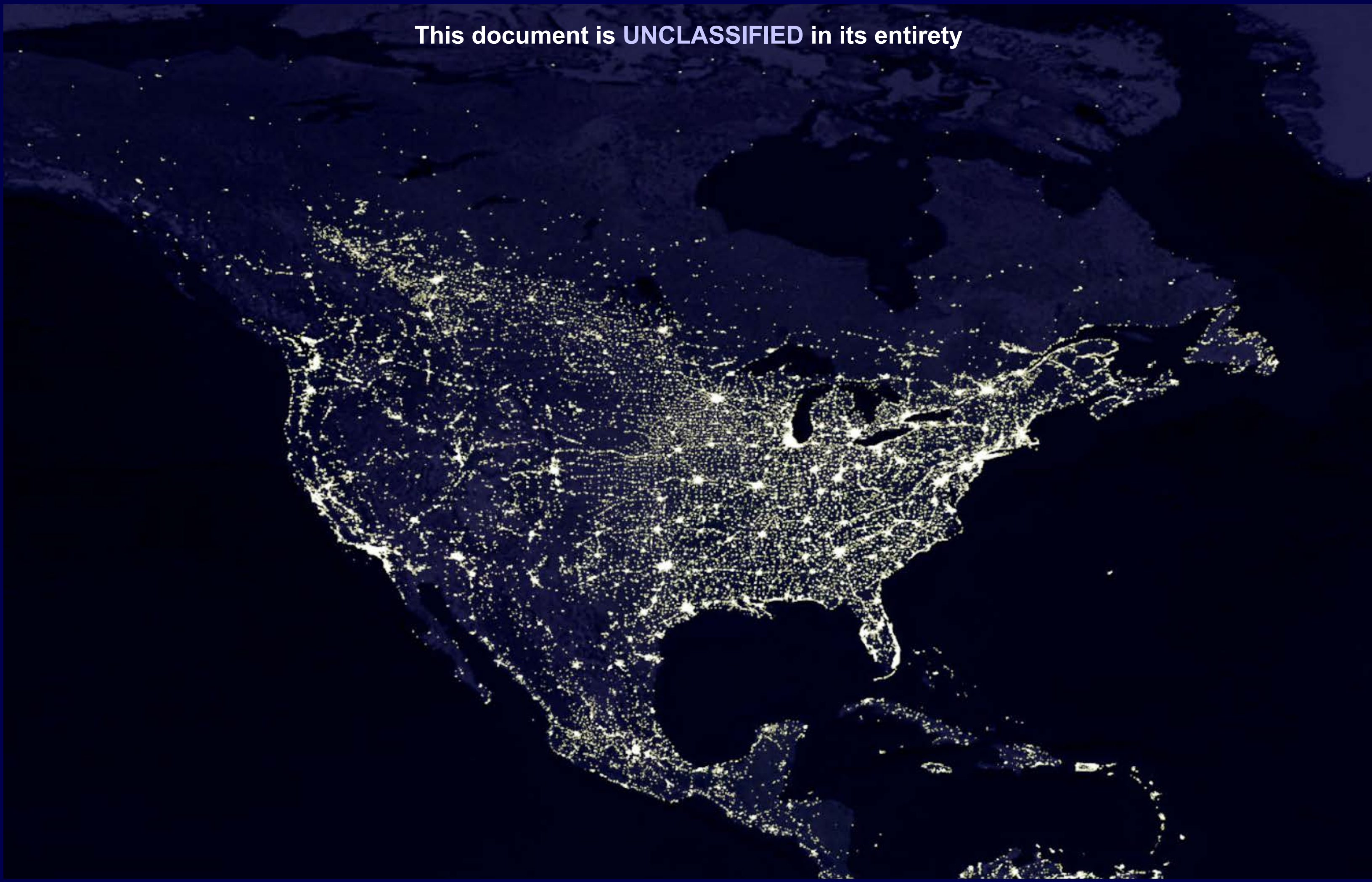

Strategic National Risk Assessment 2011

Unclassified Documentation of Findings

Findings September 2011
Documentation May 2015

Homeland Security

Errata/Changelist from PPD-8 Review Draft 28 January 2015

The draft SNRA 2011 Unclassified Documentation of Findings was circulated to the PPD-8 Implementation Team and other PPD-8 partners as supporting documentation for the SNRA 2011 public findings, which were the focus of the substantive revision work of the SNRA 2015 project. The period for substantive review of the 2011 findings by PPD-8 partners also served as the period for review of the 2011 Unclassified Documentation of Findings for factual accuracy, as historical documentation of the 2011 assessment, by 2011 project contributors. These factual corrections were incorporated into this final unclassified documentation of the 2011 SNRA. At the end of May 2015, this document comprises part of the full documentation of the 2015 SNRA which informed the 2015 revision of the National Preparedness Goal. A single SNRA technical report integrating the substantive updates and revisions of the 2015 SNRA project with the unchanged 2011 material is in preparation.

Original	Current	Errata/Corrigenda
10, 15	242, 247	Added: Classified findings regarding the adversarial events, and more significantly the comparative findings for the set of SNRA national-level events as a whole, are not provided in the following pages. For these findings, please see the full (classified) SNRA Technical Report. Footnote: All frequency estimates for the adversarial events and fatality, injury/illness, economic, and top level (low/best/high) psychological distress estimates for the chemical/biological/radiological/nuclear (CBRN) events are classified at the SECRET or SECRET//NOFORN level. Top level (low/best/high) estimates for the fatality, injury/illness, economic, and psychological distress metrics for the Aircraft as a Weapon, Armed Assault, and Explosives Terrorism Attack events are unclassified, but are For Official Use Only. All other data, including all social displacement and environmental consequence estimates, are unclassified without caveats.
12	244	Table 1 (Comparative Risk in the SNRA): Changed to logarithmic shading. Linear shaded version moved to new Appendix N.
14, 96, 103	246, 328, 335	For each mention of S&T Human Factors Division (psychological distress, social displacement discussions), footnote: DHS/S&T Resilient Systems Division (RSD) is the current (2015) organizational successor to Human Factors Division.
24, 42	256, 274	Hong Kong flu case fatality rate corrected from 0.5% to 0.05%.
35	267	Environmental Risk, last paragraph: Duplicate mention of space weather removed.
48	280	Footnote 96 [old]/100 [new]: Typo corrected (author's name misspelled).
49, 183	281, 415	Replaced "A terrorist nuclear weapon would be expected to have a yield of less than 1 to several kilotons." with "Generally, when considering nuclear explosion scenarios perpetrated by terrorists, experts assume a low-yield nuclear device detonated at ground level, where low yield in this context ranges from factions of a kiloton (kT) to 10 kT."
49	281	Replaced "A terrorist nuclear attack could be carried out with…" with "A terrorist attack could be carried out with…"
49	281	Changed "The primary obstacle to a terrorist nuclear attack…"to "The primary obstacle to a terrorist IND attack…"
50, 185	282, 417	Deleted "radiological dust" from "heat, debris, radiological dust, and force"
67	299	"…with comparatively little uncertainty around that frequency" removed (last phrase, last bullet, after "1 in 100 years") as potentially misleading.
93	325	Flood, direct economic loss best estimate: Typo of 1,600 corrected to 16,000.
123	355	Added "were" in "these U//FOUO portions were provided…"
125, 127, 131, 134, 137, 143, 145, 148, 150, 152, 159, 162	357, 359, 363, 366, 369, 375, 377, 380, 382, 384, 391, 394	Data Summary, above data table for each event reporting high/best/low frequencies and consequences: In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.
126	358	Additional Relevant Information: Changed "We estimate", to "DHS Office of Health Affairs experts" and "we also use 0.1 in a given year as our best estimate" to "the SNRA project team selected 0.1 in a given year as the best estimate for this event."
135	367	Changed "decrease by 5% - equivalent to $735 billion... it represents a worst case scenario rather than a dominant risk scenario. A 1918-type pandemic is considered highly unlikely" to "decrease by 4.25% - equivalent to $625 billion… it represents a comparatively less likely worst case scenario." Changed CBO citation from unpublished December 2005 paper to published July 2006 paper.
138	369	Table 3 (Social Displacement) caption: Corrected TS Frances date from 2006 to 1998.
176	408	Assumptions, column 2, paragraph "Chemical agents can be disseminated in various modes…" moved to Event Background.
178-179	410-411	Deleted content from and references to U.S. Food and Drug Administration Center for Food Safety and Applied Nutrition (FDA CFSAN) (2003, October 7), Risk assessment for food terrorism and other food safety concerns [incorporated as unclassified replacement for original U//FOUO SNRA content, but reference is not currently available on FDA website – was made public by FDA but withdrawn].
180	412	Table 2 (Damage radius): "High Explosives Only" clarification added to "Explosive Capacity" header.
181	413	Bullet, overpressure damage: "HE" clarification added to blast lung injury sentence.
202	434	New Appendix N: Reproduces linear shaded version of Table 1 (Comparative Risk in the SNRA) (color gradient supports 'X' markings)
204	436	New Appendix O: Reproduces December 2011 public findings report reviewed by the PPD-8 Implementation Team for the 2015 SNRA update.

Unclassified Documentation of Findings

This document is an unclassified adaptation of the classified SNRA Technical Report, the primary written documentation of the 2011 Strategic National Risk Assessment (SNRA). Its purpose is to allow the unclassified content of the United States' first national risk assessment to be communicated and used outside of classified environments.[1]

The quantitative comparison of risk to the Nation from both adversarial threats and non-adversarial (natural and accidental) hazards was a central goal, and accomplishment, of the first SNRA. While the following document retains unclassified discussions of the methods used to obtain the data and findings for the adversarial events, their omission makes this document an incomplete picture of the full SNRA and the national risk picture which it describes. This absence must be kept in mind while reading the following pages.

The SNRA was executed by the DHS Office of Risk Management and Analysis (RMA) in calendar year 2011, in support of Presidential Policy Directive 8 (PPD-8). Its data and findings were reported to FEMA in September 2011 to inform the National Preparedness Goal.[2] The unclassified findings of the SNRA were reported to the public in December 2011.[3]

The following document provides the unclassified data, analysis, and models, and identifies the classified data and models, that were used to derive the publicly disseminated findings of the 2011 SNRA. It additionally describes the analytic judgments used in the selection and analysis of the SNRA data, including assumptions, defaults, and uncertainties; the rationale for these judgments; and the influence of these judgments, and other limitations, upon the findings.

The PPD-8 Program Executive Office (PEO), National Integration Center (NIC), FEMA, assumed project responsibility for the SNRA in March 2014. This adaptation of the SNRA Technical Report was prepared to communicate the data and analysis of the SNRA at an unclassified level so that it can be reviewed, used, and built upon by the whole community of its stakeholders.

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[1] The primary sources for this document are the classified SNRA Technical Report and event risk summary sheets, as circulated for interagency review in December 2011 and January 2012. Some minor additions and changes to the documentation made subsequent to the SNRA's transfer to the DHS Office of Policy in March 2012, where consistent with the 2011 findings reported to FEMA and the interagency, are also reflected in this document.

All classified information, material which may be classified by compilation, and Sensitive But Unclassified (SBU) content has been removed. Where possible, this content has been replaced with analogous but fully unclassified content. These substitutions include comparative analyses re-written to refer to non-adversarial events (natural and accidental hazards) only, and extended background discussions of individual adversarial events replaced with text from DHS and U.S. Government products written for public dissemination.

The complete technical documentation of the 2011 SNRA consists of this document; the July 2013 final draft of the classified SNRA Technical Report as delivered to FEMA; the technical documentation of the DHS/NPPD 2010 Risk Analysis Process for Informed Decision-making (RAPID) engine; and the classified technical reports, appendices, and annexes of the DHS/S&T 2011 Integrated CBRN Terrorism Risk Assessment (ITRA) and its component assessments.

[2] U.S. Department of Homeland Security (2011, September). National Preparedness Goal. Federal Emergency Management Agency (FEMA): at http://www.fema.gov/media-library/assets/documents/25959. Presidential Policy Directive 8 is reproduced in Appendix P.

[3] U.S. Department of Homeland Security (2011, December). The Strategic National Risk Assessment in Support of PPD 8: A Comprehensive Risk-Based Approach toward a Secure and Resilient Nation (public summary). At http://www.dhs.gov/xlibrary/assets/rma-strategic-national-risk-assessment-ppd8.pdf.

Strategic National Risk Assessment 2011
Introduction to the Technical Report

The SNRA was executed by the DHS National Protection and Programs Directorate (DHS/NPPD) Office of Risk Management and Analysis (RMA) in calendar year 2011.

The Strategic National Risk Assessment (SNRA) was coordinated by the Federal Emergency Management Agency (FEMA) Program Executive Office (PEO) on behalf of the Secretary of Homeland Security in support of Presidential Policy Directive/PPD-8. Representatives of the Director of National Intelligence and the Attorney General, as well as other members of the Federal interagency, supported this effort.

This report documents the technical approach and findings from the SNRA. The methodology, event-specific data and assumptions used to generate frequency, consequence and risk estimates have not yet undergone formal review. As such, all findings reported here should be considered provisional. The use of Federal interagency data sources or subject matter expertise should not be interpreted as reflecting formal concurrence from participating agencies.

It is important to note that the SNRA is a *strategic national* risk assessment. As such, it does not present a full view of the risk facing local communities. To fully support preparedness planning, it is necessary to both consider national and regional risks, many of which differ from region to region. The SNRA Technical Report is best used as one of many strategic-level inputs to planning and risk management activities.

Inquiries about PPD-8 should be directed to FEMA via email at PPD8-NationalPreparedness@fema.dhs.gov.

Cover image courtesy of the NASA's Visible Earth Project. Data and image by the NASA Goddard Space Flight Center and NOAA National Geophysical Data Center.

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EXECUTIVE SUMMARY

This report highlights unclassified findings from the Strategic National Risk Assessment (SNRA) and provides technical documentation of its data sources and methodology.

- The SNRA was executed in support of Presidential Policy Directive/PPD-8, which called for national preparedness to be based on core capabilities that support "strengthening the security and resilience of the United States through systematic preparation for the threats that pose the greatest risk to the security of the Nation, including acts of terrorism, cyber attacks, pandemics, and catastrophic natural disasters."
- Given PPD-8's emphasis on contingency events with defined beginning and endpoints (e.g. hurricanes, terrorist attacks), the SNRA does not explicitly assess persistent, steady-state risks such as border violations, illegal immigration, and drug trafficking, which are also important considerations for DHS and the homeland security enterprise.

Classified findings regarding the adversarial events, and more significantly the comparative findings for the set of SNRA national-level events as a whole, are not provided in the following pages. For these findings, please see the full (classified) SNRA Technical Report.[1]

Analytic Approach

The SNRA methodology is built on the estimation of frequencies and consequences of a set of national-level events with the potential to test the Nation's preparedness and responds specifically to the question: *With what frequency is it estimated that an event will occur and what are the consequences of an event if it does occur?* Annualized loss estimates, constructed by multiplying these estimates of frequency and consequence, are used as a measure of risk.

Key Findings

The assessment finds that a wide range of threats and hazards pose a significant risk to the Nation, affirming the need for an all-threats/hazards, capability-based approach to preparedness planning.

- Many events are estimated to have the potential to happen more than once every 10 years, meaning that it is likely that the Nation's preparedness will be tested in this decade.

Of the natural hazard and accidental events, as shown in Table 1 below, two national-level events in the SNRA stand out for their generally high risk profiles across many consequence categories: *pandemic influenza outbreaks* and *hurricanes*.

- Human pandemic influenza is assessed to dominate the fatality and injury/illness risk of all the non-adversarial events in the SNRA. *The pandemic influenza scenario assessed in the SNRA has more fatality risk and injury/illness risk, at the best estimate, than every other measured natural-hazard or accidental event in the SNRA combined.*

There is a substantial amount of uncertainty concerning the likelihood, and in some cases the consequences, of the threats and hazards examined in the SNRA.

[1] All frequency estimates for the adversarial events and fatality, injury/illness, economic, and top level (low/best/high) psychological distress estimates for the chemical/biological/radiological/nuclear (CBRN) events are classified at the SECRET or SECRET//NOFORN level. Top level (low/best/high) estimates for the fatality, injury/illness, economic, and psychological distress metrics for the Aircraft as a Weapon, Armed Assault, and Explosives Terrorism Attack events are unclassified, but are For Official Use Only. All other data, including all social displacement and environmental consequence estimates, are unclassified without caveats.

Critical areas for future study in the SNRA include the risk associated with cyber events (affecting both data and physical infrastructure) and a subset of natural hazards (including space weather, tsunami, and volcanoes). Data, modeling, and resource limitations prevented the risk of these events from being assessed quantitatively in the SNRA.

Impacts and Future Uses

The SNRA was executed in support of PPD-8 implementation and served as an integral part of the development of the 2011 National Preparedness Goal, assisting in integrating and coordinating identification of the core capabilities and establishing a risk-informed foundation for the National Preparedness System.

The SNRA provides an understanding of the risks that pose the greatest challenge to the Nation's security and resilience. This understanding is crucial for preparedness planning and prioritization. It enables:

- A shared understanding of the potential incidents for which communities should prepare
- A prioritization of the incidents that may pose the greatest negative impact to communities and thus require preparedness
- The evaluation of needed capabilities, and capability levels across all five focus areas: Prevention, Protection, Mitigation, Response, and Recovery.

The results of the SNRA can also assist with a wide range of efforts which are crucial to execute the Preparedness Cycle in support of the National Preparedness System, including planning, organizing and equipping, training, exercises, and evaluation.

Although the development of the SNRA is an important first step, further analysis through the conduct of regional- and community-level risk assessments will help communities better understand their risks and form a foundation for their own security and resilience. In conjunction with Federal, state, and local partners, the SNRA will continue to be expanded and enhanced, and will ultimately serve as a unifying national risk profile to facilitate preparedness efforts.

Table 1: Comparative Risk in the SNRA - Natural Hazard and Accidental Events

National-Level Event	Best Estimate Risk: Fatality	Injury/Illness	Direct Economic	Social Displacement	Psychological Distress	Environmental
Animal Disease			X			
Earthquake			X			
Flood			X	X		X
Human Pandemic Outbreak	X	X	X		X	
Hurricane			X	X	X	X
Wildfire			X	X		
Biological Food Contamination						
Chemical Substance Spill or Release						X
Dam Failure						
Radiological Substance Release						
Insufficient quantitative data to support comparisons to other events						
Space Weather						
Tsunami						
Volcanic Eruption						
Cyber Event affecting Data						
Cyber Event affecting Physical Infrastructure						
Risk estimates are classified						
Aircraft as a Weapon	See classified SNRA results					
Armed Assault						
Biological Terrorism Attack (non-food)						
Chemical/Biological Food Contamination Terrorism Attack						
Chemical Terrorism Attack (non-food)						
Explosives Terrorism Attack						
Nuclear Terrorism Attack						
Radiological Terrorism Attack						

How to read this table:

Best estimate risk is assessed to fall within or bound the top order of magnitude of fatality, injury/illness, direct economic, social displacement, or psychological distress risk or the highest risk bin (Figure 8) of best estimate environmental risk among the natural and accidental hazard events in the SNRA. The relative magnitude (on a logarithmic scale) of the quantitatively based best estimate risks is indicated by background coloring in each cell. [2]

Insufficient quantitative risk data to support comparisons with other events.

In this approach, the relative risk on each consequence axis is considered in isolation, rather than combined. Relative weightings between different consequence measures are subjective value judgments that may vary by decision context and decision maker.

The best estimate of risk for each SNRA event is used to identify highest-magnitude risks. However, there is considerable uncertainty, varying data quality, and substantial overlap in the risk estimates of the SNRA events, making it difficult to generate a rank-ordered list of events based solely on the SNRA risk results.

[2] The distinction between risk levels for cells with or without 'X' marks may be more clear by reference to the version of this table presented in Appendix N, which shades cells by a linear rather than a logarithmic scale.

Table 2: National-Level Events Assessed in the SNRA

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
Natural	Animal Disease Outbreak	An unintentional introduction of the foot-and-mouth disease virus into the domestic livestock population in a U.S. state
	Earthquake	An earthquake occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Flood	A flood occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Human Pandemic Outbreak	A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace
	Hurricane	A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million
	Space Weather	The sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure
	Tsunami	A tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the U.S.
	Volcanic Eruption	A volcano in the Pacific Northwest erupts impacting the surrounding areas with lava flows and ash and areas east with smoke and ash
	Wildfire	A wildfire occurs within the U.S. resulting in direct economic losses greater than $100 Million
Technological/ Accidental	Biological Food Contamination	Accidental conditions where introduction of a biological agent (e.g., *Salmonella*, *E. coli*, botulinum toxin) into the food supply results in 100 hospitalizations or greater and a multi-state response
	Chemical Substance Spill or Release	Accidental conditions where a release of a large volume of a chemical acutely toxic to human beings (a toxic inhalation hazard, or TIH) from a chemical plant, storage facility, or transportation mode results in either one or more offsite fatalities, or one or more fatalities (either on- or offsite) with offsite evacuations/shelter-in-place
	Dam Failure	Accidental conditions where dam failure and inundation results in one fatality or greater
	Radiological Substance Release	Accidental conditions where reactor core damage causes release of radiation
Adversarial/ Human-Caused	Aircraft as a Weapon	A hostile non-state actor(s) crashes a commercial or general aviation aircraft into a physical target within the U.S.
	Armed Assault	A hostile non-state actor(s) uses assault tactics to conduct strikes on vulnerable target(s) within the U.S. resulting in at least one fatality or injury
	Biological Terrorism Attack (non-food)	A hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target, directed at a concentration of people within the U.S.
	Chemical/Biological Food Contamination Terrorism Attack	A hostile non-state actor(s) acquires, weaponizes, and disperses a biological or chemical agent into food supplies within the U.S. supply chain
	Chemical Terrorism Attack (non-food)	A hostile non-state actor(s) acquires, weaponizes, and releases a chemical agent against an outdoor, indoor, or water target, directed at a concentration of people using an aerosol, ingestion, or dermal route of exposure
	Cyber Event affecting Data	A cyber event which seriously compromises the integrity or availability of data (the information contained in a computer system) or data processes resulting in economic losses of $1 Billion or greater
	Cyber Event affecting Physical Infrastructure	A cyber event in which cyber means are used as a vector to achieve effects which are "beyond the computer" (i.e., kinetic or other effects) resulting in one fatality or greater or economic losses of $100 Million or greater
	Explosives Terrorism Attack	A hostile non-state actor(s) deploys a man-portable improvised explosive device (IED), Vehicle-borne IED, or Vessel IED in the U.S. against a concentration of people, and/or structures such as critical commercial or government facilities, transportation targets, or critical infrastructure sites, etc., resulting in at least one fatality or injury
	Nuclear Terrorism Attack	A hostile non-state actor(s) acquires an improvised nuclear weapon through manufacture from fissile material, purchase, or theft and detonates it within a major U.S. population center
	Radiological Terrorism Attack	A hostile non-state actor(s) acquires radiological materials and disperses them through explosive or other means (e.g., a radiological dispersal device or RDD) or creates a radiation exposure device (RED)

Table 3: SNRA Data Sources

National-Level Event	Frequency	Fatalities	Injuries/Illnesses	Direct Economic Loss
Animal Disease	USDA Economic Research Service modeling & DHS/OHA and DHS/S&T subject matter expertise			
Hurricane	Historic data compiled from NOAA, the Center for Science and Technology Policy Research at University of Colorado-Boulder & FEMA HAZUS modeling			
Earthquake	Historic data compiled from the Center for Science and Technology Policy Research at University of Colorado-Boulder & FEMA HAZUS modeling			
Flood	Historic data compiled from NOAA National Climactic Data Center (NCDC) and FEMA HAZUS modeling			
Human Pandemic Outbreak	CDC analysis of historic record	CDC modeling		
Space Weather	SNRA Project Team analysis of NOAA data and Oak Ridge National Laboratories assessments			
Tsunami	USGS analysis	USGS & FEMA HAZUS modeling		
Volcanic Eruption	USGS analysis	USGS & FEMA HAZUS modeling		
Wildfire	Historic data compiled from Spatial Hazard Events and Losses Database for the United States (SHELDUS) – University of South Carolina			
Biological Food Contamination	CDC Foodborne Outbreak Online Database (FOOD) and FDA / USDA subject matter expertise			Open source historic examples
Chemical Substance Spill or Release	DOT Pipeline & Hazardous Materials Safety Administration (PHMSA) and EPA Risk Management Program (RMP) incident databases			
Dam Failure	Historic data, U.S. Bureau of Reclamation modeling, & USACE National Inventory of Dams			Open source historic examples
Radiological Substance Release	U.S. Nuclear Regulatory Commission license renewal applications			
CBRN Terrorism Attacks	DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)			
Armed Assault	SNRA IC Elicitation (NCTC, DHS/I&A, FBI)	START Global Terrorism Database		SNRA Project Team modeling using ITRA/RAPID approach
Aircraft-as-a-Weapon	DHS/RMA 2010 Risk Assessment Process for Informed Decision-Making (RAPID)	Open source historic data (Planes hitting buildings or crowds)		SNRA Project Team modeling using ITRA/RAPID approach
Explosives Terrorism Attack	DHS/RMA 2010 RAPID	START Global Terrorism Database		SNRA Project Team modeling using ITRA/RAPID approach
Cyber Events (affecting Infrastructure & Data)	SNRA IC Elicitation (ODNI, CIA, FBI, NSA, NSS, DHS/NPPD/CS&C)	Open source historic examples and NCICC data		

Consequence Type	Data Sources and Subject Matter Expertise
Social Displacement	• University of Maryland, National Consortium for the Study of Terrorism & Responses to Terrorism (START) • Institute for Alternative Futures • University of Pittsburgh Medical Center, Center for Biosecurity
Psychological Distress	• National Center for Disaster Mental Health Research • University of California-Irvine, Department of Psychology and Social Behavior • Carnegie Mellon University, Dept. of Social & Decision Sciences, Dept. of Engineering & Public Policy • University of Maryland, START • DHS/S&T Human Factors Division[3]
Environmental Impacts	• Environmental Protection Agency

[3] DHS/S&T Resilient Systems Division (RSD) is the current (2015) organizational successor to Human Factors Division.

OVERVIEW

The Strategic National Risk Assessment (SNRA) was executed in support of Presidential Policy Directive 8 (PPD-8), which calls for creation of a National Preparedness Goal, a National Preparedness System, and a National Preparedness Report. Specifically, national preparedness is to be based on core capabilities that support "strengthening the security and resilience of the United States through systematic preparation for the threats that pose the greatest risk[4] to the security of the Nation, including acts of terrorism, cyber attacks, pandemics, and catastrophic natural disasters."

As part of the effort to develop the National Preparedness Goal and identify core capabilities, the Secretary of Homeland Security led an effort to conduct a strategic national risk assessment to help identify the types of incidents that pose the greatest threat to the Nation's homeland security. Representatives from the offices of the Director of National Intelligence and the Attorney General, as well as other members of the Federal interagency, supported this effort. The assessment was used:

- To identify high risk factors that supported development of the core capabilities and capability targets in the National Preparedness Goal;
- To support the development of collaborative thinking about strategic needs across prevention, protection, mitigation, response, and recovery requirements; and
- To promote the ability for all levels of Government to share common understanding and awareness of National threats and hazards and resulting risks so that they are ready to act and can do so independently but collaboratively.

The subsequent pages provide an overview of the findings and the analytic approach used to conduct the SNRA. It should be emphasized, however, that although the initial version of the SNRA is a significant step toward the establishment of a new homeland security risk baseline, it contains data limitations and assumptions that will require additional study, review, and revision as the National Preparedness System is developed. These limitations are discussed below, and future iterations of the assessment are expected to reflect an enhanced methodology and improved data sets.

Classified findings regarding the adversarial events, and more significantly the comparative findings for the set of SNRA national-level events as a whole, are not provided in the following pages. For these findings, please see the full (classified) SNRA Technical Report.[5]

[4] The DHS Lexicon defines risk as the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences. Available from http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf.

[5] All frequency estimates for the adversarial events and fatality, injury/illness, economic, and top level (low/best/high) psychological distress estimates for the chemical/biological/radiological/nuclear (CBRN) events are classified at the SECRET or SECRET//NOFORN level. Top level (low/best/high) estimates for the fatality, injury/illness, economic, and psychological distress metrics for the Aircraft as a Weapon, Armed Assault, and Explosives Terrorism Attack events are unclassified, but are For Official Use Only. All other data, including all social displacement and environmental consequence estimates, are unclassified without caveats.

STRATEGIC NATIONAL RISK ASSESSMENT SCOPE

To inform homeland security preparedness and resilience activities, the SNRA evaluated the risk from known threats and hazards that have the potential to significantly impact the Nation's homeland security. These threats and hazards were grouped into a series of national-level events with the potential to test the Nation's preparedness.

SNRA participants – including Federal agencies, DHS Components, and the intelligence community, among others – developed a list of national-level events (Table 2 above) for assessment in the initial SNRA. The events are grouped into three categories: 1) natural hazards; 2) technological/ accidental hazards; and 3) adversarial, human-caused threats/hazards.

For the purposes of the assessment, DHS analysts identified thresholds of consequence necessary to create a national-level event. These thresholds were informed by subject matter expertise and available data, and are shown in Table 2 of this report.

- For some events, economic consequences were used as thresholds, while for others, fatalities or injuries/illnesses were deemed more appropriate as the threshold to determine a national-level incident.
- In no case, however, were economic and casualty thresholds treated as equivalent to one another (i.e. dollar values were not assigned to fatalities).

Event descriptions in Table 2 that do not explicitly identify a threshold signify that no minimum consequence threshold was employed. This allows the assessment to include events for which the psychological impact of an event could cause it to become a national-level event even though it may result in a low number of casualties or a small economic loss.

Only events having both a distinct beginning and end and an explicit nexus to homeland security missions were included. This approach excluded:

- Persistent, steady-state risks such as border violations, illegal immigration, and drug trafficking which fall within the homeland security mission space, but which do not have a defined beginning and end point;
- Chronic societal concerns, which can represent a large fraction of fatality, economic, and other risks for an average American, such as cancer or car accidents, but which are generally not related to homeland security national preparedness;
- Political, economic, environmental, and societal trends that may contribute to a changing risk environment but are not explicitly homeland security national-level events (e.g. demographic shifts, economic trends). These trends will be important to include in future iterations of a national risk assessment, however.

The SNRA participants identified the 23 events listed in Table 2 as those with the potential to pose the greatest risk to the security of the Nation and formed the analytic basis of the SNRA. Table 2 is not a complete list of risks that exist and will be reconsidered in future iterations of the assessment. Additional threats and hazards, such as droughts, heat waves, winter storms, rain storms, and different types of technological/accidental or human-caused hazards, can also pose a risk to jurisdictions across the country and should be considered, as appropriate, in preparedness planning. Non-influenza diseases with pandemic potential and other animal diseases should also be considered. In addition, assessment participants identified a number of events for possible inclusion in future iterations of the SNRA, including electric grid failure, plant disease outbreak, and transportation system failure.

Analytic Approach

> *Risk management is essential for homeland security leaders in prioritizing competing requirements and enabling comprehensive approaches to measure performance and detail progress.*
>
> *DHS Risk Management Fundamentals, 2011*

The SNRA methodology is built on the estimation of frequencies[6] and consequences[7] of national-level events, specifically, *With what frequency is it estimated that an event will occur and what are the consequences of an event if it does occur?* Annualized loss estimates, constructed by multiplying these estimates of frequency and consequence, are a straightforward measure of risk.[8] This annualized loss approach was chosen because it allowed a straightforward construction of risk for all events, even those for which minimal data existed.

Measures of Risk

Homeland security hazards are dissimilar in important ways. Some hazards, such as natural disasters, have a long historical record. Others, including terrorist attacks, have a limited or nonexistent historical record and are initiated by adaptive adversaries who have the ability to respond to our defensive posture. Still other hazards, such as technological accidents, may have been subject to multi-jurisdictional regulations aimed at risk reduction for many years, but are only recently being analyzed in the context of national preparedness. In addition, these disparate types of hazards often have varied and unexpected consequences on society and security when they do occur.

Different consequences can result from homeland security hazards, including health and safety, economic, environmental, and social impacts. Indeed, a recent National Research Council (NRC) Report[9] recommended that DHS risk assessments "should consider a full range of public health, safety, social, psychological, economic, political, and strategic outcomes." An assessment using only some of these consequences (e.g., solely those easy to quantify) would not reflect the full impact on the U.S. and resulting comparisons across hazards would be biased and less informative.

The SNRA examined the risks associated with six categories of harm: loss of life, injuries and illnesses, direct economic costs,[10] social displacement, psychological distress, and environmental impact. Each consequence, when combined with the frequency of the national-level event, produces a different type of risk, such as fatality risk, injury and illness risk, and direct economic risk. This multi-faceted view of potential consequences draws attention to the broad and often interdependent effects of incidents that require whole-of-community preparation and cooperation across the homeland security enterprise. For instance, community resilience relates to both mitigating human and economic consequences and addressing the psychological and social distress caused by the incident within the community. Similarly, other types of resilience involve

[6] Frequency is defined in the DHS Risk Lexicon, 2010 edition, as the "number of occurrences of an event per defined period of time or number of trials."

[7] Consequence is defined in the DHS Risk Lexicon, 2010 edition, as the "effect of an event, incident, or occurrence."

[8] Risk is defined in the DHS Risk Lexicon, 2010 edition, as the "potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and associated consequences."

[9] National Research Council (2010). *Review of the Department of Homeland Security's approach to risk analysis.* Washington, DC: National Academies Press.

[10] Direct economic losses were defined to include decontamination, disposal, and physical destruction costs, lost spending due to fatalities, medical costs, and business interruptions. Indirect and induced economic impacts, which are often larger than direct losses, are not included in this assessment due to time and resource constraints. Additional information regarding the limitations of the economic analysis in the SNRA is provided on the following pages and Appendix E.

withstanding environmental and infrastructure degradations to ensure essential services continue to be delivered.

The NRC's Review recommended against aggregating these consequences (and risks) into a single metric in a strategic assessment that includes both terrorism and natural disasters, given the current capabilities of risk science. In accordance with the NRC's recommendation, the methodology reports each type of risk separately, as many strategic decisions can be informed without aggregation. Instead, the assessment treated consequence categories differently and allows stakeholders in the National Preparedness System to apply their own expert judgments to the findings and the implications of those findings on core capability targets.

The SNRA relied on the best available quantitative estimates of frequency and consequences from existing Government models and assessments, peer-reviewed literature, and expert judgment. Where sufficient quantitative information was not available or additional research is warranted – such as data related to the frequency of high-consequence space weather incidents – events were assessed semi-quantitatively or qualitatively. The estimates of the frequency and consequences for each of the events was compared where appropriate.

The SNRA used the following approaches to estimate frequency and consequence:

Frequency

In order to apply a consistent methodology across all SNRA event types, frequency was selected as a metric for the likelihood of event occurrence. Frequency was estimated as the potential number of successful attacks (for adversarial/human-caused events) or potential number of occurrences (for natural and technological hazards), per year. Adversarial/human-caused frequencies were estimated primarily using elicitation from subject matter experts.[11] Estimates of natural and technological hazard frequencies were drawn heavily from the historical record.

Frequency ranges included in the SNRA for adversarial/human-caused events are estimates of the frequency of successful attacks. Where subject matter expert judgment was used to determine frequency of successful attacks, adversary intent and capability were considered implicitly by the experts, but were not explicitly quantified or characterized. Attack initiations may occur with higher frequency than the ranges provided.

Fatalities

For events that have occurred in the past, the expected number of fatalities was estimated primarily from the historical record. For events that have never occurred (primarily in terrorism), consequences were estimated using data from previous government risk assessments, which rely on models and simulations.

[11] Subject matter expert (SME) elicitation was a component of modeling frequency in two of the prior assessments leveraged for the SNRA: the 2011 ITRA conducted by DHS/S&T (chemical, biological, radiological, and nuclear terrorism attacks) and the 2010 Risk Assessment Process for Informed Decision-making (RAPID) conducted by DHS/Office of Risk Management & Analysis (aircraft as a weapon, explosives terrorism attack). Separate SME elicitations were conducted for the SNRA with representatives from the Intelligence Community in July 2011 for the armed assault and cyber events. In all cases, the outputs from these models/elicitations were converted to equivalent units of successful events per year for comparison to the frequencies of natural and technological hazards drawn from the historical record.

SME estimation of the frequency of rare, adversarial/human-caused events is challenging, and SME frequency judgments in the SNRA reflect significant uncertainty. As with all data in the SNRA, these SME frequency judgments should be interpreted as order of magnitude estimates for the purposes of comparison.

Injuries and Illnesses

Injuries and illnesses were estimated similarly to fatalities. However, this category mixed permanent debilitating injuries (such as those resulting from chemical accidents) with temporary illnesses (such as those resulting from pandemic influenza). Therefore, the injury and illness consequences should be considered in context with the types of injuries and illnesses likely to result from each hazard.

Direct Economic Loss

Direct economic losses were estimated similarly to fatalities. Direct economic losses were defined to include decontamination, disposal, and physical destruction costs, lost spending due to fatalities, medical costs, and business interruptions. Due to constraints on the time available to execute the SNRA and the community's lack of a broadly agreed upon method for calculating indirect and induced economic impacts, these impacts, which are often larger than direct losses, are not included in this assessment.

- Indirect economic impacts include costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs. Induced costs include those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries.
- Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Attempts were made to assess direct economic losses as comparably as possible across the range of event types in the SNRA; however, data availability made this challenging.

- For example, direct economic losses from certain natural hazards (including wildfires and floods) primarily reflect property and crop losses only, as business interruption estimates were not available. However, property/crop losses were judged to be the dominant component of the direct economic impacts for these events and therefore to be representative of the direct losses, within the precision of the SNRA.
- Further, some sources of direct economic impact data for the SNRA, such as DHS/S&T's 2011 Integrated CBRN Terrorism Risk Assessment (ITRA), include some types of substitution effects and other offsetting activity in their reported estimates of the net direct economic impacts from chemical, biological, radiological, and nuclear terrorism attacks. Such substitution effects would be expected to reduce the reported estimates for events for which they represented a significant contribution in the calculation of direct economic loss relative to events for which they did not.

The comparability of economic consequence estimates in the SNRA is an important area for future study.

Social Displacement

The number of people forced to leave their home for a period of two days or longer was used as a measure of social displacement. Estimates of displacement were obtained from open source social science literature and emergency management databases for historical events and from relevant models for events with limited historic precedence. The measure of social displacement used in the

SNRA does not capture the significant differences between short-term evacuation and long-term permanent relocation, which is a limitation of the current analysis.

Psychological Distress

Experts in the psychosocial impacts of disasters consulted for the SNRA recommended that *significant and/or prolonged psychological distress* caused by national-level events would be the most meaningful psychological metric for strategic capabilities planning and national preparedness. These experts recommended a methodology to assess significant distress which reflected empirical findings indicating that the psychological consequences of a disaster may follow from the other types of consequences being assessed in the SNRA. Specifically, the experts recommended a consequence index[12] which was a function of the SNRA estimates for deaths, injuries, and displacement related to each national-level event. This approach represents the first attempt to include psychological consequences in a DHS strategic, national-level risk assessment. Additional analysis is required to verify and validate the approach used, and experts consulted about psychological consequences emphasized caution in the application of the SNRA's measure of psychological distress and the need for additional research.[13]

Environmental Impact

For the purposes of the SNRA, environmental risk was defined as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.[14] Environmental effects within urban areas and all human health effects were not included within the scope of this environmental risk assessment, because these impacts were already addressed separately in the other consequence analyses for the SNRA. An *ad hoc* group of experts from the Environmental Protection Agency (EPA) judged the relative environmental impact of each national-level event by selecting one of four categories of severity: *de minimus* (or minimal), low, moderate, and high. In doing so, the experts considered the areal extent of the impact, the potential for adverse consequences, and the severity of adverse consequences.[15]

Documentation

All sources and estimates were documented to promote credibility, defensibility, and transparency within the assessment. Additional information on data sources and methods for frequency and consequences is available in the appendices to this report.

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[12] The consequence index used in the SNRA for psychological distress is analogous to a risk index, an approach which allows multiple factors which affect the level of risk to be incorporated into a single numerical score for the level of risk. For more information, see: International Standards Organization (2009). *Risk management – risk assessment techniques* (ISO 31010).

[13] The Department of Homeland Security and its partner organizations leveraged previously funded social and behavioral science research to better understand how to anticipate, prepare for, counteract, and mitigate the effects of terrorist acts, natural disasters, and technological accidents. Additional research is required to further explore psychosocial factors that enable resilience and affect recovery in individuals, organizations, communities, and at the societal level.

[14] This definition is aligned with the EPA's definition of environmental risk. Source: U.S. Environmental Protection Agency (2012). Terminology Services. Retrieved from http://www.epa.gov/OCEPAterms/eterms.html.

[15] The resulting comments and rankings have not undergone review by the EPA and only represent the opinions of the group.

Interpretation of SNRA Results

The targeted precision of the SNRA is an order-of-magnitude. The results of an order-of-magnitude estimate are intended to be accurate only within a factor of 10, a level of precision which is often sufficient to inform strategic decisions. Scientists and engineers often use order-of-magnitude estimates to quickly develop an understanding of the main factors and relationships in a system before undertaking a more detailed study. This level of precision is particularly appropriate to strategic all-hazard risk assessments, since the frequencies and consequences of the hazards considered differ by many orders-of-magnitude. In many cases, available information regarding a particular hazard was more precise than an order of magnitude, and this higher-fidelity information was retained in the SNRA.

Uncertainty in frequency and consequences was explicitly included in the analysis by representing low and high bounds in addition to the best estimates. Examples of sources of uncertainty include incomplete knowledge of adversary capabilities and intent, uncertainty in the effectiveness of countermeasures, variability in possible event severity and location, or lack of historical precedence.

The SNRA captures uncertainty in various ways, depending on the data source. For frequencies derived from the historical record, upper and lower bounds are estimated using the historic maximum number of occurrences per year and the longest time gap between historic occurrences. For frequencies derived from expert elicitation, the uncertainty is captured using structured techniques to determine the 5th and 95th percentile confidence intervals. For consequences derived from the historical record, upper and lower bounds are estimated from past events. For consequences derived from previous terrorism risk assessments, 5th and 95th percentile confidence intervals were estimated which take into account terrorist capabilities and preferences in weapon and target selection.

Given the uncertainty inherent in assessing risks at a national level and the lack of information about some of the events included, the SNRA was designed to avoid false precision. Instead, the assessment identifies only those differences in risk that are still significant despite the associated uncertainties. If a strategic decision depends on a precise separation of hazards of similar risk, a more detailed assessment would be needed.

Participants designed the SNRA to capture the best information the Nation has about homeland security risks to support the development of the National Preparedness Goal, while recognizing the limitations of conducting such analysis in a shortened time frame.

Limitations in addition to the ones discussed above include:

- The SNRA is a *strategic* risk assessment. As such, it does not present a full view of the risk facing local communities. To fully support preparedness planning, it is necessary to both consider national and regional risks, many of which differ from region to region. Further, it is important to recognize that frequencies represent possible occurrences anywhere in the Nation and do not occur with equivalent frequency in any individual location.
- Only events having both a distinct beginning and end and an explicit nexus to homeland security missions were included. This approach excluded persistent, steady-state risks such as drug trafficking, cancer, or car accidents which can represent a larger fraction of risk for individuals and communities than many events considered in the SNRA.
- The comparisons of relative risk between hazard events in the following pages and charts do not include many risks which meet the above criteria and which could significantly challenge national preparedness. These include hazards not included in the first iteration of

the SNRA, such as ice storms and heat waves, and events included in the SNRA but which could not be treated quantitatively, such as cyber events and space weather.[16] As the SNRA is intended to be used as a comparative treatment of risks within its scope, these absences must be kept in mind while reading or using its charts and findings.

[16] Terrorist attacks treated by the SNRA but leveraging classified or For Official Use Only (FOUO) data are also omitted from quantitative comparisons in this unclassified companion document. The full SNRA documentation should be consulted for these adversarial risks, and their absence from the charts and comparisons of relative risk in the following pages should also be kept in mind.

FINDINGS

The results of the SNRA include a comparison of risks for potential incidents in terms of the likelihood (estimated as a frequency, i.e., number of events per year) and consequences of threats and hazards, as well as an analysis of the uncertainty associated with those incidents.

The assessment finds that a wide range of threats and hazards pose a significant risk to the Nation, affirming the need for an all threats/hazards, capability-based approach to preparedness planning. Many events are estimated to have the potential to happen more than once every 10 years, meaning that it is likely that the Nation's preparedness will be tested in this decade.

Key findings are discussed below. Note that all comparative statements in the following are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

High Risk Events

Of the non-adversarial events, the national-level events that are estimated to have generally high risk across many consequence categories in the SNRA are pandemic influenza outbreaks and hurricanes (see Table 1 above).

To identify these high risk events, the results for each type of risk (estimated as an annualized loss) were considered independently and not aggregated. Events which were estimated to have high risk in each consequence category, taking into account uncertainty and the quality of the underlying data, were identified. The events identified above are those which were identified as high risk across the majority of consequence types.

- Pandemic influenza is estimated to be the highest risk event of all the non-adversarial events in the SNRA for fatality, illness/injury, and psychological distress risk, and is near the top for direct economic risk. At the best estimate, it has more fatality and injury/illness risk than every other natural hazard or accident in the SNRA combined. It is estimated to have no social displacement risk and relatively low environmental risk (Figures 6, 8).
- Hurricanes are the highest direct economic risk, at the best estimate, and present the highest social displacement risks to the Nation of all the non-adversarial events included in the SNRA, coupled with relatively high psychological distress and environmental risks. Though not amongst the largest fatality and injury/illness risks within this set, hurricanes do carry some risk in these dimensions.

When considering the high risk events listed above, it is important to consider that many hazards have the potential to be catastrophic, and many additional natural and accidental hazard national-level events in the SNRA pose significant risk to the Nation.

It is also important to note that this identification process considered each type of risk equally (i.e., fatality and economic risks are equally important to flagging events as "high risk" in this process); however, decision-makers may weigh each type of risk differently, depending on their risk tolerances and the decision context. Further, risk is not the only consideration for capability development and prioritization, and events identified here as high risk are not necessarily those for which the risks are most easily or inexpensively mitigated; additional information about the cost of preparedness capabilities and their effectiveness at reducing risk is necessary for making resource allocation prioritization decisions.

Additional findings specific to each risk type are discussed below. Supplementary information about the data sources and methods used to estimate frequencies and consequences is provided in the appendices to this report.

Human Pandemic Influenza Outbreaks Present Risk to the U.S.

The most salient finding identified within the SNRA is the dominance of the fatality risk and injury/illness risk associated with a human pandemic influenza outbreak, when compared with every other natural hazard and accidental event not only individually, but also in sum. *The pandemic influenza outbreak event considered in the SNRA has more fatality risk and injury/illness risk, at the best estimate, than every other measured natural or unintentional hazard event in the SNRA combined.*

- The SNRA considers a pandemic influenza outbreak with a 25 percent gross clinical attack rate[20] and similar case fatality rate to the 1968-1969 Hong Kong flu pandemic. A pandemic of this type is expected to occur once every 10 to 60 years and cause hundreds of thousands of fatalities. For comparison, deaths in the United States from annual seasonal influenza are on the order of 40,000 each year.

The pandemic influenza scenario and data sources were determined in collaboration with the Centers for Disease Control and Prevention (CDC). The pandemic scenario selected for the SNRA is moderate relative to the characteristics of recent influenza pandemics. For example, the three major influenza pandemics of the 20th century (1918, 1957, and 1968) had gross clinical attack rates (adjusted to current population) of 24% to 34% of the population; therefore, the 25% attack rate assumed for the SNRA scenario is conservative. Further, the 1968-1969 Hong Kong flu pandemic had a relatively low case fatality rate of less than 0.05%, in contrast to the 1918 Spanish influenza which had a much higher case fatality rate of between 2.5% and 10%.[21]

Figure 1 illustrates the relative amount of fatality risk and illness/injury risk, at the best estimate, associated with the SNRA human pandemic influenza outbreak event relative to other natural hazard and accident events in the SNRA. The area of the shapes in the figure represents the relative amount of risk.

[20] The gross clinical attack rate is the fraction of a population that becomes clinically ill from influenza during the pandemic.

[21] For reference sources and additional discussion, refer to the Pandemic Influenza Outbreak section on p.40.

Figure 1: Dominance of Human Pandemic Influenza Outbreak Over All Other Natural and Accidental Hazards – Fatality Risk and Injury/Illness Risk

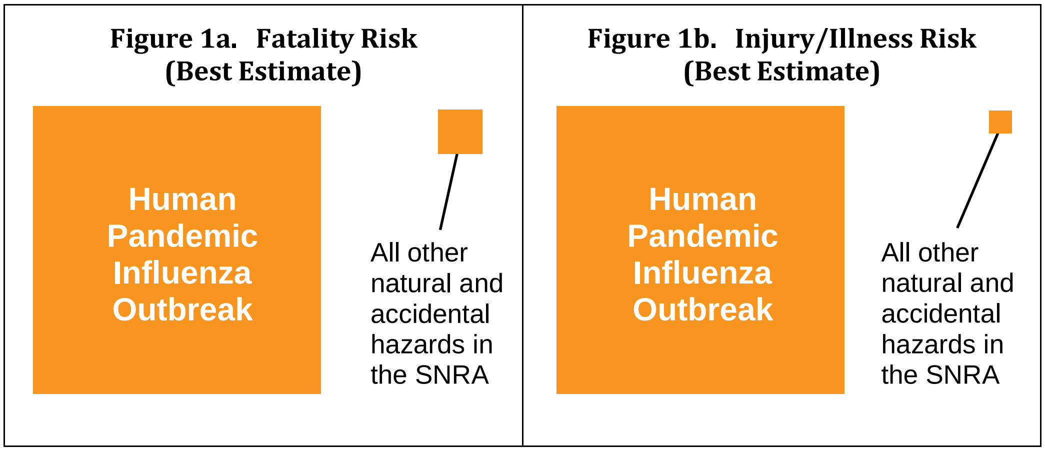
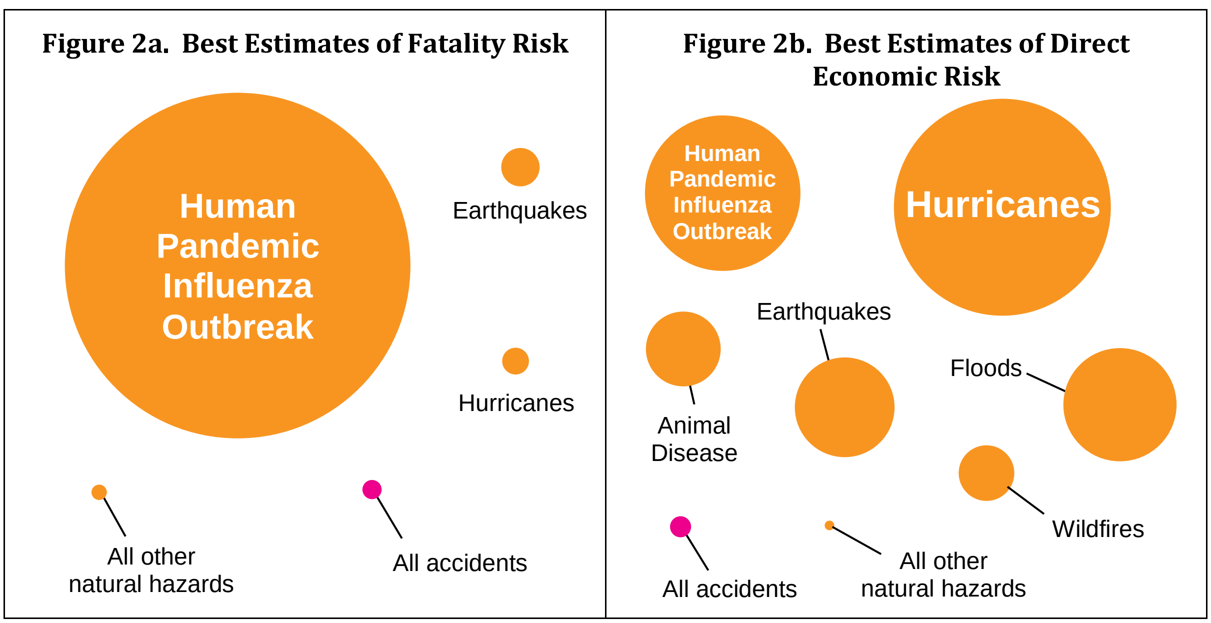


Figure 2 depicts the best estimates of the fatality and direct economic risk for the SNRA's quantitatively assessed natural hazards and accidents, as measured by the product of the best estimates of frequency and fatalities given occurrence (Figure 2a, fatality risk) or the product of the best estimates of frequency and direct economic impacts given occurrence (Figure 2b, direct economic risk). Although it is not the one largest or dominant contributor to direct economic risk among national-level events as it is for human fatality and illness/injury risk, the pandemic influenza outbreak scenario ranks with the most catastrophic natural disaster events assessed in the SNRA.

Figure 2: Best Estimates of Risk in the SNRA Natural-Hazard and Accidental Events



When interpreting Figure 2, it is important to remember that there is significant uncertainty in the frequencies and consequences associated with many events assessed in the SNRA.

Significant Risks May Be Masked By Limited Data

In the course of conducting the SNRA, a number of events were not assessed because of limited quantitative data availability. The SNRA is therefore unable to comment on the relative risk associated with these events, some of which are qualitatively believed to have potential for significant impact. These events include cyber events, space weather, tsunamis, and volcanic eruptions. For each of these identified risks, specific questions have been identified which require further study: these are presented in Table 4.

Table 4: Summary of Outstanding Research Questions

Event	Existing Models and Data	Outstanding Research Questions
Cyber Event affecting Data	Estimated frequency of large-scale events; probable targets	Impacts of large-scale cyber events; Cascading effects in broader network
Cyber Event affecting Physical Infrastructure	Estimated frequency of large-scale events; probable targets	Impacts of large-scale cyber events
Space Weather	Frequency of coronal mass ejections (CMEs) from the Sun	Impacts of a severe space weather event to technology, particularly the sustained impacts to the electric power grid and transformer equipment
Tsunami	Physics-based impact models for specific locations and wave height	Probabilistic modeling of the frequency and severity of tsunami impacts on a national scale
Volcanic Eruption	Physics-based impact models for specific locations and severity of eruption	Probabilistic modeling of the frequency and severity of volcanic impacts on a national scale

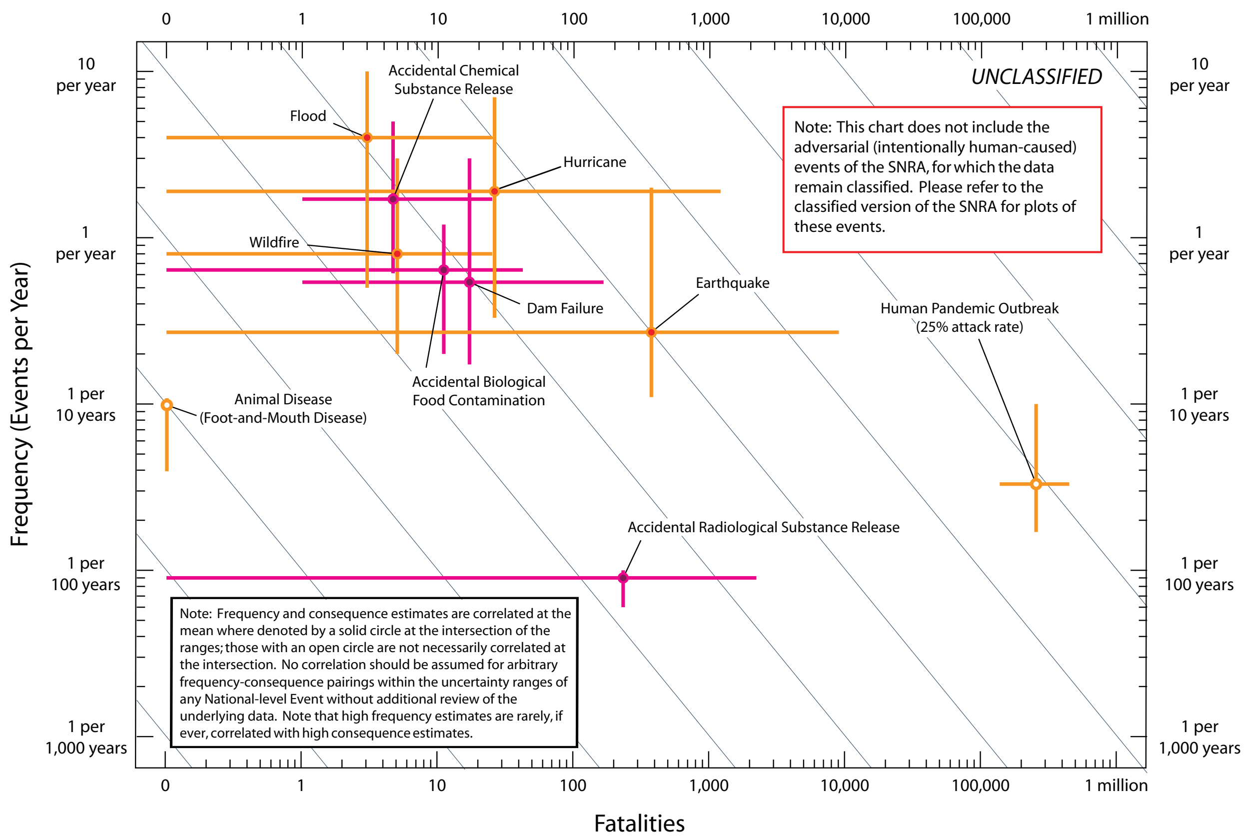
Of the events listed in Table 4, cyber events are the most challenging to consider in the current SNRA framework which focuses on high-impact events with defined beginning and endpoints. It is clear that while a cyber event could result in high-impact and widespread consequences with cascading effects, cyber risks are most prominently persistent threats which require significant focus on an ongoing basis. Cyberspace has become inseparable from our daily lives. And while this increased connectivity has led to remarkable transformations and global advances across society, the corollary of this openness and connectivity is that it has also increased the complexity of the risks we face as a nation. Future efforts to expand the SNRA to include cyber events will pay particular attention to the overall national impact of both high-frequency, low-consequence cyber events and lower-frequency, higher-consequence events.

Fatality Risk

Fatality risk was estimated for each national-level event by multiplying the best estimate of the frequency by the best estimate of the resulting fatalities given occurrence. Figure 3 presents a visual depiction of fatality risk across the SNRA-assessed accidental and natural hazard events.

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Figure 3: Fatality Risk



Legend:
Natural Hazards
Technological Hazards

Events Not Displayed:
- Space Weather
- Tsunami
- Volcanic Eruption
- Adversarial Events

As discussed above, the pandemic influenza outbreak event considered in the SNRA has greater fatality risk, at the best estimate, than every other measured natural or technological hazard in the SNRA combined.

- The SNRA considers a pandemic influenza outbreak with a 25 percent gross clinical attack rate[22] and similar case fatality rate to the 1968-1969 Hong Kong flu pandemic. A pandemic of this type is expected to occur once every 10 to 60 years and cause hundreds of thousands of fatalities. For comparison, deaths in the United States from annual seasonal flu are on the order of 40,000 each year.

Compared with hazards such as hurricanes or floods, pandemic influenza is a higher consequence, lower likelihood event. In other words, pandemic influenza is driven to be a high fatality risk by its significant expected consequences given occurrence, rather than its frequency.

At the best estimate, earthquakes and hurricanes are estimated to pose less fatality risk than a pandemic influenza outbreak by a factor of a hundred or more, but may nonetheless pose relatively high risk when uncertainty is taken into account.

22 The gross clinical attack rate is the fraction of a population that becomes clinically ill from influenza during the pandemic.

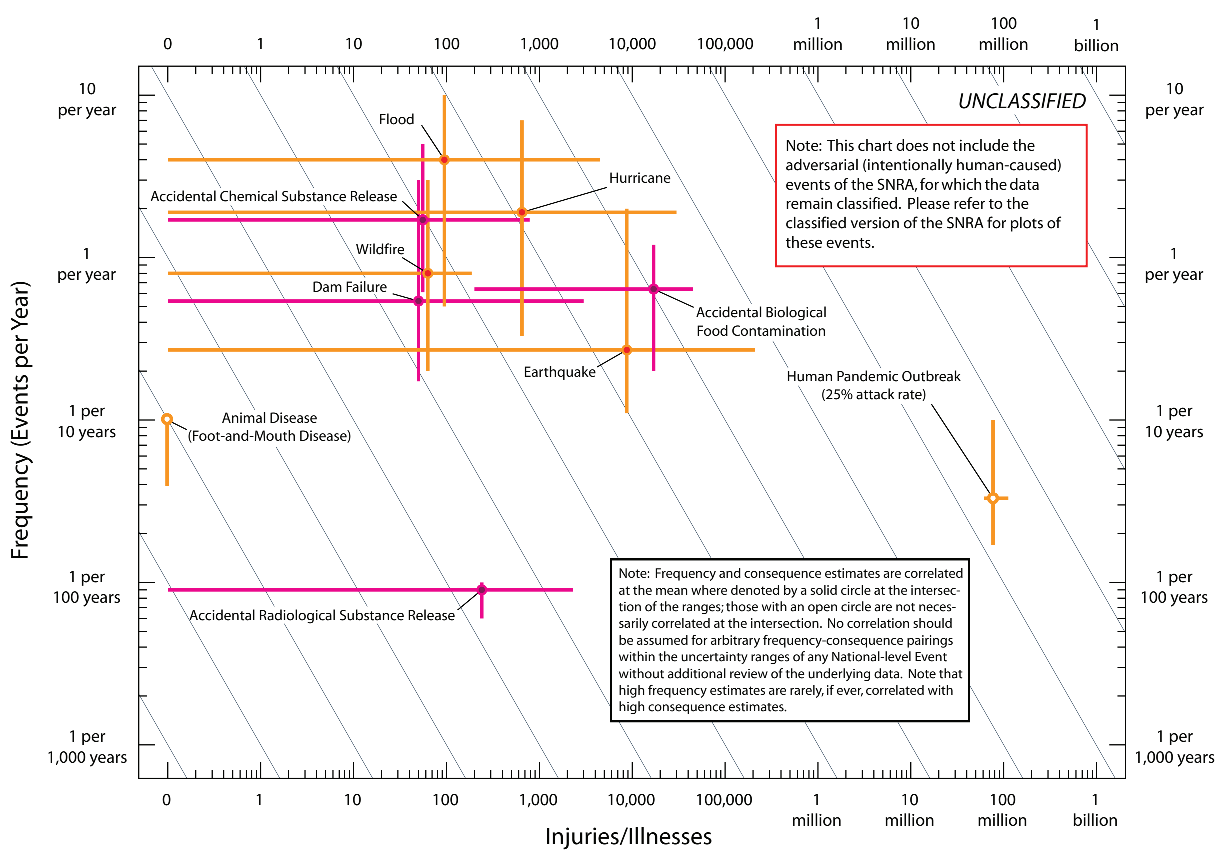
By comparison with pandemic influenza and every other natural and technological hazard quantitatively assessed by the SNRA, foot-and-mouth disease has considerably less fatality risk than other types of events in the SNRA. Although an outbreak of foot-and-mouth disease in the United States has the potential to have considerable impact on livestock and the agricultural economy, it poses little health risk to humans.

Insufficient data about the fatality risk associated with cyber events, space weather, tsunamis, and volcanoes was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 3.

Injury/Illness Risk

Injury/illness risk was estimated for each national-level event by multiplying the best estimate of the frequency by the best estimate of the resulting injuries/illnesses given occurrence. Figure 4 presents a visual depiction of injury/illness risk across SNRA-assessed events.

Figure 4: Injury/Illness Risk



Legend:
Natural Hazards
Technological Hazards

Events Not Displayed:
- Space Weather
- Tsunami
- Volcanic Eruption
- Adversarial Events

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

A pandemic influenza outbreak with a 25 percent gross clinical attack rate and similar case fatality rate to the 1968-1969 Hong Kong flu pandemic has vastly more injury and illness risk, at the best estimate, than every other measured natural or technological hazard in the SNRA combined (see Figure 4). However, pandemic influenza illnesses are different than most of the other injuries and illnesses in the SNRA, in that most victims who become ill but do not die are likely to recover fully and have no lasting physical impact on their lives.

After pandemic influenza, there are several events that cluster together with a factor of 100 to 1,000 times smaller injury/illness risk than pandemic, but which also are estimated to pose significant illness/injury risk relative to other non-adversarial events in the SNRA, at the best estimate. These events include accidental biological food contamination, earthquakes, and hurricanes. In contrast to pandemic influenza, those injured or struck ill by many of the events listed here may face chronic health problems for years after the initial event.

Floods are estimated to pose less illness/injury risk, at the best estimate, than the events listed above, but may pose relatively high risk when uncertainty is taken into account.

Foot-and-mouth disease poses little to no health risk to humans.

Insufficient data about the injury/illness risk associated with cyber events, space weather, tsunamis, and volcanoes was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 4.

Direct Economic Risk

Direct economic risk was estimated for each national-level event by multiplying the best estimate of the frequency times the best estimate of the resulting direct economic losses given occurrence.

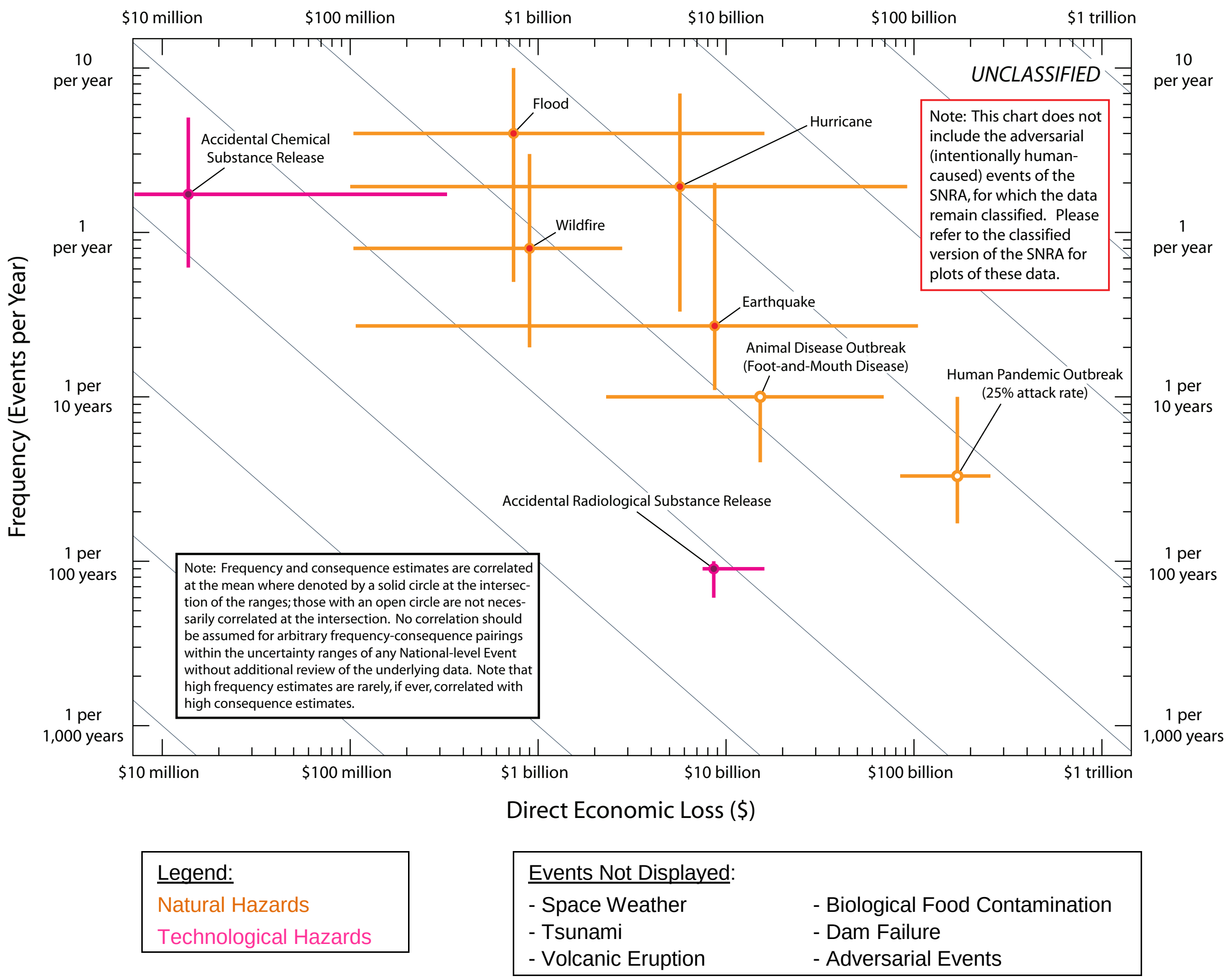
Note that all comparative statements are made within the set of natural and technological hazards treated by this extract of the SNRA.

No single national-level event dominates direct economic risk among the natural and technological hazards of the SNRA to the extent that pandemic influenza outbreaks dominate the fatality and injury/illness risk. Hurricanes pose the largest direct economic risk of natural and technological hazards in the SNRA at the best estimate, given the precision of the SNRA, although there is considerable uncertainty (see Figure 1). Other SNRA events that pose the same order of magnitude of direct economic risk as hurricanes, at the best estimate, are pandemic influenza outbreaks, foot-and-mouth disease, earthquakes, and floods.

- For many high-consequence disasters such as hurricanes and floods, mitigation strategies resulting from advanced warning, such as advance evacuations from areas expected to be impacted, have reduced human health risks over time. However, the physical destruction from natural disasters, combined with their frequency, results in significant direct economic risk.
- Pandemic direct economic costs are dominated by factors directly related to the high numbers of fatalities and illnesses resulting from a pandemic. Primarily, these are the value of lost productivity due to the hundreds of thousands of fatalities, and from the millions unable to work while ill, or caring for someone who is ill.
- The direct economic risk associated with a foot-and-mouth disease (FMD) outbreak in the United States is driven by the immediate reduction in international trade which would occur given an outbreak as well as disease control and eradication efforts. Given the value placed on FMD-free status, a confirmed case of FMD in the U.S. would result in an immediate

restriction of exports. The current control strategy in U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) regulations to regain FMD-free status is to cull all infected and susceptible animals.[23,24] The APHIS Administrator has discretion to examine other options based on the size of the outbreak.

Figure 5: Direct Economic Risk



Events which are assessed to pose relatively low direct economic risk in the SNRA in comparison with the other non-adversarial hazards include accidental radiological substance release (a lower frequency, higher consequence event) and accidental chemical substance release (a higher frequency, lower consequence event).

The direct economic consequences associated with accidental radiological substance release (a nuclear power plant accident) are highly dependent upon the assumed decontamination standard.

It is important to note that none of the above risk estimates include indirect or induced economic costs, which have the potential to be as large or greater than the direct economic consequences.

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23 U.S. Code of Federal Regulations (2011). Title 9, Section 53.4. *Destruction of animals*. Washington, DC: U.S Government Printing Office. Retrieved from http://www.gpo.gov/fdsys/pkg/CFR-2011-title9-vol1/pdf/CFR2011-title9-vol1-sec53-4.pdf.

24 U.S. Government Accountability Office (2002, July). *Foot and mouth disease: To protect U.S. livestock, USDA must remain vigilant and resolve outstanding issues* (GAO-02-808). Retrieved from http://www.gao.gov/new.items/d02808.pdf.

Social Displacement Risk

Social displacement risk was estimated in a semi-quantitative manner using a risk matrix displayed in Figure 6 below. These risks are assessed and communicated in this manner due to the inherent challenges in obtaining best estimates of social displacement that were correlated to the best estimates for the frequency of each event. Higher-fidelity social displacement data is required to defensibly multiply the best estimates of event frequency and displacement to approximate an expected loss.

Figure 6: Social Displacement Risk

Frequency (Best Estimate, events per year)

Greater than 1 per year		Accidental Chemical Substance Release	Flood Hurricane	Higher Risk
Between 1 per year and 1 per 10 years		Accidental Biological Food Contamination Dam Failure	Wildfire Earthquake	
Less than 1 per 10 years	Pandemic Influenza Lower Risk	Animal Disease Outbreak	Accidental Radiological Substance Release	
	None	**Between 1 and 10,000**	**Between 10,000 and 1 million**	**Greater than 1 million**

Consequences only (events for which frequencies are classified)	Chemical/Biological Food Contamination Terrorism Attack* Cyber Event affecting Data	Armed Assault Biological Terrorism Attack (non-food) Cyber Event affecting Physical Infrastructure Explosives Terrorism Attack	Aircraft as a Weapon Chemical Terrorism Attack (non-food) Radiological Terrorism Attack	Nuclear Terrorism Attack
	None	**Between 1 and 10,000**	**Between 10,000 and 1 million**	**Greater than 1 million**

Social Displacement

How to read this chart: This is a plot of social displacement risk, as drawn from the best estimates of frequency and social displacement. Higher risk national-level events tend toward the upper right of the chart, lower risk ones towards the lower left. One national-level event can be said to be higher risk than another when it is both higher frequency AND higher consequence. The color coding of the national-level events corresponds to the hazard type: **technological/accidental hazards** and **natural disasters**. As the likelihoods and hence the social displacement risk of adversarial events are classified, the unclassified social displacement consequences of **adversarial events** are displayed without likelihood information. For social displacement consequences (without the likelihood component of risk) for all events including adversarial events, see Appendix F.

* While a best estimate for social displacement could not be determined, subject matter experts consulted for the SNRA judged that displacement was likely to be minimal.

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

- Low, best, and high estimates of social displacement conditional upon event occurrence are unclassified for all events in the SNRA, and may be found in the event risk summary sheets and Appendix F. As social displacement *risk* represents the product of these consequence measures with estimated frequencies of event occurrence which are classified for all adversarial SNRA events, only natural and technological hazards are discussed below. Comparative analysis among all SNRA events based on social displacement consequences alone, independently of frequency of occurrence, is presented in Appendix F.

Two events were judged to have relatively high social displacement risk among the natural and technological hazards: hurricanes and floods.

- Hurricanes and floods are relatively high frequency and result in moderate to high social displacement. These natural hazard events possess significant displacement risk in part because of advance warning of the event and evacuations to safer locations.

Pandemic influenza outbreaks were estimated to pose minimal social displacement risk, because displacement due to hospitalizations was not included in the social displacement consequence assessment.

None of the technological hazards was estimated to pose a high social displacement risk compared with the natural hazards.

Note that there is a significant difference between short-term evacuations up to a week and longer term permanent relocation – a distinction that is not made in the SNRA. As such, caution is advised when interpreting the social displacement risks in Figure 6.

Insufficient data about the social displacement risk associated with space weather, tsunamis, and volcanoes was collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 6.

Psychological Distress Risk

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as inputs.[25] More details regarding the SNRA psychological distress consequence analysis and the limitations of this analysis are available in Appendix G.

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Psychological distress risk was estimated in a semi-quantitative manner using a risk matrix similar to the one used for social displacement risk above, and is displayed in Figure 7 below. To our knowledge, the SNRA was the first systematic effort to compare psychological impacts and risks from national-level events; as such, additional research into the psychological consequences of disasters is required to improve the understanding of these consequences at a strategic, national level to permit better estimates of expected loss.

[25] The index approach currently does not include a component for translating economic losses into psychological distress. If estimates of homes destroyed and jobs lost (rather than overall direct economic consequences) are obtained as consequence estimates for various national-level events, it would be possible to capture financial loss as part of the equation for psychological distress in future iterations of the SNRA.

Two events were estimated to have relatively high psychological distress risk compared with other non-terrorism related hazards: pandemic influenza outbreaks and hurricanes. These findings are driven by the underlying method used to estimate significant distress in the SNRA, which heavily weighted contributions from events' fatalities and injuries/illnesses, as well as social displacement to a lesser extent. As discussed above, pandemic influenza dominates the fatality and injury/illness risk, while hurricanes pose a significant social displacement risk. Because the equation used to represent significant distress considers each of these consequence types, events that are high risk in these three categories will correspondingly pose relatively high psychological distress risk.

Other events that are not estimated to pose the highest psychological distress risks among the non-adversarial hazards, but which are still noteworthy, include floods and wildfires.

Insufficient data about the psychological distress risk associated with cyber events, space weather, tsunami, and volcanoes were collected during the SNRA to support quantitative comparisons to other national-level events. For this reason, these events are not displayed in Figure 7.

Figure 7: Psychological Distress Risk

Frequency (Best Estimate, events per year) \ Psychological Distress	Less than 500	Between 500 and 5,000	Between 5,000 and 50,000	Between 50,000 and 500,000	Between 500,000 and 5 million	Greater than 5 million
Greater than 1 per year	Accidental Chemical Substance Release		Flood	Hurricane		Higher Risk
Between 1 per year and 1 per 10 years	Dam Failure		Accidental Biological Food Contamination Earthquake	Wildfire		
Less than 1 per 10 years	Lower Risk			Accidental Radiological Substance Release		Pandemic Influenza

How to read this chart: This is a plot of psychological distress risk, as drawn from the best estimates of frequency and psychological distress. Higher risk national-level events tend toward the upper right of the chart, lower risk ones towards the lower left. One national-level event can be said to be higher risk than another when it is both higher frequency AND higher consequence. The color coding of the national-level events corresponds to the hazard type: **technological/accidental hazards** and **natural disasters**. Psychological distress likelihood and consequences for adversarial events are classified or restricted at the U//FOUO level, and are not displayed on this chart.

Environmental Risk

Since environmental impacts are measured on a four-level ordinal scale (minimal, low, moderate, high), estimating environmental risk is not as straightforward as for other types of risk. Analysts' judgments were used to choose events with high combinations of environmental impact and frequency. The lack of quantitative environmental risk estimates necessitates a subjective judgment of high risk events; this is an area of the SNRA recognized for future improvement.

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Figure 8: Environmental Risk

Frequency (Best Estimate, events per year)	De Minimus	Low	Moderate	High
Greater than 1 per year			Flood Hurricane Accidental Chemical Substance Release	Higher Risk ↗
Between 1 per year and 1 per 10 years		Wildfire	Accidental Biological Food Contamination Dam Failure Earthquake	
Less than 1 per 10 years	↙ Lower Risk	Animal Disease Outbreak Pandemic Influenza	Accidental Radiological Substance Release	

	De Minimus	Low	Moderate	High
Consequences only (events for which frequencies are classified)	Armed Assault Cyber Event affecting Data Cyber Event affecting Physical Infrastructure Radiological Terrorism Attack	Aircraft as a Weapon Biological Terrorism Attack (non-food) Chemical/Biological Food Contamination Terrorism Attack Explosives Terrorism Attack	Chemical Terrorism Attack (non-food)	Nuclear Terrorism Attack

Environmental Consequences

How to read this chart: This is a plot of environmental risk, as drawn from the best estimates of frequency and environmental impact. Higher risk national-level events tend toward the upper right of the chart, lower risk ones towards the lower left. One national-level event can be said to be higher risk than another when it is both higher frequency AND higher consequence. The color coding of the national-level events corresponds to the hazard type: **technological/accidental hazards** and **natural disasters**. As the likelihoods and hence the environmental risk of adversarial events are classified, the unclassified environmental impacts of **adversarial events** are displayed without likelihood information.

- Estimates of environmental conditional upon event occurrence are unclassified for all events in the SNRA, and may be found in the event risk summary sheets and Appendix H. As environmental *risk* represents the product of these consequence measures with estimated frequencies of event occurrence which are classified for all adversarial SNRA events, only natural and technological hazards are discussed below. Comparative analysis among all SNRA events based on environmental consequences alone, independently of frequency of occurrence, is presented in Appendix H.

Three national-level events among the natural and technological hazards are estimated to have relatively high environmental risk: floods, hurricanes, and accidental chemical substance releases (toxic inhalation hazards). These events were judged to be of high environmental risk because they were judged to result in the most significant environmental impacts (moderate, at the best estimate) of the events with the highest frequency estimates in the SNRA (greater than one event per year, at the best estimate).

No natural or technological hazards were assessed to have a high environmental impact and hence high environmental risk at the best estimate, although some were assessed to have the potential to have high adverse impacts on the environment at the second best estimate (see Appendix H for table).

Although it did not have a quantitative likelihood estimate allowing it to be included in this matrix, space weather was judged to have *de minimis* (minimal) environmental risk because of its assessed *de minimis* adverse environmental impact, at the best estimate. If a space weather event affecting physical infrastructure were to result in extended power outages, the potential for environmental impacts would increase to low/moderate as chemical and treatment plants failed.

Insufficient data about the environmental risk associated with tsunamis and volcanoes was collected during the SNRA to support comparisons to other national-level events. For this reason, these events are not displayed in Figure 8.

Risks Requiring Additional Study

While the analysis of all events in the SNRA would benefit from additional research and deliberate, long-term study, four event types considered in the SNRA – cyber events, space weather, tsunamis, and volcanoes – were judged to have insufficient data, or data of such uncertainty, that quantitative estimates of frequency, consequences, or annualized loss were not included in most of the visualizations presented in this Findings section.

Highly Uncertain Risks

Cyber events and space weather events were determined to be highly uncertain risks in the SNRA, as the risk from these events is difficult to quantify.

Regarding cyber events, the SNRA includes elicited quantitative frequency information for two types of adversarial cyber events: Cyber Event affecting Physical Infrastructure and Cyber Event affecting Data. For each of these events, the specific consequence thresholds outlined in Table 2 were provided to subject matter experts from whom cyber event frequencies were elicited.[26] Since cyber security is a relatively new field with few prior studies, a more complete range of consequences could not be generated and included in this iteration of the SNRA given time limitations.

In addition to data and modeling limitations, future attempts to study cyber events will need to address unique challenges that continue to challenge the cyber community. First, the cyber environment is constantly evolving, with both new attack types being developed and new vulnerabilities being created. Cyber systems are frequently probed and tested, but system operators are not fully aware of what these attacks are seeking to exploit, making consequence estimation problematic. Additionally, cyber attacks are frequently directed at private sector targets, whose owners may be reticent to share data regarding potential consequences of a major cyber event. Cascading effects across assets and sectors are also poorly understood for attacks that would impact the operation of the internet backbone itself. Finally, the current scoping of cyber event consequences in the SNRA does not include the loss of intellectual property, since it is very complex to link ultimate market impact with a cyber event that is separate in space and time.

Despite these challenges, cyber risk is an issue of concern within the homeland security enterprise and warrants further analysis. Programs within DHS and the interagency are working to better understand strategic-level cyber risk and may be positioned to provide additional data in the future.

Regarding space weather, most experts agree that a large and prolonged disruption of the electric grid would produce significant displacement of the impacted population, and significant economic impacts. However, there is significant disagreement among experts regarding whether or not

[26] These frequencies may be found in the classified (full) SNRA Technical Report.

coronal mass ejections from the sun – "geomagnetic storms" – could cause the systemic scale outage required to produce those consequences. While studies by Kappenman[27,28,29] connect these storms (particularly the March, 1989 storm) to failures in electric grid transformers, there is some skepticism from the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability that the transformer failures referenced in the studies can be credibly attributed specifically to the storms. Although very severe solar storms are known to have occurred in the past, the vulnerability of the modern U.S. national grid to permanent, widespread damage from such events postulated by catastrophic scenarios is due to particular technological and organizational characteristics of the grid which are comparatively recent, and hence these scenarios have not been effectively tested. In the absence of definitive evidence of long-term transformer problems directly caused by a solar storm event, no clear consensus on the likelihood or likely extent of such damage presently exists in the scientific and technical communities concerned with space weather risk.[30]

Historically, it is known that space weather events present a risk to electric grid infrastructure, but there is significant uncertainty in the expected consequences from these events as well as the expected frequencies with which consequential events are expected to occur. For these reasons, we note that considerable research must be done to further characterize these events before quantified expected losses can be included in assessments such as the SNRA.

Tsunamis and Volcanoes

Significant work has been done by the United States Geological Survey and other Federal interagency partners to understand the risks that tsunamis and volcanoes pose at the local and regional level. However, such work typically focuses on specific volcanoes or coastal regions, and additional work is needed to scale local and regional scales up to the national level. For example, the estimated frequencies with which individual volcanoes have historically erupted could be aggregated to arrive at a national frequency for volcanic eruption, but such analysis was not possible within the time frame of the SNRA. For this reason, a specific volcano (Mount Rainer) and a specific tsunami (inundation of the Oregon coast due to an earthquake in the Cascadia Subduction Zone) were studied. Frequency and consequence data for this specific volcano and tsunami is provided in the appendices to this report, but the risk from these events is only a subset of the risk from all types of national-level volcano and tsunami events, and thus is not comparable to the other analysis in the SNRA.

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[27] Kappenman, J. G. (1996). Geomagnetic storms and their impact on power systems. *IEEE Power Engineering Review*, 16(5), 5-8.

[28] Kappenman, J. G. (2010). Geomagnetic storms and their impacts on the U.S. power grid. Metatech, report Meta-R-319, for the U.S. EMP Commission; at http://www.fas.org/irp/eprint/geomag.pdf.

[29] Chapter 7 of National Research Council (2008). *Severe space weather events – understanding societal and economic impacts: A workshop report*. Washington, DC: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=12507.

[30] Kappenman (1996), (2010), *op. cit.*; National Research Council (2008). *Severe space weather events – understanding societal and economic impacts: A workshop report*. Washington, DC: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=12507; Holdren, John P, Beddington, John, 2011. Celestial storm warnings. *New York Times* 2011/03/10, Opinion; at http://www.nytimes.com/2011/03/11/opinion/11iht-edholdren11.html?_r=1; JASONS, MITRE Corporation (2011), for DHS Science & Technology Directorate*. Impacts of severe space weather on the electric gri*d. MITRE report JSR-11-320, November 2011; at http://www.fas.org/irp/agency/dod/jason/spaceweather.pdf; North American Electric Reliability Corporation (NERC) (2012). *Effects of geomagnetic disturbances on the bulk power system*; at http://www.nerc.com/files/2012GMD.pdf; Oak Ridge National Laboratory (1991). *Electric utility industry experience with geomagnetic disturbances*. ORNL-6665.; at http://www.ornl.gov/~webworks/cpr/v823/rpt/51089.pdf; CENTRA Consulting (2011), for DHS Office of Risk Management & Analysis. *Geomagnetic Storms*. Issue paper for Future Global Shocks report, Organization of Economic Cooperation & Development (OECD) paper IFP/WKP/FGS(2011)4; at http://www.oecd.org/dataoecd/57/25/46891645.pdf.

RISK INFORMATION BY HAZARD AREA

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Natural Hazards Discussion

Hurricanes

> *Natural hazards, including hurricanes, earthquakes, tornados, wildfires, and floods, present a significant and varied risk across the country.*
>
> *National Preparedness Goal, September 2011*

Hurricanes are estimated to present the largest direct economic and social displacement risks to the Nation of all the natural and technological hazards included in the SNRA, coupled with relatively high psychological distress and environmental risks. Though not among the largest, hurricanes do carry some fatality and injury/illness risk.

- For the purpose of the SNRA, a national-level hurricane is defined as a hurricane producing direct economic loss in excess of $100 million dollars.

Over 50 percent of U.S. citizens live in coastal communities, a 45 percent increase from 1970, and this number is expected to grow another 10 percent by 2020.[31] As more people move to coastal communities that experience hurricanes, population and economic growth in these areas increases societal vulnerability to extreme weather. A recent study on hurricane damage suggests that "potential damage from storms is growing at a rate that may place severe burdens on society. Avoiding huge losses will require either a change in the rate of population growth in coastal areas, major improvements in construction standards, or other mitigation actions."[32]

Economic losses from hurricane impacts vary depending on characteristics of the area being impacted (e.g., density, building features, wind building codes, land use, and evacuation plans/execution), as well as the size and strength of the storm itself. For example, Hurricane Andrew (1992) was a fast-moving, compact but strong Category 5 storm that heavily impacted a small area in South Florida, while Hurricane Katrina (2005) was a lesser Category 3 storm that impacted a very large area. Hurricane Irene (2011), by contrast, was an even weaker storm but also impacted a very large area. All three storms created considerable losses though the specific nature of their impacts were different. Preparedness efforts for hurricanes will need to account for both potential storm strength and breadth of impact area.

Floods

Floods are one of the most common hazards in the United States. Their effects can be local, impacting a neighborhood or community, or large, affecting entire river basins and multiple

[31] National Oceanic and Atmospheric Administration (2012). State of the coast. Retrieved from http://stateofthecoast.noaa.gov/population/welcome.html.

[32] Pielke, R. J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized hurricane damage in the United States: 1900-2005. *Natural Hazard Review*, 9(1), 29-42.

states.[33] For the purpose of the SNRA, a national-level flood is defined as a flood producing direct economic loss in excess of $100 million dollars using data from 1993 to 2005. All hurricanes were removed from flood events to avoid over-reporting flooding already captured in the hurricane data.

Similar to hurricanes, fatality risk from floods is relatively small due to advanced warning and effective evacuation. Economic consequences from floods are significant, however. The historical average and maximum direct economic damage from a national-level flood in the SNRA analysis were $740 million and $16 billion respectively (see Table 1 in Appendix E). It is also important to note that the SNRA used historical data to estimate flood risk. A number of trends could increase flood risk in the future, including greater economic development and population growth in high-risk areas, lack of adequate flood insurance coverage, and climate change.

Wildfires

Wildfires, as evidenced by the historical record, do not have the same potential for causing catastrophic loss of life as other natural-hazard events: the last time a wildfire killed hundreds of people in the United States was 1918.[34] Rather, most of their potential harm comes from the economic damage they can cause, largely by direct destruction of property, and their capacity to significantly challenge local and federal response efforts.[35] For this reason, an economic threshold of $100 million in direct losses is used to define a national-level wildfire in the SNRA. It is not uncommon for a wildfire to spread to and threaten a large geographic area, requiring a month or more of federally-supported firefighting efforts to successfully contain and extinguish the threat.[36]

The historical period of 1990-2009, selected by the SNRA team because of the completeness and uniformity of available historical data,[37] shows a sharp increase in the frequency and severity of super-catastrophic wildfires affecting human populations in the United States compared with prior years.[38] Two possible drivers of this trend are the unintended consequences of long-term changes in forest management practices intended to reduce the threat of wildfires, but which many scholars argue have had the opposite effect,[39] and the spread of wildfire-favoring intensive grass species in the Western United States in recent decades.[40] Two other drivers which have been identified as responsible for this upward trend in frequency and impact on human populations are population

[33] Federal Emergency Management Agency (2011, November 9). Flood. Retrieved from http://www.fema.gov/hazard/flood/ .

[34] National Interagency Fire Center (n.d.). Historically significant wildland fires. Retrieved from http://www.nifc.gov/fireInfo/fireInfo_stats_histSigFires.html.

[35] National Interagency Fire Center (n.d.). Total Wildland Fires and Acres (1960-2009). Retrieved from http://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html; U.S. Fire Administration (2002). Fires in the wildland/urban interface. *Topical Fire Research Series*, 2(16). Retrieved from http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; U.S. Fire Administration (2001). Wildland fires: A historical perspective. *Topical Fire Research Series*, 1(3). Retrieved from http://www.usfa.fema.gov/downloads/pdf/statistics/v1i3-508.pdf; Western Forestry Leadership Coalition (2010). The true cost of wildfire in the western U.S. Retrieved from http://www.wflccenter.org/news_pdf/324_pdf.pdf.

[36] See note 35.

[37] Hazards & Vulnerability Research Institute (2011). The Spatial Hazard Events and Losses Database for the United States (SHELDUS), version 8.0 [online database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org.

[38] See notes 41 - 43.

[39] U.S. Fire Administration (2002). Fires in the wildland/urban interface. *Topical Fire Research Series*, 2(16). Retrieved from http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. (2006). Warming and earlier spring increase western U.S. forest wildfire activity. *Science,* 313(5789), 940-943. Retrieved from http://www.sciencemag.org/content/313/5789/940.full.pdf.

[40] Balch et al (2013). Introduced annual grass increases regional fire activity across the arid western USA (1980-2009). *Global Change Biology*, 19(1), 173-183.

growth in vulnerable areas[41] and the early effects of climate change,[42] drivers shared with the potential increase in risk of floods and hurricanes. As these common drivers are expected to continue to increase, there is a substantial likelihood that the overall risk to populated regions in the U.S. from wildfires will continue to increase in coming years.[43]

Earthquakes

According to the United States Geological Survey (USGS), there are two primary areas with the highest probability of seismic impacts that could significantly impact the U.S.: California and the New Madrid Seismic Zone (NMSZ) in the central United States.[44] Because scientists cannot yet make precise predictions of their date, time, and place, earthquake forecasts are presented in the form of probabilities. According to the Southern California Earthquake Center, the chance of having one or more magnitude 6.7 or larger earthquakes in California over the next 30 years is 99.7 percent. For powerful quakes of magnitude 7.5 or greater, there is a 37 percent chance that one or more will occur in the next 30 years in southern California.[45] For the NMSZ, scientists estimate that the probability of a magnitude 6.0 or larger earthquake occurring in within any 50 year period is 25-40 percent.[46] While California and the NMSZ have the highest probability of significant impacts, earthquakes have the potential to occur throughout the United States, and for this reason a threshold of $100 million in direct economic losses was used to characterize the frequency and consequences of earthquakes in the SNRA, regardless of geographic location.

The range of potential loss and damage can be extremely high. Structural damage in the form of cracked or unstable foundations, damage to support beams, broken connections in walls or floors, and collapsed tiers can severely hamper rescue efforts. Further, damage to transportation networks like bridges and roads would slow down rescue work, construction repair teams, and disaster relief efforts. The blockages of waterways would also reduce the viability of major shipping channels. Specific to the NMSZ, interruption of oil, natural gas, electricity and water delivery is likely for the region affected as well as more distant places like New England. All of these large systems could further be affected by factors such as population density, building codes, and time of the event.

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[41] U.S. Fire Administration (2002). Fires in the wildland/urban interface. *Topical Fire Research Series*, 2(16). Retrieved from http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf.

[42] Committee on America's Climate Choices, National Research Council (2011). *America's Climate* Choices. Washington, DC: National Academies Press. Available from http://dels.nas.edu/Report/Americas-Climate-Choices/12781; U.S. Global Change Research Program (2009). *Global Climate Change Impacts in the United States*, p 82. Cambridge: Cambridge University Press. Available from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf; U.S. Climate Change Science Program and the Subcommittee on Global Change Research (2008). *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* (Synthesis and Assessment Product 4.3). Washington, DC: U.S. Department of Agriculture. Available from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf; Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. (2006). Warming and earlier spring increase western U.S. forest wildfire activity. *Science,* 313(5789), 940-943. Retrieved from http://www.sciencemag.org/content/313/5789/940.full.pdf.

[43] Federal Emergency Management Agency (2011). Strategic Foresight Initiative project papers, including *Summary of Findings, U.S. Demography Shifts*, and *Climate Change*. At http://www.fema.gov/about/programs/oppa/strategic_foresight_initiative.shtm#3 .

[44] United States Geological Survey (2008). *United States national seismic hazard maps*. Available from http://earthquake.usgs.gov/hazards/products/conterminous/2008/.

[45] Southern California Earthquake Center (2012). Uniform California Earthquake Rupture Forecast (UCERF). Retrieved from http://www.scec.org/ucerf/.

[46] Central United States Earthquake Consortium (n. d.). New Madrid Seismic Zone. Retrieved from http://www.cusec.org/earthquake-information/new-madrid-seismic-zone.html.

Unlike some natural disasters, there is no warning before an earthquake. This lack of a warning system makes mitigation strategies like evacuation unlikely. Therefore, options like building codes and retrofitting older structures are necessary to minimize consequences.

Tsunamis

All oceanic regions of the world can experience tsunamis, but there are more frequent large, destructive tsunamis in the Pacific Ocean because of the many large earthquakes along the highly seismically active Pacific Rim. The SNRA included an analysis of the risk from a large tsunami originating from the Cascadia Subduction Zone with a wave of approximately 50 feet impacting the Oregon coast of the United States. The range of potential loss could be broad depending upon factors such as the population density of low-lying coastal areas, presence of agricultural assets such as crops and livestock, and location of nearby drinking water supplies. Like hurricanes and floods, fatalities from tsunamis are assumed to be minimal except in areas that do not receive warning in time, in communities not trained in evacuation, in flat areas where no evacuation routes exist, and for persons who do not obey orders to evacuate. The direct economic costs of the tsunami analyzed in the SNRA were dominated by building losses. The consequences caused by a tsunami can be mitigated through preparedness strategies like warning and monitoring systems such as those used by the National Weather Service Pacific Tsunami Warning Center, identifying evacuation routes and training communities in how to use them, and communicating the importance of evacuation to individuals living or working in vulnerable areas.

Volcanic Eruptions

The SNRA also included an analysis of a volcanic eruption scenario associated with Mount Rainier, Washington that impacts the surrounding areas with lava flows and ash, and areas east with smoke and ash. The average time interval between eruptions of Mount Rainier is estimated at 100 to 1,000 years,[47] with the most recent Mount Rainier volcanic event estimated to be between 1820 and 1870. According to the USGS, there is no immediate indication of renewed activity at Mount Rainier; however, hazard mitigation actions should be explored given the large population in the surrounding area. Possible negative consequences of volcanic ash include, but are not limited to: disruption of ground and air transportation, damage to electronics and machinery, crop damage, interruption of telecommunications, water contamination, respiratory effects, eye and skin irritation, indirect effects like reduction of visibility on roadways, and increased demand on power leading to electricity loss.[48] The consequences of a volcanic eruption will depend on the severity of the eruption, the sophistication of the monitoring and warning systems, and the level of preparedness of the surrounding population areas.

Space Weather

The SNRA considered national risk from a G-5 level (extreme) space weather event as defined by NOAA's Geomagnetic Storm Space Weather Scale. Space weather occurs when the sun emits bursts of electromagnetic radiation and energetic particles. Technologies that can be directly affected by extreme space weather are the electric power, spacecraft, aviation, and GPS-based positioning industries. Within the last 30 years, space weather events have disrupted all of these technologies. Severe storms could result in additional consequences for numerous systems that rely on the

[47] Hoblitt, R. P., Walder, J. S., Driedger, C. L., Scott, K. M., Pringle, P. T., & Wallace, J. W. *Volcano Hazards from Mount Rainier, Washington*, (U.S. Geological Survey Open-File Report 98-428). Available from http://vulcan.wr.usgs.gov/Volcanoes/Rainer/Hazards/OFR98-428/framework.html.

[48] International Volcanic Health Hazard Network (n. d.). The health hazards of volcanic ash: A guide for the public. Retrieved from http://www.ivhhn.org/images/pamphlets/Health_Guidelines_English_WEB.pdf.

electrical grid. As stated in a 2008 NRC workshop report on severe space weather events, "Impacts would be felt on interdependent infrastructures, with, for example, potable water distribution affected within several hours; perishable foods and medications lost in about 12-24 hours; and immediate or eventual loss of heating/air conditioning, sewage disposal, phone service, transportation, fuel resupply, and so on."[49] The potential effects of a more severe event have been studied but are still subject to considerable uncertainty (see discussion in "Highly Uncertain Risks" in the "Findings" section above). Direct environmental and health effects are expected to be minimal as damage occurs mainly through the medium of disruption of technology.

Human and Animal Disease Discussion

Pandemic Influenza Outbreak

> *A virulent strain of pandemic influenza could kill hundreds of thousands of Americans, affect millions more, and result in economic loss. Additional human and animal infectious diseases may present significant risks.*
>
> *National Preparedness Goal, September 2011*

A pandemic influenza outbreak with similar characteristics to the 1968-1969 Hong Kong pandemic flu is estimated to present the largest risk to the Nation of the natural and technological hazard events included in the SNRA for fatality, illness/injury, and psychological distress risk, and has relatively high direct economic risk. At the best estimate, it has more fatality and injury/illness risk than every other natural or accidental hazard in the SNRA combined (see Figures 1 and 2). However, pandemic influenza illnesses are different than most of the other injuries and illnesses in the SNRA, in that most victims who become ill but do not die are likely to recover fully and have no lasting economic impact on their lives. Pandemic influenza poses no social displacement risk[50] and relatively low environmental risk.

Despite advances in medical care over the last 50 years, pandemic influenza events, such as the Hong Kong flu of 1968-1969, are nevertheless assessed to have the potential to produce large numbers of fatalities and illnesses (and therefore economic impacts) in the United States. Influenza pandemics are caused by a family of influenza viruses that are usually transmitted from person to person through aerosolized virus-containing droplets generated by coughing or sneezing, or through interaction with contaminated surfaces.[51,52] Influenza viruses infect humans by binding to, and invading, epithelial cells in the nose, throat, and mouth – this attachment and invasion is facilitated by a particular virus protein on its surface, called Hemagglutinin, or "HA". Once the viruses hijack cells' internal machinery to make copies of themselves, those new virus copies escape the human cell to continue the infection via another virus surface protein called Neuraminidase, or "NA". These two virus proteins, along with others, determine a particular strain's ability to invade and escape cells, and form the basis for the "H" and "N" influenza strain designations. For example,

[49] Committee on the Societal and Economic Impacts of Space Weather Events, National Research Council (2008). *Severe space weather events – understanding societal and economic impacts: A workshop report*, p. 77. Washington, DC: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=12507.

[50] Hospitalizations due to pandemic influenza were not considered displacement for the purposes of the SNRA. The direct economic loss estimates account for the cost of medical care.

[51] Kramer, A., Schewebke, I., & Kampf, G. (2006). How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. *BMC Infectious Diseases*, 6, 130.

[52] Jones, R. M. & Adida, E. (2011). Influenza infection risk and predominant exposure route: Uncertainty analysis. *Risk Analysis,* 31(10), 1622-1631.

the "swine flu" pandemic of 2009 had HA and NA proteins both of type one, and was designated H1N1. In contrast, the 1968-1969 Hong Kong flu was an H3N2 influenza strain since its HA protein was type three, and its NA protein was type two.

At a high level, there are two important rates associated with an influenza pandemic that determine its impact. The first is the overall gross clinical "attack" rate, which is defined as the fraction of the population that becomes clinically ill from influenza during the pandemic. While it varies by age, typically the overall attack rate for seasonal influenza each year is between 5% and 20% of the population of the United States.[53,54,55,56] In contrast, the three influenza pandemics of the 20th century (1918, 1957, and 1968) had gross clinical attack rates (adjusted to current population) of 24% to 34% of the population,[57,58,59,60,61] a significant increase over the yearly seasonal rates. Given this range of observed clinical attack rates for recent influenza pandemics (24% to 34%), the 25% attack rate assumed for the SNRA scenario is conservative.

The second important rate affecting the impact of an influenza pandemic is the case fatality rate, or CFR, defined as the proportion of people with influenza illness who die. Assessed to be a "Category 2" pandemic on the Centers for Disease Control and Prevention's (CDC's) Pandemic Severity Index[62] based on its CFR, the Hong Kong Flu caused an estimated 34,000 deaths in the United States (one million worldwide).[63] The 1968-1969 Hong Kong Flu had a relatively low CFR of less than 0.05% in contrast to the 1918 Spanish Flu which had a much higher CFR of between 2.5% and 10%.[64,65]

Beyond the attack rate and the CFR, there are a number of drivers that explain why pandemic influenza is a significant risk, the first being influenza virus biology and ecology. Since an influenza strain's ability to invade, reproduce in, and escape human cells depends in part on the particular H and N surface proteins as well as other proteins, variations in them can determine how quickly an

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[53] Bridges, C. B., Thompson, W. W., Meltzer, M. I., Reeve, G. R., Talamonti, W. J., Cox, N. J., et al. (2000). Effectiveness and cost-benefit of influenza vaccination of healthy working adults: a randomized control trial. *Journal of the American Medical Association,* 824(13), 1655-63.

[54] Edwards, K. M., Dupont, W. D., Westrich, M. K., Plummer, W. D., Palmer, P. S., & Wright, P. F. (1994). A randomized control trial of cold-adapted and inactivated vaccines for the prevention of influenza A disease. *Journal of Infectious Disease,* 169, 68-76.

[55] Keitel, W. A., Cate, T. R., Couch, R. B., Huggins, L. L., & Hess, K. R. (1997). Efficacy of repeated annual immunization with inactivated influenza virus vaccines over a five year period. *Vaccine*, 15(10), 1114-1122.

[56] Neuzil, K., Zhu, Y., Griffin, M., Edwards, K. M., Thompson, J., Tollefson, S., et al. (2002). Burden of interpandemic influenza in children younger than 5 years: a 25-year prospective study. *Journal of Infectious Disease,* 185, 147-152.

[57] Brundage, J. F. (2006). Cases and deaths during pandemic influenza in the United States. *American Journal of Preventative Medicine,* 31(3), 252-256.

[58] Davis, L. E., Caldwell, G. C., Lynch, R. E., & Bailey, R. E. (1970). Hong Kong influenza: The epidemiologic features of a high school family study analyzed and compared with a similar study during the 1957 Asian influenza epidemic. *American Journal of Epidemiology,* 92, 240-257.

[59] Elveback, L. R., Fox, J. P., & Ackerman, E. (1976). An influenza simulation model for immunization studies. *American Journal of Epidemiology*, 103, 152-165.

[60] Longini, I. M., Ackerman, E., & Elveback, L. R. (1978). An optimization model for influenza A epidemics. *Mathematical Biosciences,* 38, 141-157.

[61] Sharrar, R. G. (1969). National influenza experience in the USA, 1968-1969. *Bulletin of the World Health Organization*, 41, 361-366.

[62] U.S. Department of Homeland Security and U.S. Department of Health and Human Services (2008). *Guidance on allocating and targeting pandemic influenza vaccine.* Retrieved from http://www.flu.gov/individualfamily/vaccination/allocationguidance.pdf.

[63] Patel, R., Longini, I. M., & Halloran, M. E. (2005). Finding optimal vaccination strategies for pandemic influenza using genetic algorithms. *Journal of Theoretical Biology*, 234, 201-212.

[64] Ibid.

[65] Taubenberger, J. K. & Morens, D. M. (2006). 1918 influenza: The mother of all pandemics. *Emerging Infectious Diseases,* 12(1), 15-22.

influenza outbreak spreads, and is a factor along with others in the case fatality rate and other aspects of the pandemic.[66,67] In addition to contributing to transmissibility, the large amount of variability and frequency of mutations in the influenza H/N proteins accounts for much of the lack of immunity within the general population. This lack of immunity is by far the largest driver of the high illness/fatality statistics from a scientific standpoint.

An additional driver for pandemic influenza's risk is the fact that vaccine production for an emerging pandemic influenza strain currently takes a significant amount of time (planning estimates are on the order of several months,[68] with the actual experience of H1N1 in 2009 being about a year to produce sufficient vaccine to protect the entire nation[69]). This fact means that other control measures such as isolation of symptomatic individuals and identifying and quarantining their contacts are important components of a pandemic response prior to vaccine availability.[70] However, recent research and epidemiological modeling indicates that the biggest determinant of the success of these control measures (even more than the virus's inherent transmissibility) is the degree to which the particular pandemic strain can be transmitted by individuals who have the virus but are not yet symptomatic.[71] If individuals can unknowingly spread the virus, while they themselves do not have symptoms, then the effectiveness of these control measures will be reduced. Consequently, direct estimation of the degree of asymptomatic and presymptomatic transmissibility is important during pandemic influenza outbreaks to guide response. New epidemiological analysis of the 2009 H1N1 influenza pandemic and other recent research appears to indicate that presymptomatic transmission can in fact occur, as early as a day before the onset of symptoms;[72,73,74] however, other previous research has been inconclusive regarding this important aspect of the virus's transmissibility.[75]

Since it is not feasible to prevent the emergence of new strains of influenza that could give rise to a potentially high-consequence pandemic, mitigation options generally fall into three categories, the "pillars" of the 2005 National Strategy for Pandemic Influenza:[76] preparedness, surveillance and detection, and response and containment. The strategy notes that a foundation of influenza

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[66] Connor, R. J., Kawaoka, Y., Webster, R. G., & Paulson, J. C. (2004). Receptor specificity in human, avian, and equine H2 and H3 influenza virus isolates. *Virology*, 205, 17-23.

[67] Van Doremalen N., Shelton H., Roberts K. L., Jones, I. M., Pickles, R. J., et al. (2011). A single amino acid in the HA f pH1N1 2009 influenza virus affects cell tropism in human airway epithelium, but not transmission in ferrets. *PLoSOne,* 6(10), e25755.

[68] World Health Organization (2009, August 9). Pandemic influenza vaccine manufacturing process and timeline: Pandemic (H1N1) 2009 briefing note 7. Retrieved from http://www.who.int/csr/disease/swineflu/notes/h1n1_vaccine_20090806/en/index.html.

[69] President's Council of Advisors on Science and Technology (2010, August). *Report to the President on reengineering the influenza vaccine production enterprise to meet challenges of pandemic influenza*. Retrieved from: http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST-Influenza-Vaccinology-Report.pdf.

[70] Homeland Security Council (2005). *National strategy for pandemic influenza*. Retrieved from http://www.flu.gov/planning-preparedness/federal/pandemic-influenza.pdf.

[71] Fraser, C., Riley, S., Anderson, R. M., & Ferguson, N. M. (2004). Factors that make an infectious disease outbreak controllable. *Proceedings of the National Academies of Science,* 101(16), 6146-6151.

[72] Gu, Y., Komiya, N., Kamiya, H., Yasui, Y., Taniguchi, K., & Otabe, N. (2011). Pandemic (H1N1) 2009 transmission during presymptomatic phase, Japan. *Emerging Infectious Diseases,* 17(9), 1737-1739.

[73] Dawood, F. S., Jain, S., Finelli, L., Shaw, M. W., Lindstrom, S., Garten, R. J., et al. (2009). Emergence of a novel swine-origin influenza A (H1N1) virus in humans. *New England Journal of Medicine*, 360, 2605-2615.

[74] Carrat, F., Vergu, E., Ferguson, N. M., Lemaitre, M., Cauchemez, S., Leach, S., et al. (2008). Time lines of infection and disease in human influenza: A review of volunteer challenge studies. *American Journal of Epidemiology*, 167, 775-785.

[75] Patrozou, E. & Mermel, L. A. (2009). Does influenza transmission occur from asymptomatic infection or prior to symptom onset? *Public Health Reports*, 124(2), 193-196.

[76] Homeland Security Council (2005). *National strategy for pandemic influenza*. Retrieved from http://www.flu.gov/planning-preparedness/federal/pandemic-influenza.pdf.

preparedness is vaccination, similar to seasonal influenza. However, given the time required for vaccine development, and the limited advanced warning for a pandemic strain's emergence, vaccination alone is not sufficient to limit the impact of a pandemic. However, coupled with new approaches for decreasing the time for vaccine development,[77] early detection and surveillance can limit the spread of the pandemic and increase the time available for vaccine production and distribution. Finally, containment and effective public health response can limit fatalities and economic impacts through sufficient public health surge capacity for severe influenza cases, and through other containment measures to limit or slow the spread of disease.

While influenza was the only type of pandemic outbreak considered in the SNRA, a number of biological agents are currently known to have the potential for epidemic or pandemic outbreaks that produce significant human health and economic impacts. Zoonotic agents (agents that usually infect animals, but that can infect humans as well) and new emerging infectious disease agents that are unanticipated may present significant risks as well. Recent examples of emerging diseases are the emergence of Ebola virus in 1976 in which the index case was thought to have become infected from bats in the Zaire cotton factory in which he worked,[78] and the SARS coronovirus originating in Asia which nearly became a pandemic in 2002 and 2003.[79]

Animal Disease Outbreak

The SNRA included an unintentional introduction of the foot-and-mouth disease (FMD) virus into a single dairy cattle herd in California. FMD is one of the most devastating diseases affecting cloven-hoof animals such as cattle, swine, sheep and deer. The virus is highly contagious and robust, with seven types and more than 80 sub-types, and vaccination for one type does not confer immunity to the others. While there are no significant human health implications of FMD, an outbreak of the disease can have important economic consequences. In 2001, the United Kingdom suffered one of the largest FMD epidemics in a developed country in several decades. Approximately seven million animals were culled, and the outbreak devastated the nation's farming industry. It is estimated that the outbreak cost the UK an estimated $11.9-$18.4 billion, including $4.8 billion in losses to agriculture, the food industry and the public sector, $4.2-$4.9 billion in lost tourism and $2.9-$3.4 billion in indirect losses.[80] As noted in the Findings section, a confirmed case of FMD in the U.S. would result in an immediate restriction of exports. The current control strategy in U.S. Department of Agriculture (USDA) Animal and Plant Inspection Service (APHIS) regulations to regain FMD-free status is to cull all infected and susceptible animals.[81,82]

[77] President's Council of Advisors on Science and Technology (2010, August). *Report to the President on reengineering the influenza vaccine production enterprise to meet challenges of pandemic influenza*. Retrieved from: http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST-Influenza-Vaccinology-Report.pdf.

[78] Pourrut, X., Kumulungui, B., Wittman, T., Moussavou, G., Delicat, A., Yaba, P., et al. (2005, June). The natural history of Ebola virus in Africa. *Microbe and Infection / Institut Pasteur*, 7(7-8), 1005-1014.

[79] Chan-Yeung, M. & Xu, R. H. (2003, November). SARS: epidemiology. *Respirology*, 8(Suppl.), S9-S14.

[80] Carpenter, T.E. O'Brien, J.M. Hagerman, A.D. McCarl, B.A. (2011). Epidemic and economic impacts of delayed detection of foot-and-mouth disease: A case study of an outbreak in California. *Journal of Veterinary Diagnostic Investigation*, 23, 26-33.

[81] U.S. Code of Federal Regulations (2011). Title 9, Section 53.4. *Destruction of animals.* Washington, DC: U.S. Government Printing Office. Retrieved from http://www.gpo.gov/fdsys/pkg/CFR-2011-title9-vol1/pdf/CFR-2011-title9-vol1-sec53-4.pdf.

[82] U.S. Government Accountability Office (2002, July). *Foot and mouth disease: To protect U.S. livestock, USDA must remain vigilant and resolve outstanding issues* (GAO-02-808). Retrieved from http://www.gao.gov/new.items/d02808.pdf.

Technological and Accidental Hazards Discussion

Accidental Biological Food Contamination

> *Technological and accidental hazards, such as dam failures or chemical spills or releases, have the potential to cause extensive fatalities and severe economic impacts, and the likelihood of occurrence may increase due to aging infrastructure.*
>
> *National Preparedness Goal, September 2011*

The SNRA included an analysis of an accidental introduction of a biological agent (e.g., *Salmonella*, *E. coli*, botulinium toxin) into the food supply (e.g., milk, meat, vegetables, processed food) that results in harm to the public. The analysis utilized data from the Center for Disease Control and Prevention's (CDC's) Foodborne Outbreak Online Database[83] to identify accidental food contamination events. Most foodborne outbreaks are investigated by the state, local, territorial, and tribal health departments where the outbreak occurs. Outbreak information is then reported to the CDC by the public health agency that conducted the investigation. The SNRA analysis used CDC correction factors to account for known underreporting and underdiagnosis of food contamination.[84]

Public health consequences of biological food contamination can be mitigated by identifying and recalling the contaminated food product. Recalls and lost sales, in addition to the immediate costs associated with medical care, drive the direct economic consequences of a biological food contamination event.[85] Further economic damage may be incurred by industry due to uncertainty in determining the correct product as the source of the outbreak. For example, in 2008, a *Salmonella* outbreak was erroneously blamed on tomatoes early in the investigation before jalapeño and serrano peppers were identified as the cause. As a result of the initial misidentification, the tomato industry was severely impacted even though all tomatoes tested negative for *Salmonella*. Economic estimates of losses to the tomato industry exceeded $100 million in Florida and almost $14 million in Georgia.[86,87]

Dam Failure

In a recent report on the progress of the National Dam Safety Program, FEMA noted that, "while the data reveal encouraging trends in many areas, the larger picture of dam safety remains problematic at best."[88] Many Americans are living below structurally deficient high-hazard potential dams whose failure would cause loss of human life. They are, for the most part, unaware of the risk, and unaware of the existence or lack of existence of plans to evacuate them to safety in the event of a failure.[89] The Interagency Committee on Dam Safety classifies dams whose failure would cause loss

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83 Centers for Disease Control and Prevention (2012). Foodborne Outbreak Online Database (FOOD). Retrieved from http://wwwn.cdc.gov/foodborneoutbreaks/.

84 Scallan, E., Hoekstra, R. M., Angulo, F. J., Tauxe, R. V., Widdowson, M. A., Roy, S. L., et al. (2011). Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases*, 17(1), 7-15.

85 U.S. Food and Drug Administration (2007, July 18). *An overview of the CARVER Plus Shock Method for food sector vulnerability assessments.* Retrieved from http://www.fsis.usda.gov/PDF/Carver.pdf.

86 Produce Safety Project (2008, November 17). *Breakdown: Lessons to be learned from the 2008* Salmonella *Saint Paul outbreak*. Georgetown University. Available from http://www.producesafetyproject.org/reports?id=0001.

87 Center for Agribusiness and Economic Development (2008, July). *Economic impact of Georgia tomato production value losses due to the U.S. Salmonella outbreak* (Center Report CR-08-17). University of Georgia. Retrieved from http://www.caed.uga.edu/publications/2008/pdf/CF-08-17.pdf.

88 Federal Emergency Management Agency (2009, February). *Dam safety in the United States: A progress report on the National Dam Safety Program* (FEMA Publication No. P-759), p. 5.

89 Ibid.

of human life as “high-hazard potential”, and dams whose failure would result in no probable loss of life but could cause economic loss, environmental damage, or other impacts as “significant-hazard potential”. The number of high-hazard potential dams in the U.S. is currently about 13,000, with more than 3,300 high and significant dams located within one mile of a downstream population center and more than 2,400 located within two miles.[90]

A significant factor influencing loss of life to dam failure is the suddenness of the dam collapse and the magnitude of the emergency planning and preparedness required for such an incident. Deaths on a massive scale may result if an evacuation cannot be quickly implemented to move people above inundation levels. The loss of life from dam collapse can be reduced if decision making for protective actions is informed by risk management, alert and notification systems are robust and timely, the public is educated and prepared to mobilize, evacuation is preplanned, and citizens are not unable to evacuate due to traffic congestion.

Data provided to the U.S. Army Corps of Engineers Dam Safety Program Management Tools (DSPMT) indicate that progress is being made in increasing the percentage of state-regulated high-hazard potential dams (an increase from 32 percent in 1999 to 51 percent in 2006) and that states are continuing to increase their inspections of dams. State dam safety programs are continuing to improve through assistance from the National Dam Safety Program and the Interagency Committee on Dam Safety, and such progress is crucial as the Federal Government owns or regulates only about 5 percent of dams in the United States.[91]

Accidental Radiological Substance Release

Though anticipated to be unlikely (see Table B1, Appendix B), an accidental radiological release from a nuclear power plant accident or public exposure to lost or stolen radioactive sources could produce significant public health and economic consequences. Given the severe consequences of a large, radiological release from a power plant, the SNRA analysis focused on nuclear power plant accidents. A national-level power plant accident is defined as any accident that damages the reactor core. The risk to the public and environment is highly dependent on radiation containment and the location of the reactor.[92]

Should the unlikely event of an accident occur, the consequences caused by a nuclear release would be mitigated through several preparedness strategies. Monitoring systems would help individuals in the designated evacuation zone evacuate to the recommended safe distance. Regular testing of monitoring and warning systems ensures that they are functioning properly when an event occurs. In addition, medical countermeasures in the form of potassium iodide tables are currently distributed to all individuals working or residing within 10 miles of nuclear power plants.[93] Taken shortly after a radioactive release, potassium iodide has some protective effect against thyroid cancer resulting from exposure to any radioactive iodine released in the accident. Finally,

[90] Association of State Dam Safety Officials (2012). Dam Safety 101. Available from http://www.damsafety.org.

[91] See note 88.

[92] While the SNRA analysis did not explicitly consider the risk of cascading events such as the Fukushima disaster in Japan (i.e., an earthquake, tsunami, and nuclear release happening concurrently), the frequency of core damage failure caused by external events (fire, seismic events, floods, high winds) is included in some of the publicly-available nuclear power plant license renewal applications used as data sources in the SNRA. The license renewal applications are available from the public website of the U.S. Nuclear Regulatory Commission at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html.

[93] Marburger, J. H. (2008, January 22). *Decision on delegation of section 127(f) of the Public Health Security and Bioterrorism Preparedness and Response Act of 2002*. [Decision memorandum]. Washington, DC: Office of Science and Technology Policy, Executive Office of the President. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/ki-memo-2008.pdf.

evacuation and safe routes are identified and communicated in nuclear power plant communities, and exercises are regularly conducted to test and refine planning for many communities.

Accidental Chemical Substance Spill or Release

The potentially catastrophic consequences of a worst-case scenario accidental spill or release of a highly toxic chemical substance have been frequently studied: models of a release of a highly toxic gas such as chlorine in a densely populated area have projected thousands, even hundreds of thousands of casualties.[94] There have been historical examples of high-consequence releases of chemical substances, including the 1984 Union Carbide accident in India which killed thousands of people in the nearby city of Bhopal, and the massive casualty figures from uses of chlorine and other toxic gases as a deliberate weapon of war.[95] However, these consequence models do not attempt to estimate the likelihood of an accident causing fatalities on such a scale to occur in the United States. Because no national-scale quantitative risk assessments of fixed chemical plants and storage facilities were available, the SNRA analysis utilized 1994-2010 historical accident data reflecting higher-probability but lower-consequence accidents in the U.S. to derive the findings for chemical accidents at fixed facilities.[96] Although chemical accidents in the transportation sector have been extensively and quantitatively modeled on a national scale,[97] it appears that no quantitative national risk assessment for catastrophic accidents in the fixed sector has been completed for the U.S.[98]

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[94] U.S. Department of Homeland Security (2005). *National Planning Scenario #8: Chlorine*; Risk Management Solutions (2004). *Catastrophe, injury, and insurance: the impact of catastrophes on workers compensation, life, and health insurance*, pp. 54-59. Retrieved from http://www.rms.com/Publications/Catastrophe_Injury_Insurance.pdf; Branscomb, L. M., Fagan, M., Auerswald, P., Ellis, R. N., & Barcham, R. (2010, February). *Rail transportation of toxic inhalation hazards: policy responses to the safety and security externality* (Discussion Paper 2010-01). Belfer Center for Science and International Affairs, Harvard Kennedy School. Available from http://belfercenter.ksg.harvard.edu/files/Rail-Transportation-of-Toxic-Inhalation-Hazards-Final.pdf. A significant counterexample is Chang, Y. S., Samsa, M. E., Folga, S. M., & Hartmann, H. M. (2007, November). *Probabilistic consequence model of accidental or intentional chemical releases* (ANL/DIS-08/3). Decision and Information Sciences Division, Argonne National Laboratory. Retrieved from http://www.dis.anl.gov/pubs/61981.pdf.

[95] Branscomb et al, note 94 above; Pastel, Ross, What we have learned about mass chemical disasters. *Psychiatric Annals,* (11), 754-765. Retrieved from http://www.psychiatricannalsonline.com/showPdf.asp?rID=24853. A significant historical counterexample is the 1979 Mississauga accident.

[96] From the EPA's Risk Management Program (RMP) accident data for chemical accidents at fixed facilities, and the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) accident data for chemical accidents during transportation by road, rail, air, water, or pipeline, in both cases limited to casualties and economic damages directly caused by a toxic inhalation hazard gas (and excluding flammable and explosive materials such as gasoline, propane, and ammonium nitrate). RMP data is publicly available at http://www.rtknet.org. PHMSA data is publicly available at https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch.

[97] See for instance Raj, P. K. (1988, November). *A risk assessment study on the transportation of hazardous materials over the U.S. railroads* (DOT/FRA/ORD-88/14). Washington, DC: Federal Railroad Administration, U.S. Department of Transportation. Retrieved from http://www.fra.dot.gov/downloads/research/ord8814.pdf; Raj, P. K., and Turner, C. K. (1993, May 15). *Hazardous material transportation in tank cars: Analysis of risks – Part I* (DOT/FRA/ORD-92/34). Washington, DC: Federal Railroad Administration, U.S. Department of Transportation. Retrieved from http://www.fra.dot.gov/downloads/Research/ord9234.pdf; Brown, D. F., Dunn, W. E., & Policastro, A. J. (2000, December). *A national risk assessment for selected hazardous materials in transportation* (ANL/DIS-01-1). Decision and Information Sciences Division, Argonne National Laboratory. Retrieved from http://www.ipd.anl.gov/anlpubs/2001/01/38251.pdf; Vanderbilt Center for Transportation Research (2012). Intermodal GIS network risk assessment. Vanderbilt University. Retrieved from http://www.vanderbilt.edu/vector/?page_id=340.

[98] Fullwood, R. R. (2000). Probabilistic Safety Assessment in the Chemical and Nuclear Industries. Woburn, MA: Elsevier; Mannan, S. (Ed.). (2005). Lees' Loss Prevention in the Process Industries (3rd ed.). Burlington, MA: Elsevier.

Adversarial Events

Overview[99]

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) for likelihood and fatality, illness/injury, and economic loss estimates for the five CBRN national-level events. As the ITRA is designed to generate customized reports to inform multiple decision contexts, including differing thresholds and splits or aggregations by specific agents or targets, the DHS Directorate of Science & Technology (S&T) provided data corresponding to the scope of the five CBRN events as defined in the SNRA. Chemical and biological attacks on the food supply chain were split out from the ITRA chemical and biological attack events and combined into a single SNRA event.

All likelihood and consequence estimates derived from the ITRA, the psychological distress estimates derived from the ITRA fatality and injury/illness data, and comparative risk judgments are classified at the SECRET//NOFORN level and may be found in the full SNRA Technical Report. The methodology and analysis of the ITRA are described in detail in the technical reports of the ITRA and its three component assessments, the Biological Terrorism Risk Assessment (BTRA), the Chemical Terrorism Risk Assessment (CTRA), and the Radiological/Nuclear Terrorism Risk Assessment (RNTRA). The TRAs leverage a probabilistic risk assessment (PRA) methodology of substantial complexity and maturity which is difficult to treat fairly in a compact manner, and thus the methodological discussion for these events is limited to the key parameters needed for a reviewer with the appropriate clearances to replicate the SNRA's quantitative estimates from the ITRA computational engine. Detailed discussion of the PRA methodology and its adaptation for DHS's terrorist risk assessments may be found in the unclassified literature.[100]

For the three conventional attack method national-level events (Armed Assault, Aircraft as a Weapon, and Explosives Terrorism Attack) the SNRA leveraged open-source literature and prior work by the DHS Office of Risk Management & Analysis for the fatality, injury and illness, and economic loss estimates. While these consequence estimates and the psychological consequence estimates derived from them are U//FOUO, the majority of the methodology and sources used to derive them are unclassified (non-FOUO) and may be found in the corresponding risk summary sheets. Event frequencies were elicited from subject-matter experts provided by multiple agencies in the Intelligence Community, and are also classified at the SECRET or SECRET//NOFORN level.

Classified frequency estimates for the two cyber events were also obtained by expert elicitation from the Intelligence Community and DHS and U.S. Government agencies responsible for cyber security. The SNRA project was not able to obtain consensus consequence estimates corresponding to the elicited frequencies, however. For this reason, while the classified frequency estimates themselves may be found in the full SNRA Technical Report, the remainder of the SNRA's cyber event analysis and discussion is unclassified and included here in full.

The SNRA's social displacement and environmental consequence estimates are unclassified and non-FOUO for all events and are included here in full. However, since the SNRA defines the *risk* corresponding to a measure of consequence to be the product of these consequences with event frequencies, all of which are classified for adversarial events, risk judgments and visualizations comparing the adversarial events among themselves or with other events are classified at the SECRET or SECRET//NOFORN level and may be found in the full SNRA Technical Report.

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[99] Additional discussion of the classified data sources of the SNRA is provided in Appendix M.

[100] See Ezell et al (2010, April), Probabilistic risk analysis and terrorism risk, *Risk Analysis* 30(4) 575-589.; and pp 101-104, Gerstein, Daniel M. (2009), *Bioterror in the 21st Century: Emerging Threats in a New Global Environment*, Naval Institute Press, Annapolis MD. While somewhat dated, the most comprehensive and critical review remains National Research Council (2008), *Department of Homeland Security Bioterrorism Risk Assessment: a call for change*, National Academies Press, Washington DC.

Nuclear Terrorism Attack

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) to estimate the risk from nuclear terrorism attacks. Specifically, the SNRA included analysis of a nuclear attack in which a hostile non-state actor(s) acquires an improvised nuclear weapon through manufacture from fissile material, purchase, or theft, and detonates it. Nine U.S. cities were considered in calculating the frequency and consequences of the attack. The cities were chosen to sample a variety of locations and population densities and included New York, Washington, Houston, and Miami. Impacts of the attack were evaluated for four yields across the nine cities and were evaluated 12 times throughout the year to sample atmospheric conditions at detonation.[101]

A successful nuclear attack would cause substantial fatalities, injuries, and infrastructure damage from the heat and blast of the explosion, and significant radiological consequences from both the initial nuclear radiation and the radioactive fallout that settles after the initial event. A nuclear detonation in a modern urban area would impact the medical system more than any disaster previously experienced by the Nation.[102] An electromagnetic pulse from the explosion could also disrupt telecommunications and power distribution. Significant economic, social, psychological, and environmental impacts would be expected.[103]

Nuclear explosions are classified by yield, or the amount of energy they produce, relative to how many tons of TNT would be needed to produce an equivalent explosive yield. Strategic nuclear weapon systems held by state actors deliver weapons with yields in the multi-hundred kilotons to megaton (1,000 kiloton) range. Generally, when considering nuclear explosion scenarios perpetrated by terrorists, experts assume a low-yield nuclear device detonated at ground level, where low yield in this context ranges from factions of a kiloton (kT) to 10 kT.[104] A terrorist attack could be carried out with an improvised nuclear device (IND), which is a crude nuclear device built from the components of a stolen weapon or from scratch using nuclear material (plutonium or highly enriched uranium).

The primary obstacle to a terrorist IND attack is limited access to weapon-grade nuclear materials: highly enriched uranium, plutonium, and stockpiled weapons are carefully inventoried and guarded. Nuclear attack is also impeded because:

1. Building nuclear weapons is difficult – general principles are available in open literature, but constructing a workable device requires advanced technical knowledge in areas such as nuclear physics and materials science.
2. Crude nuclear weapons are typically very heavy, ranging from a few hundred pounds to several tons, and are difficult to transport, especially by air. Specially designed small nuclear weapons, including the so-called "suitcase nuclear weapons" are much lighter, but they are difficult to acquire and to construct.[105]

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[101] U.S. Department of Homeland Security (2011, October 24). *2011 Radiological/Nuclear Terrorism Risk Assessment (RNTRA)*, Vol. 1. (Reference is SECRET//NOFORN: Extracted information is UNCLASSIFIED.)

[102] National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (2010, June). *Planning Guidance for Response to a Nuclear Detonation* (2nd ed), p. 81.

[103] National Academies, U.S. Department of Homeland Security (2005). Nuclear attack. Fact sheet for the public (series, Communicating in a Crisis). Retrieved from http://www.dhs.gov/xlibrary/assets/prep_nuclear_fact_sheet.pdf via http://www.ready.gov (checked April 2015).

[104] It should be noted that if a state-built weapon were available to terrorists, the presumption of low yield may no longer hold. NSS (2010) *op cit.,* p. 15.

[105] National Academies & DHS (2004). Nuclear attack public fact sheet, *op. cit.*

Radiological Terrorism Attack

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) to estimate the risk from radiological terrorism attacks. The analysis only included data for successful attacks (e.g. detonation of the device or successful spread into the food or water system). Failed attacks, whether from interdiction during the fabrication and assembly of the dispersal device, interdiction during travel to United States, or failure of the dispersal device, were not included in this analysis.

Radiological devices used for terrorism may include radiological dispersal devices (RDD) and radiological exposure devices (RED). The principal type of RDD is a “dirty bomb” that combines a conventional explosive with radioactive material. A second type involves radioactive material dispersed in air or water by other mechanical means, such as a water spray truck, a crop duster, or manually spread. An RED may comprise a powerful radioactive source hidden in a public place, such as a trash receptacle in a busy train or subway station, to expose passers-by to a potentially significant dose of radiation.[106]

It is very difficult to design an RDD that would deliver radiation doses high enough to cause immediate health effects or fatalities in a large number of people. Most injuries from a dirty bomb would probably occur from the heat, debris, and force of the conventional explosion used to disperse the radioactive material, affecting individuals close to the site of the explosion. At the low radiation levels expected from an RDD, the immediate health effects from radiation exposure would likely be minimal.[107] Subsequent decontamination of the affected area could involve considerable time and expense. A dirty bomb could have significant psychological and economic effects.[108]

Most radiological devices would have very localized effects, ranging from less than a city block to several square miles. Factors determining the area of contamination would include the amount and type of radioactive material, the means of dispersal, the physical and chemical form of the radioactive material (for example, material dispersed in the form of fine particles may be carried by the wind over a relatively large area), local topography and location of buildings, and local weather conditions.[109]

Preparedness and effectiveness of response teams will play a significant role in mitigating the consequences caused by an RDD attack. Early identification of a radiological attack is important in determining whether or not to evacuate the area or shelter in place and the size of the area requiring cordoning.

Biological Terrorism Attack (non-food)

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) in order to estimate risk from non-food biological terrorism attacks.

The SNRA considered the risk from a non-food biological attack in which a hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target with a concentration of people within the United States. Frequency estimates for this event only include data for successful attacks (e.g., detonation of a device or release of an agent). Examples of failed attacks not included in the SNRA include interdiction during the fabrication and

[106] U.S. Environmental Protection Agency (2006, October). OSC Radiological Response Guidelines. Office of Solid Waste and Emergency Response, Office of Air and Radiation, U.S. EPA; at http://www.uscg.mil/hq/nsfweb/foscr/ASTFOSCRSeminar/References/EnvResponsePapersFactSheets/OSCRadResponseGuidelines.pdf (retrieved April 2013).

[107] National Academies and U.S. Department of Homeland Security (2004). Radiological attack: dirty bombs and other devices. Retrieved from http://www.dhs.gov/radiological-attack-fact-sheet via http://www.ready.gov.

[108] EPA (2006) OSC Radiological Response Guidelines, *op. cit.*

[109] Ibid.

assembly of the dissemination device, interdiction during travel to the United States, or failure of the dissemination device.

Biological agents can be isolated from sources in nature, acquired from laboratories or a state bioweapons stockpile, or synthesized or genetically manipulated in a laboratory. Potential dissemination mechanisms of a biological agent by terrorists include aerosol dissemination from sprayers or other devices outdoors or through the ventilation system of a building, subway, or airplane, human carriers, insects or other animal vectors, or physical distribution through the U.S. Mail or other means. Biological agents include transmissible agents that spread from person to person (e.g. smallpox, Ebola) or agents that may cause adverse effects in exposed individuals but which do not make these individuals contagious (e.g. anthrax, botulinium toxin).[110]

Unlike a nuclear or chemical attack, a biological attack may go undetected for hours, days, or potentially weeks (depending on the agent) until humans, animals, or plants show symptoms of disease. If there are no immediate signs of the attack as with the anthrax letters, a biological attack will probably first be detected by local health care workers observing a pattern of unusual illness, or by early warning systems that detect airborne pathogens. There may be uncertainties about crucial facts such as the exact location or extent of the initial release, the type of biological agent used, and likelihood of additional releases. The exact infectious dose (the number of organisms needed to make one sick, referred to as dose response) and the long-term health consequences for those who survive exposure are key scientific knowledge gaps for many biological agents: while approximate ranges and prognoses for humans have been extrapolated from animal studies, they comprise additional uncertainties which may complicate the public health response to a biological attack.[111]

Chemical Terrorism Attack (non-food)

The SNRA leveraged the 2011 DHS Integrated Terrorism Risk Assessment (ITRA) in order to estimate risk from non-food chemical terrorism attacks.

The SNRA considered the risk from a non-food chemical attack in which a hostile non-state actor(s) releases a chemical agent against an outdoor, indoor, or water target with a concentration of people within the United States. Frequency estimates for this event only include data for successful attacks (e.g. detonation of a device or release of an agent). Examples of failed attacks not included in the SNRA include interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to the United States, or failure of the dissemination device.

Chemical agents can be acquired from a variety of different sources (e.g., chlorine, mustard gas, sarin) and disseminated in various modes. Potential delivery mechanisms of a chemical agent by terrorists include building ventilation systems, misting or aerosolizing devices, passive release (container of chemical left open), explosives, improvised devices combining readily available chemicals to produce a dangerous chemical, or sabotage of industrial facilities or vehicles containing chemicals.[112]

According to the 2010 Chemical Terrorism Risk Assessment (CTRA), exposure to a chemical threat can result in health effects within a matter of minutes. This stands in contrast to many biological scenarios, and significantly impacts the risk reduction potential that exists in the chemical scenarios where casualties can occur rapidly after exposure. For chemicals with a delayed

[110] National Academies and U.S. Department of Homeland Security (2004). Biological attack: human pathogens, biotoxins, and agricultural threats. Retrieved from http://www.dhs.gov/biological-attack-fact-sheet via http://www.ready.gov.

[111] Ibid.

[112] National Academies and U.S. Department of Homeland Security (2004). Chemical attack: warfare agents, industrial chemicals, and toxins. Retrieved from http://www.dhs.gov/chemical-attack-fact-sheet via http://www.ready.gov.

symptom onset, the 2010 CTRA identified related critical issues, including the timeliness of event detection and the logistics associated with successfully delivering medical countermeasures to exposed victims. These scenarios continue to be good candidates for risk management effort because improvements in event detection time or in medical countermeasure delivery were assessed to have the potential to significantly reduce chemical terrorism risk.[113]

Chemical/Biological Food Contamination Terrorism Attack

The SNRA also examined a national-level event involving successful chemical/biological attacks targeting food within the U.S. supply chain. The DHS Science and Technology Directorate (S&T) extracted data from the 2011 DHS Integrated Terrorism Risk Assessment (ITRA)[114] for chemical and biological attacks on food and beverage targets for analysis as a national-level event in the SNRA distinct from attacks on non-food targets.[115]

Chemical and biological weapons differ in potential toxicity, specificity, speed of action, duration of effect, controllability, and residual effects.[116] Children, the elderly, pregnant women, and immune-compromised individuals are particularly susceptible to the adverse effects of a chemical/biological food contamination.[117]

A terrorist attack on the Nation's food supply chain using chemical or biological agents may initially be indistinguishable from an unintentional food contamination. Depending on the type of agent used in the attack, it could take several days for individuals to show symptoms and possibly weeks before public health, food, and medical authorities suspect terrorism as the source.[118] In 1984 members of the Rajneeshees, a religious community in an accelerating political dispute with the Oregon county where they had established their commune, deliberately contaminated salad bars at eight county restaurants with *Salmonella* bacteria, infecting or sickening 751 people and hospitalizing 45.[119] However, deliberate contamination was not identified until a year later, when

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[113] U.S. Department of Homeland Security (2010, May). *Chemical Terrorism Risk Assessment (CTRA): Full report.* (Reference is SECRET: Extracted information is UNCLASSIFIED.)

[114] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

[115] The scope of the SNRA chemical/biological food contamination event (e.g. the portions of the ITRA event tree for which the event's data were calculated) included water products (i.e. bottled water) distributed through the food consumer supply chain, but all other attacks against water targets (e.g. piped water) were included with the chemical and biological non-food attacks.

Attacks on agriculture were excluded from all events. While intentional attacks on agriculture were prioritized for inclusion in the SNRA as a national-level event corresponding to the unintentional Animal Disease event, methodological issues involving data comparability prevented the use of ITRA data on agricultural targets in the first iteration of the SNRA.

[116] United Nations (1970). Chemical and Bacteriological (Biological) Weapons and the Effects of Their Possible Use, p. 12. Report of the Secretary-General, UN Publication no. E.69.I.24. Reprinted by Ballantine Books, 1970.

[117] FEMA (2008), *op. cit.*

[118] Federal Emergency Management Agency (August 2008), Food and Agricultural Incident Annex, p. 2, at http://www.fema.gov/pdf/emergency/nrf/nrf_FoodAgricultureIncidentAnnex.pdf (retrieved January 2015).

[119] This was to test a plan to poison the county water supply on Election Day, to suppress voter turnout and enable the group to take over the county board by electing their own candidates. Török et al (1997, August 6). A large community outbreak of Salmonellosis caused by intentional contamination of restaurant salad bars. *Journal of the American Medical Association (JAMA)* 278(5) 389-395; at http://www.cdc.gov/phlp/docs/forensic_epidemiology/Additional%20Materials/Articles/Torok%20et%20al.pdf (retrieved May 2014). Although unsuccessful in identifying deliberate action as the cause of the poisoning, CDC and FBI investigations following the incident may have deterred the group from carrying out their planned Election Day attack in November. Sobel et al (2002, March 9). Threat of a biological attack on the US food supply: the CDC perspective. *Lancet* 359(9309) 874-880.

the commune collapsed and criminal investigations into its other activities uncovered its clandestine biological laboratories.[120,121]

Population exposure can be limited with fast and accurate identification of the agent and vehicle (water, milk, lettuce, etc.) utilized to target the food supply system. A prepared public communications plan will assist in further limiting the spread while also mitigating the economic losses associated with falsely identifying the food contaminant.

Aircraft as a Weapon

Terrorists have long viewed aviation as a target for attack and exploitation. Successful attacks in the air domain can inflict mass casualties and grave economic damage, and attract significant public attention. Historically, large passenger aircraft have been at the greatest risk to terrorism, whether bombings, taking of hostages, traditional hijacking, and attack using human-portable surface-to-air missiles. Aircraft have also been used as weapons against targets on the ground, most notably but not limited to the attacks of September 11, 2001.[122]

For this incident, the SNRA only considered the risk of aircraft being used as a kinetic mode of attack (e.g. a 9/11 style attack) rather than the risk of an improvised explosive device (IED) being detonated on an aircraft. The latter risk is considered under the explosives incident category in the SNRA.

Explosives Terrorism Attack

Terrorism attacks using explosives are a familiar threat to the American public, having occurred at the World Trade Center in 1993, Oklahoma City in 1995, and the Summer Olympics in 1996, amongst other occasions. Explosive devices can come in many forms, ranging from a small pipe bomb to a sophisticated device capable of causing massive damage and loss of life. Explosives can be carried or delivered in a vehicle; carried, placed, or thrown by a person; delivered in a package; or concealed on the roadside.[123] The reliability and availability of needed components and materials make it likely that explosives will remain a major part of terrorists' inventory in the future. Additionally, recent innovations in explosive use by groups such as al Qaeda in the Arabian Peninsula (AQAP) suggest that terrorist explosive attacks will remain a complex defensive challenge to the Nation in coming years.[124]

The SNRA analyzed the risk of a hostile non-state actor(s) successfully deploying a man-portable explosive device such as an improvised explosive device (IED), vehicle-borne IED (VBIED), or vessel IED in the U.S. against a concentration of people and/or structures like critical commercial or government facilities, transportation targets, or other critical infrastructure sites. Bombings of

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[120] Török et al, *op cit.*

[121] Carus, W. Seth (2001, February). Bioterrorism and biocrimes: the illicit use of biological agents since 1900. Pages 50-58. National Defense University; at http://www.ndu.edu/centercounter/full_doc.pdf (retrieved March 2013). Agents experimented with included *Salmonella typhimurium*, the variant which was used in the salad bar attacks, *Salmonella typhi* which causes hepatitis and typhoid fever, *Giardia*, HIV, and multiple chemical and pharmaceutical poisons. *Giardia lamblia* was to be introduced into the county water supply via dead rats and beavers, which carry the parasite (p. 54).

[122] U.S. Department of Homeland Security (2007, March 26). *National Strategy for Aviation Security.* At http://www.dhs.gov/publication/national-strategy-aviation-security.

[123] National Academies and U.S. Department of Homeland Security (2004). IED attack: improvised explosive devices. Retrieved from http://www.dhs.gov/ied-attack-fact-sheet.

[124] Clapper, James R. (2011, February 16). Statement for the Record on the Worldwide Threat Assessment of the U.S. Intelligence Community for the Senate Select Committee on Intelligence [written testimony]. Retrieved from http://www.intelligence.senate.gov/110216/dni.pdf.

aircraft (as opposed to use of an airplane as a weapon which was treated separately) were also included within the scope of the Explosives Terrorism Attack event.

Armed Assault

For the SNRA, the health and safety consequences of a hostile, non-state actor(s) using assault tactics to conduct strikes on vulnerable target(s) was estimated using historical data from the Global Terrorism Database (GTD).[125] To capture the range of terrorist attacks with small arms including large-scale assault/siege-type attacks like the 2008 complex attack in Mumbai, India, historical incidents of successful armed assault and explosives attacks, involving the use of firearms but excluding biological and chemical weapons were included in the data set used to determine fatality and injury estimates. Direct economic damage estimates for incidents of corresponding scope to this historical incident set were calculated using the DHS RAPID 2010 risk modeling engine.[126]

However, the SNRA incorporates new data about the frequency of successful armed assault attacks in the United States which was elicited from Intelligence Community subject matter experts. An overview of the elicitation process is given in Appendix B: additional details and results may be found in Appendix B of the classified SNRA Technical Report.

[125] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970 to 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and – when identifiable – the group or individual responsible. National Consortium for the Study of Terrorism and Responses to Terrorism (START) (2011, July). Global Terrorism Database [Data file]. Available from http://www.start.umd.edu/gtd.

[126] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.

Cyber Event Discussion

The SNRA included two types of cyber events: cyber events affecting data and cyber events affecting physical infrastructure. Cyber events which are intentionally caused by any type of human actor, including hackers, activists, states, terrorists, malicious insiders, or criminals, were considered. Unintentional human-caused events (such as unintentional breaches or accidents) or non-human caused events (such as those caused by natural disasters or equipment malfunctions) were not considered.

All types of cyber weapons, including but not limited to malicious software, botnets, distributed denial-of-service attacks, etc., were considered. Note that for the purposes of the SNRA – which is intended to inform civilian capability development – direct attacks on defense systems were not considered. Additionally, state and non-state espionage was not considered.

Cyber Event affecting Data

> *Cyber attacks can have their own catastrophic consequences and can also initiate other hazards, such as power grid failures or financial system failures, which amplify the potential impact of cyber incidents.*
>
> *National Preparedness Goal, September 2011*

The SNRA evaluated cyber events that focus on compromising data or data processes as the primary result. Although events in this category almost always have indirect effects that "occur beyond the computer", events for which impacts to physical infrastructure is a primary objective of the attack were excluded and considered separately. For the purposes of the SNRA, a national-level cyber event affecting data was defined as an event which resulted in at least $1 billion in economic losses. Such events could take many forms and be perpetuated in order to achieve many goals. Some examples include the altering of records in a healthcare or financial system or an event that causes the internet or communications networks to cease.

Frequency information about the type of data/data processes targeted in cyber events is difficult to locate in open source material, but as one example, a 2010 Verizon report analyzed 141 data breach cases from 2009.[127] To obtain the SNRA frequency for this type of event, the frequency of successful cyber events affecting data resulting in $1 billion in economic losses or greater was elicited from Intelligence Community (IC) subject matter experts. The frequency elicitation is described in greater detail in Appendix B.

Consequences for cyber events are difficult to quantify because of the cascading impacts which can originate from a cyber event. The consequences included in the above referenced Verizon report estimate the total number of data records compromised to exceed 143 million.[128] For those data breaches included in the Verizon report, most of the losses came from only a few of the 141 breaches, which was consistent with breaches which had occurred in previous years.[129]

More anecdotally, the Wall Street "Flash Crash" of 2010 also highlights potential consequences of a cyber event. As a result of complex automated trades, this incident created enough market volatility to hemorrhage approximately $1 trillion in only minutes, with some stocks dropping more than 90 percent in value. While the volatility was unintentional and the stocks recovered, the crash

[127] Verizon RISK Team (2010). *2010 Data breach investigations report*, p. 7. Retrieved from http://www.verizonbusiness.com/resources/reports/rp_2010-data-breach-report_en_xg.pdf.

[128] Ibid.: p. 7.

[129] Ibid.: p. 40.

illustrates the potential consequences of sophisticated cyber attacks against a financial system that relies increasingly on automated high-frequency trading.[130]

Cyber Event affecting Physical Infrastructure

The SNRA assessed the risk of cyber events affecting physical infrastructure or assets that have the potential to produce national-level events outside the physical world. For the purposes of the SNRA, a national-level cyber event affecting physical infrastructure was defined as an event which resulted in at least one fatality or $100 million in economic losses. These types of events could involve a variety of targets, such as the electric grid, a dam, or a water system. While the events in this category may involve the manipulation of data as a means to an end, an event whose *direct* result is only compromised data (such as intellectual property theft or altered healthcare records) was not considered.

The threat of cyber events affecting physical infrastructure has seen increased prominence recently, as the extent of the Stuxnet infections have come to light. A 2010 CSIS-McAfee survey of 200 critical infrastructure executives from the energy, oil/gas, and water sectors in 14 countries found that around 40 percent of respondents had discovered Stuxnet on their computers.[131] While three-quarters of respondents who found Stuxnet were confident it had been removed from their systems, the potential for widespread sabotage through the introduction of malware into SCADA systems was clearly demonstrated.[132]

To obtain the SNRA frequency for this type of event, the frequency of successful cyber events affecting physical infrastructure resulting in $100 million in economic losses or greater was elicited from Intelligence Community (IC) subject matter experts. This frequency elicitation is described in greater detail in Appendix B.

Consequences for these types of cyber events are sector-dependent and difficult to quantify. Approximately 85 percent of critical infrastructure is believed to be owned and operated by the private sector, and system vulnerability and resilience is highly sector-dependent and localized.[133]

Final Notes

The SNRA findings detailed above provide a broad analysis of the risks from the varied threats and hazards faced by the Nation. As noted above, the assessment finds that a wide range of threats and hazards pose a significant threat to the Nation, affirming the need for an all-threats/hazards, capability-based approach to preparedness planning. Many opportunities exist to implement broad preparedness strategies that cut across many different threats and hazards. It is also important to keep in mind that within an all-hazards preparedness context, particular events which present risk to the Nation – such as nuclear attacks or chemical releases – require additional specialized response activities.

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[130] Quoted in full from Pett, D. (2010, May 8). High-frequency swaps, dark pools under scrutiny. *National Post's Financial Post & FP Investing;* and from Scannell, K. & Lauricella, T. (2010, October 2). Flash crash is pinned on one trade. *The Wall Street Journal*; as originally cited in Lord, K.M. & Sharp, T. (2011, June). *America's cyber future: Security and prosperity in the information age,* Vol. 1. Washington, DC: Center for a New American Security, p. 25.

[131] McAfee and the Center for Strategic and International Studies (2011, April). *In the dark: Crucial industries confront cyberattacks*, p. 8. Retrieved from http://www.mcafee.com/us/resources/reports/rp-critical-infrastructure-protection.pdf.

[132] Ibid.

[133] U.S. Department of Homeland Security, Office of Infrastructure Protection (2011, September 12). Critical infrastructure sector partnerships. Retrieved from http://www.dhs.gov/files/partnerships/editorial_0206.shtm.

IMPACTS AND FUTURE USES

The SNRA was executed in support of PPD-8 implementation and served as an integral part of the development of the National Preparedness Goal, assisting in integrating and coordinating identification of the core capabilities and establishing a risk-informed foundation for the National Preparedness System.

In addition, conducting a Strategic National Risk Assessment supported the National Preparedness System by providing a consolidated list of "national level events" for consideration and augmentation for Threat and Hazard Identification and Risk Assessment (THIRA) processes at multiple jurisdiction levels. Some events, such as explosives or earthquakes, generally cause more localized consequences, while other events, such as human pandemics, may cause consequences that are dispersed throughout the Nation, thus creating different types of impacts for preparedness planners to consider.

The SNRA provides an understanding of the risks that pose the greatest challenge to the Nation's security and resilience. This understanding is crucial for preparedness planning and prioritization. It enables:

- A shared understanding of the potential incidents for which communities should prepare
- A prioritization of the incidents that may pose the greatest negative impact to communities and thus require preparedness
- The evaluation of needed capabilities, and capability levels across all five focus areas: Prevention, Protection, Mitigation, Response, and Recovery

More specifically, the SNRA has already served as an integral part of the development of the National Preparedness Goal, assisting in integrating and coordinating identification of core capabilities. The core capabilities identified in the Goal were mapped to the events assessed in the SNRA to identify any additional core capabilities that may be needed and/or any capabilities that did not address high priority risks.

In addition to supporting the development of the National Preparedness Goal, the SNRA has the potential to assist with a wide range of efforts which are crucial to executing the Preparedness Cycle.

Figure 9: The Preparedness Cycle

These include:

- *Planning* – The SNRA findings can help a planning team decide which hazards deserve special attention, what actions must be planned for and what capabilities (and eventually resources) are likely to be needed. Since the SNRA is a strategic and national assessment, it was designed first and foremost to support planning at the national level. It can do so by being an input to help identify national planning factors that support the ability to deliver a target level of capabilities. According to the National Preparedness System, planning factors are based on assessments of risk and the desired outcome(s) to be achieved. For example, if a desired outcome is to prevent an imminent terrorist attack, then a set of planning factors that help to define the adversary or modes of attack will aid in identifying the level of capability required to prevent the attack. These planning factors help inform decisions about the capability level required and the resources needed to achieve it.

  Ultimately, however, it is important for communities to develop their own planning factors, tailored to their specific circumstances. Therefore, it is necessary to not only consider national risks as done through the SNRA but also risks at a regional level, many of which differ from region to region. This will allow for the development of regional planning factors that will support community planning consistent with the National Planning System.

- *Organizing and Equipping* – The SNRA, along with other risk assessments, should be a key component of an analytically-driven approach to allocate resources at the national level. By better understanding the risks facing the Nation, the Federal government and its partners can identify realistic capability requirements and organize and equip to deliver these capabilities. This can be done via the development of new policy or regulatory approaches, an increase in organizational capacity, and the prioritization of new research and development efforts, as well as other mechanisms for building capability.

- *Training and Exercises* – The SNRA can help focus limited training and exercising resources and ensure they are targeted to incidents of the highest risk. The SNRA can also be used as an input to help identify core capabilities that should be tested in training and exercises in order to reduce risks from identified threats and hazards. This is true for many types of exercises – whether an exercise-based planning session, a drill, or a functional or full-scale exercise.

- *Evaluate/Improve* – A principal aim of the National Preparedness System is to support the ability to measure how prepared we are at the national and community level. Assessments aid in that endeavor. As capabilities are assessed, they may be included in future iterations of the SNRA to better understand the impact of enhanced preparedness on the national risk picture and support dynamic and flexible planning to emerging risks.

In summary, the SNRA informs prioritization and tradeoff decisions by enabling the analysis of which capabilities are likely to have an impact at reducing identified high-risk events. Using the SNRA, the homeland security enterprise can better understand which scenarios are more likely to impact them, what the consequences would be, what risks merit special attention, what actions must be planned for, and what resources are likely to be needed. This allows for making risk-informed tradeoffs within and across core capabilities.

The SNRA is, of course, not the only input to such tradeoff decisions. Organizations will appropriately continue to consider other factors – including costs and expected performance of capabilities, stakeholder input, policy and statutory considerations, and other types of risk analysis. Still, the SNRA provides a common national risk picture to serve as an additional input into preparedness prioritization, which is crucial to achieve the vision of the National Preparedness

System. Future versions of the assessment will refine and improve our understanding of the national risk picture.

Although the development of the SNRA is an important first step, further analysis through the conduct of regional- and community-level risk assessments will help communities better understand their risks and form a foundation for their own security and resilience. In conjunction with Federal, state, and local partners, the SNRA will continue to be expanded and enhanced, and will ultimately serve as a unifying national risk profile to facilitate preparedness efforts.

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APPENDIX A: DATA VISUALIZATION IN THE SNRA

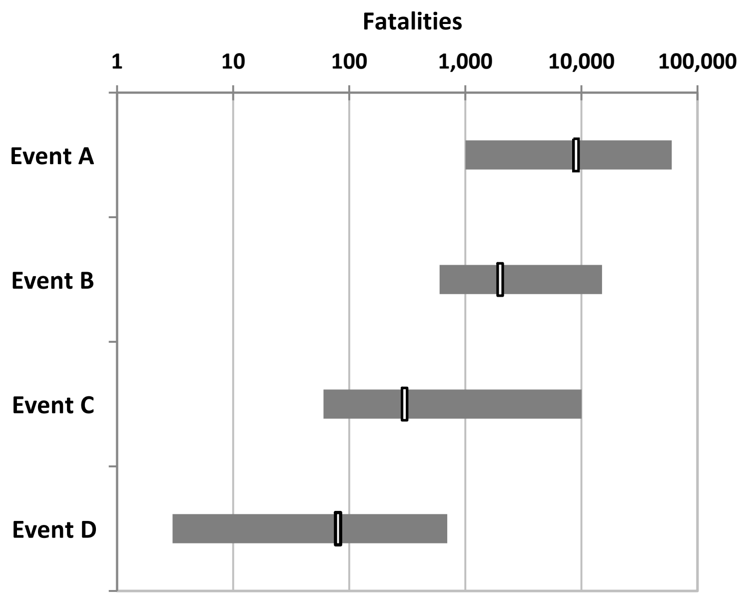
The main body and appendices of the SNRA Technical Report include two types of quantitative charts: bar plots and scatter plots. Bar plots are used when analyzing a single type of information (such as frequency or consequence, but not both at the same time), and scatter plots are used to analyze two types of information simultaneously (such as frequency and fatalities).

Bar Plots

On a bar plot, each bar represents a single national-level event. Bars that are located toward the top of the chart are larger in the plotted quantity than points at the bottom. Each bar is a visual representation of the uncertainty in the value of the plotted quantity for a specific national-level event. As illustrated in Figure A1, three points characterize each bar: (1) the best estimate of the plotted quantity, represented by a vertical stripe; (2) the high estimate of the plotted quantity, represented by the right end of the bar; and (3) the low estimate of the plotted quantity, represented by the left end of the bar. When two bars overlap (meaning that one can draw a vertical line that intersects both bars), then there is some uncertainty as to which of the two quantities is larger. The larger the degree of overlap, the more uncertain it is which quantity is larger.

Each bar plot included in this report is constructed using a logarithmic horizontal axis. This means that each vertical background line denotes a change in the plotted quantity (whether frequency or consequence) by a factor of ten. As a result, the difference between the left and the right of the SNRA bar plots can be quite large, even factors of thousands or millions. Logarithmic axes allow quantities that differ by very large ratios to be plotted on the same chart, and straightforwardly compared.

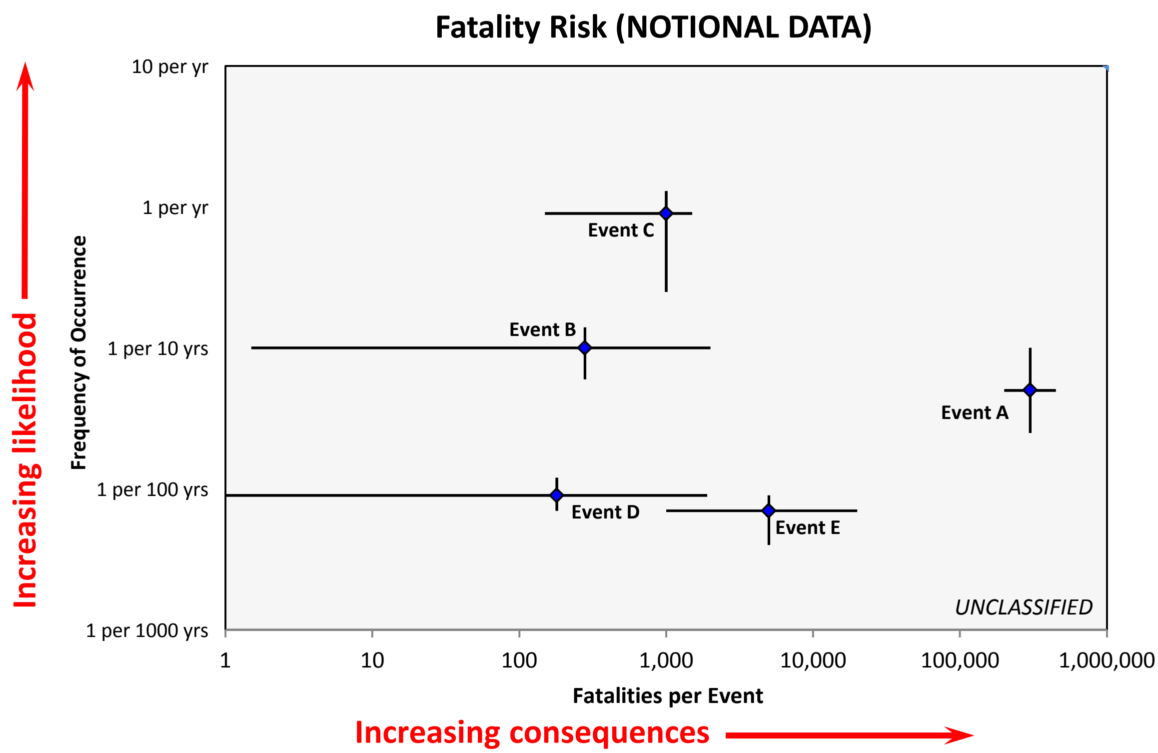
Figure A1: Example Bar Plot



Scatter Plots

On a scatter plot, each point, with crosshairs, represents a single national-level event. Since frequency (events per year) is the vertical axis, events that are higher frequency tend toward the top of the plot. Similarly, events with higher consequence tend toward the right of the plot. This is illustrated in Figure A2.

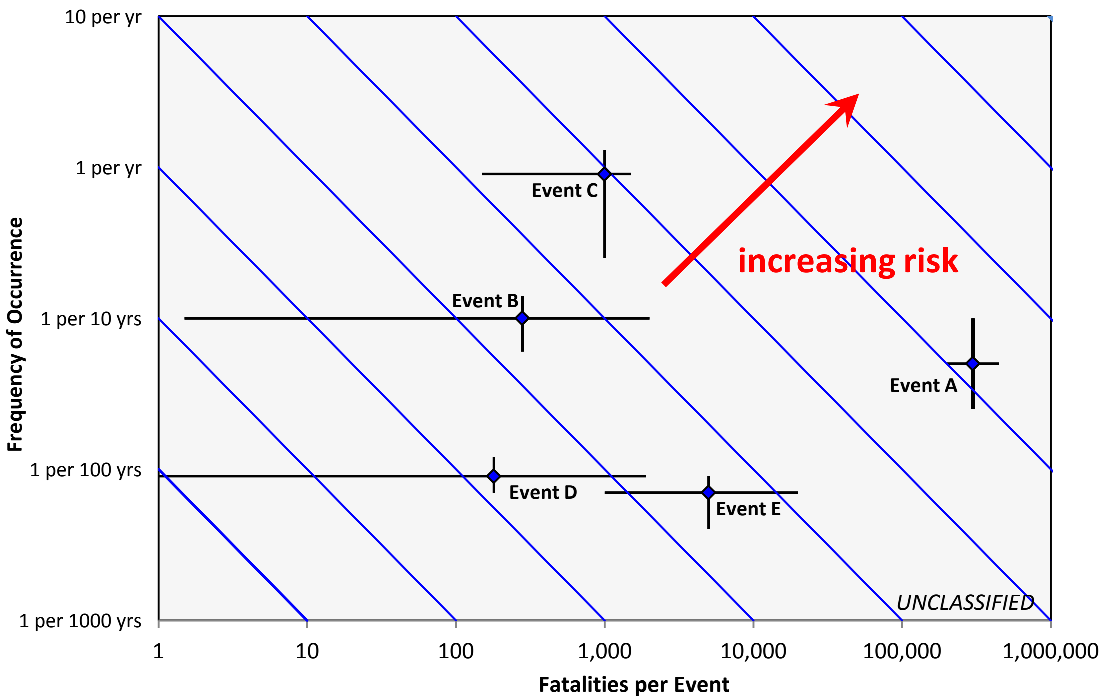
Figure A2: Example Scatter Plot



The vertical line of the crosshair denotes the uncertainty in frequency and the horizontal line denotes the uncertainty in consequence. The interpretation of the crosshairs depends on how the data was gathered for that particular national-level event and is guided by the text that accompanies each scatter plot: "Frequency and consequence estimates are correlated at the mean where denoted by a solid circle at the intersection of the ranges; those with an open circle are not necessarily correlated at the intersection. No correlation should be assumed for arbitrary frequency-consequence pairings within the uncertainty of any national-level event without additional review of the underlying data. Note that high frequency estimates are rarely, if ever, correlated with high consequence estimates."

Like the bar plots, scatter plots are constructed using logarithmic axes. However, in contrast to the bar plots, the scatter plots are logarithmic in both the vertical and horizontal axes. Scatter plots have an additional useful interpretation when they are constructed with logarithmic frequency and consequence axes: the highest risk national level events congregate in the upper right hand corner and the lowest risk events in the lower left. The diagonal background lines, drawn in the upper left to lower right direction, represent lines of constant risk, as illustrated in figure A3. This means that two national level events that fall on the same line have a similar level of risk.[1] The diagonal lines are drawn to differentiate between factors of ten in risk. This means that if there are two national level events that fall on adjacent diagonal lines, the one on the higher diagonal line has ten times as much risk as the one on the lower diagonal line. The lines act multiplicatively, meaning that if one event falls exactly on a diagonal line and a second event falls two lines below it, the first event has one hundred times more risk than the second.

Figure A3: Interpreting Risk Results in Scatter Plots



The uncertainty in the frequencies and consequences complicates this discussion. Even if a crosshair is centered on a line, it does not imply that the national level event has exactly that amount of risk. If the frequency and consequence data is correlated for that particular national level event, the best estimate of risk is likely near the intersection point. If the data are uncorrelated, the estimated risk is likely to appear somewhere in the crosshairs, but it is unclear exactly where.

[1] This interpretation depends on a particular definition of risk, and does not account for differing risk preferences.

APPENDIX B: FREQUENCY ASSESSMENT

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Overview

In order to apply a consistent methodology across all SNRA event types, frequency was selected as a metric for the likelihood of event occurrence. Frequency was estimated as the potential number of successful attacks (for adversarial/human-caused events) or potential number of occurrences (for natural and technological hazards), per year. Adversarial/human-caused frequencies were estimated primarily using elicitation from subject matter experts.[1] Estimates of natural and technological hazard frequencies were drawn heavily from the historical record.

When interpreting the frequency results presented below, it is important to consider that the frequency data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for floods indicate that *floods causing greater than $100 million in direct economic losses* are estimated to occur with a frequency between once every two years and ten times per year, with a best estimate of four times per year. For reference, the full national-level event definitions, including thresholds, can be found in Table 2 of the main report.

Frequency ranges included in the SNRA for adversarial/human-caused events are estimates of the frequency of successful attacks. Where subject matter expert judgment was used to determine frequency of successful attacks, adversary intent and capability were considered implicitly by the experts, but were not explicitly quantified or characterized. Attack initiations may occur with higher frequency than the ranges provided.

A designated Intelligence Community (IC) agency reviewed and commented on the relative frequency of the adversarial/human-caused events for which data was derived from previous governmental risk assessments, including DHS/S&T's Integrated Terrorism Risk Assessment (ITRA) and DHS/NPPD/RMA's Risk Assessment Process for Informed Decision-making (RAPID). To accomplish this, the agency reviewed frequency data, including the 5th, mean, and 95th percentiles of the frequency distributions. The review was performed in the summer of 2011.

The IC agency did not comment on the absolute values of the frequencies.

Through this process, the IC agency did not comment on the relative ordering of the frequencies for the two cyber events or armed assault, since those frequencies had not yet been elicited from the Intelligence Community SMEs within the SNRA project's structured elicitation process.

[1] Subject matter expert (SME) elicitation was a component of modeling frequency in two of the prior assessments leveraged for the SNRA: the 2011 ITRA conducted by DHS/S&T (chemical, biological, radiological, and nuclear terrorism attacks) and the 2010 Risk Assessment Process for Informed Decision-making (RAPID) conducted by DHS/Office of Risk Management and Analysis (RMA) (aircraft as a weapon, explosives terrorism attack). Separate SME elicitations were conducted for the SNRA with representatives from the Intelligence Community in July 2011 for the armed assault and cyber attack events. In all cases, the outputs from these models/elicitations were converted to equivalent units of successful events per year for comparison to the frequencies of natural and technological hazards drawn from the historical record.

SME estimation of the frequency of rare, adversarial/human-caused events is challenging, and SME frequency judgments in the SNRA reflect significant uncertainty. As with all data in the SNRA, these SME frequency judgments should be interpreted as order of magnitude estimates for the purposes of comparison.

Elicited Frequency Data

Within the adversarial/human-caused set of events, there were two event types, armed assault and cyber (affecting data and affecting physical infrastructure) for which appropriate frequency data sources could not be located. For these events, an elicitation protocol was developed and separate elicitations were conducted of IC experts.

For the cyber elicitation, representatives from DHS/NPPD/CS&C, ODNI, CIA, FBI, NSS, and NSA participated in a two part elicitation. All participants attended a half day working session to discuss the scope of the cyber events, identify event thresholds, and begin to provide frequency data. A subset of the participating agencies (ODNI, CIA, FBI, NSS) then completed the frequency elicitation tool and submitted it as input for consideration and review by the larger group.

- Elicitations for the cyber event affecting data incorporated three specific target types (financial institution system, public health/emergency system, internet) and asked that the elicitees provide individual frequency judgments for each of these target types.
- Elicitations for the cyber event affecting physical infrastructure incorporated five specified target types (dam failure, chemical release, electric grid failure, radiological release from a nuclear reactor, transportation system failure) and asked that the elicitees provide individual frequency judgments.
- As noted in the body of this report, no consensus consequence estimates corresponding to these elicited frequency judgments were obtained for the cyber events.

For the armed assault elicitation, representatives from DHS/I&A, FBI, and NSS participated in a group elicitation. All participants attended a half day working session to discuss the scope of the armed assault event, identify event thresholds, and provide frequency data. All data was collected during this group session, with the exception of one domestic terrorism expert who was individually elicited to ensure that domestic terrorism perspectives were included. No specific target types were articulated by the group.

For all elicitations, elicitees were asked to assign a frequency range to the events leveraging structured bins. Elicitees identified whether the frequency of these events were more or less frequent than once per year. If more frequent, elicitees then assigned the events to one of four buckets, each of varying order of magnitude (1-10 events per year, 11-100 events per year, 101-400 events per year, or greater than 400 events per year). If less frequent than once per year, elicitees assigned the events to one of four probability ranges (1% or less probable per year, 10% probable per year, 25% probable per year, or 50% probable per year). Elicitee input was aggregated into a range, which is represented within the SNRA frequency data.

Major Findings

- Many events are estimated to have the potential to happen more than once every 10 years, meaning that it is likely that the Nation's preparedness will be tested in this decade.
- By their best estimates, the most frequent natural and technological hazard events in the SNRA are floods, hurricanes, and accidental chemical substance releases (toxic inhalation hazards), which are expected to occur a few times per year. However, other events have the potential to occur at least this frequently, when uncertainty is considered.
- Of the non-adversarial events with frequency data of sufficient quality upon which to base comparisons, the least frequent event, a radiological substance release, is expected to have only a 1% chance of happening each year (or a frequency of approximately 1 in 100 years.

Additional Information

Frequency information of sufficient quality upon which to base comparisons could not be found for every national-level event.

- The space weather event analyzed for the SNRA is assessed to have a frequency of approximately 1 in 100 years, but no information was obtained about the uncertainty associated with the frequency of space weather during the time frame of this assessment.
- The specific cases of tsunami (Oregon coast) and volcanic eruption (Mount Rainier) assessed in the SNRA have expected frequencies of 1 in 200 years and 1 in 500 years, respectively, at the best estimate. These frequencies do not necessarily represent the rate of occurrence of tsunamis and volcanic eruption across the entire Nation, so this data is not appropriate for comparison to other national-level events.

Figure B1: Frequency by National-level Event

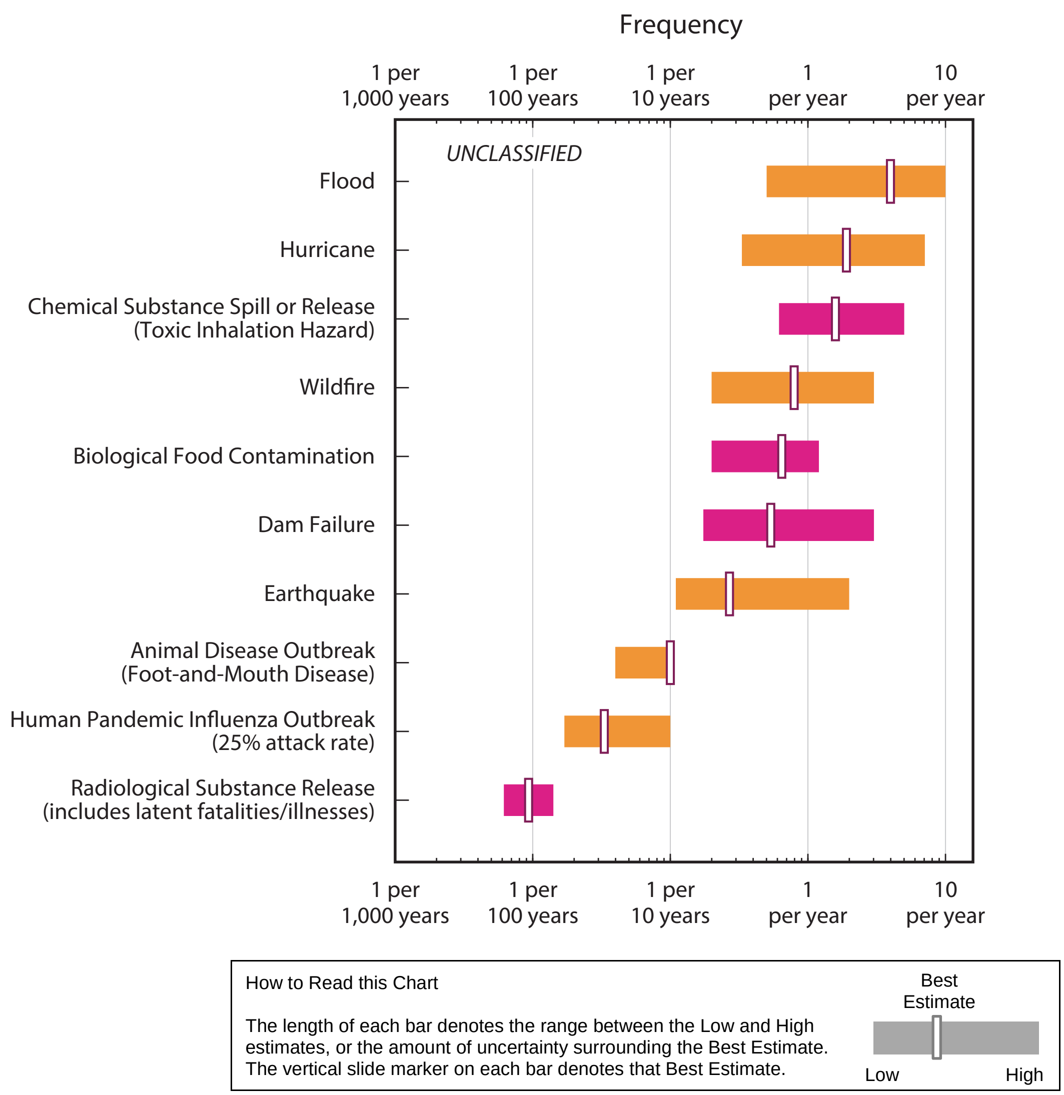


Table B1: SNRA Frequency Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Frequency Estimate (number of events per year)		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low		Data reflects the 5th percentile, mean, and 95th percentile of DHS RAPID 2010 estimates of the frequency of successful aircraft as a weapon terrorism attacks.[1]
		Best		
		High		
	Armed Assault	Low		Frequency data was elicited from the Intelligence Community (IC) by the SNRA project team in July 2011.[2]
		Best		
		High		
	Biological Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of biological terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., release of an agent.[3]
		Best		
		High		
	Chemical Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of chemical terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical/Biological Food Contamination Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of chemical/biological food contamination terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Cyber Event affecting Data	Low		Frequency data was elicited from the Intelligence Community (IC) by the SNRA project team in July 2011.[4] Only attacks resulting in $1 Billion in losses or greater were considered.
		Best		
		High		
	Cyber Event affecting Physical Infrastructure	Low		Frequency data was elicited from the Intelligence Community (IC) by the SNRA project team in July 2011.[5] Only attacks resulting in 1 fatality or greater or $100 Million in losses or greater were considered.
		Best		
		High		
	Explosives Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile of DHS RAPID 2010 estimates of the frequency of successful man-portable improvised explosive device (IED), vessel borne IED, and vehicle borne IED terrorism attacks.[6]
		Best		
		High		
	Nuclear Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of nuclear terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology
		Best		
		High		

Threat/ Hazard Group	Threat/Hazard Type	Frequency Estimate (number of events per year)		Source Information
				Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., detonation of a device.
	Radiological Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile frequency of events matching the SNRA definition of radiological terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Frequency estimates in the SNRA only include data for successful attacks, e.g., detonation of a device or radiation exposure.
		Best		
		High		
Technological/ Accidental	Biological Food Contamination	Low	0.20	Historic events in the CDC's Foodborne Outbreak Online Database (FOOD) which were multistate outbreaks requiring greater than 100 hospitalizations formed the data set. Frequency estimates correspond to the inverse of the number of years between outbreaks (low), the mean frequency of the outbreaks (best), and the greatest number of outbreaks within one year (high). Years included in FOOD include 1998-2008.[7]
		Best	0.64	
		High	1.2	
	Chemical Substance Spill or Release	Low	0.61	Estimates correspond to the inverse of the number of years between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) within the U.S. historic data set used for the SNRA analysis.[8]
		Best	1.6	
		High	5	
	Dam Failure	Low	0.17	Estimates correspond to the inverse of the number of years between dam failures causing 1 fatality or greater (low), the mean frequency of dam failures causing 1 fatality or greater (best), and the greatest number of dam failures causing 1 fatality or greater within one year (high) from the U.S. historic events during the time period from 1960-2009.[9]
		Best	0.54	
		High	3	
	Radiological Substance Release	Low	0.0062	Estimates are drawn from core damage failure frequencies in the license renewal applications available on the public website of the U.S. Nuclear Regulatory Commission.[10]
		Best	0.0093	
		High	0.014	
Natural	Animal Disease Outbreak	Low	0.04	Estimates provided by DHS Office of Health Affairs subject matter experts. These estimates only reflect the likelihood of an outbreak of Foot-and-Mouth Disease (FMD).
		Best	0.1	
		High	0.1	
	Earthquake	Low	0.11	Estimates correspond to the inverse of the number of years between earthquakes causing greater than $100 M in damages (low), the mean frequency of earthquakes causing greater than $100M in damages (best), and the greatest number of earthquakes causing greater than $100 M in damages within one year (high) from the U.S. historic events between 1906-2005.[11]
		Best	0.27	
		High	2	
	Flood	Low	0.5	Estimates correspond to the inverse of the number of years between floods causing greater than $100
		Best	4	

Threat/ Hazard Group	Threat/Hazard Type	Frequency Estimate (number of events per year)		Source Information
		High	10	M in damages (low), the mean frequency of floods causing greater than $100M in damages (best), and the greatest number of floods causing greater than $100 M in damages within one year (high) from the U.S. historic events between January 1, 1993 to December 31, 2005.[12]
	Human Pandemic Outbreak	Low	0.017	Estimates provided by CDC subject matter experts, informed by the historic frequency of influenza pandemics since 1729.[13]
		Best	0.033	
		High	0.10	
	Hurricane	Low	0.33	Estimates correspond to the inverse of the number of years between hurricanes causing greater than $100 M in damages (low), the mean frequency of hurricanes causing greater than $100M in damages (best), and the greatest number of hurricanes causing greater than $100 M in damages within one year (high) from the U.S. historic events between 1970-2010.[14]
		Best	1.9	
		High	7	
	Space Weather	Low	N/A	The space weather scenario analyzed for the SNRA is judged to be a 1 in 100 year event.[15]
		Best	0.01	
		High	N/A	
	Tsunami	Low	0.0024	Estimates informed by the likelihood of a major earthquake along the Cascadia Subduction Zone, causing a tsunami to hit the Oregon coast.[16]
		Best	0.005	
		High	0.0074	
	Volcanic Eruption	Low	0.001	Estimates informed by the average time intervals between eruptions of Mount Rainier.[17]
		Best	0.002	
		High	0.01	
	Wildfire	Low	0.2	Estimates correspond to the inverse of the number of years between wildfires causing greater than $100 M in damages (low), the mean frequency of wildfires causing greater than $100M in damages (best), and the greatest number of wildfires causing greater than $100 M in damages within one year (high) from the U.S. historic events between 1990-2009.[18]
		Best	0.8	
		High	3	

[1] DHS' RAPID assessment (the Risk Assessment Process for Improved Decision-making), estimates "residual threat" or the frequency of a successful attack. This estimate is a weighted average that incorporates adversary preferences among different attack scenarios as well as the ability of DHS and non-DHS programs to detect and interdict these attacks.

[2] IC participants in the Armed Assault frequency elicitation included subject matter experts from NSS, DHS/I&A, and FBI. The frequency estimates reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.

[3] Examples of failed attacks not considered in the SNRA frequency estimates include interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to the United States, or failure of the dissemination device.

[4] IC participants in the Cyber Event affecting Data frequency elicitation included subject matter experts from ODNI, CIA, FBI, NSA, NSS, and DHS/CS&C. The frequency estimates reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.

[5] IC participants in the Cyber Event affecting Physical Infrastructure frequency elicitation included subject matter experts from ODNI, CIA, FBI, NSA, NSS, and DHS/CS&C. The frequency estimates reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.

[6] See note (1) above.

[7] Centers for Disease Control and Prevention (CDC) Foodborne Outbreak Online Database (FOOD) is available online at http://www.cdc.gov/foodborneoutbreaks.

[8] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents.

[9] Historic data for U.S. dam failures were provided by the U.S. Bureau of Reclamation via the DHS Office of Infrastructure Protection Dams Sector Branch. Dam failures which were caused by cascading events (e.g., a failing dam upstream) were combined into single events.

[10] The best estimate for frequency uses a simulation of the expected core damage frequencies and expected consequences obtained from the license renewal applications for a number of individual reactors available from the public website of the U.S. Nuclear Regulatory commission at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html. The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recently publicly available data and adequate for order of magnitude estimates in the SNRA. An alternative analysis was also conducted using fatality, injury, and core damage frequency data from NUREG-1150, and the best estimates from this analysis were within an order of magnitude of the results obtained using data from license renewal applications (U.S. Nuclear Regulatory Commission (1990). *NUREG-1150 Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*. Washington, DC: U.S. NRC). The low frequency estimate is the 5th percentile of the core damage frequencies, taking into account variability across the different reactors and the uncertainty of a single reactor. Note that this frequency incorporates the uncertainty and variability of the expectation and does not directly correspond to the Low consequence values. The high frequency estimate is the 95th percentile of the core damage frequencies, taking into account variability across the different reactors and the uncertainty of a single reactor. This does not correspond to the High consequence values which have likelihoods one to two orders of magnitude lower than the Best CDF value.

[11] The U.S. historic earthquake record for events causing greater than $100 Million in damages was obtained from the published report by Vranes, K. and Pielke, R. (2009). Normalized earthquake damage and fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3), 84:101.

[12] The U.S. historic flood record for events causing greater than $100 Million in damages was obtained by aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC). Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss reports were aggregated based on distance and time. Flood damage reports that occurred within 100 miles of one another and within plus or minus one calendar day are aggregated into composite flood events. The composite flood events above the $100 Million (2011 dollar) threshold were used for reporting frequency, fatality, injury, and direct economic loss estimates in the SNRA. All hurricanes were removed from flood events to avoid double-counting flooding damages included in the SNRA hurricane analysis.

[13] Potter, C. W. (2001). A history of influenza. *Journal of Applied Microbiology*, 91, 572-579.

[14] The U.S. historic hurricane record for events causing greater than $100 Million in damages was obtained from the ICAT Damage Estimator (http://www.icatdamageestimator.com), which uses a methodology for computing economic losses similar to that published by Pielke, R.J., Gratz, J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review* 9(1), 29-42.

[15] Kappenman, J. (2010, January). *Geomagnetic Storms and their Impacts on the U.S. Power Grid* (Metatech Publication No. Meta-R-319), Chapter 4, p. 3-13. Prepared for Oak Ridge National Laboratory. Retrieved from http://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_meta-r-319.pdf.

[16] Geologists studying the Cascadia Subduction Zone have concluded that there is a 37 percent chance of an 8.2 or larger magnitude event in the next 50 years and a 10-15 percent chance for a rupture along the entire fault from a 9.0 or larger event in the next 50 years. "Odds are 1-in-3 that a huge quake will hit Northwest in next 50 years," Oregon State University press release, 24 May 2010, announcing preliminary results later published as Goldfinger et al (2012); at http://oregonstate.edu/ua/ncs/node/13426 (accessed 3/17/2013). Risk of giant quake off American west coast goes up. *Nature News*, 31 May 2010, citing results later published as Goldfinger et al (2012); at www.nature.com/news/2010/100531/full/news.2010.270.html. Goldfinger et al, 2012. Turbidite event history – Methods and implications for

Holocene paleoseismicity of the Cascadia Subduction Zone. USGS p 1661-F, 17 July 2012: http://pubs.usgs.gov/pp/pp1661f/ (accessed 3/17/13).

[17] Hoblitt, R. P., Walder, J. S., Driedger, C. L., Scott, K. M., Pringle, P. T., & Wallace, J. W. *Volcano Hazards from Mount Rainier, Washington* (U.S. Geological Survey Open-File Report 98-428). Available from: http://vulcan.wr.usgs.gov/Volcanoes/Rainier/Hazards/OFR98-428/framework.html.

[18] The U.S. historic wildfire record for events causing greater than $100 Million in damages was compiled from the SHELDUS database (Hazards & Vulnerability Research Institute (2011). The Spatial Hazards Events and Losses Database for the United States, Version 8.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org). SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double-counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events. All wildfires (after consolidation) above the $100 Million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS v8.0 to May 2011 values) from 1970-2009 were used in the SNRA analysis.

APPENDIX C: FATALITY CONSEQUENCE ASSESSMENT

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Overview

For events that have occurred in the past, the number of fatalities was estimated primarily from the historical record. For events that have never occurred (primarily in terrorism), consequences were estimated using data from previous DHS risk assessments, which rely on models and simulations.

When interpreting the fatality results presented below, it is important to consider that the consequence data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for floods indicate that *floods causing greater than $100 million in direct economic losses* are estimated to cause between 0 and 25 fatalities, with a best estimate of 3 fatalities. For reference, the full national-level event definitions, including thresholds, can be found in Table 2 of the main report.

In many cases, the high estimates for fatalities in the SNRA were constructed from either historic maximums (e.g. natural hazards) or the 95th percentile of a modeled distribution (e.g. terrorism events). Thus, the high estimates associated with each national-level event may not be reflective of the fatalities which may occur from a “worst-case scenario”. Additional analysis is necessary to better characterize the “worst-case” upper bounds for fatalities associated with each national-level event.

Major Findings

- At the best estimate, a pandemic influenza outbreak with a 25% gross clinical attack rate and a case fatality rate similar to the 1968-1969 Hong Kong flu pandemic is estimated to result in the most fatalities, given occurrence, of any event among the natural and technological hazards considered by the SNRA. Such a pandemic influenza outbreak is estimated to cause between 140,000 and 440,000 fatalities, with a best estimate of 250,000 fatalities.
- With the exception of a pandemic influenza outbreak, earthquakes are assessed to have the largest expected consequences per occurrence of the natural hazards, at the best estimate. The expected fatalities due to an earthquake are assessed to be of a comparable order of magnitude (hundreds of fatalities) as accidental radiological substance releases, at the best estimate.
- Foot-and-mouth disease (FMD) is assessed to have no potential of causing human fatalities. FMD affects livestock but poses no health risk to humans.

Additional Information

Fatality information of sufficient quality upon which to base comparisons could not be found for every national-level event.

- *Tsunami*: FEMA HAZUS modeling of a tsunami wave hitting the Oregon coast with height 15 meters resulted in estimates ranging from one to 1000 fatalities.
- *Volcanic Eruption:* FEMA analysis of the areal extent of lahar flow from an eruption of Mount Rainier results in estimates ranging from 350 to 800 fatalities.

- *Cyber Events and Space Weather:* Additional analysis is necessary to quantify the fatalities which might result from these events.

Figure C1: Fatalities by National-level Event

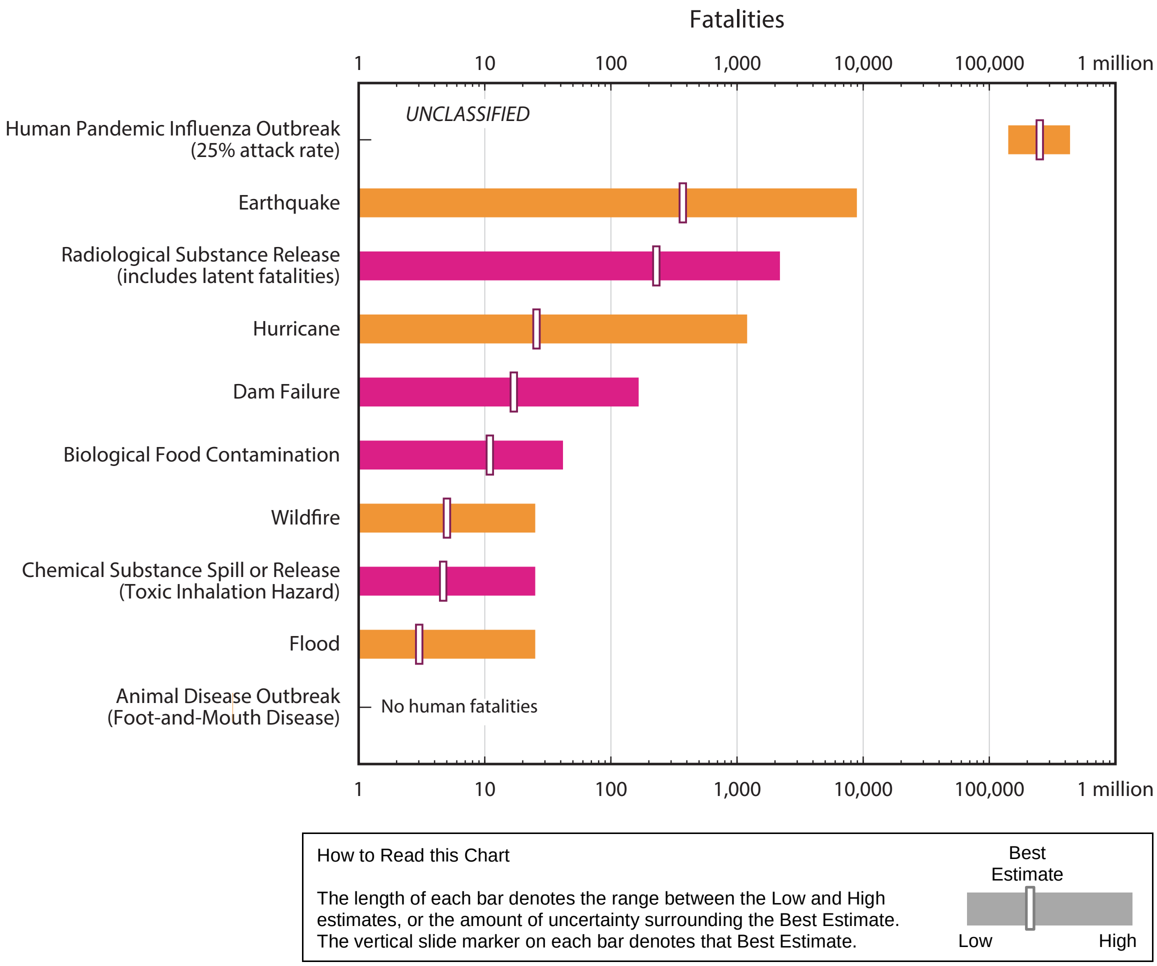


Table C1: SNRA Fatality Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Fatality Estimates		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low		Fatality estimates constructed from SNRA project team analysis of historic events in which aircraft intentionally or unintentionally crashed into buildings or crowds of people. The 9/11 attacks in New York are used as a maximum case. The analysis does not take into account higher-consequence events which have not yet occurred.
		Best		
		High		
	Armed Assault	Low		Fatality estimates were calculated using historical data on armed assault events from the Global Terrorism database.[1,2]
		Best		
		High		
	Biological Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of biological terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of chemical terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical/Biological Food Contamination Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of chemical/biological food contamination terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Cyber Event affecting Data	Low	N/A	Additional analysis is necessary to quantify the fatalities caused by cyber events affecting data. Consequences for the types of attacks in this event category are difficult to quantify, as they depend upon the particular system attacked, the vulnerability and resilience of the network, specific data backup provisions, etc.
		Best	N/A	
		High	N/A	
	Cyber Event affecting Physical Infrastructure	Low	N/A	Additional analysis is required to quantify the fatalities caused by cyber events affecting physical infrastructure. Consequences for the types of attacks in this event category are sector dependent and difficult to quantify. Approximately 85% of critical infrastructure is owned and operated by the private sector, and system vulnerability and resilience is highly sector-dependent and localized. Only attacks resulting in 1 fatality or greater or $100 Million in losses or greater were considered.
		Best	N/A	
		High	N/A	

Threat/ Hazard Group	Threat/Hazard Type	Fatality Estimates		Source Information
	Explosives Terrorism Attack	Low		Fatality estimates were calculated using historical data on explosives events from the Global Terrorism database.[3]
		Best		
		High		
	Nuclear Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of nuclear terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., detonation of a device.
		Best		
		High		
	Radiological Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile fatalities associated with events matching the SNRA definition of radiological terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Fatality estimates in the SNRA include data for successful attacks, e.g., detonation of a device or radiation exposure.
		Best		
		High		
Technological/ Accidental	Biological Food Contamination	Low	0	Estimates were obtained from historic events in the CDC's Foodborne Outbreak Online Database (FOOD) which were multistate outbreaks requiring greater than 100 hospitalizations. Years included in FOOD include 1998-2008.[4]
		Best	11	
		High	42	
	Chemical Substance Spill or Release	Low	1	Estimates correspond to the low, average, and high fatalities reported per incident within the U.S. historic data set used for the SNRA analysis.[5]
		Best	5	
		High	25	
	Dam Failure	Low	1	Estimates correspond to the low, average, and high fatalities from U.S. dam failures causing 1 fatality or greater during the time period from 1960-2009.[6]
		Best	17	
		High	170	
	Radiological Substance Release	Low	0	Estimates are drawn from the historic case of Three Mile Island as well as license renewal applications available on the public website of the U.S. Nuclear Regulatory Commission.[7]
		Best	230	
		High	2,200	
Natural	Animal Disease Outbreak	Low	0	There are no significant human health implications of Foot-and-Mouth Disease (FMD), the animal disease considered in the SNRA.
		Best	0	
		High	0	
	Earthquake	Low	0	Estimates correspond to the low, average, and high fatalities from earthquakes causing greater than $100 M in damages from the U.S. historic events between 1906-2011.[8]
		Best	370	
		High	8,900	
	Flood	Low	0	Estimates correspond to the low, average, and high fatalities from floods causing greater than $100M in damages from the U.S. historic events between January 1, 1993 to December 31, 2005.[9]
		Best	3	
		High	25	
	Human Pandemic Outbreak	Low	140,000	Fatality estimates provided by CDC assuming a 25% gross clinical attack rate, using case fatality rates associated with the 1968-1969 Hong Kong flu pandemic.[10]
		Best	250,000	
		High	440,000	

Threat/ Hazard Group	Threat/Hazard Type	Fatality Estimates		Source Information
	Hurricane	Low	0	Estimates correspond to the low, average, and high fatalities from hurricanes causing greater than $100 M in damages from the U.S. historic events between 1970-2010.[11]
		Best	26	
		High	1,200	
	Space Weather	Low	N/A	Credible published estimates for the fatalities due to a space weather event were not found.
		Best	N/A	
		High	N/A	
	Tsunami	Low	1	Estimates were informed by FEMA HAZUS modeling of a tsunami wave of height 15 meters hitting the Oregon coast. It was assumed that 1% of the exposed population may be killed or injured, with 50% counted as killed and 50% counted as injured by the event.[12]
		Best	300	
		High	1,000	
	Volcanic Eruption	Low	340	Estimates were informed by the total population within an inundation zone for Case I Debris Flows near Mount Rainier, as well as the percentage of population killed during the 1980 Mt Saint Helens eruption.[13]
		Best	520	
		High	780	
	Wildfire	Low	0	Estimates correspond to the low, average, and high fatalities from wildfires causing greater than $100 M in damages from the U.S. historic events between 1990-2009.[14]
		Best	5	
		High	25	

[1] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970-2010. The GTD is an open-source database including information on terrorist events around the world (including domestic, transnational, and international incidents) from 1970 through 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and - when identifiable - the group or individual responsible. The GTD is maintained at the University of Maryland by the National Consortium for the Study of Terrorism and Responses to Terrorism (START), a DHS Center of Excellence. National Consortium for the Study of Terrorism and Responses to Terrorism (START), 2011. Global Terrorism Database [Data file]. Retrieved from: http://www.start.umd.edu/gtd.

[2] In order to identify events in the GTD database that were most comparable to the SNRA definition of Armed Assault, the following search criteria were used: Attack Type: Armed Assault or Bombing/Explosion; Weapon Type: Require Firearms; Exclude biological, chemical, radiological, nuclear; Terrorism Criteria: Require (a) The act must be aimed at attaining a political, economic, religious, or social goal, (b) There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims, (c) The action must be outside the context of legitimate warfare activities, i.e., the act must be outside the parameters permitted by international humanitarian law; Ambiguous cases, where there is a strong possibility, but not a certainty, that an incident represents an act of terrorism, were excluded; Unsuccessful attacks were excluded. Events that produced zero injuries and zero deaths were removed from the resulting set, in order to meet the SNRA national-level event threshold. All events involving vehicle borne explosives were also removed. The highest injury-producing event (10,000 injured in Peru) was considered an outlier and removed. Incidents that were part of multi-incident events were aggregated to produce more comprehensive injury/death totals. The resulting set included 10,161 incidents, which were then used to calculate the minimum, maximum, and mean, which are presented as low, high, and best estimates in the table above.

[3] In order to identify events in the GTD database that were most comparable to the SNRA definition of Explosives Terrorism Attack, the following search criteria were used: Attack Type: Bombing/Explosion; Weapon Type: Explosives/Bombs/Dynamite OR Incendiary; Terrorism Criteria: Require (a) The act must be aimed at attaining a political, economic, religious, or social goal, (b) There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims, (c) The action must be outside the context of legitimate warfare activities, i.e., the act must be outside the parameters permitted by international humanitarian law; Ambiguous cases, where there is a strong possibility, but not a certainty, that an incident represents an act of terrorism, were excluded; Unsuccessful attacks were excluded; Target Type: limited to Airports and Airlines, Business, Government (Diplomatic), Government (General), Military, Other, Telecommunication, Tourists, Transportation, Unknown, Utilities. Events that produced zero injuries and zero deaths were removed from the resulting set, in order to

meet the SNRA national-level event threshold. The resulting set was then used to calculate the minimum, maximum, and mean, which are presented as low, high, and best estimates in the table above.

[4] Centers for Disease Control and Prevention (CDC) Foodborne Outbreak Online Database (FOOD) is available online at http://www.cdc.gov/foodborneoutbreaks. Reported fatalities were adjusted to account for underreporting or underdiagnosis using the latest multipliers published by the CDC (a factor of 2 for fatalities). The low, best, and high fatality estimates represent the low, average, and high adjusted fatalities in the set of outbreaks meeting the multistate and 100+ reported hospitalizations thresholds. Scallan, E., Hoekstra, R. M., Angulo, F. J., Tauxe, R. V., Widdowson, M. –A., Roy, S. L., et al. (2011). Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases*, 17(1), 7-15. Available from URL: http://www.cdc.gov/EID/content/17/1/7.htm. Accessed on 22 August 2011.

[5] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents.

[6] Historic data for U.S. dam failures were provided by the U.S. Bureau of Reclamation via the DHS Office of Infrastructure Protection Dams Sector Branch. Dam failures which were caused by cascading events (e.g., a failing dam upstream) were combined into single events.

[7] The low estimate of zero fatalities is drawn from the Three Mile Island core meltdown (Perham, C. (1980, October). EPA's Role at Three Mile Island. Retrieved from http://www.epa.gov/aboutepa/history/topics/tmi/02.html). The best estimate for fatalities uses a simulation of the expected core damage frequencies and expected consequences obtained from the license renewal applications for a number of individual reactors available from the public website of the U.S. Nuclear Regulatory Commission (NRC) at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html. The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recently publicly available data and adequate for order of magnitude estimates in the SNRA. An alternative analysis was also conducted using fatality, injury, and core damage frequency data from NUREG-1150, and the best estimates from this analysis were within an order of magnitude of the results obtained using data from license renewal applications (U.S. Nuclear Regulatory Commission (1990). *NUREG-1150 Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*. Washington, DC: U.S. NRC). The expected consequences are weighted by the likelihood of a core damage accident for each reactor using a Crystal Ball simulation to determine the best fatality estimate. The high consequence estimates also come from the license renewal applications; these consequences correspond to the highest consequence scenarios outlined in the report. These usually involve a large, early release and assume that there is not enough time for successful evacuation. The frequency of these events is typically one-to-two orders of magnitude less than the frequency of any core damage event. Note that the frequency values reported in Appendix B do not correspond to the high and low fatality estimates. The fatality estimates include latent cancer fatalities: deaths resulting from cancer that become active after a latent period following exposure to radiation.

[8] The U.S. historic earthquake record for events causing greater than $100 Million in damages was obtained from the published report by Vranes, K. and Pielke, R. (2009). Normalized earthquake damage and fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3), 84:101. Normalized fatality estimates take into account changes in population densities, community wealth, mitigation factors (such as improved building codes and emergency response), and inflation. A 1% annual mitigation factor was used, as described in Vranes and Pielke (2009).

[9] The U.S. historic flood record for events causing greater than $100 Million in damages was obtained by aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC). Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss reports were aggregated based on distance and time. Flood damage reports that occurred within 100 miles of one another and within plus or minus one calendar day were aggregated into composite flood events. The composite flood events above the $100 Million (2011 dollar) threshold were used for reporting frequency, fatality, injury, and direct economic loss estimates in the SNRA. All hurricanes were removed from flood events to avoid double-counting flooding damages included in the SNRA hurricane analysis.

[10] Expert judgments provided by CDC subject matter experts to the SNRA project, and informed by similar scenario assumptions and modeling as was used for the National Strategy for Pandemic Influenza and the National Planning Scenarios. All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).

[11] U.S. historic hurricane record for events causing greater than $100 Million in damages was obtained from the ICAT Damage Estimator (http://www.icatdamageestimator.com), which uses a methodology for computing economic losses similar to that published by Pielke, R.J., Gratz, J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review* 9 (1), 29-42. Fatality estimates are based

directly upon the historic record, published by Blake, E.S., Landsea, C.W., and Gibnew, E.J. (2011, August). *The deadliest, costliest, and most intense United States tropical cyclones from 1851-2010 (and other frequently requested hurricane facts)*. Miami, FL: National Climactic Data Center, National Hurricane Center.

[12] Fatalities were expected to occur in areas that do not receive a warning in time, communities not trained in evacuation, flat areas where no evacuation routes exist, and for persons who do not obey orders or who happen to be in vulnerable areas with no warning systems.

[13] For the low estimate of volcanic eruption fatalities, the total population within lahar hazard areas near Mount Rainier was calculated using a GIS shape file representing the Inundation Zones for Case I Debris Flows. Such zones represent areas that could be affected by cohesive debris flow that originates as enormous avalanches of weak chemically altered rock from the volcano. (Digital Data for Volcano Hazards from Mount Rainier, Washington Revised 1998: Data to accompany U.S. Geological Survey Open-File Report 98-428; USGS; 2007.) For the high estimate of volcanic eruption fatalities, a multiplier of 1% of the total population surrounding Mount Rainier was used, informed by the percentage of the population killed during the 1980 Mount Saint Helens eruption. (USGS Cascades Volcano Observatory, Vancouver, Washington Mount St. Helens "On This Day in 1980" October 6, 1980 http://vulcan.wr.usgs.gov/Volcanoes/MSH/May18/OnThisDay1980/Days/1980October06.html.) The best estimate is the geometric mean of the low and high estimates.

[14] The U.S. historic wildfire record for events causing greater than $100 Million in damages was compiled from the SHELDUS database (Hazards & Vulnerability Research Institute (2011). The Spatial Hazards Events and Losses Database for the United States, Version 8.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org). SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double-counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events. All wildfires (after consolidation) above the $100 Million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS v8.0 to May 2011 values) from 1970-2009 were used in the SNRA analysis.

APPENDIX D: INJURY/ILLNESS CONSEQUENCE ASSESSMENT

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Overview

Injuries and illnesses were estimated similarly to fatalities. For events that have occurred in the past, the number of fatalities was estimated primarily from the historical record. For events that have never occurred, primarily but not limited to the adversarial events, consequences were estimated using data from previous DHS risk assessments which rely on models and simulations.

It is important to note that this consequence category mixed permanent debilitating injuries (such as those resulting from chemical accidents) with temporary illnesses (such as those resulting from pandemic influenza). Therefore, the injury and illness consequences should be considered in context with the types of injuries and illnesses likely to result from each hazard.

When interpreting the injury/illness results presented below, it is important to consider that the consequence data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for wildfires indicate that *wildfires causing greater than $100 million in direct economic losses* are estimated to cause between 0 and 190 injuries, with a best estimate of 63 fatalities. For reference, the full national-level event definitions, including thresholds, can be found in Table 2 of the main report.

In many cases, the high estimates for injuries/illnesses in the SNRA were constructed from either historic maximums (e.g. natural hazards) or the 95th percentile of a modeled distribution (e.g. terrorism events). Thus, the high estimates associated with each national-level event may not be reflective of the injuries/illnesses which may occur from a "worst-case scenario". Additional analysis is necessary to better characterize the "worst-case" upper bounds for injuries/illnesses associated with each national-level event.

Major Findings

- At the best estimate, a pandemic influenza outbreak with a 25% gross clinical attack rate and a case fatality rate similar to the 1968-1969 Hong Kong flu pandemic is estimated to result in the most injuries/illnesses given occurrence of any of the non-adversarial events in the SNRA by more than a factor of one hundred. Such a pandemic influenza outbreak is estimated to cause between 62 million and 110 million illnesses, with a best estimate of 72 million illnesses. These estimates are given absent any intervention (i.e., before interventions are applied or attempted).
- After pandemic influenza, the non-adversarial events in the SNRA with the highest expected illnesses or injuries (at the best estimate) given occurrence include accidental food contamination and earthquakes.
  - The expected injuries/illnesses due to an earthquake are assessed to be of comparable order of magnitude (tens of thousands of injuries) as the accidental biological food contamination event, at the best estimate.
- All natural and technological hazard events in the SNRA are expected to result in non-zero injuries/illnesses, at the best estimate, with the exception of foot-and-mouth disease (FMD) which affects livestock but poses no health risk to humans.

Additional Information

Injury/illness information of sufficient quality upon which to base comparisons could not be found for every national-level event.

- *Tsunami:* FEMA HAZUS modeling of a tsunami wave hitting the Oregon coast with height 15 meters resulted in estimates ranging from one to 1000 injuries.
- *Volcanic Eruption:* FEMA analysis of the areal extent of lahar flow and atmospheric dispersal of ash from an eruption of Mount Rainier results in estimates ranging from 2,000 to 150,000 injuries.
- *Cyber Events and Space Weather:* Additional analysis is necessary to quantify the injuries/illnesses which might result from these events.

Figure D1: Injuries/Illnesses by National-level Event

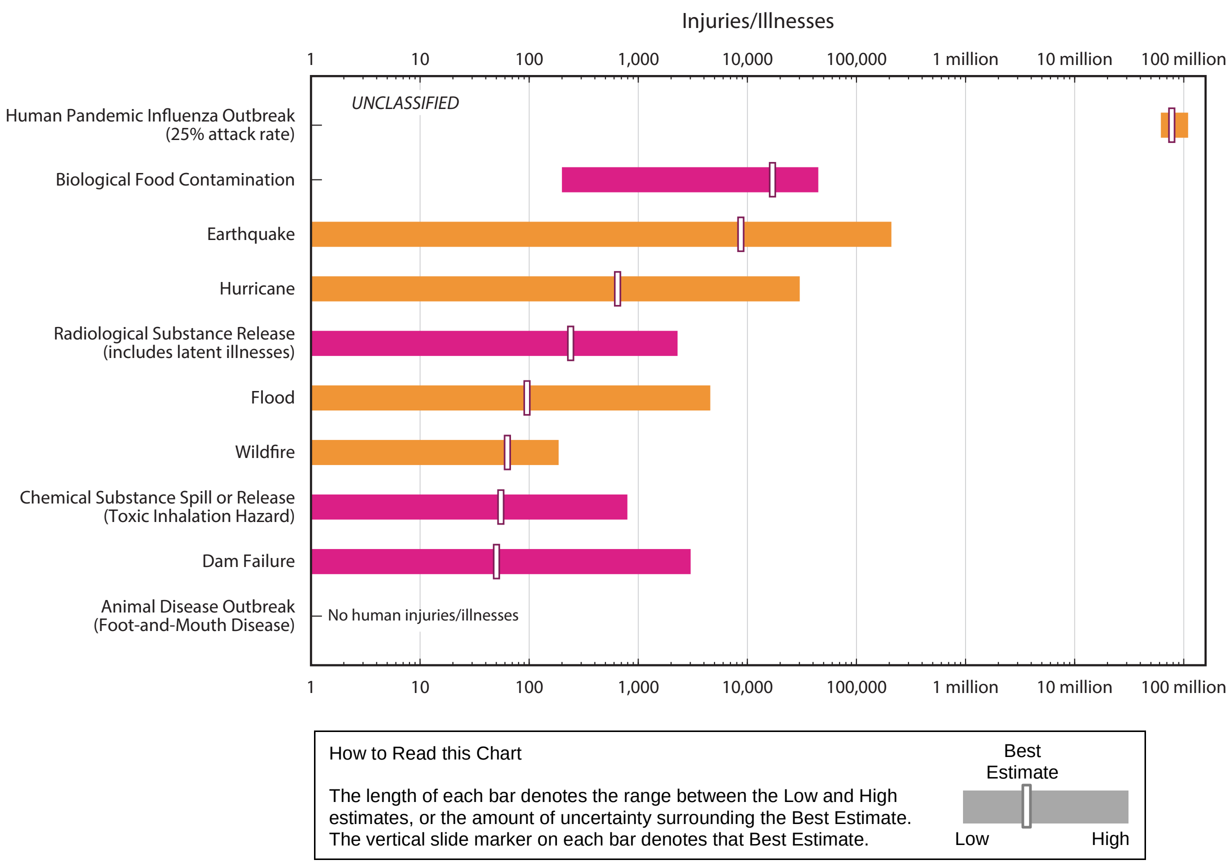


Table D1: SNRA Injury/Illness Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Injury/Illness Estimates		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low		Injury estimates constructed from SNRA project team analysis of historic events in which aircraft intentionally or unintentionally crashed into buildings or crowds of people. The 9/11 attacks in New York are used as a maximum case. The analysis does not take into account higher-consequence events which have not yet occurred.
		Best		
		High		
	Armed Assault	Low		Injury estimates were calculated using historical data on armed assault events from the Global Terrorism database.[1,2]
		Best		
		High		
	Biological Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile injuries/illnesses associated with events matching the SNRA definition of biological terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile injuries/illnesses associated with events matching the SNRA definition of chemical terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical/Biological Food Contamination Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile injuries/illnesses associated with events matching the SNRA definition of chemical/ biological food contamination terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Cyber Event affecting Data	Low	N/A	Additional analysis is necessary to quantify the injuries/illnesses caused by cyber events affecting data. Consequences for the types of attacks in this event category are difficult to quantify, as they depend upon the particular system attacked, the vulnerability and resilience of the network, specific data backup provisions, etc.
		Best	N/A	
		High	N/A	
	Cyber Event affecting Physical Infrastructure	Low	N/A	Additional analysis is required to quantify the injuries/illnesses caused by cyber events affecting physical infrastructure. Consequences for the types of attacks in this event category are sector dependent and difficult to quantify. Approximately 85% of critical infrastructure is believed to be owned and operated by the private sector, and system vulnerability and resilience is highly sector-dependent and localized.[3]
		Best	N/A	
		High	N/A	

Threat/ Hazard Group	Threat/Hazard Type	Injury/Illness Estimates		Source Information
	Explosives Terrorism Attack	Low		Injury/illness estimates were calculated using historical data on explosives events from the Global Terrorism database.[4]
		Best		
		High		
	Nuclear Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile injuries/illnesses associated with events matching the SNRA definition of nuclear terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., detonation of a device.
		Best		
		High		
	Radiological Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile injury/illness estimates associated with events matching the SNRA definition of radiological terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Injury/illness estimates in the SNRA include data for successful attacks, e.g., detonation of a device or radiation exposure.
		Best		
		High		
Technological/ Accidental	Biological Food Contamination	Low	200	Estimates obtained from historic events in the CDC's Foodborne Outbreak Online Database (FOOD) which were multistate outbreaks requiring greater than 100 hospitalizations. Years included in FOOD include 1998-2008.[5]
		Best	17,000	
		High	45,000	
	Chemical Substance Spill or Release	Low	0	Estimates correspond to the low, average, and high injuries/illnesses reported per incident within the U.S. historic data set used for the SNRA analysis.[6]
		Best	60	
		High	790	
	Dam Failure	Low	0	Estimates correspond to reported injuries from U.S. dam failures causing 1 fatality or greater during the time period from 1960-2009, for which injury reporting was available.[7]
		Best	50	
		High	3,000	
	Radiological Substance Release	Low	0	Estimates are drawn from the historic case of Three Mile Island as well as license renewal applications available on the public website of the U.S. Nuclear Regulatory Commission.[8]
		Best	240	
		High	2,300	
Natural	Animal Disease Outbreak	Low	0	There are no significant human health implications of Foot-and-Mouth Disease (FMD), the animal disease considered in the SNRA.
		Best	0	
		High	0	
	Earthquake	Low	0	Estimates correspond to the low, average, and high injuries from earthquakes causing greater than $100 M in damages from the U.S. historic events between 1906-2011.[9]
		Best	8,700	
		High	210,000	
	Flood	Low	0	Estimates correspond to the low, average, and high injuries from floods causing greater than $100M in damages from the U.S. historic events between January 1, 1993 to December 31, 2005.[10]
		Best	95	
		High	4,500	

Threat/ Hazard Group	Threat/Hazard Type	Injury/Illness Estimates		Source Information
	Human Pandemic Outbreak	Low	62 Million	Illness estimates provided by CDC assuming a 25% gross clinical attack rate, using the case fatality rate associated with the 1968-1969 Hong Kong flu pandemic.[11]
		Best	77 Million	
		High	110 Million	
	Hurricane	Low	0	Estimates correspond to the low, average, and high injuries from hurricanes causing greater than $100 M in damages from the U.S. historic events between 1970-2010.[12]
		Best	650	
		High	30,000	
	Space Weather	Low	N/A	Credible published estimates for the injuries/illnesses due to a space weather event were not found.
		Best	N/A	
		High	N/A	
	Tsunami	Low	1	Estimates were informed by FEMA HAZUS modeling of a tsunami wave of height 15 meters hitting the Oregon coast. It was assumed that 1% of the exposed population may be killed or injured, with 50% counted as killed and 50% counted as injured by the event.[13]
		Best	300	
		High	1,000	
	Volcanic Eruption	Low	2,000	Estimates were informed by the population in the State of Washington Census tracts immediately surrounding Mount Rainier, as well as those susceptible to a potential 60-mile radius ash cloud from Mount Rainier.[14]
		Best	17,000	
		High	150,000	
	Wildfire	Low	0	Estimates correspond to the low, average, and high injuries from wildfires causing greater than $100 M in damages from the U.S. historic events between 1990-2009.[15]
		Best	63	
		High	190	

[1] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970-2010. The GTD is an open-source database including information on terrorist events around the world (including domestic, transnational, and international incidents) from 1970 through 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and - when identifiable - the group or individual responsible. The GTD is maintained at the University of Maryland by the National Consortium for the Study of Terrorism and Responses to Terrorism (START), a DHS Center of Excellence. National Consortium for the Study of Terrorism and Responses to Terrorism (START), 2011. Global Terrorism Database [Data file]. Retrieved from: http://www.start.umd.edu/gtd.

[2] In order to identify events in the GTD database that were most comparable to the SNRA definition of complex attack, the following search criteria were used: Attack Type: Armed Assault or Bombing/Explosion; Weapon Type: Require Firearms; Exclude biological, chemical, radiological, nuclear; Terrorism Criteria: Require (a) The act must be aimed at attaining a political, economic, religious, or social goal, (b) There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims, (c) The action must be outside the context of legitimate warfare activities, i.e., the act must be outside the parameters permitted by international humanitarian law; Ambiguous cases, where there is a strong possibility, but not a certainty, that an incident represents an act of terrorism, were excluded; Unsuccessful attacks were excluded. Events that produced zero injuries and zero deaths were removed from the resulting set, in order to meet the SNRA national-level event threshold. All events involving vehicle borne explosives were also removed. The highest injury-producing event (10,000 injured in Peru) was considered an outlier and removed. Incidents that were part of multi-incident events were aggregated to produce more comprehensive injury/death totals. The resulting set included 10,161 incidents, which were then used to calculate the minimum, maximum, and mean, which are presented as low, high, and best estimates in the table above.

[3] Office of Infrastructure Protection, Department of Homeland Security: http://www.dhs.gov/files/partnerships/editorial_0206.shtm.

[4] In order to identify events in the GTD database that were most comparable to the SNRA definition of Explosives Terrorism Attack, the following search criteria were used: Attack Type: Bombing/Explosion; Weapon Type: Explosives/Bombs/Dynamite OR Incendiary; Terrorism Criteria: Require (a) The act must be aimed at attaining a

political, economic, religious, or social goal, (b) There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims, (c) The action must be outside the context of legitimate warfare activities, i.e., the act must be outside the parameters permitted by international humanitarian law; Ambiguous cases, where there is a strong possibility, but not a certainty, that an incident represents an act of terrorism, were excluded; Unsuccessful attacks were excluded; Target Type: limited to Airports and Airlines, Business, Government (Diplomatic), Government (General), Military, Other, Telecommunication, Tourists, Transportation, Unknown, Utilities. Events that produced zero injuries and zero deaths were removed from the resulting set, in order to meet the SNRA national-level event threshold. The resulting set was then used to calculate the minimum, maximum, and mean, which are presented as low, high, and best estimates in the table above.

[5] The Centers for Disease Control and Prevention (CDC) Foodborne Outbreak Online Database (FOOD) is available online at http://www.cdc.gov/foodborneoutbreaks. Reported illnesses were adjusted to account for underreporting or underdiagnosis using the latest multipliers published by the CDC (26.1 for *STEC O157 [E. coli]*, 29.3 for *Salmonella spp., nontyphoidal*, 2.1 for *Listeria monocytogenes*). Scallan, E., Hoekstra, R. M., Angulo, F. J., Tauxe, R. V., Widdowson, M. –A., Roy, S. L., et al. (2011). Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases*, 17(1), 7-15. Available from URL: http://www.cdc.gov/EID/content/17/1/7.htm. Accessed on 22 August 2011.

[6] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents.

[7] Historic data for U.S. dam failures were provided by the U.S. Bureau of Reclamation via the DHS Office of Infrastructure Protection Dams Sector Branch. Dam failures which were caused by cascading events (e.g., a failing dam upstream) were combined into single events. Injuries were not reported in this dataset and were obtained separately for a limited set of dam failures. Of this set, the low number of injuries was 2 (Bergeron Pond Dam failure, New Hampshire, 1996; http://www.uswaternews.com/archives/arcsupply/6newhamp.html) and the high number of injuries was 3000 (Canyon Lake Dam, South Dakota, 1972; http://www.damsafety.org/media/Documents/PRESS/US_FailuresIncidents(1).pdf). It was assumed that a reasonable low estimate for injuries was 1 and the high estimate of 3000 was used. The best estimate used in the SNRA is the geometric mean of the low and high estimates. Injury reports for additional dams suggest that such an assumption may be warranted; reports of injuries numbering less than 10 were found for some dam failures, as well as reports of injuries greater than 800 for other dam failures.

[8] The low estimate of zero injuries/illnesses is drawn from the Three Mile Island core meltdown (Perham, C. (1980, October). EPA's Role at Three Mile Island. Retrieved from http://www.epa.gov/aboutepa/history/topics/tmi/02.html.) The best estimate for injuries/illnesses uses a simulation of the expected core damage frequencies and expected consequences obtained from the license renewal applications for a number of individual reactors available from the public website of the U.S. Nuclear Regulatory Commission (NRC) at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html. The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recently publicly available data and adequate for order of magnitude estimates in the SNRA. An alternative analysis was also conducted using fatality, injury, and core damage frequency data from NUREG-1150, and the best estimates from this analysis were within an order of magnitude of the results obtained using data from license renewal applications (U.S. Nuclear Regulatory Commission (1990). *NUREG-1150 Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*. Washington, DC: U.S. NRC). The expected consequences are weighted by the likelihood of a core damage accident for each reactor using a Crystal Ball simulation to determine the best injury/illness estimate. The high consequence estimates also come from the license renewal applications; these consequences correspond to the highest consequence scenarios outlined in the report. These usually involve a large, early release and assume that there is not enough time for successful evacuation. The frequency of these events is typically one-to-two orders of magnitude less than the frequency of any core damage event. Note that the frequency values reported in Appendix B do not correspond to the high and low injury/illness estimates. The injury/illness estimates include latent cancer morbidities.

[9] The U.S. historic earthquake record for events causing greater than $100 Million in damages was obtained from the published report by Vranes, K. and Pielke, R. (2009). Normalized earthquake damage and fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3), 84:101. Normalized consequence estimates take into account changes in population densities, community wealth, mitigation factors (such as improved building codes and emergency response), and inflation. A 1% annual mitigation factor was used, as described in Vranes & Pielke (2009). Since published normalized injury estimates were not available, a linear multiplier of the normalized fatalities reported by Vranes *et al* was used; this was deemed of sufficient precision for the purposes of the SNRA. The linear model assumed 23.5 injuries per fatality, based on New Madrid Seismic Zone estimates published by Elnashai et al. (2009), *Impact of New Madrid Seismic Zone earthquakes on the Central USA, Vol. 1*. Mid America Earthquake Center: University of Illinois. Available online at: http://hdl.handle.net/2142/14810.

[10] The U.S. historic flood record for events causing greater than $100 Million in damages was obtained by aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC). Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss reports were aggregated based on distance and time. Flood damage reports that occurred within 100 miles of one another and within plus or minus one calendar day were aggregated into composite flood events. The composite flood events above the $100 Million (2011 dollar) threshold were used for reporting frequency, fatality, injury, and direct economic loss estimates in the SNRA. All hurricanes were removed from flood events to avoid double-counting flooding damages included in the SNRA hurricane analysis.

[11] Expert judgments provided by CDC subject matter experts to the SNRA project, and informed by similar scenario assumptions and modeling as was used for the National Strategy for Pandemic Influenza and the National Planning Scenarios. The central estimate of 77 million is tied to the 25% attack rate of the scenario (25% of the 2009 U.S. population of 307 million falls clinically ill at the best estimate). All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).

[12] U.S. historic hurricane record for events causing greater than $100 Million in damages was obtained from the ICAT Damage Estimator (http://www.icatdamageestimator.com), which uses a methodology for computing economic losses similar to that published by Pielke, R.J., Gratz, J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized Hurricane Damage in the United States: 1900-2005. *Natural Hazards Review* 9: 29-42. Injury/illness estimates were produced for each hurricane based on a linear model relating fatalities to injury and illness. The model is derived from Hurricane Andrew in 1992; the CDC published injury/illness and fatality estimates for 19 parishes during Andrew and there were approximately 25 injuries to every fatality in the study group (CDC (1993). Injuries and Illnesses Related to Hurricane Andrew – Louisiana, 1992. *Morbidity and Mortality Weekly Report (MMWR)*, 42, 243-246.). It is important to note that evacuees can travel hundreds of miles before receiving medical attention, making it difficult to account for the number of storm-related injuries (Faul, M., Weller, N. F., and Jones, J. A. (2011, September). Injuries after Hurricane Katrina among Gulf Coast Evacuees Sheltered in Houston, Texas. *Journal of Emergency Nursing*, 37 (5), 460-468.

[13] Injuries were expected to occur in areas that do not receive a warning in time, communities not trained in evacuation, flat areas where no evacuation routes exist, and for persons who do not obey orders or who happen to be in vulnerable areas with no warning systems.

[14] For the low estimate of injuries/illnesses due to volcanic eruption, the population in the State of Washington U.S. Census tracts immediately surrounding Mt. Rainier was used. Approximately 20,000 people live in the surrounding Census tracts, and it was assumed that 10% of this population would be vulnerable to injury or illness as a result of ashfall. (10% figure: Blong, R. J. (1984). *Volcanic hazards: a sourcebook on the effects of eruptions*. Australia: Academic Press, p. 424. Population estimates were constructed using U.S. Census Data obtained from http://factfinder2.census.gov, accessed on September 18, 2011.) For the high estimate of injuries/illnesses due to volcanic eruption, a 60-mile radius ashfall centered at Mount Rainier was overlaid on 2000 U.S. Census block data. 1.5 million people were estimated to live within this radius, and it was assumed that 10% of this population would be susceptible to injury/illness from ashfall (see Blong (1984) reference above). The best estimate is the geometric mean of the low and high estimates.

[15] The U.S. historic wildfire record for events causing greater than $100 Million in damages was compiled from the SHELDUS database (Hazards & Vulnerability Research Institute (2011). The Spatial Hazards Events and Losses Database for the United States, Version 8.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org). SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double-counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events. All wildfires (after consolidation) above the $100 Million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS v8.0 to May 2011 values) from 1970-2009 were used in the SNRA analysis.

APPENDIX E: DIRECT ECONOMIC CONSEQUENCE ASSESSMENT

Note that all comparative statements are made within the set of natural and technological hazards treated by this unclassified adaptation of the SNRA Technical Report.

Overview

The direct economic losses associated with each national-level event were estimated in the SNRA. Direct costs include:

- *Decontamination, Disposal, and Physical Destruction:* DDP costs covered the repair, replacement, and environmental clean-up costs. It was assumed that the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services sectors is treated as increase in annual output for these sectors.
- *Business Interruption:* Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.
- *Loss in Spending from Fatalities:* A loss in spending of $42,500 was estimated for each fatality. In addition, $6,000 was included as increased output for mortuary services for each fatality.[1]
- *Medical Costs:* Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

For each national-level event, an attempt was made to assess each of the above types of direct costs. In some cases, this was not possible or it was judged that one type of direct costs would dominate the others such that the other types of direct costs were assumed to be negligible. In other cases, economic analysis from previous assessments or studies was leveraged for the SNRA even though the methodology for calculating direct costs differed somewhat from what is listed above. Details of the assumptions and approach used to estimate direct costs for each national-level event are provided in Table E1.

Due to time and resource constraints on the execution of the SNRA, indirect and induced economic impacts, which are often larger than direct losses, are not included in this assessment. This is a serious limitation that will be corrected in a future iteration of the SNRA. Indirect economic impacts include costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above. Induced costs include those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

[1] These figures were chosen for consistency with the 2011 ITRA. DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET/NOFORN; extracted information is UNCLASSIFIED).

When interpreting the direct economic loss results presented below, it is important to consider that the consequence data in the SNRA is directly related to the threshold included in each national-level event definition. For example, the results for wildfires indicate that *wildfires causing greater than $100 million in direct economic losses* are estimated to cause between $100 million and $3 billion in direct losses, with a best estimate of $800 million. For reference, the full national-level event definitions, including thresholds, can be found in Table 2 of the main report.

In many cases, the high estimates for direct economic losses in the SNRA were constructed from either historic maximums (e.g. natural hazards) or the 95th percentile of a modeled distribution (e.g. terrorism events). Thus, the high estimates associated with each national-level event may not be reflective of the direct economic losses which may occur from a "worst-case scenario". Additional analysis is necessary to characterize the "worst-case" upper bounds for direct economic losses associated with each national-level event.

Major Findings

- When considering the SNRA economic findings, it is important to remember that the direct economic losses are often dwarfed by the indirect and induced economic losses that occur in the aftermath of an event. The direct economic losses alone do not represent the full picture of the economic impacts to the Nation given the occurrence of a national-level event.
- The event among the natural and technological hazards treated by the SNRA having the highest direct economic losses given occurrence is a pandemic influenza outbreak with a 25% gross clinical attack rate and a case fatality rate similar to the 1968-1969 Hong Kong flu pandemic.
    - Such a pandemic influenza outbreak is estimated to cause between $85 billion and $255 billion in direct economic losses, with a best estimate of $170 billion.
- Many events in the SNRA have best estimates for direct economic losses on the order of $10 billion, including foot-and-mouth disease ($15B), earthquakes ($9B), accidental radiological substance releases ($9B), and hurricanes ($6B). However, the uncertainty and variability associated with the direct economic losses for each of these events varies significantly.
    - The uncertainty and variability associated with accidental radiological substance releases and foot-and-mouth disease is approximately a factor of ten and one hundred, respectively.
    - The uncertainty and variability associated with earthquakes and hurricanes is approximately a factor of one thousand.
- The following events have best estimates for direct economic losses which are $1 billion or less, with associated high estimates less than $20 billion: wildfires, floods, and accidental chemical substance releases (toxic inhalation hazards). Even though these events are estimated to have comparatively lower direct economic losses given occurrence, extreme cases of these events could still result in relatively significant losses.

Additional Information

Direct economic loss information of sufficient quality upon which to base comparisons could not be found for every national-level event. Source documents for the events discussed below are provided in the annotations to Table E1.

- *Space Weather:* Additional analysis is needed to better quantify the direct economic losses which may be caused due to a space weather event which disrupts power to a significant portion of the United States for months to years. The August 2003 blackout in the Eastern U.S. caused an estimated $4-10 billion in economic losses; this blackout was smaller in extent than the estimate for a national-level space weather event and was only hours to days in duration. One published estimate suggests that a space weather event could cause $1-2 trillion in the first year after the event, with a potential total duration of 4-10 years.

- *Tsunami:* FEMA HAZUS modeling of a tsunami wave hitting the Oregon coast with height 13 to 17 meters resulted in direct economic loss estimates ranging from $700 million to $3 billion. Costs are dominated by building losses.
- *Volcanic Eruption:* FEMA and USGS analysis estimates the direct economic impacts of an eruption of Mount Rainer to range from $4 billion to $16 billion.
- *Dam Failure:* Additional analysis is required to estimate the direct economic impacts of dam failure. Studies of some specific dams have estimated economic impacts in the hundreds of millions to billions of dollars, but may not be representative of the full set of dams in the United States.
- *Accidental Biological Food Contamination:* Additional analysis is required to estimate the direct economic impacts of accidental biological food contamination. Estimates for lost productivity and medical costs in the CDC's Foodborne Outbreak Online Database (FOOD) range from $3-11 million, but business interruption costs could be found only for the 2006 *E. coli* – spinach outbreak ($61.4 million).
- *Cyber Events:* The potential economic consequences of cyber events are sector-dependent and difficult to quantify.

Figure E1: Direct Economic Loss by National-level Event

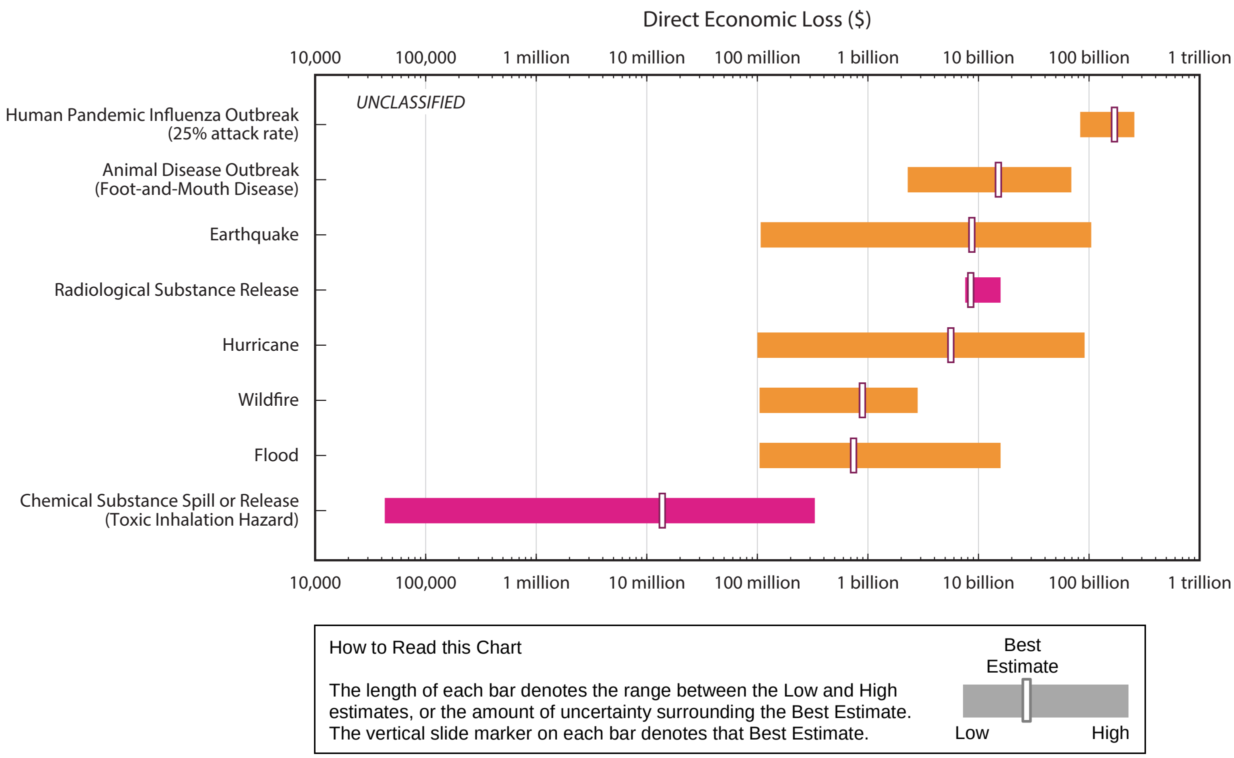


Table E1: SNRA Direct Economic Loss Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Direct Economic Loss Estimates ($ Millions)		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low		Direct economic costs were estimated using the 2010 DHS RAPID methodology for the economic consequences of explosives/kinetic/incendiary (EKI) events.[1]
		Best		
		High		
	Armed Assault	Low		Direct economic costs were estimated using an approach similar to the 2010 DHS RAPID methodology for the economic consequences of explosives/kinetic/incendiary (EKI) events.[2]
		Best		
		High		
	Biological Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile direct economic costs associated with events matching the SNRA definition of biological terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., release of an agent.[3]
		Best		
		High		
	Chemical Terrorism Attack (non-food)	Low		Data reflects the 5th percentile, mean, and 95th percentile direct economic costs associated with events matching the SNRA definition of chemical terrorism attacks (non-food) in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Chemical/Biological Food Contamination Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile direct economic costs associated with events matching the SNRA definition of chemical/biological food contamination terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., release of an agent.
		Best		
		High		
	Cyber Event affecting Data	Low	1,000	Additional analysis is necessary to quantify the direct economic losses caused by cyber events affecting data. Consequences for the types of attacks in this event category are difficult to quantify, as they depend upon the particular system attacked, the vulnerability and resilience of the network, specific data backup provisions, etc. The minimum direct economic loss considered in the definition of this national-level event in the SNRA is $1 B.
		Best	N/A	
		High	N/A	
	Cyber Event affecting Physical Infrastructure	Low	100	Additional analysis is required to quantify the direct economic losses caused by cyber events affecting physical infrastructure. Consequences for the types of attacks in this event category are sector dependent and difficult to quantify. Approximately 85% of critical infrastructure is believed to be owned and operated by the private sector, and system vulnerability and resilience is highly sector-
		Best	N/A	
		High	N/A	

Threat/ Hazard Group	Threat/Hazard Type	Direct Economic Loss Estimates ($ Millions)		Source Information
				dependent and localized.[4] Only attacks resulting in 1 fatality or greater or $100 Million in direct economic losses or greater were considered.
	Explosives Terrorism Attack	Low		Direct economic costs were estimated using the 2010 DHS RAPID methodology for the economic consequences of explosives/kinetic/incendiary (EKI) events.[5]
		Best		
		High		
	Nuclear Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile direct economic costs associated with events matching the SNRA definition of nuclear terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., detonation of a device.
		Best		
		High		
	Radiological Terrorism Attack	Low		Data reflects the 5th percentile, mean, and 95th percentile injury/illness estimates associated with events matching the SNRA definition of radiological terrorism attacks in the 2011 Integrated Terrorism Risk Assessment (ITRA) conducted by the DHS Science & Technology Directorate. Direct economic cost estimates in the SNRA include data for successful attacks, e.g., detonation of a device or radiation exposure.
		Best		
		High		
Technological/ Accidental	Biological Food Contamination	Low	N/A	Additional analysis is required to estimate the direct economic impacts of accidental biological food contamination. Estimates for lost productivity and medical costs in the CDC's Foodborne Outbreak Online Database (FOOD) range from $3-11 Million[6], but business interruption costs could be found only for the 2006 *E. Coli* – spinach outbreak ($61.4M).[7]
		Best	N/A	
		High	N/A	
	Chemical Substance Spill or Release	Low	0.04	Estimates correspond to the low, average, and high direct economic loss reported per incident within the U.S. historic data set used for the SNRA analysis.[8]
		Best	14	
		High	330	
	Dam Failure	Low	N/A	Additional analysis is required to estimate the direct economic impacts of dam failure. Studies of some specific dams have estimated economic impacts in the hundreds of millions to billions of dollars, but may not be representative of the full set of dams in the U.S.[9]
		Best	N/A	
		High	N/A	
	Radiological Substance Release	Low	7,500	Estimates are drawn from the historic case of Three Mile Island as well as license renewal applications available on the public website of the U.S. Nuclear Regulatory Commission.[10]
		Best	8,600	
		High	16,000	
Natural	Animal Disease Outbreak	Low	2,300	Direct economic cost estimate informed by a case study of the impacts of an introduction of the disease into dairy herds in California.[11]
		Best	15,200	
		High	69,000	
	Earthquake	Low	107	Estimates correspond to the low, average, and high direct economic losses from earthquakes causing greater than $100 M in damages from the U.S. historic events between 1906-2011.[12]
		Best	8,700	
		High	105,000	

Threat/ Hazard Group	Threat/Hazard Type	Direct Economic Loss Estimates ($ Millions)		Source Information
	Flood	Low	104	Estimates correspond to the low, average, and high direct economic losses from floods causing greater than $100 M in damages from the U.S. historic events between January 1, 1993 to December 31, 2005.[13]
		Best	740	
		High	16,000	
	Human Pandemic Outbreak	Low	84,000	Direct economic cost estimates provided by CDC assuming a 25% attack rate, using case fatality rates associated with the 1968-1969 Hong Kong flu pandemic.[14]
		Best	170,000	
		High	260,000	
	Hurricane	Low	100	Estimates correspond to the low, average, and high injuries from hurricanes causing greater than $100 M in damages from the U.S. historic events between 1970-2010.[15]
		Best	5,700	
		High	92,000	
	Space Weather	Low	N/A	Additional analysis is needed to better quantify the direct economic losses which may be caused due to a space weather event. The August 2003 blackout in the Eastern U.S. caused an estimated $4-10 Billion in economic losses; this blackout was smaller in extent than the estimate for a national-level space weather event and was only hours to days in duration. One published estimate suggests that a space weather event could cause $1-2 trillion in the first year after the event, with a potential total duration of 4-10 years.[16]
		Best	N/A	
		High	N/A	
	Tsunami	Low	700	Low, best, and high estimates were determined by FEMA HAZUS modeling of a tsunami wave hitting the Oregon coast of height 13, 15, and 17 meters, respectively. Costs are dominated by building losses.
		Best	1,500	
		High	3,300	
	Volcanic Eruption	Low	4,300	Estimates informed by FEMA and USGS economic analysis of the economic impacts of an eruption of Mount Rainier.[17]
		Best	10,000	
		High	16,000	
	Wildfire	Low	100	Estimates correspond to the low, average, and high economic costs from wildfires causing greater than $100 M in damages from the U.S. historic events between 1990-2009.[18]
		Best	900	
		High	2,800	

[1] RAPID, or the Risk Informed Process for Improved Decision-making, includes business interruption costs, disposal, decontamination, and physical destruction (DDP) costs, medical costs, and lost demand from fatalities in its estimates of direct economic impact.

[2] The direct economic analysis for Armed Assault included: Business interruption costs from the 2010 RAPID EKI models for government sector buildings, commercial sector buildings, and national monuments and icons as targets; DDP cost assumptions for an EKI man portable IED from the 2010 RAPID EKI models for government buildings, commercial sector buildings, national monuments and icons, and airports as targets; medical costs based on assumptions for the 2010 RAPID EKI incident set; and lost demand from fatalities based on assumptions from the 2010 RAPID assessment.

[3] Direct costs in the 2011 ITRA include business interruption costs, DDP costs, medical costs, and lost demand from fatalities.

[4] Office of Infrastructure Protection, Department of Homeland Security: http://www.dhs.gov/files/partnerships/editorial_0206.shtm.

[5] The direct economic analysis for Explosives Terrorism Attacks included: Business interruption costs and DDP costs from the 2010 RAPID EKI models for man portable IED, vessel IED, and vehicle borne IED against all target classes; medical costs based on assumptions for the 2010 RAPID EKI incident set; and lost demand from fatalities based on assumptions from the 2010 RAPID assessment.

[6] The Centers for Disease Control and Prevention (CDC) Foodborne Outbreak Online Database (FOOD) is available online at http://www.cdc.gov/foodborneoutbreaks. Estimates were obtained from historic events in FOOD which were multistate outbreaks requiring greater than 100 hospitalizations. Years included in FOOD include 1998-2008. To compute lost productivity due to illness and medical costs, the USDA's Economic Research Service's Foodborne Illness Cost Calculator was used, with the Value of a Statistical Life (VSL) set to $0. (http://www.ers.usda.gov/Data/FoodBorneIllness; accessed on 19 August 2011.)

[7] Arnade, C., Calvin, L., & Kuchus, F. (2010, March). *Consumers' response to the 2006 foodborne illness outbreak linked to spinach*. United States Department of Agriculture, Economic Research Service. Available from: http://www.ers.usda.gov/AmberWaves/March10/Features/OutbreakSpinach.htm. Accessed on 19 August 2011.

[8] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other than or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents. Direct economic damages which fixed facilities are required to report, and update for accuracy, to the RMP database are property damage to equipment or the facility itself, and all known or readily knowable property damage outside the facility. Direct economic damages which transport carriers are required to report to the PHMSA transportation database are the value of the material (spilled chemical) which was lost, physical damage sustained by the carrier (vehicles or other cargo), damage caused to public or private property, the dollar value of the response cost, and the dollar value of any remediation and clean-up cost. These damages do not include business interruption costs, medical or insurance costs, or litigation or settlement costs not overlapping with the costs listed above. The SNRA project team added medical cost estimates ($6,600 per injury/illness) and the loss in demand due to fatalities ($42,000 per fatality) to the direct economic costs above for consistency with the terrorism events. Business interruption costs were not considered in this analysis but judged to be low relative to the included costs.

[9] Examples of studies of the direct economic consequences of dam failure include: estimates ranging from $400M to $2.9B for failures of the Miller Dam and Mansfield Dam in Austin, Texas (Texas Colorado River Floodplain Association, *Creating a Disaster-Resistant Lower Colorado River Basin*, Section 15); estimates ranging from $78M to $1.3B for the failure of dams in Northeastern Idaho (*Regional All-Hazards Mitigation Plan for Northeastern Idaho*); and an estimate of approximately $20 B for a catastrophic failure of the Hills Creek Dam in Oregon (Goettel, K. A. (2001). *Regional All Hazard Mitigation Master Plan for Benton, Lane, and Linn Counties, Phase Two*. Prepared for the Benton County Project Impact and the Oregon Cascades Regional Emergency Management Coordinating Council).

[10] The best estimate for direct economic loss uses a simulation of the expected core damage frequencies and expected consequences obtained from the license renewal applications for a number of individual reactors available from the public website of the U.S. Nuclear Regulatory Commission (NRC) at http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html. The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recently publicly available data and adequate for order of magnitude estimates in the SNRA. The expected consequences are weighted by the likelihood of a core damage accident for each reactor using a Crystal Ball simulation to determine the best direct economic loss estimate. The low and high consequence estimates also come from the license renewal applications; these consequences correspond to the most frequent types of core damage accidents in each report and the highest consequence scenarios outlined in each report, respectively. For the low estimates, the economic costs are mostly fixed values associated with business interruption and are consistent with the $1B in decontamination costs from the shutdown of Reactor 2 at Three Mile Island (14-Year Cleanup at Three Mile Island Concludes. *New York Times*, August 15, 1993). The highest consequence scenarios usually involve a large, early release and assume that there is not enough time for successful evacuation. The frequency of these events is typically one-to-two orders of magnitude less than the frequency of any core damage event. Note that the frequency values reported in Appendix B do not correspond to the high and low direct economic loss estimates.

[11] Carpenter, T. E., O'Brien, J. M., Hagerman, A. D., McCarl, B. A. (2011). Epidemic and economic impacts of delayed detection of foot-and-mouth disease: A case study of an outbreak in California. *Journal of Veterinary Diagnostic Investigation*, 23, 26-33. The direct economic impact of an FMD outbreak will come from an immediate reduction in lost international trade as well as disease control and eradication efforts, which can include the cost of maintenance of animal movement controls, control areas, intensified border inspections, vaccines, depopulation, carcass disposal, indemnification to farmers for losses, and disinfection and decontamination efforts.

[12] The U.S. historic earthquake record for events causing greater than $100 Million in damages was obtained from the published report by Vranes, K. and Pielke, R. (2009). Normalized earthquake damage and fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3), 84:101. Normalized economic estimates take into account changes in population densities, community wealth, mitigation factors (such as improved building codes and emergency response), and inflation. A 1% annual mitigation factor was used, as described in Vranes & Pielke (2009).

[13] The U.S. historic flood record for events causing greater than $100 Million in damages was obtained by aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC). Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss reports were aggregated based on distance and time. Flood damage reports that occurred within 100 miles of one another and within plus or minus one calendar day were aggregated into composite flood events. The composite flood events above the $100 Million (2011 dollar) threshold were used for reporting frequency, fatality, injury, and direct economic loss estimates in the SNRA. All hurricanes were removed from flood events to avoid double-counting flooding damages included in the SNRA hurricane analysis.

[14] Meltzer, M.I., Cox, N.J., and Fukuda, K. (1999). The economic impact of pandemic influenza in the United States: Priorities for intervention. *Emerging Infectious Diseases* 5, 659-671. The pandemic influenza scenario is based upon a U.S. population of approximately 307 million; all of the estimates are given absent any intervention (i.e., before interventions are applied or attempted). The economic impact for the 1968 scenario was taken from Meltzer *et al.* and updated from 1995 values to 2010 dollar estimates, using the Consumer Price Index conversion factor (CPI – 1.431 conversion factor. http://www.bls.gov/data). The dollar values provided estimates for lost productivity due to time off work to either convalesce or care for a family member who is ill. Approximately 83% of the estimated impact for this scenario is associated with the value of lost productivity due to premature death. Beyond the inclusion of value of time lost from work, these estimates do not include any valuation for lost economic activity, such as business closing or notable reduction in economic activity.

[15] The U.S. historic hurricane record for events causing greater than $100 Million in damages was obtained from the ICAT Damage Estimator (http://www.icatdamageestimator.com), which uses a methodology for computing economic losses similar to that published by Pielke, R.J., Gratz, J., Landsea, C., Collins, D., Saunders, M., and Musulin, R. (2008). Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review* 9: 29-42. Historic economic damage estimates were updated to a 2011 base year by taking into account changes in populations, building structures, and infrastructure. These estimates potentially include indirect economic losses. There is not a clear disambiguation for economic loss estimates as there is no readily available record for each loss estimate. Due to this ambiguity, economic loss estimates have the potential to be biased high.

[16] Committee on the Societal and Economic Impacts of Space Weather Events, National Research Council (2008). *Severe space weather events – understanding societal and economic impacts: A workshop report*, p. 77. Washington, DC: National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=12507.

[17] To calculate the low estimate of direct economic losses for volcanic eruption, the Mount Rainier Inundation Zone for Case I Debris Flows GIS boundary (Hoblitt, R. P., Walder, J. S., Driedger, C. L., Scott, K. M., Pringle, P. T., & Wallace, J. W. (1998), *Volcano Hazards from Mount Rainier, Washington*. U.S. Geological Survey Open-File Report 98-428 [Data file]. Available from: http://vulcan.wr.usgs.gov/Volcanoes/Rainier/Hazards/OFR98-428/framework.html) was overlaid on 2000 U.S. Census data in HAZUS. The General Building Stock Exposure (replacement amount) designated by occupancy in census blocks was used to calculate the total dollar exposure of the combined amounts for commercial, industrial, agricultural, religion, government, and educational industries. To calculate the high estimate of direct economic losses, USGS analysis was used (Wood, N. J. & Soulard, C. E. (2009, September 16). *Community exposure to lahar hazards from Mount Rainier, Washington*. USGS Scientific Investigations Report 2009-5211). The best estimate is the geometric mean of the low and high estimates.

[18] The U.S. historic wildfire record for events causing greater than $100 Million in damages was compiled from the SHELDUS database (Hazards & Vulnerability Research Institute (2011). The Spatial Hazards Events and Losses Database for the United States, Version 8.0 [Online Database]. Columbia, SC: University of South Carolina. Available from http://www.sheldus.org). SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double-counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events. All wildfires (after consolidation) above the $100 Million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS v8.0 to May 2011 values) from 1970-2009 were used in the SNRA analysis. Economic losses reported in SHELDUS include property and crop losses. These were judged to dominate any business interruption, medical costs, or loss in spending due to fatalities.

APPENDIX F: SOCIAL DISPLACEMENT CONSEQUENCE ASSESSMENT

All social displacement consequence estimates in the SNRA are unclassified.

Overview

In the SNRA, social displacement is defined as the number of people forced to leave their home for a period of two days or longer due to a national-level event. Displacement estimates were obtained primarily by research staff at the National Consortium for the Study of Terrorism and Responses to Terrorism (START),[1] who consulted the open social sciences literature and various open source databases for historical events and relevant models providing analysis and results comparable to the national-level events described in the SNRA. Additional social displacement inputs were obtained from FEMA technical staff providing modeling support using HAZUS MH software, and SNRA project team analysis of open source literature and incident management databases.

The Department of Homeland Security (DHS) Office of Risk Management (RMA), in partnership with the DHS Science and Technology (S&T) Human Factors/Behavioral Sciences Division (HFD),[2] utilized START's network of experts for advice on social displacement data and metrics. Experts advised that displacement is a reasonable first proxy for many additional social impact metrics, while also noting the importance of accounting for the time dimension in displacement. There is a significant difference between short-term evacuation for a week versus longer-term permanent relocation, and the SNRA displacement measure of number of people displaced currently does not differentiate between these two types of displacement. Because of this, the experts emphasized extreme caution in using these social consequence results, particularly when this metric is being considered in isolation.

The initial SNRA social displacement analysis presented below was conducted to support the development of the National Preparedness Goal. The resulting data have not undergone extensive review by any Federal Agency, and have not been extensively verified and validated by social sciences academic researchers.

The Department of Homeland Security and its partner organizations are funding social and behavioral research to better understand the psychosocial impacts of terrorist acts, natural disasters, and technological accidents. In addition to providing means for more accurately assessing these impacts, this research will inform programs that have been developed to promote resilience in individuals, organizations, communities, and at the national level. Results and new insights for preparedness are expected over the next five years.

Major Findings

The highest potential for adverse social displacement results from nuclear attack and hurricane events.

There is substantial uncertainty about the social displacement that would be caused by a space weather event. Since a space weather event has the potential to significantly disrupt the electric grid, communications and GPS services, and damage critical infrastructure (i.e., power

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[1] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes. Based at the University of Maryland, START supports research efforts of leading social scientists at more than 50 academic and research institutions.

[2] DHS/S&T Resilient Systems Division (RSD) is the current (2015) organizational successor to Human Factors Division.

transformers), the affected areas are essentially out of commission, leaving the population(s) literally and figuratively "in the dark" for weeks to months.[3] However, the potential for a space weather event to cause large-scale consequences is under debate.

Estimates for displacement due to a nuclear terrorism attack range from 330,000 to 3 million, and are informed by published evacuation/shelter-in-place estimates for a detonated 10-kiloton improvised nuclear device. Hundreds of thousands of people in the affected area may seek shelter in safe areas or shelter-in-place in their residence as the plume moves across the region, and many more may self-evacuate from major urban areas. Chemical, radiological, and biological terrorism attacks may also cause significant displacement: this is dependent upon agent, dispersal mechanism, and target location.

Conventional terrorism attacks (e.g., explosives and armed assaults) and cyber events are judged to have relatively lower displacement than many events in the assessment, but high estimates for the displacement due to these events were not available in the time frame of this initial assessment. The evacuations from Lower Manhattan following the use of aircraft as a weapon in the September 11, 2001 attacks illustrates the potential for non-CBRN adversarial/human-caused events to cause significant displacement.

Hurricanes have the potential to displace millions of people from their homes for two days or longer, but much of this displacement is proactive short-term evacuation intended to prevent loss-of-life or injuries, in addition to the long-term or permanent displacement caused by the destruction of housing. Many of the natural hazard and technological/accidental hazard events, including earthquakes, floods, tsunamis, volcanoes, and dam failure, also have the potential to cause long-term/permanent displacement in addition to temporary evacuations.

Displacement due to natural hazards is better understood overall than displacement from adversarial or accidental events, but recent natural hazards (i.e., Hurricanes Katrina, Rita, Gustav, and Ike) have demonstrated the lack of available, high quality social science research focusing on the social consequences of these types of catastrophes and how to best mitigate them.

Given the diversity of hazards and the range of communities in the United States, it will remain difficult to predict with absolute certainty how a specific event will affect a specific community. It is, however, both possible and necessary to improve our understanding of the social impacts of events and to use this knowledge to inform risk assessment and management strategies.

[3] Jaggard, V. (2011, August 3). As sun storms ramp up, electric grid braces for impact. *National Geographic News*. Retrieved from http://news.nationalgeographic.com/news/energy/2011/08/110803-solar-flare-storm-electricity-grid-risk/ (accessed August 8, 2011).

Figure F1: Social Displacement by National-level Event

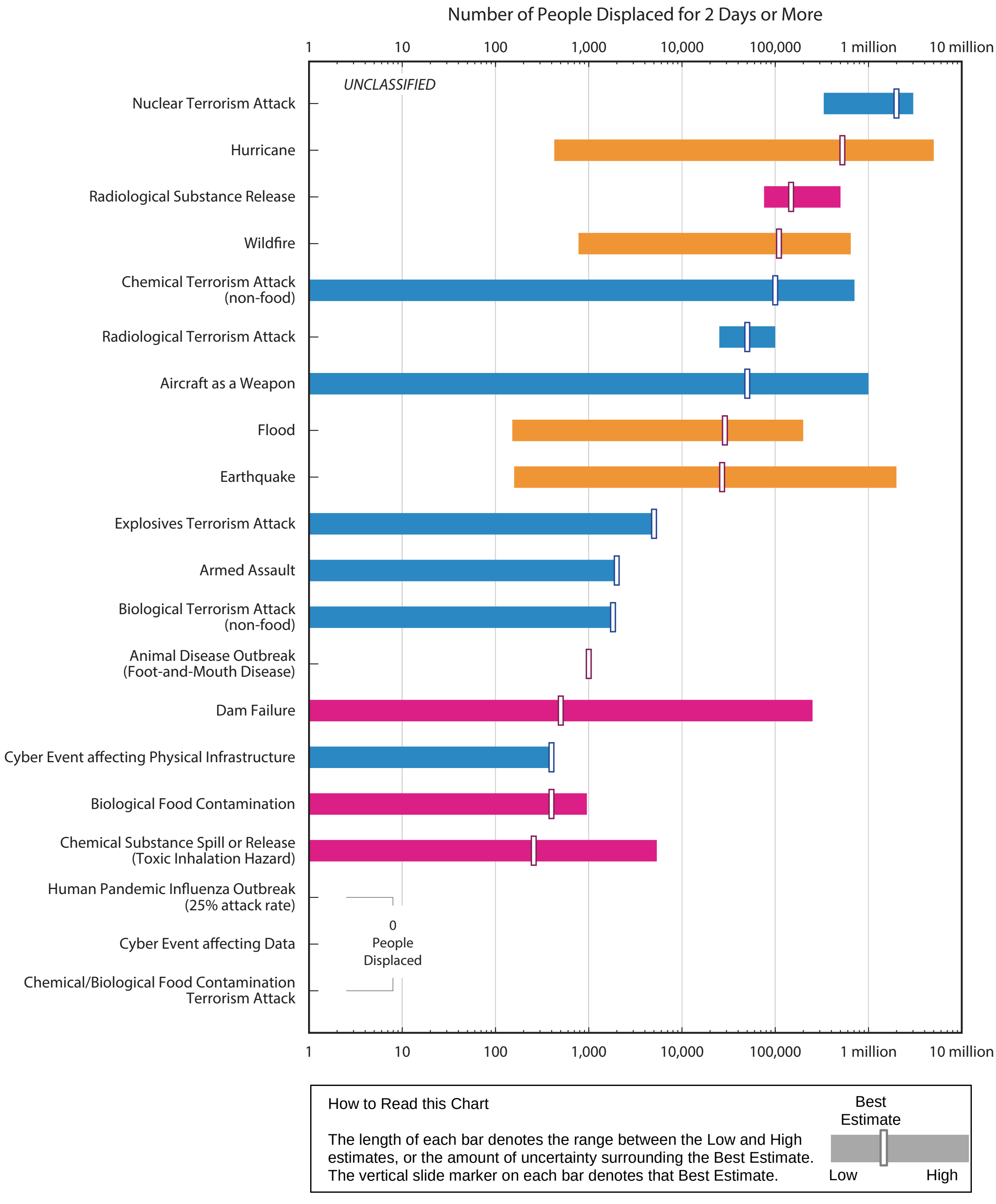

Table F1: SNRA Social Displacement Data and Sources

Threat/ Hazard Group	Threat/Hazard Type	Displacement Estimate		Source Information
Adversarial/ Human-Caused	Aircraft as a Weapon	Low	0	Low estimate assumed to be zero.
		Best	50,000	Expert judgment.
		High	1,000,000	Displacement estimate from Lower Manhattan after 9/11.[1]
	Armed Assault	Low	0	Low estimate assumed to be zero.
		Best	2,000	Expert judgment.
		High	N/A	High estimate not available.
	Biological Terrorism Attack (non-food)	Low	0	Low estimate assumed to be zero.
		Best	1,800	Historical displacement due to a natural outbreak is used as a proxy estimate for a small-scale, deliberate dissemination of a contagious agent.[2]
		High	N/A	High estimate not available.
	Chemical Terrorism Attack (non-food)	Low	0	Low estimate assumed to be zero.
		Best	100,000	Estimated evacuation and dispersal number for a chemical attack (blister agent) aimed at a large gathering such as a football game.[3]
		High	700,000	Estimated evacuation and dispersal number for a chemical attack (industrial chemicals) where a terrorist uses explosive devices aimed at a petroleum plant.[3]
	Chemical/Biological Food Contamination Terrorism Attack	Low	0	Low estimate assumed to be zero.
		Best	N/A	Best and high estimates not available. Experts judged that displacement is likely to be minimal.
		High	N/A	
	Cyber Event affecting Data	Low	0	No physical damage or harm, so no displacement expected.
		Best	0	
		High	0	
	Cyber Event affecting Physical Infrastructure	Low	0	Low estimate assumed to be zero.
		Best	400	Estimate based on case study of Army base evacuation due to accidental power outage, judged to be a proxy estimate for an intentional outage.[4]
		High	N/A	High estimate not available. Experts noted that a prolonged power outage over a large area could result in several thousand evacuating, regardless of outage cause.
	Explosives Terrorism Attack	Low	0	Low estimate assumed to be zero.
		Best	5,000	Expert judgment based on an evacuation radius of several blocks from the location of an improvised explosive device (IED).
		High	N/A	High estimate not available.
	Nuclear Terrorism Attack	Low	330,000	Low, high, and best estimates are informed by published evacuation/shelter-in-place estimates for a detonated 10 kiloton improvised nuclear device.[5]
		Best	2,000,000	
		High	3,000,000	
	Radiological Terrorism Attack	Low	25,000	Low, best, and high estimates are informed by published evacuation/shelter-in-place estimates for a radiological dispersal device (RDD).[6]
		Best	50,000	
		High	100,000	

Threat/ Hazard Group	Threat/Hazard Type	Displacement Estimate		Source Information
Technological/ Accidental	Biological Food Contamination	Low	0	Low estimate assumed to be zero.
		Best	400	Expert judgment.
		High	950	High estimate based on historic case study of *E. coli* in town water supply.[7]
	Chemical Substance Spill or Release	Low	0	Low, best, and high estimates obtained from analysis of the EPA Risk Management Program and the DOT Pipeline and Hazardous Substance Management Agency databases for the defined national-level event.[8]
		Best	255	
		High	5,400	
	Dam Failure	Low	1	Low estimate assumed to be 1 (minimal).
		Best	500	Best estimate computed as the geometric mean of the low and high estimate.
		High	250,000	High estimate informed by published displacement estimates for the Hills Creek Dam in Oregon and the Folsom Dam in California.[9]
	Radiological Substance Release	Low	76,000	Low and best estimates reflect published estimates of displacement from the Three Mile Island incident.[10]
		Best	150,000	
		High	500,000	High estimate reflects published estimates of displacement from the Chernobyl incident.[11]
Natural	Animal Disease Outbreak	Low	0	Low estimate assumed to be zero.
		Best	1,000	Expert judgment. Those working on or near farms may be asked to relocate to reduce the chance of transmitting foot-and-mouth disease to other livestock.
		High	N/A	High estimate not available.
	Earthquake	Low	160	Estimates reflect historic low and average reports of "total affected" for earthquakes causing greater than $100 M in economic damage as recorded in EM-DAT during the time period 1970-2011.[12]
		Best	27,000	
		High	2,000,000	Expert judgment provided by FEMA.
	Flood	Low	150	Estimates reflect historic low, average, and high reports of "total affected" for floods causing greater than $100 M in economic damage as recorded in EM-DAT during the time period 1970-2011.[12]
		Best	29,000	
		High	200,000	
	Human Pandemic Outbreak	Low	0	Negligible displacement assumed. Hospitalizations of 2 days or greater are not counted as displacement in this assessment.
		Best	0	
		High	0	
	Hurricane	Low	430	Estimates reflect historic low, average, and high reports of "total affected" for hurricanes causing greater than $100 M in economic damage as recorded in EM-DAT during the time period 1970-2011.[12]
		Best	520,000	
		High	5,000,000	
	Space Weather	Low	N/A	Additional analysis is needed to understand the potential for social displacement due to a space weather event.
		Best	N/A	
		High	N/A	
	Tsunami	Low	8,600	Estimates provided by FEMA based on HAZUS modeling of tsunami hitting the Oregon coast.
		Best	15,000	
		High	N/A	High estimate not available.

Threat/ Hazard Group	Threat/Hazard Type	Displacement Estimate		Source Information
	Volcanic Eruption	Low	1,300	Low, best, and high estimates based on USGS and HAZUS modeling of eruption of Mount Rainier.
		Best	130,000	
		High	2,100,000	
	Wildfire	Low	770	Estimates reflect historic low, average, and high reports of "total affected" for wildfires causing greater than $100 M in economic damage as recorded in EM-DAT during the time period 1991-2011.[12]
		Best	110,000	
		High	640,000	

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[1] Sources for the Aircraft as a Weapon displacement estimates include: (1) Fritsch, Jane (2001, September 12). A day of terror – the response: rescue workers rush in, and many do not return, *The New York Times*; and (2) Marine Log (2001, September 19). Boats evacuated one million New Yorkers after WTC attack. Retrieved from http://www.marinelog.com/DOCS/NEWSMM/MMISep19.html. The high estimate may count residents as well as non-resident workers evacuating from Lower Manhattan, and thus may be an overestimate of displacement.

[2] The best estimate of displacement for a Biological Terrorism Attack is based on the number evacuated in East Timor in 1999 during a natural outbreak of tuberculosis. Source: Connolly, Maire (1999). Communicable Disease Surveillance and Control in East Timor. Geneva: World Health Organization. Retrieved from http://www.who.int/disasters/repo/7839.doc. Subject matter experts consulted for the SNRA noted that this estimate is arbitrary given the large range of potential biological attack scenarios; the high estimate could be significantly higher than the best estimate provided if there is a need to decontaminate a large area.

[3] Bea, Keith (2005, March 10). *National Preparedness System: Issues in the 109th Congress*. Congressional Research Service Report for Congress.

[4] Reed, C. & Okubo, G. (2010, July 6). Flooding, power outages force evacuations at Yokota. *Stars and Stripes.* Retrieved from http://www.stripes.com/news/pacific/japan/flooding-power-outages-force-evacuations-at-yokota-1.110071.

[5] Davis, Tracy C. (2007). *Stages of Emergency: Cold War Nuclear Civil Defense*. Durham NC: Duke University Press; Meade C., Molander R. C. (2006). *Considering the Effects of a Catastrophic Terrorist Attack*. Santa Monica, CA: RAND Center for Terrorism Risk Management Policy. Retrieved from http://www.rand.org/pubs/technical_reports/2006/RAND_TR391.pdf; National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats (2010). *Planning Guidance for Response to a Nuclear Detonation* (2nd ed.). Retrieved from http://www.remm.nlm.gov/PlanningGuidanceNuclearDetonation.pdf.

[6] Worcester, Maxim (2008). *International Terrorism and the Threat of a Dirty Bomb*. Berlin: Institute Für Strategie-Politik-Sicherheits-und Wirtschaftsberatung. Available from http://www.isn.ethz.ch/isn/Digital-Library/Publications/Detail/?id=46567.

[7] Contamination of the water by *E. coli* in the Ontario community of Kashechewan forced the evacuation of the town. Source: Virchez, J. & Brisbois, R. (2007). A historical and situational summary of relations between Canada and the First Nations: The case of the community of Kashechewan in Northern Ontario. *Revista Mexicana de Estudios Canadienses (nueva época), otoño-invierno*, 014, 87-100. Note that contamination of the food supply is likely to cause minimal displacement (see Chemical/Biological Food Contamination Terrorism Attack estimate).

[8] The set of historic chemical substance release events used for analysis in the SNRA were those which met the following criteria: 1) at least one "public" fatality, defined as one fatality other than or in addition to an employee fatality, caused by the hazardous material; or 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order. This set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's Risk Management Program (RMP) accident database for fixed industrial producers and consumers of the listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents. For consistency with the other national-level events, reported numbers of total people evacuated were counted only for those events where the reported total evacuation time (PHMSA) or total release duration of the toxic chemical (RMP) was 48 hours or more. Since evacuations may last longer (to ensure the released chemical has fully dissipated) or shorter (when they begin after a delay from the onset of the toxic leak) than the chemical release duration, the events from the RMP database meeting this criterion may be somewhat more or fewer than the ones counted here: but given that these are variations in hours compared with the minimum inclusion of two days, a substantial deviation is unlikely. It is important to note that there is international precedent for displacement in the hundreds of thousands, including the chlorine leakage caused by a railroad accident in Mississauga, Canada, and the explosion at a Union Carbide plant and subsequent release of methylisocynate (MIC) in Bhopal, India (Soffer, Y., Schwartz,

D., Goldberg, A., Henenfeld, M., & Bar-Dayan, Y. (2008). Population evacuations in industrial accidents: A review of the literature about four major events. *Prehospital and Disaster Medicine*, 23(3), 276-281.)

[9] Source for Hills Creek Dam: Oregon Partnership for Disaster Resilience. (2009, October). *Eugene/Springfield multi-jurisdictional natural hazards mitigation plan: Prepared for the cities of Eugene and Springfield, Oregon*. Retrieved from: http://www.eugene-or.gov/portal/server.pt/gateway/PTARGS_0_2_355923_0_0_18/NHMP09.pdf. Source for Folsom Dam: Ayyaswamy, P., Hauss, B., Hseih, T., Moscati, A., Hicks, T. E., & Okrent, D. (1974, March). *Estimates of the Risks Associated with Dam Failure* (UCLA-ENG-7434). Los Angeles, CA: UCLA School of Engineering and Applied Science.

[10] Sources for the low and best estimates of displacement due to Accidental Radiological Substance Release are: Cutter, S. & Barnes, K. (1982). Evacuation Behavior and Three Mile Island. *Disasters*, 6(2): 116-124; and Soffer, Y., Schwartz, D., Goldberg, A., Henenfeld, M., & Bar-Dayan, Y. (2008). Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events. *Prehospital and Disaster Medicine*, 23(3), 276-281.

[11] Soffer, Y., Schwartz, D., Goldberg, A., Henenfeld, M., & Bar-Dayan, Y. (2008). Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events. *Prehospital and Disaster Medicine*, 23(3), 276-281.

[12] Centre for Research on the Epidemiology of Disasters (2011). EM-DAT: The OFDA/CRED International Disaster Database. [Data file]. Brussels: Université Catholique de Louvain. Available from http://www.emdat.be. EM-DAT, an emergency events database maintained by the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters with support from USAID, provides estimates of the "total number affected" by disaster events. The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to natural disasters is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA. Note that the low estimate may be biased low due to incomplete reporting of displacement and evacuations in EM-DAT.

Appendix G: Psychological Distress Consequence Assessment

Note that all comparative statements based upon quantitative findings are made within the set of natural and technological hazards treated by this extract from the SNRA.

Overview

The DHS Office of Risk Management (RMA), in partnership with DHS Science and Technology (S&T) Human Factors/Behavioral Sciences Division (HFD),[1] consulted with several nationally recognized academic researchers investigating psychosocial impacts of disasters and terrorism, including the effects on public health, civil society, and public trust. These experts recommended a methodology to assess psychological distress which would permit comparison across national-level events included in the SNRA.

Methodology

Substantial academic research has been conducted on the psychological consequences of disasters.[2,3,4,5] This research primarily has focused on individual, family, and community impacts rather than the strategic, national-level impacts of interest in this assessment. However, the results have provided a scientific basis for preliminary methodologies for estimating psychological consequences in the SNRA.

The DHS Office of Risk Management (RMA), in partnership with DHS Science and Technology (S&T) Human Factors/Behavioral Sciences Division (HFD), consulted with several nationally recognized academic researchers investigating psychosocial impacts of disasters and terrorism, including the effects on public health, civil society, and public trust. These experts recommended a methodology to assess psychological distress which would permit comparison across national-level events included in the SNRA.

Experts recommended that *significant and/or prolonged psychological distress* caused by national-level events would be the most meaningful psychological metric for strategic capabilities planning and national preparedness. *Fear* is pervasive during the initial impact of a disaster. It is natural and normal, virtually universal, and not harmful within limits (although it can have more serious and lasting consequences under certain conditions). In contrast, the concept of *distress* goes beyond the reactions experienced only at the time of disaster impact. Past research has documented a wide range of psychosocial consequences, including various psychological problems such as depression, anxiety, and posttraumatic stress disorder (PTSD); physical health problems, such as sleep disruption, somatic complaints, and impaired immune function; chronic problems in living, such as troubled interpersonal relationships and financial stress; and resource loss, such as declines in perceived control and perceived social support. The field of disaster behavioral health often distinguishes between *distress* and *disorder*, the latter of which refers to specific criterion-based conditions that may require professional intervention. *Distress* is a broader outcome,

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[1] DHS/S&T Resilient Systems Division (RSD) is the current (2015) organizational successor to Human Factors Division.

[2] Bonanno, G. A., Brewin, C. R., Kaniasty, K., & La Greca, A. M. (2010). Weighing the costs of disaster: consequences, risks, and resilience in individuals, families, and communities. *Psychological Science in the Public Interest*, 11(1), 1-49.

[3] Norris, F. H., & Wind, L. (2009). The experience of disaster: trauma, loss, adversities, and community effects. In Neria, Y., Galea, S., & Norris, F. (Eds.), *Mental Health and Disasters* (pp. 29-44). New York, NY: Cambridge University Press.

[4] Norris, F. H., Friedman, M. J., Watson, P. J., Byrne, C. M., Diaz, E., & Kaniasty, K. (2002). 60,000 disaster victims speak: Part I. An empirical review of the empirical literature, 1981-2001. *Psychiatry*, 65, pp. 207-239.

[5] Norris, F. H., Friedman, M. J., & Watson, P. J. (2002). 60,000 disaster victims speak: Part II. Summary and implications of the disaster mental health research. *Psychiatry*, 65, 240-260.

referring to a combination of cognitive, behavioral, and emotional reactions that do not necessarily conform to specific diagnostic criteria but nonetheless are serious enough to impair daily role functioning and quality of life. For the SNRA psychological consequences index, experts focused on distress rather than disorder, and used labels such as "significant" or "prolonged" distress to indicate that they would not include mild distress, such as would be expected in any person who has experienced a stressful event.

Prevalence estimates of distress (and disorder) vary markedly across studies. About 10% of the time, there is little or only very fleeting distress. About 50% of the time, distress is common, but rates of psychopathology are below 25%. About 40% of the time, distress is common with rates of psychopathology at 25% or greater. Published studies are biased toward more devastating events and vulnerable populations, and thus an interpretation that 40% of disasters have severe consequences for 25% or more of the population may not be fully justified. However, because the national-level events included in the SNRA all have the potential to be severe, this broad summary conclusion may be reasonable.

One challenging aspect of assessing psychological distress in the SNRA is the requirement to estimate the impacts of specific national-level events. Existing research on psychological consequences is not well-aligned with a focus on specific events or hazards. In general, researchers have learned that the type of event is not as important as it was once assumed to be in disaster mental health. What matters most is the scope and severity of an event, i.e., the prevalence of serious stressors that place great demands on the coping ability of the public. Disaster-related stressors that matter for mental health can be grouped into four broad categories: trauma, loss, ongoing adversities, and event familiarity/dread. The primary sources of trauma are threat to life, injury, and exposure to horrible sights, smells, and sounds. The primary sources of loss are property damage, such as to homes and vehicles, financial loss, and declines in psychosocial resources. Deaths cause both trauma and loss for survivors. Ongoing adversities include the challenges of living in damaged housing and communities, dealing with insurance companies and aid, or being displaced. Displacement causes both losses and adversities. Event familiarity/dread captures the intangible, subjective aspects of disaster exposure. All other things being equal, human-caused disasters, especially when intentional, are generally believed to be more distressing than others. Disasters that are followed by uncertainty regarding unseen consequences or fear of recurrence likewise are more distressing.

Such empirical findings indicate that the psychological consequences of a disaster may follow from the other types of consequences being assessed in the SNRA. To apply this working knowledge, a consequence index[6] for significant psychological distress was proposed by the experts that used the SNRA estimates for deaths, injuries, and displacement related to each national-level event. To reflect the empirical findings that losing a loved one is the most severe stressor, followed by injury, followed by displacement, the following formula for a Significant Distress Index was proposed:

[6] The consequence index used in the SNRA for psychological distress is analogous to a risk index, an approach which allows multiple factors which affect the level of risk to be incorporated into a single numerical score for the level of risk. For more information see: Information Standards Organization (2009). *Risk management – risk assessment techniques* (ISO 31010).

$$N_{SD} = C_{EF} \times \left(5\ N_F + N_I + ½\ N_D\right)$$

N_{SD} : number of persons with significant distress
N_F : number of fatalities
N_I : number of injuries/illnesses
N_D : number of people displaced
C_{EF} : Event Familiarity Factor

This formula suggests that, on average, there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. Note also that an Event Familiarity Factor is applied as an attempt to capture the extent to which psychosocial consequences might be exacerbated by an event entailing an ongoing threat with uncertainty about long term effects, that is unfamiliar, or that people dread. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA. Thus unfamiliar events (terrorism events, earthquake, chemical or radiological substance release, etc.) are weighted to have more psychological consequences compared to more familiar events (pandemic, flood, hurricane, etc.).

Uncertainty in the significant psychological distress caused by an event is captured by applying the formula to low, best and high estimates of deaths, injuries, and number displaced. Thus the formulaic approach yields a low-best-high index estimate for significant psychological distress. In addition, experts recommended that events scoring higher than 1,000,000 on this index could be considered to result in “high” psychological distress; events scoring between 50,000 to 1,000,000 on this index could be considered to result in “moderate” psychological distress; and events scoring less than 50,000 on this index could be considered to result in “low” psychological distress, in a relative sense.

Limitations

The methodological approach for psychological distress used in the SNRA represents a first attempt to include psychological consequences in a strategic, national-level risk assessment focused on national preparedness. While this approach is straightforward and transparent, it also has important limitations that should be considered when interpreting the psychological distress results:

- Time limitations for completing the SNRA did not allow for a thorough investigation of the structural form of the equation used for computing psychological distress or weights used in the equation. Additional analysis is required to verify and validate this approach, and the sensitivity of the results to the selection of weights in the formula should also be explored. The resulting data and initial analysis have not undergone extensive review by any Federal agency, and have not been extensively verified and validated by the broader community of academic researchers focused on psychosocial effects of disasters.
- The index approach currently does not include a component for translating economic losses into psychological distress. If estimates of homes destroyed and jobs lost (rather than overall direct economic losses) are obtained as consequence estimates for various national-level events, it would be possible to capture financial loss as part of the equation for psychological distress in future iterations of the SNRA.

- The current social displacement measure (counting people as displaced if they are forced to leave home for two or more days) does not differentiate between short term displacement (i.e., short term evacuation) and long term permanent displacement (i.e., the home is destroyed). Ideally, the psychological consequence index would differentiate these two types of displacement, because the long term displacement is much more impactful for "significant distress" and "prolonged distress" psychological consequences.
- The duration of distress is an important factor which is not considered in the current approach. Most people do recover over time, although individuals vary greatly in the speed with which they rebound. Empirical evidence suggests that four out of five people with significant disaster-related distress will recover. In combination with the formula used, this means that the experts consulted estimated that there is 1 psychological casualty (i.e., a person with serious and prolonged distress) for each life lost, for every 5 injures, and for every 10 displacements.

The Department of Homeland Security and its partner organizations are funding social and behavioral science research to better understand how to anticipate, prepare for, counteract, and mitigate the effects of terrorist acts, natural disasters, and technological accidents. This research is intended to explore psychosocial factors that enable resilience and affect recovery in individuals, organizations, communities, and at the national level. Additional results and new insights for preparedness are expected over the next five years. Experts consulted about the psychological consequences measures have emphasized *extreme caution* in using these psychological consequence results. A collection of articles published in a September 2011 special issue of the journal *American Psychologist*[7] relates a succession of mistakes in dealing with psychosocial effects after the attacks. Experts greatly overestimated the number of people in New York who would suffer lasting emotional distress from the September 11, 2001 terrorist attacks, and therapists used methods to soothe victims that later proved to be harmful to some.[8,9]

Major Findings

- Among natural and technological hazards, a pandemic influenza outbreak with similar gross clinical attack rate and case fatality rate to the 1968-1969 Hong Kong pandemic flu has the highest "significant distress" index score for psychological consequences due to deaths and injuries. Its index score is over an order of magnitude greater than that of any other non-adversarial event in the SNRA.
- Hurricanes also are estimated to have high psychological distress index scores in the SNRA. This event is very different in character than pandemic influenza. Pandemic influenza would result in extensive fatalities and illnesses, while the high score of hurricanes is driven primarily by displacement.
- Event preparedness and evacuation planning can reduce "significant distress" by reducing injuries. However, it is difficult to plan capabilities to address long term social displacement when events such as floods, earthquakes, hurricanes, dam failures, etc. cause loss of homes.

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[7] Special issue: "9/11: Ten Years Later." (2011, September 6). *American Psychologist*, 66(6). Available from http://www.apa.org/pubs/journals/special/4016609.aspx.

[8] Carey, B. (2011, July 28). Sept. 11 revealed psychology's limits, review finds. *The New York Times*, A18. Retrieved from http://www.nytimes.com/2011/07/29/health/research/29psych.html.

[9] Cohen Silver, R. (2005, November 10). Psychological Responses to Natural and Man-made Disasters. *The role of social science research in disaster preparedness and response: Hearing before the Subcommittee on Research of the Committee of Science, U.S. House of Representatives, 109th Session* (24-463PS). Washington, DC: U.S. Government Printing Office.

- Experts commented that preparedness and resilience of individuals and communities can be improved over time. As noted, roughly 20% of the exposed population will still experience "prolonged distress" due to an event, but this percentage can be reduced, perhaps down to 5% to 10%, with good community preparedness and resilience. Ongoing social science research will assist federal, state, and local government in better understanding and investing in preparedness and resilience capabilities.

Figure G1: Psychological Distress by National-level Event

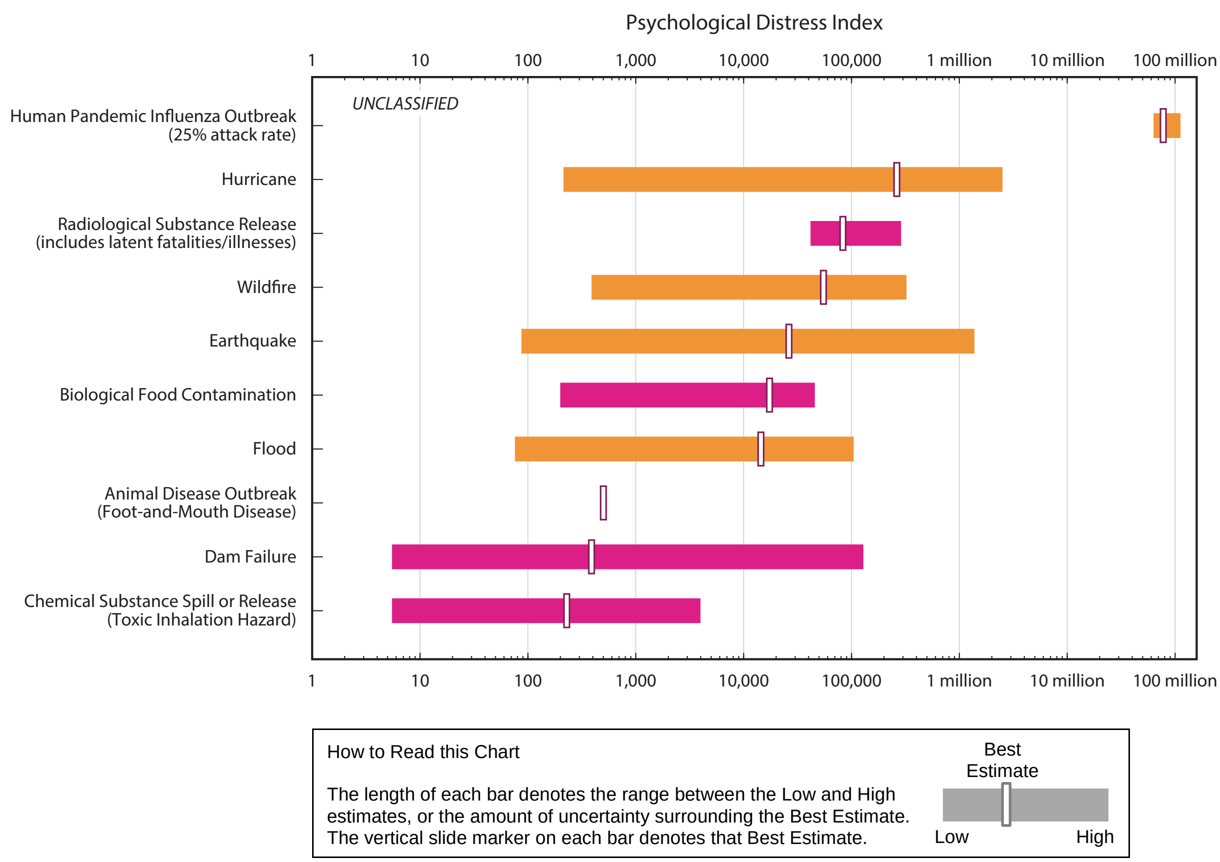

Table G1: SNRA Psychological Distress Data

Threat/ Hazard Group	Threat/Hazard Type	Event Familiarity Factor	Significant Distress Index		Notes/Comments
Adversarial/ Human-Caused	Aircraft as a Weapon	1.2	Low		
			Best		
			High		
	Armed Assault	1.1	Low		
			Best		
			High		
	Biological Terrorism Attack (non-food)	1.3	Low		
			Best		
			High		
	Chemical Terrorism Attack (non-food)	1.3	Low		
			Best		
			High		
	Chemical/Biological Food Contamination Terrorism Attack	1.3	Low		
			Best		
			High		
	Cyber Event affecting Data	1.0	Low	N/A	Index cannot be computed since insufficient information is available for fatalities, injuries, and social displacement.
			Best	N/A	
			High	N/A	
	Cyber Event affecting Physical Infrastructure	1.0	Low	N/A	Index cannot be computed since insufficient information is available for fatalities, injuries, and social displacement.
			Best	N/A	
			High	N/A	
	Explosives Terrorism Attack	1.2	Low		
			Best		
			High		
	Nuclear Terrorism Attack	1.3	Low		
			Best		
			High		
	Radiological Terrorism Attack	1.3	Low		
			Best		
			High		
Technological/ Accidental	Biological Food Contamination	1.0	Low	200	
			Best	17,000	
			High	46,000	
	Chemical Substance Spill or Release	1.1	Low	6	
			Best	230	
			High	4,000	
	Dam Failure	1.0	Low	6	
			Best	390	
			High	130,000	
	Radiological Substance Release	1.1	Low	42,000	
			Best	82,000	
			High	290,000	

Threat/ Hazard Group	Threat/Hazard Type	Event Familiarity Factor	Significant Distress Index		Notes/Comments
Natural	Animal Disease Outbreak	1.0	Low	N/A	Only a best estimate is available because of the underlying displacement data.
			Best	500	
			High	N/A	
	Earthquake	1.1	Low	90	
			Best	27,000	
			High	1,400,000	
	Flood	1.0	Low	75	
			Best	15,000	
			High	100,000	
	Human Pandemic Outbreak	1.0	Low	63,000,000	
			Best	78,000,000	
			High	110,000,000	
	Hurricane	1.0	Low	220	
			Best	260,000	
			High	2,500,000	
	Space Weather	1.0	Low	N/A	Index cannot be computed since insufficient information is available for fatalities, injuries, and social displacement.
			Best	N/A	
			High	N/A	
	Tsunami	1.0	Low	4,300	These estimates are constructed for the case of a tsunami originating from the Cascadia Subduction Zone striking the Oregon coast.
			Best	9,200	
			High	13,000	
	Volcanic Eruption	1.0	Low	4,400	These estimates are constructed for the case of a significant eruption of Mount Rainier.
			Best	85,000	
			High	1,200,000	
	Wildfire	1.0	Low	390	
			Best	55,000	
			High	320,000	

APPENDIX H: ENVIRONMENTAL CONSEQUENCE ASSESSMENT

Note that all comparative statements refer to unclassified assessed consequences, not risks which are in part derived from classified frequency information for the adversarial events.

Overview

The U. S. Environmental Protection Agency (EPA) convened an *ad hoc* group of environmental experts to develop environmental impact estimates for the SNRA. The group of experts included representation from the fields of environmental science, ecological risk, toxicology, and disaster field operations management. The resulting comments and rankings have not undergone review by the EPA and only represent the opinions of the group.

For the purposes of the SNRA, environmental risk was defined as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.[1] Environmental effects within urban areas and all human health effects were not included within the scope of this environmental risk assessment, because these impacts were already addressed separately in the other consequence analyses for the SNRA.

EPA experts judged the relative environmental impact of each national-level event by selecting one of four categories of severity: *de minimis* (or minimal), low, moderate, and high. In doing so, the experts considered the areal extent of the impact, the potential for adverse consequences, and the severity of adverse consequences. The four categories of severity used in the SNRA allow for a relative comparison of environmental impacts between events, but do not provide absolute estimates of impacts for use outside the context of this assessment.

For each event, EPA experts provided a best estimate and a secondary estimate. This was done to capture variability in the potential location of the event, how it might unfold, and/or its areal extent, as well as uncertainty about the adverse environmental consequences associated with the event.

The estimates provided in this environmental impact assessment were developed using rudimentary assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables, such as chemical or biological agent, contamination extent, persistence and toxicity (both chronic and acute), or infectivity.

Major Findings

- Nuclear terrorism attacks and volcanic eruptions were assessed to have high potential for adverse environmental impacts relative to other events, at the best estimate. Both events have in common the potential to disrupt ecosystems over a large area through either airborne nuclear fallout or volcanic ash. The experts used their second choice to mark the chemical terrorism attack (non-food), accidental chemical substance release, accidental radiological substance release, hurricane, earthquake, and tsunami events as having the potential for high environmental impacts. Of all the events, only nuclear terrorism attacks were judged as high environmental consequence events with minimal uncertainty.

[1] This definition is aligned with the EPA's definition of environmental risk. Accessed at: http://www.epa.gov/OCEPAterms/eterms.html .

- Multiple events were judged to have *de minimis* potential for adverse environmental impacts at the best estimate, including armed assaults, cyber events affecting data, cyber events affecting physical infrastructure, and space weather events. Of these, armed assaults and cyber events affecting data were judged to have *de minimis* impacts with high certainty. If the space weather event or cyber event affecting physical infrastructure were to result in extended power outages, the potential for environmental impacts would increase to low/moderate as chemical and treatment plants failed.
- Many terrorism events, with the exception of nuclear and chemical terrorism attacks, are judged to have low or *de minimis* potential for adverse environmental impacts at the best estimate. This is primarily driven by the relatively low areal extent of many terrorism events when compared to natural disasters, especially outside urban areas.
- The meteorological/geological natural hazard events were judged to have moderate or high potential for adverse environmental impacts at the best estimate, with the exception of space weather. This is driven by the potential for large areal extent.
- All events in the technological/accidental hazards category, including biological food contamination, chemical substance release, dam failure, and radiological substance release, were judged to have moderate environmental impacts at the best estimate.

Table H1: SNRA Environmental Impact Data and Comments

Threat/ Hazard Group	Threat/Hazard Type	Best Estimate	Second-Best Estimate	Comments
Adversarial/ Human-Caused	Aircraft as a Weapon	Low	Moderate	Low; one airplane could cause tens of acres of environmental impact of a limited duration, likely within an urban environment. Could be moderate depending upon the target (e.g., a chemical plant).
	Armed Assault	*De minimis*	*De minimis*	Minimal environmental impact.
	Biological Terrorism Attack (non-food)	Low	Low	Depends upon agent and persistence, but potential for environmental consequences is low given focus on human disease. Highest environmental consequences would be an incident resulting in an increase in animal disease. Disposal of contaminated waste could result in higher consequences.
	Chemical Terrorism Attack (non-food)	Moderate	High	Aquatic run-off could disseminate a persistent chemical and increase the impact on the environment, depending upon the chemical. Toxicity, spread, and persistence of chemical agent would be the defining characteristics that change the impacts from moderate to high (or low).
	Chemical/Biological Food Contamination Terrorism Attack	Low	Moderate	Since the effect is directed toward humans, this should have low impact. If introduced into an agricultural setting, there could be impact on the local ecosystem. There could be a waste disposal issue, and depending upon the contaminant and the volume of material this could be significant.
	Cyber Event affecting Data	*De minimis*	*De minimis*	Minimal environmental impact.
	Cyber Event affecting Physical Infrastructure	*De minimis*	Low	Depends upon target and duration. For a short power outage (day to few days), the impact would be relatively minimal. If a power outage persisted for weeks, then there is potential for failure of backup systems. Once backup systems (diesel fuel delivery, etc.) fail, treatment plants and chemical plants failing could have a significant impact.
	Explosives Terrorism Attack	Low	Moderate	Low, but if a water treatment plant or chemical plant were targeted, the impact could increase to moderate.
	Nuclear Terrorism Attack	High	High	High, due to duration, size of affected area, and toxicity. A large, dirty device detonated in a metropolitan area could create a large fallout trail of highly persistent material. There may be high levels of fallout material for dozens of miles, and outside the city limits. The long-term environmental impact may be moderate; the isotopes could be remediated, and if the area is zoned off-limits for human use (similar to Chernobyl), there is potential for the environment to return to a state that is more

Threat/ Hazard Group	Threat/Hazard Type	Best Estimate	Second-Best Estimate	Comments
				pristine than the initial state.
	Radiological Terrorism Attack	Low	Moderate	Likely low, given the relatively low toxicity of the likely materials and the relatively low area for dispersion. Moderate if there is fallout outside the urban area.
Technological/ Accidental	Biological Food Contamination	Moderate	Low	Moderate, but could be low if the specific event involves a biological agent with a low probability of impacting native species. Moderate impacts would most likely result from either waste disposal (e.g., disposing of food supply that had become contaminated) or dissemination of an infectious agent through some type of accidental application (e.g., pesticide application in crops). If the agent just affects people, the environmental/ecological impact would be low.
	Chemical Substance Spill or Release	Moderate	High	Widespread release of an acutely toxic compound would result in moderate impacts. Could impact tens to thousands of acres with lethal material. Release of acutely toxic materials in a low-populated area would lead to greater ecological damage than a release in an urban area. The more persistent the chemical, the greater the impact. There is a potential for water contamination, which could elevate this to a high impact.
	Dam Failure	Moderate	Moderate	Water released could impact a significant area, but the duration of impact would likely be relatively short term, with a year or more for recovery.
	Radiological Substance Release	Moderate	High	Nuclear power plant disruption (e.g., Fukushima) could cause radioactive airborne releases that could travel for large distances and settle into down-range eco-systems, with possible disruptions. In addition, releases into water bodies may have impacts on aquatic life.
Natural	Animal Disease Outbreak	Low	Moderate	Depends upon the acreage required for disposal of infected carcasses. There is some potential for introduction into wild animal populations, which could lead to re-introduction into crop animal species from the wild animals and greater economic losses.
	Earthquake	Moderate	High	Debris, devastation, and resulting chemical/contaminant releases have the potential to impact large areas.
	Flood	Moderate	Moderate	Flooding of agricultural areas is a typical impact. The severity of the impact depends upon whether there is release of contaminants from urban areas.
	Human Pandemic Outbreak	Low	Moderate	Impacts become moderate in cases where the pandemic is significant enough that

Threat/ Hazard Group	Threat/Hazard Type	Best Estimate	Second-Best Estimate	Comments
				environmental protection resources are diminished (e.g., garbage collection is halted due to sanitation workers not working due to illness or concern about becoming ill).
	Hurricane	Moderate	High	Hurricanes can cause ecological impacts, beach erosion, nutrient loading, chemical contamination, salt water intrusion into fresh water bodies, and removal of plants leading to erosion. Large areas can experience impacts.
	Space Weather	*De minimis*	Moderate	Depends upon duration of power outage. For a short outage (day to few days), the impact would be relatively minimal. If a power outage persisted for weeks, then there is potential for failure of backup systems. Once backup systems (diesel fuel delivery, etc.) fail, treatment plants and chemical plants failing could have a significant impact. The difference between this event and the Cyber Event affecting Physical Infrastructure event is that a space weather event would most likely affect a much greater geographic area and has the potential for a longer duration.
	Tsunami	Moderate	High	Depends upon the precise location, barriers, and channels along the coast.
	Volcanic Eruption	High	Moderate	Potential for disruption of aquatic life, ecosystems, etc., over a large area. In addition, there is potential for long-term climate change effects if the airborne plume is extreme.
	Wildfire	Low	High	Many wildfires have low long-term effects on ecosystems and can provide longer-term benefits such as reseeding of plants and assisting the growth of forested areas. If the wildfire threatens an urban U.S. setting, the fire could envelop oil/chemical storage tanks and cause widespread release of such materials, resulting in high environmental impacts.

APPENDIX I: THRESHOLDS IN THE SNRA

National-Level Events

To inform homeland security preparedness and resilience activities, the SNRA evaluated the risk from known threats and hazards that have the potential to significantly impact the Nation's homeland security. These included natural hazards, technological/accidental hazards, and adversarial, human-caused threats/hazards.

For assessment in the initial SNRA, participating stakeholders – including Federal agencies, DHS Components, and the intelligence community, among others – developed these threats and hazards into a list of ***national-level events*** having the potential to test the Nation's preparedness.

For the purposes of the assessment, DHS analysts identified thresholds of consequence necessary to create a national-level event. These thresholds were informed by subject matter expertise and available data, and are given in Table 2 at the front of this report.

The selection of appropriate thresholds for each event was among the most significant challenges for the SNRA project.

- As the Nation's preparedness may be challenged by events having impacts across any or all of the consequence categories of the SNRA, it is not possible to identify any one generic consequence threshold capable of adequately capturing this distinction for all the hazards in the SNRA.
- Wherever possible, common thresholds across multiple events were sought to minimize the total number of different threshold criteria needed to define the set of national-level events as a whole. However, the unique impacts of each event, and in many cases data availability,[1] precluded the assignment of every event to a larger, harmonized-threshold class.

Since there is no one objective or context-independent answer to this question, these determinations ultimately came down to the best, but human, judgment of the SNRA project team.

- For some events, economic consequences were used as thresholds. For others, fatalities or injuries/illnesses were deemed more appropriate as the threshold to determine a national-level incident.
- In no case, however, were economic and casualty thresholds treated as equivalent to one another (i.e., dollar values were not assigned to fatalities).

Event descriptions in Table 2 that do not explicitly identify a threshold signify that no minimum consequence threshold was employed. This allows the assessment to consider events for which the

[1] During the SNRA's review process, several stakeholders noted that the SNRA's thresholds tend to be on the low side compared with what many people consider to be a truly catastrophic event (for instance, the threshold of NOAA's Billion Dollar Disaster List). As noted below, a low choice of threshold may not appreciably affect a best estimate risk calculated by multiplying the average likelihood and consequence measure of a set of events. However, it can significantly depress best estimate consequences when they are calculated as an average of the set of events, and the low and high consequence estimates when they are calculated as percentiles of the distribution defined by the set.

For many events, however, limited quantitative data comprised a significant constraint on the range of thresholds which could be practically selected in the SNRA. Although the high-consequence 'tail' of more catastrophic incidents may be of greater interest for many purposes, the higher the threshold selected to isolate these incidents the sparser becomes the data set used to determine the estimates characterizing the event. By including more historical incidents or modeled data points within the scope of an event, lower thresholds maximize the data fidelity of the set used to determine quantitative estimates and hence the defensibility of these estimates.

psychological impact of an event could cause it to become a national-level event even though it may result in a low number of casualties or a small economic loss.

- For example, any terrorist attack resulting in the successful release or detonation of a chemical, biological, radiological, or nuclear weapon, even if it resulted in no fatalities or injuries, would be considered a national-level event for the purposes of the SNRA.
- By contrast, a much higher threshold was set for the accidental Biological Food Contamination event, requiring a multi-state outbreak resulting in 100 or more hospitalizations[2] for an incident to be considered a national-level event. Unintentional food poisoning is estimated to cause 3,000 deaths, 128,000 hospitalizations, and 48 million illnesses every year in this country.[3] However, the very ubiquity of this hazard makes it such a part of the background level of risk addressed by steady-state national capabilities that only the largest and most consequential outbreaks were considered to rise to a level of impact characteristic of a national-level event.[4]

Assessed best estimates of annualized *risk*, when calculated by multiplying the average likelihood and average consequences of a set of incidents, may be relatively insensitive to threshold choices. However, this is not generally true for the best estimates of *likelihood* and *consequence* individually reported by the SNRA, or for those high estimates of consequence which represent percentiles of a distribution. These differences can have significant implications for risk communication, and are discussed at further length below.

Best Estimates in the SNRA

The best estimates of consequence measures in the SNRA were assessed by different methods, depending on the particular consequence type and event.

Social displacement best estimates, with a few exceptions, were chosen according to the best judgment of subject matter experts and analysts who conducted the research for these estimates. The qualitative environmental impact estimates represent subject matter expert judgment. Some of the SNRA national level events leverage subject matter expert judgment for their best estimates on other consequence metrics as well.

For most events in the SNRA, best estimates for fatality, injury/illness, and direct economic consequence measures represent the weighted average consequences over a distribution of possible consequences, given an event occurrence. Weighted average consequence is a measure of the average impact (number of fatalities, illnesses/injuries, or cost) across a set of scenarios.

[2] Note that neither of these two criteria, nor the successful-release criterion of the CBRN terrorist attack events, directly corresponds to measures of consequence used by the SNRA. These further illustrate the difficulty of capturing the factors elevating an incident to the level of a 'national-level event' capable of challenging national preparedness by some single, simple and uniform quantitative measure.

[3] U.S. Centers for Disease Control and Prevention (2011). *CDC Estimates of Foodborne Illness in the United States.*

[4] Since this highly restrictive definition excludes all but a very few incidents of this type, the SNRA's reported consequence estimates for accidental food contamination are lower than these annual national totals by two orders of magnitude. This discrepancy may give the appearance that the SNRA substantially understates the risks from a well known hazard. The reason for this apparent discrepancy is that the SNRA attempts to capture not the annual death toll of known and constant hazards which are handled by steady-state capabilities, but the small set of exceptional incidents having disproportionate potential to cause harm and disruption because steady state capabilities are not prepared to handle them. For the accidental food contamination event, such incidents comprise only a very small subset of all such accidents, even of those causing injury, illness, and death, occurring every day in this country.

- For estimates derived from a data set of historical incidents, the weighted average is simply the average of the set.
- For estimates derived from modeled distributions, weighted average consequences are constructed by weighting each scenario in the set by its relative likelihood, such that more probable scenarios have greater influence on the mean impact.[5]

When a set of incidents (or a modeled distribution) chosen to represent a national-level event has consequences distributed over several orders of magnitude – that is, there are many small-consequence incidents and a few very large-consequence incidents – a best estimate of risk that is calculated by multiplying an average likelihood of occurrence by a weighted average consequence is relatively insensitive to the choice of minimum threshold that is used to define the national-level event.

- As a concrete illustration, a set of historical incidents for a set defined by a threshold of 1 or more fatalities might have ten incidents with fatalities {1, 1, 1, 1, 2, 2, 3, 5, 9, 200}, occurring over ten years. The average frequency of occurrence is 1 per year (10 in 10 years = 1/year). The average of the set is 22.5 fatalities. Then the best estimate fatality risk would be 1 event/year × 22.5 average fatalities/incident = 22.5 fatalities/year.
- Selecting a different threshold of 100 fatalities will reduce the set to only one member, {200}. Because only one incident in ten years is counted instead of ten, the likelihood (1 in 10 years = 0.1 incidents/year) of this set is one-tenth of what it was before. However, the average of this new set is 200 fatalities. The best estimate risk would then be 0.1 incident/year × 200 average fatalities/incident = 20 fatalities per year. This is similar to the calculated risk of the original set, even though it is defined by a much higher threshold.[6]

While resourcing decisions often use best-estimate annualized risk as a primary measure of comparison, operational planning and policy decisions must consider a more complex picture of risk which focuses on measures of likelihood and consequence separately. This is especially true for decisions taken from a preparedness standpoint. Continuing the example above, front-line stakeholders must be able to effectively respond to both the frequent 1 fatality incidents and the rare 200 fatality catastrophe, not the 22.5 average fatality incident which is never seen. For such decisions, the use of a weighted average may be misleading.

For hazards dominated by a large number of low-consequence incidents and a relatively smaller number of very high-consequence incidents, the average-consequence best estimates may mask the low and high consequence scenarios which will be of most interest to decision-makers in many contexts. Communicating information about higher and lower consequence scenarios is one of the reasons for the SNRA's emphasis on representing variability and uncertainty in its estimates.

[5] Description of weighted average consequence adapted from the 2011 ITRA, page 2-7. DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET/NOFORN; extracted information is UNCLASSIFIED).

[6] It is worth noting that the annualized risk is actually *higher* for the set having a lower threshold. Lower minimum thresholds only add more incidents to the set being counted as a whole. This counterintuitive property is generically true for any annualized risk measure calculated in this manner.

Variability and Uncertainty in the SNRA

The SNRA reports both high and low bounds, in addition to best estimates, as part of its treatment of uncertainty in frequency and consequence. Uncertainty in the SNRA includes both uncertainty in our *knowledge* about an event, and *variability* over a known range or distribution of consequences for an event.[7,8] This distribution, if known, may indicate the relative probabilities of different consequences should an incident of this type occur. However, it is insufficient to definitively predict what the magnitude of the *next* incident will be.

Examples of sources of uncertainty include incomplete knowledge of adversary capabilities and intent, uncertainty in the effectiveness of countermeasures, variability in possible event severity and location, and lack of historical precedence.

The SNRA captures uncertainty in various ways, depending on the data source:

- For frequencies derived from the historical record, upper and lower bounds are estimated using the historic maximum number of occurrences per year and the longest time gap between historic occurrences.
- For frequencies derived from expert elicitation, uncertainty is captured using structured techniques to determine the 5th and 95th percentile confidence intervals.[9]
- For consequences derived from the historical record, upper and lower bounds are estimated from the highest and lowest consequences in the observed set of past events.
- For consequences derived from previous terrorist risk assessments, 5th and 95th percentile confidence intervals were estimated, which take into account terrorist capabilities and preferences in weapon and target selection.

In many cases, the high estimates for consequence measures in the SNRA were constructed from either historic maximums (e.g., natural hazards) or the 95th percentile of a modeled distribution (e.g., terrorism events). These measures were chosen for defensibility, and for consistency with common practice of reporting the 95th percentile as a "reasonable worst-case scenario" useful for many decision contexts.

However, this reporting choice means that the high estimates associated with each national-level event may not be reflective of the consequences which may occur from what would be considered a "worst-case scenario" in other decision contexts. For planning purposes, in particular, it may be important to recognize that consequences of events have a small probability of being higher than the estimates of consequences reported in the SNRA. By definition, there is a 5% chance that the consequences given an attack or incident could be higher than an estimate drawn from the 95th percentile.

To help illustrate this concept, Figure I1 displays an alternate visualization of the fatality consequence data for the SNRA natural hazard events taken as a whole, incorporating the full range of consequences reflected by the data.[10]

[7] These two types of uncertainty are sometimes referred to as epistemic (knowledge) uncertainty, and aleatory (probabilistic) uncertainty.

[8] This description is something of an oversimplification for explanatory purposes. For events such as natural hazards where the range of frequencies come from a well-defined historical record and represent the observed variability in timing between successive incidents (inter-arrival times), reported frequency ranges represent variability (the measure from the data set) as much as uncertainty in our knowledge (of how representative the historical data set will be of similar events over the next 3-5 years [the timeframe of the SNRA]).

[9] It is important to note that, however they are determined, low and high frequency estimates do not correspond to the low and high consequence estimates. In other words, the high frequency is not the expected frequency of an incident occurring which results in the high consequences on one or more metrics.

Figure I1: Natural Hazard Risk: Probability of Exceedance given Event Occurrence (Fatalities)

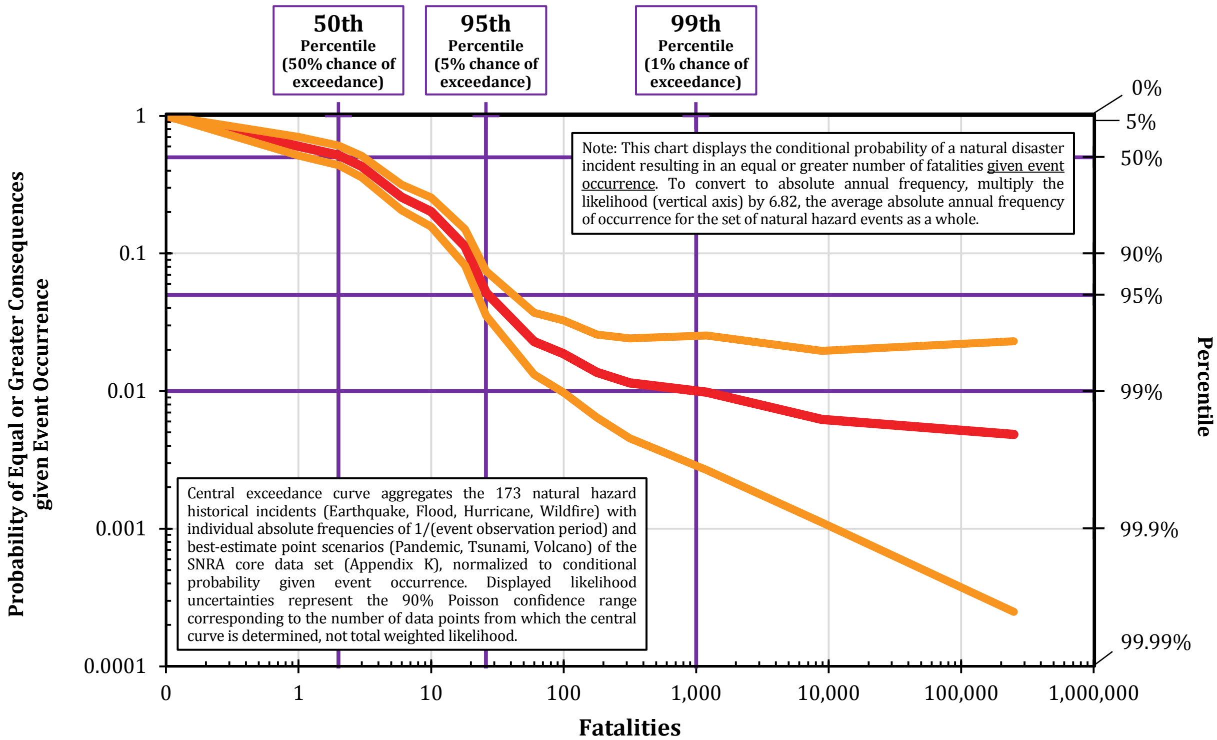

Figure I1 displays a set of *exceedance curves.* These represent the estimated frequency with which a natural hazard event, given occurrence, will[11] be equal to or greater than the corresponding consequence according to this model.[12] The middle curve represents the best estimate (expected) exceedance curve, while the surrounding curves represent the uncertainty. The violet crosshairs indicate the 50th percentile (median), 95th percentile, and 99th percentile of consequences, in this case fatalities.

- The 50th percentile disaster, on the best estimate (middle) curve, corresponds to two fatalities. This means, given the occurrence of a natural hazard incident from the set of events meeting the thresholds of inclusion for the SNRA (e.g. an earthquake, flood, hurricane, or wildfire causing $100 million or greater of direct economic damage, or

[10] Note that all charted uncertainties correspond to the 90% Poisson confidence interval for the corresponding number of events, plotted as ratios of the central estimate, following the convention of WASH-1400 chapter 6 (footnote 12). This includes the point scenario events (Pandemic, Tsunami, Volcano): although low and high likelihood estimates were provided by the same methods as the best estimate for these events, their comparability with the 90% Poisson interval used for historical incident data points was unknown and so the best estimate likelihood was used uniformly, including the largest-fatality point (Pandemic).

[11] All instances of "will" in the following mean "according to this model, will". Additionally, all statements in the following refer only to the best estimate (red) exceedance curve, and do not account for the model uncertainties represented in part by the orange lines, nor to the substantial additional uncertainties deriving from the many significant limitations of the SNRA method and data set.

[12] This type of exceedance curve, where the event is assumed to have already occurred (the total probability is normalized to 100%), is called a conditional cumulative distribution function (CCDF). Exceedance curves can also show the absolute likelihood of an event of a particular magnitude (or greater) occurring: these are sometimes referred to as F-N curves. A good example of exceedance curves used in a context similar to that of the SNRA may be found in chapter 6 of the 1975 Reactor Safety Study (WASH-1400), also referred to as the Rasmussen Report. Rasmussen, Norman, U.S. Nuclear Regulatory Commission (1975, October). *Reactor Safety Study: An assessment of accident risks in U.S. commercial nuclear power plants.* WASH-1400 (NUREG 75/014). Available at http://teams.epri.com/PRA/Big%20List%20of%20PRA%20Documents/WASH-1400/02-Main%20Report.pdf.

pandemic, animal disease, tsunami, or volcano events on the scale of the SNRA best-estimate scenarios[13]), 50% of these incidents will result in zero or one fatalities, and 50% will result in two or more, at the best estimate.

  - Although not marked on the chart, one fatality is approximately the 40th percentile on the best estimate curve. This means that while 60% of the natural disaster events considered in the 2011 SNRA will result in one or more human fatalities, 40% – nearly half – will result in no human fatalities at all, at the best estimate.

- The 95th percentile disaster in terms of fatalities is 26, on the best estimate curve. This means that 95 out of a hundred such disasters (95%) will result in 25 or fewer fatalities, but five out of a hundred (5%) will result in 26 or more, at the best estimate.
- The 99th percentile disaster on the best estimate curve is approximately one thousand fatalities.[14] This means that 99 out of every 100 such disasters will result in fewer than 1,000 fatalities. However, one in a hundred such disasters will result in 1,000 fatalities or more, at the best estimate.[15]
- Other percentiles corresponding to specific consequence thresholds (i.e. 10, 50, 100) may be read by drawing crosshairs centered on the red exceedance curve: after drawing a vertical line from the consequence (horizontal) axis, the horizontal crosshair will indicate the corresponding percentile on the likelihood (vertical) axis.

These curves are normalized to relative frequencies (a maximum of 100%) to illustrate the use of percentiles for reporting consequence estimates in the SNRA, and to illustrate how different selections of percentile can result in seemingly dramatically different “reasonable worst-case” scenarios being reported from the same underlying data.

These relative frequencies can be converted to absolute frequencies (actual number of events occurring per year) by multiplying by 6.82, the total annual frequency of occurrence of this set of events as a whole. In other words, the Nation may expect to be challenged by an average of seven natural disaster incidents (including human pandemics) meeting the minimum threshold of the SNRA every year, or about one every two months on the average. Nearly half of these will result in no human fatalities at all. However, half will result in two or more, five of every hundred will result in more than 25, and one of every hundred will result in 1,000 fatalities or greater, at the best estimate.

As noted above, high estimates of consequences for many events in the SNRA correspond to the 95th percentile.[16] However, significant dialogue within the preparedness community is needed to define the level of potential consequences for which the community should be planning. The SNRA is the first U.S. national all-hazards risk assessment reporting its findings as quantitative and directly comparable measures of risk: among its contributions are a methodology and an initial data set which make it possible to ask this question, and see what different answers would look like. One such choice of levels, determined by the data and reporting thresholds selected for the first

[13] The tsunami and volcano event scenarios are included: their partial coverage of the national risk space which precluded event-to-event comparison in the SNRA’s charts and findings does not present an issue for aggregation across events.

[14] Within the degree of precision of the data set (173 points) and the numerical interpolation of the charted curve.

[15] The data points in this 1% include the 1906 San Francisco earthquake, Hurricane Katrina, and the Human Pandemic Influenza Outbreak scenario (Appendix K).

[16] For individual natural hazard events leveraging finite data sets, high estimates also correspond to the highest percentile of each event’s data set. For example, the high value of a set of twenty data points also represents the 95th exceedance percentile of that set (the top 5% or top 1/20th), and the high value of a set of fifty data points represents the 98th exceedance profile (the top 2%) of that set.

iteration of the SNRA, may be seen in the visual depictions of the SNRA's likelihood and consequence estimates presented throughout this report.

However, it is only one such choice, and one which was primarily motivated by data availability and past practice in the Department which led the execution of the first SNRA. Many other choices are possible, and equally valid. These considerations pertain not just to the internal math and methodology of the SNRA, but political, normative, and practical considerations determined by the larger context for which the SNRA was commissioned and used. For this reason, active stakeholder engagement across the emergency preparedness community, the federal interagency, and the homeland security enterprise will be key to improving and refining the thresholds and measures used in the next iteration of the SNRA.

APPENDIX J: RISK SUMMARY SHEETS

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For each national-level event, the research, assumptions, and data which were used to produce the low, best, and high estimates of likelihood and measures of consequence were documented in an event-specific risk summary sheet by the SNRA project team. Summary sheets with common reporting formats to document staff research and analysis of individual hazards have been used by past comparative risk assessments, in part because of their utility in guiding research efforts to identify data capable of being expressed in terms of a predetermined set of measures designed to be comparable across all events.[1]

The risk summary sheets shared a standardized data table format to facilitate the comparability and harmonization of estimates across diverse events (Table J1). This table specified the categories, types, and most importantly the metrics which were to be used to measure likelihood and each type of consequence. Each of these was baked into the table to ensure that what the numbers meant would be communicated with them. As space considerations precluded printing the whole table in each summary sheet in this compilation, the original is presented below so that it will accompany them as a set.

Because of the heterogeneity and roughness of these internal risk summary sheets, they were not originally included with the review drafts of the SNRA technical report. However, stakeholder concerns raised in the review process, which could not be answered without reference to the source documentation contained in the individual event risk summary sheets, made it apparent that the SNRA results as otherwise presented could not be fully understood or replicated without the additional documentation they provided: and so they are included here.

In their present form, these summary sheets are essentially the staff research notes of the SNRA project team. At the time of their finalization, they were not contemplated as potential parts of the ultimate SNRA documentation for external stakeholders. They are highly heterogeneous in style, format, depth, and approach. No attempt has been made to standardize them beyond correcting typos, clarifying obscure points, and fixing or completing missing documentation such as incomplete footnotes, broken links, or omitted sources. The reader should expect such variations and use these sheets as supplementary documentation to the main report as needed, rather than as polished products intended to stand on their own.

Other than substantial reformatting to compress them into a minimum number of pages, few significant changes have been made to the 2011 summary sheet drafts for the natural hazard, technological accident, and cyber events. The summary sheets for the remaining adversarial events required substantial rewriting to remove For Official Use Only text.[2] For the most part, however, these U//FOUO portions were provided as general overview and background text for the different events rather than SNRA-specific analysis or explanation of data origins. These extended overview and background portions were removed wholesale, and replaced with text content from DHS and USG documents prepared with the same purpose but for the public.

- The most significant losses, unfortunately, included details of the economic modeling performed for several adversarial events using the Risk Informed Process for Improved Decision-making (RAPID) calculational engine, the flagship analytic product of the former DHS Office of Risk Management & Analysis (RMA) which led the design and execution of the first SNRA. As much generic non-FOUO description of the procedures and parameters used for the economic modeling as possible was included to communicate the flavor and general approach of its methodology. However, as nearly all details of the RAPID model are FOUO it was not possible to communicate sufficient detail for end users to replicate the method for use in other contexts.

Other than these differences, incorporation of data missing from the summary sheets but communicated to FEMA separately, and a few minor corrections, the unclassified data and analysis communicated in the following pages are the same unclassified data and analysis communicated to FEMA in September 2011 to inform the National Preparedness Goal.

The primary documentation of how the (classified) quantitative frequency, fatality, injury/illness, and economic damage estimates for the five CBRN terrorist attack events were obtained are the reports of the 2011 Integrated CBRN Terrorism Risk Assessment (ITRA), and the Biological, Chemical, and Radiological-Nuclear Terrorism Risk Assessments (BTRA, CTRA, RNTRA) which the ITRA integrates and harmonizes. Because of the great complexity of these computational engines, other than the unclassified event overviews and documentation for the social displacement, psychological distress, and environmental consequence measures, the summary sheets for these events include only those parameters needed to validate or replicate the SNRA's results using the ITRA engine.

All frequency estimates for the adversarial events, including the cyber events, and all the fatality, injury/illness, and economic consequence estimates for the five CBRN events are classified SECRET or SECRET//NOFORN.[3] For these data and the U//FOUO conventional terrorist consequence data discussed above, the reader is directed to the appendices of the full SNRA technical documentation.

[1] Lundberg, Russell (2013, September). Comparing homeland security risks using a deliberative risk ranking methodology. Dissertation, Pardee RAND Graduate School, RAND document RGSD319; at http://www.rand.org/about/people/l/lundberg_russell.html#publications. Willis et al (2012). Comparing security, accident, and disaster risks to guide DHS strategic planning. *Current Research Synopses* paper 43, RAND Corporation, and the National Center for Risk and Economic Analysis of Terrorism Events (CREATE), University of Southern California. Near-final draft versions of the ten risk summary sheets in the back of Dr Lundberg's dissertation were kindly provided to the SNRA project by RAND in early 2011 to assist in project formulation. Lundberg's dissertation research paralleled (and in a number of ways went further than) the SNRA project: it is the only other current comparative U.S. national risk assessment and is comparable to the SNRA in scope, methodological approach, and source research.

The risk summary sheet documentation has been used in the past for comparative ecological risk assessments in particular: see Willis et al (2004, April), Ecological risk ranking: development and evaluation of a method for improving public participation in environmental decision making, *Risk Analysis* 24(2) 363-78; Florig et al (2001), A deliberative method for ranking risks (Parts I, II), *Risk Analysis* 21(5) 913-937; and Fisheries and Oceans Canada (2012), Terms of Reference, Risk-based Assessment of Climate Change Impacts and Risks on the Biological Systems and Infrastructure within Fisheries and Oceans Canada's Mandate: http://www.dfo-mpo-gc.ca/csas-sscs/Schedule-Horraire/2012/11_15-17-eng.html (electronic resource: retrieved July 2013). See Lundberg (2013) for additional discussion of risk summary sheets in comparative risk assessment.

[2] There are also classified versions of the risk summary sheets, but as these exist on compartmented systems only the FOUO versions were needed for this section.

[3] No quantitative fatality, injury/illness, or economic consequence estimates were determined for the two cyber events.

Table J1: SNRA Risk Summary Sheet Data Table

TABLE OF FINDINGS

Category		Description	Metric	Low	Best	High
CONSEQUENCE	Health and Safety	Fatalities	Number of Fatalities			
		Injuries and Illnesses	Number of Injuries or Illnesses			
	Economic	Direct Economic Loss	U.S. Dollars			
		Indirect Economic Loss	U.S. Dollars			
	Social	Social Displacement	Number of Displaced from Homes for ≥ 2 Days			
	Psychological	Psychological Distress	Qualitative Bins			
	Environmental	Environmental Impact	Qualitative Bins			
LIKELIHOOD		Frequency of Events	Number per Unit of Time			

Animal Disease Outbreak

An unintentional introduction of the foot-and-mouth disease (FMD) virus into the domestic livestock population in a U.S. state.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	0[1]		
Injuries and Illnesses	Number of Injuries and Illnesses			
Direct Economic Loss	U.S. Dollars	$2.3 Billion	$15.2 Billion	$69.0 Billion
Social Displacement[2]	Displaced from Homes ≥ 2 Days	0	1,000	N/A[3]
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[4]	Low[5]		
Frequency of Events	Number per Year[6]	0.04	0.1	0.1

Event Background

Foot and mouth disease (FMD) is one of the most devastating diseases affecting cloven-hoof animals such as cattle, swine, sheep and deer. The viral disease is highly contagious, with 7 types and more than 80 sub-types, and vaccination for one type does not confer immunity to the others. Additionally, the FMD virus can survive freezing temperatures but not temperatures above 50 degrees Celsius.[7] Thus far, a pan-viral vaccination that would protect against all types has not been developed. FMD is easily transmitted and spreads rapidly through respiration and through contact with milk, semen, blood, saliva and feces. Pigs are particularly efficient amplifiers of the disease as they shed large amounts of virus into the air, while cattle are highly susceptible to the airborne-transmitted virus, owing to the large lung capacity and high volumes of air these animals respire. The FMD virus remains viable for long periods of time in both animate and inanimate objects and can be spread by contact with:

- Animals
- Animal products, such as meat, milk, hides, skins and manure
- Transport vehicles and equipment
- Clothes and shoes
- Hay, feed and other veterinary biologics
- Human nasal passages and skin

While there are no significant human health implications of FMD, an outbreak of the disease can have important economic consequences. FMD is found in 60 percent of the world's countries and is endemic in many countries in South America, Africa, Asia and the Middle East. The international community values products that come from FMD-free countries and typically restricts trade in FMD-susceptible products from endemic countries or those affected by an ongoing outbreak. The Office International des Epizooties (OIE), an intergovernmental organization comprised of 158 member countries, was established in 1924 to guarantee the sanitary safety of world trade by developing rules for international trade in animals and animal products. OIE classifies member countries, or zones within countries, as being FMD-free with or without vaccination; the U.S. currently does not vaccinate for FMD and maintains an FMD-free without vaccination status. When an outbreak of FMD occurs in an FMD-free without vaccination country, OIE standards require that country wait 3 months after the last reported case of FMD when a "stamping out" approach has been used for eradication to apply for reinstatement of FMD-free status. If vaccination is used in the eradication process, the country cannot apply for reinstatement of FMD-free status until 3 months after the last vaccinated animal is slaughtered, or 6 months if the animal(s) are vaccinated and not slaughtered. In all cases, serological surveillance evidence must be submitted to prove the disease has been eradicated.

Given the value placed on FMD-free status, a confirmed case of FMD in the U.S. would result in an immediate restriction of exports. The current control strategy (9 CFR 53.4 Destruction of Animals with FMD) in USDA Animal and Plant Health Inspection Service (APHIS) regulations to regain FMD-free status is to stamp out, or cull all infected and susceptible animals.[8] The APHIS Administrator has discretion to examine other options based on the size and/or extent of an outbreak.

Assumptions

Economic Impact

For this scenario, a potential introduction of the disease in California is considered. Although limited to one state, a single case of FMD can be considered a national-level event with repercussions across the country.

Carpenter et al[9] studied epidemic and economic impacts of FMD virus spread and control using epidemic simulation and economic optimization models. The simulated index herd was a single 2,000 cow dairy herd located in California. Although the initial infection was presumed to come from an FMD infected feral swine, similar results would come from any single infected animal introduced to the herd. Disease spread was limited to California, but economic consequences, including international trade effects, were felt throughout the U.S. There were five separate index detection delays examined, ranging from 7 to 22 days, with 100 iterations each. This led to a median economic impact estimated at $2.3-$69.0 billion, depending on the number of days delay until detection of disease. The "Low" and "High" estimates on economic burden are extrapolated from these numbers. Similarly direct costs and indirect costs are calculated from these totals. The indirect costs may be significantly higher given the variability in the potential costs listed above. The best case estimate is based on a detection delay of 14 days. This number is extremely difficult to estimate since the actual time from infection to diagnosis is impossible to ascertain.

The direct economic impact of an FMD outbreak will come from an immediate reduction in lost international trade as well as disease control and eradication efforts, which include the cost of:

- Maintenance of animal movement controls
- Control areas
- Intensified border inspections
- Vaccines
- Depopulation
- Carcass disposal
- Indemnification to farmers for losses
- Disinfection and decontamination efforts

Indirect costs can include:

- Impacts on local economies
- Loss in upstream/downstream industries
- Reduction in visitorship and tourism loss
- Treatment of groundwater or other environmental remediation necessitated by carcass disposal or burning
- Land value implications on animal disposal property
- Changes in livestock and meat industry structure
- Short term adjustments in meat consumption based on real or uncertain information[10]

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as

[1] There are no significant human health implications resulting from a foot and mouth disease outbreak.
[2] See discussion.
[3] A high estimate was not determined.
[4] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[5] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[6] Estimates provided by subject matter experts from the Office of Health Affairs (OHA), DHS.
[7] United States General Accounting Office, July 2002; Foot and Mouth Disease: To Protect U.S. Livestock, USDA Must Remain Vigilant and Resolve Outstanding Issues; GAO-02-808; at http://www.gao.gov/new.items/d02808.pdf (accessed 10 March 2013).

[8] United States General Accounting Office, July 2002; Foot and Mouth Disease: To Protect U.S. Livestock, USDA Must Remain Vigilant and Resolve Outstanding Issues; GAO-02-808; at http://www.gao.gov/new.items/d02808.pdf (accessed 10 March 2013).
[9] Carpenter, T.E. O'Brien, J.M. Hagerman, A.D. McCarl, B.A. Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of an outbreak in California. *Journal of Veterinary Diagnostic Investigation*, 23, 26-33 (2011); at http://www.ncbi.nlm.nih.gov/pubmed/21217024, http://vdi.sagepub.com/content/23/1/26.long (accessed 10 March 2013).
[10] Hagerman, USDA Office of Economic Research Services, unpublished.

the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- For the Animal Disease national-level event, the SNRA project team assumed a low estimate for social displacement of zero.[11]
- The best estimate of 1,000 was provided by subject matter experts from National Consortium for the Study of Terrorism and Responses to Terrorism (START).[12] Experts noted that those working on or near farms may be asked to relocate to reduce the chance of transmitting foot-and-mouth disease to other livestock.
- A high estimate for social displacement was not determined for this event.

Psychological Distress

Psychological consequences for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[13] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Low." Experts indicated that the consequences could be higher depending on the acreage required for disposal of infected carcasses. Additionally, there is some potential for contamination to spread into wild animal populations.

Potential Mitigating Factors

In the event that an FMD outbreak does occur in the U.S., there are four possible strategies for control and eradication of FMD in domestic livestock in the event of an outbreak. Each is supported by critical activities that include surveillance, biosecurity, decontamination, epidemiological activities, movement control, and communication. These four strategies are recognized by the OIE in Article 8.5.47 of the Terrestrial Animal Health Code (2010):[14]

- Stamping out or slaughter of all clinically affected and in-contact susceptible animals.
- Stamping out, modified with emergency vaccination-to-slaughter, which includes slaughter of all clinically affected and in-contact susceptible animals and vaccination of at-risk animals, with subsequent slaughter of vaccinated animals.
- Stamping out modified with emergency vaccination-to-live, which includes slaughter of all clinically infected and in-contact susceptible animals and vaccination of at-risk animals, without subsequent slaughter of vaccinated animals.
- Vaccinate-to-live without stamping out. Vaccination used without slaughter of infected animals or subsequent slaughter of vaccinated animals.

Many factors will be considered when determining whether a particular response strategy would be appropriate and advantageous. While no factor will independently dictate a response strategy, or a decision to employ emergency vaccination, there are many factors that will influence the decision of whether to vaccinate or not. Factors will include:[15]

- Disruptions to interstate commerce
- Disruptions to international trade
- Acceptance of response strategy or strategies
- Scale of outbreak
- Rate of outbreak spread
- FMD vaccine availability
- Resources available to implement response strategies

Additional Relevant Information

Similar to estimating the economic implications, establishing the frequency of an occurrence of FMD is difficult. An outbreak of FMD has not occurred in the U.S. since 1929, so any estimate of frequency or consequence can only be based on data from other countries where recent outbreaks have occurred, as well as estimates based on models from current U.S. industry information. The United States has experienced nine known outbreaks of FMD from its first occurrence in 1870 to its final eradication in 1929, indicating a low frequency estimate of approximately 0.04, or 9 events in 235 years in the U.S.[16,17] The highest frequency of occurrence is an estimation based on the recent outbreaks during the previous decade in the United Kingdom, Japan and South Korea. DHS Office of Health Affairs experts estimate a high frequency of once per decade, or 0.1 in a given year. Since FMD is a highly communicable disease that is resilient and easily obtained, the SNRA project team selected 0.1 in a given year as the best estimate for this event.

While there is no historical data from the U.S. from which to estimate the cost of an FMD outbreak, there have been several outbreaks in other countries in the past decade which emphasize the severity of the impact. Examples of outbreaks include the following:

- In 2001, the United Kingdom (UK) suffered one of the largest FMD epidemics to occur in a developed country in several decades. Approximately 7 million animals were culled and their corpses burned on pyres. The outbreak devastated the nation's farming industry and cost the UK an estimated \$11.9-\$18.4 billion, including \$4.8 billion in losses to agriculture, the food industry and the public sector, \$4.2-\$4.9 billion in lost tourism and \$2.9-\$3.4 billion in indirect losses.[18]
- The FMD outbreak in South Korea that occurred in late 2010 and ended in April of 2011 is estimated to have cost that country over \$2.6 billion U.S. dollars and resulted in the loss of 3.47 million livestock.[19]
- Japan suffered a similar outbreak in 2010, which cost an estimated \$3.14 billion U.S. The Japan and South Korea outbreaks are believed to have been caused by the same FMD virus serotype. The source of the Japan outbreak is believed to be contaminated wheat straw imported from China.[20]

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11 Farm animals removed for euthanization as part of control efforts are not included in the SNRA's measure of social displacement.

12 START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

13 A Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + ½\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Animal Disease Outbreak was given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

14 Foreign Animal Disease Preparedness & Response Plan (FAD PReP)/Foot-and-Mouth Disease Response Plan (The Red Book) USDA Animal and Plant Inspection Service (USDA-APHIS). Chapter 5, General FMD Response, November 2010 draft, at http://www.aphis.usda.gov/animal_health/acah/downloads/documents/FMD_Response_Plan_November_2010_FINAL.pdf; Chapter 4, FMD Response Goals and Strategy, updated (June 2012) draft citing 2011 OIE Terrestrial Animal Health Code, at http://www.aphis.usda.gov/animal_health/emergency_management/downloads/fmd_responseplan.pdf.

15 Ready Reference Guide to Foot and Mouth Disease (FMD) Response and Emergency Vaccination Strategies, USDA APHIS Veterinary Services, 7/27/2011; incorporated as section 4.4.1 (General Factors that Influence the Response Strategy) of Foreign Animal Disease Preparedness & Response Plan (FAD PReP)/Foot-and-Mouth Disease Response Plan (The Red Book) USDA Animal and Plant Inspection Service (USDA-APHIS), June 2010; at http://www.aphis.usda.gov/animal_health/emergency_management/downloads/fmd_responseplan.pdf.

16 Foot and Mouth Disease Factsheet. American College of Veterinary Pathologists, July 2012; at http://www.acvp.org/media/factsheet/FootMouth.cfm (accessed 10 March 2013).

17 Foot and Mouth Disease: A threat to U.S. agriculture. Congressional Research Service, RS-20890, April 16, 2001; at http://www.nationalaglawcenter.org/assets/crs/RS20890.pdf (accessed 10 March 2013).

18 Carpenter, T.E. O'Brien, J.M. Hagerman, A.D. McCarl, B.A. Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of an outbreak in California. *Journal of Veterinary Diagnostic Investigation*, 23, 26-33 (2011); full text http://www.ncbi.nlm.nih.gov/pubmed/21217024, http://vdi.sagepub.com/content/23/1/26.long (accessed 10 March 2013).

19 'South Korea reports another FMD case'. Xinhua [China Radio International] , April 20, 2011. At http://english.cri.cn/6966/2011/04/20/2821s633266.htm (accessed 10 March 2013).

20 APHIS Evaluation of the Foot and Mouth Disease Status of Japan. Veterinary Services, Animal and Plant Health Inspection Service, USDA, April 1, 2011. At http://www.r-calfusa.com/Animal_Health/110401APHISJapanFMDEvaluation.pdf (accessed 10 March 2013).

Earthquake

An earthquake occurs within the U.S. resulting in direct economic losses greater than $100 Million.

Data Summary

Table 1 shows the minimum, average, and maximum values for frequencies and consequences of national level earthquakes. Note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories. A detailed descripton for all results is located in the Event Description and Analytical Methods section.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[1]	0	370	8,900
Injuries and Illnesses	Number of Injuries or Illnesses[1]	0	8,700	210,000
Direct Economic Loss	U.S. Dollars[1]	$110 Million	$8.7 Billion	$105 Billion
Social Displacement[2]	Number of Displaced from Homes for ≥ 2 Days[3]	160	27,000	2 Million
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[4]	High[5]		
Frequency of Events	Number per Year[6]	0.11	0.27	2

Table 1

Event Description and Analytical Methods

For planning purposes, a national-level earthquake is defined as an earthquake producing direct economic loss in excess of $100 million dollars. The historical record of U.S. earthquakes during the 105-year time period from 1906 to 2011 was used estimate the interarrival rates/frequencies and consequences for earthquakes exceeding the $100 million threshold. To provide an accurate assessment for current year planning, historic damage estimates have been updated to estimate consequences for a 2011 base year. Economic and health & safety consequences, derived directly from historic record, are updated based on changes in populations, building structures, and infrastructure. In total, 27 earthquakes[7] exceeding the $100 million threshold are aggregated in the findings of this report. The full list of national level earthquakes is located in Table 4.

Table 1 reports the maximum, average, and minimum frequency with which such earthquakes occurred in the United States, as well as the maximum, average, and minimum fatalities, injuries, and direct economic losses associated with earthquakes in the set. The oldest event included is the 1906 San Francisco earthquake and the most recent is the 2003 Paso Robles/San Simeon earthquake.

To obtain consequence estimates, normalized fatality and economic loss estimates for United States historic earthquakes reported by Vranes and Pielke (2009) were used.[8] Normalization of consequences from historic record to present day values is performed by estimating changes in consequence levels due to changes in population densities, community wealth, mitigation factors, and inflation. For most historic events, the present day community, with modern day structures and infrastructure, has a greater financial value than the community at the time of an event. Population densities have also changed. As the population increases, so too do the fatality and injury estimates for a given event. These increases, however, are offset, at least partially, by improving mitigation strategies. Improved building codes and emergency response substantially decrease the consequences caused by modern earthquakes. The consequence estimates reported by Vranes and Pielke (2009) take into account the changes in mitigation strategies, population densities and wealth profiles when normalizing loss estimates to a 2005 base year. Because of the substantial changes in mitigation factors over the historical time period analyzed, a mitigation strategy was used in the normalization routine to relate loss rates to the year an event occurred. Three alternative mitigation rates were published by Vranes and Pielke (2009): no mitigation, a 1% per annum loss mitigation rate and a 2% per annum loss mitigation rate. The 2% mitigation rate was shown to have a lower correlation when compared to damage estimates normalized by magnitude and inflation[9] than the 1% mitigation rate; therefore, the 1% mitigation rate was chosen as the best available consequence normalization factor available for the purposes of this analysis. In other words, the normalized losses were reduced by 1% for each year since the event occurred. The CPI deflator was used to convert reported economic loss estimates from 2005 to 2011 dollars; for fatality estimates, the 2005 base year was maintained. For more detailed information on the normalization routine and raw event data used in this report, please refer to Vranes and Pielke (2009).

Normalized estimates were not available for injuries. To estimate injuries, a linear model was generated that relates normalized fatalities to injuries based on the ratio of injuries to fatalities for a New Madrid event as reported by Elnashai, *et al.*[10] The linear model produces a multiplier that models the correlation between fatalities and injuries. Based on the New Madrid event estimates, a multiplier of 23.5 injuries per fatality was utilized in this report.

Low, best and high estimates were developed in the following manner from the normalized consequence estimates and historic record. For fatalities, injuries and economic loss, the low estimate is the smallest consequence for events that exceed $100 million. For economic loss, $107 million (1992 Ferndale/Fortuna/Petrolia, California earthquake) is the smallest normalized historic loss that exceeded $100 million. Six historic events exceeding the economic threshold did not result in any fatalities and, consequently, were not estimated to cause any injuries resulting in a minimum for both fatalities and injuries of zero. For event frequency, the low estimate is derived from the greatest time gap, t_{max}, between two events. The greatest gap occurs between the 1906 San Francisco and the 1915 El Centro earthquakes. This nine year time lapse between national level earthquakes results in an interarrival frequency of 0.11, or $1/t_{max}$.

The best estimate is the average consequence for events that exceed $100 million. The average economic consequence is $8.7 billion per event. On average, 370 fatalities occur per event. An average of 8,700 injuries per event is using the multiplier technique described above. The average time between national level events is 3.7 years, resulting in 0.27 events expected per year. An estimate of the average annual loss for each consequence type (e.g., fatalities per year or economic loss per year) can be obtained by multiplying the average frequency by the average consequence in a category. The average annual fatality and economic losses for the set of 27 historic events analyzed are approximately 100 fatalities per year and approximately $2.3 billion per year. The average annual economic loss estimate computed using this subset of events is 50% less than FEMA's average annual loss estimate of $5.3 billion for the full set of earthquake hazards, computed using HAZUS modeling.[11] More information about the FEMA average annual loss estimate is provided below.

The meanings of the high estimates for consequence and frequency differ. For consequences, the high estimates reflect the largest losses seen within the set of national level event earthquakes, i.e., those above the $100 million economic loss threshold. The high fatality estimate, for example, is the normalized estimate for the 1906 San Francisco earthquake of approximately 9,000 fatalities if it were to happen in the present day; this is the highest normalized fatality estimate for the events included in the analysis. A high estimate of 210,000 injuries per event is using the multiplier technique described above. The high estimate for frequency is

[1] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss are the historical minimum, average, and maximum for each consequence type in the event set. Extremal events for one consequence type may but generally do not correspond to those for other consequence types.
[2] See discussion in text.
[3] See Social Displacement section in this summary sheet for details.
[4] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[5] Earthquakes were given a best estimate of 'High' with a second best estimate of 'Moderate'. Experts assessed that the debris, devastation, and resulting chemical/contaminant releases which may be caused by an earthquake would have the potential to impact large areas.
[6] Historical lowest, average, and maximum number of events per year (calculated from interarrival times).
[7] The April 1946 earthquake near Unimak Island, Hawaii resulting in a tsunami causing twelve fatalities and $200 million in inflation-adjusted property damage was excluded from the set to avoid double-counting with the Tsunami event.
[8] Vranes, K. and Pielke, R. (2009). Normalized Earthquake Damage and Fatalities in the United States: 1900-2005. *Natural Hazards Review* 10(3): 84-101.

[9] Ibid, p. 90.
[10] Elnashai, A.S., Jefferson, T., Cleveland, L. J., and Gress, T. (2009) Impact of New Madrid Seismic Zone earthquakes on the Central USA, Vol. 1. 2009 Mid-America Earthquake Center: University of Illinois. Available online at https://www.ideals.illinois.edu/handle/2142/14810. Accessed September 28, 2011.
[11] FEMA Publication 366: Hazus-MH Estimated Annualized Earthquake Losses for the United States, April 2008.

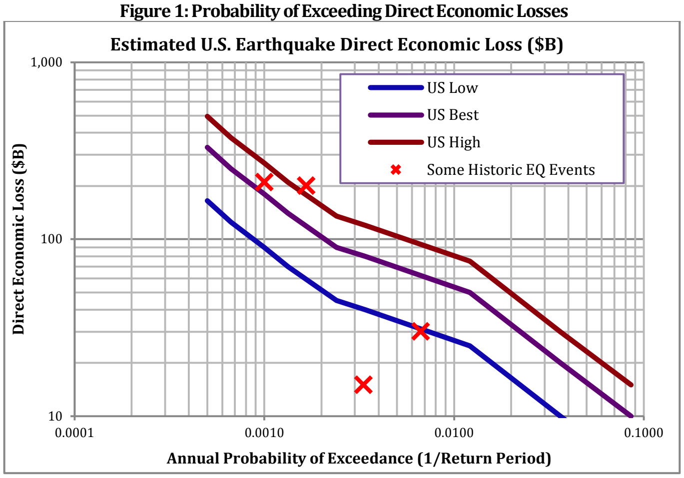
the maximum number of times an earthquake resulting in losses greater than $100 million has occurred in a calendar year, or 2 times per year.

It is important to note that the frequency estimates reported here differ from probabilities. The frequency of a national-level earthquake can be greater than one, while a probability cannot. Additionally, while the average estimates for consequences and frequency are correlated and approximate the average annual loss when multiplied together, the maximum and minimum historical values for consequence and frequency are uncorrelated and do not have meaning when multiplied together.

Expected Loss versus Return Period

Major earthquakes are commonly evaluated based on return period and expected loss. The return period vs. loss is an important perspective when evaluating historic data. The 105-year range used for consequences in Table 1 does not provide a record of all possible consequences. Low frequency events have the capacity to eclipse the greatest damage reports from historic events. Earthquake modeling can be used to estimate losses for events with limited historical precedence in the modern era. Figure 1 relates modeled earthquake economic losses to the annual probability of exceedance.[12] It is important to note that this is a modeled estimate, not actualized measured events.

Figure 1: Probability of Exceeding Direct Economic Losses



Social Displacement Estimates

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of 2 days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

Social displacement estimates for national-level earthquakes were constructed from multiple data sources. The high estimate was provided by subject matter experts at FEMA and informed by experience with Hazus modeling as well as studies such as the analysis by Elnashai *et al*. (2009) of the number of people displaced from their homes and/or without electricity for greater than 3 days due to an earthquake in the New Madrid Seismic Zone.[13] The order of magnitude of the SNRA high estimate for the number of people displaced from home for 2 days or greater was validated for this earthquake event by a subject matter expert affiliated with the National Consortium for the Study of Terrorism and Responses to Terrorism (START), who noted that "displacement in millions due to fires, damaged critical infrastructure, damaged residential areas" was plausible for the scenario of a 7.8 magnitude earthquake occurring on the San Andreas fault in the Los Angeles metropolitan area studied by the U.S. Geological Survey (USGS).[14] As a further validation point, note that displacement due to a 1906 San Francisco earthquake repeating itself in modern times were reported by Kircher *et al*. (2006) to be approximately 400,000-600,000 people due to damaged residences.[15] The latter estimates are likely to underestimate the SNRA social displacement metric because the study did not account for the effects of fires or damage to transportation and utility systems on displacement.

Low and best estimates for social displacement were constructed in an ad-hoc manner by examining published reports of displacement in the recent U.S. historic earthquake record. The low estimate is the minimum of the social displacement estimates reported below, and the best estimate is the average value of the social displacement estimates reported below. This approach, while resulting in crude estimates, was chosen so that the low and best estimates were a reflection of the best available recent historic data. The low estimate reflects the observed occurrence of earthquakes which cause more than $100M in losses while having relatively minor impact on human populations. The best estimate begins to approach the same order of magnitude of social displacement as observed from the two most costly U.S. earthquakes of the past 40 years (the 1981 Loma Prieta earthquake and the 1994 Northridge earthquake).

Table 2: Social Displacement Estimates

Date	Earthquake Name/Location	Displacement Estimate	Source
10/1/1987	Whittier, Los Angeles, Calif.	9,000	16
10/18/1989	Loma Prieta, SF Bay Area, Calif.	32,500	17
6/28/1992	Landers, Calif.	750	18
1/17/1994	Northridge, Calif.	120,000	19
2/28/2001	Seattle area, Wash.	400	20
12/22/2003	San Robles, Calif.	160	20

Note that the best estimate of social displacement is not necessarily correlated to the best estimate of frequency reported in Table 1. Also note that historic estimates reported in the table above are likely underestimates of social displacement as defined for the SNRA, because they are predominantly based upon permanent destruction of housing and may not include temporary displacement.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[21] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Consequences

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that

[12] Source: Modeling done by FEMA HAZUS contract support for the SNRA project team.
[13] Elnashai, A.S., Jefferson, T., Cleveland, L. J., and Gress, T. (2009) Impact of New Madrid Seismic Zone earthquakes on the Central USA, Vol. 1. 2009 Mid-America Earthquake Center: University of Illinois; at: https://www.ideals.illinois.edu/handle/2142/14810. Accessed on: September 28, 2011.
[14] USGS Circular 1324. (2008). The ShakeOut Earthquake Scenario – A Story that Southern Californians are Writing; at: http://pubs.usgs.gov/circ/1324/c1324.pdf. Accessed September 28, 2011.
[15] Kircher, C.A., Seligson, H.A., Bouabid, J., and Morrow, G.C. (2006). When the Big One Strikes Again – Estimated Losses due to a Repeat of the 1906 San Francisco Earthquake. *Earthquake Spectra* 22(82): 8297-8339.

[16] Whitter Daily News (2011). Whitter Narrows Earthquake: 20 Years Later. Article date 9/28/2011. At http://www.whittierdailynews.com/earthquake (accessed March 2013).
[17] U.S. Geological Survey (1998). The Loma Prieta, California Earthquake of October 17, 1989 - Building Structures. USGS Professional Paper 1552-C; http://pubs.usgs.gov/pp/pp1552/pp1552c/pp1552c.pdf (accessed March 2013). Notes 13,000 uninhabitable housing units; assumed 2.5 people per household.
[18] John A. Martin & Associates (unknown date). The Landers/Big Bear Earthquakes of June 28, 1992. At http://www.johnmartin.com/earthquakes/eqshow/lan_0000.htm (accessed March 2013).
[19] USGS (1998), *op cit*. Notes 48,000 uninhabitable housing units; assumed 2.5 people per household.
[20] EM-DAT, number of "total affected". EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium). Accessed on September 28, 2011. The number of "total affected" includes injuries, people needing immediate assistance for shelter, and people needing immediate assistance, including displacements and evacuations. The inclusion of injuries in this metric makes it imperfect for use in the SNRA; it is used for earthquake events when better estimates of displacement could not be found.
[21] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: earthquakes were given a C_{EF} of 1.1.
The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).

- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "moderate." Debris, devastation, and chemical or contaminant releases from damaged facilities have the potential to impact large areas.

Assumptions

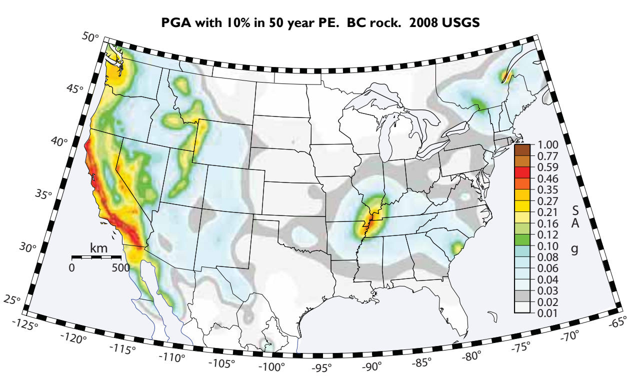
The SNRA project team used the following assumptions to estimate health and safety consequences caused by an earthquake event:

- Earthquake mitigation has improved by 1% annually.
- A linear multiplier of fatalities is sufficient for estimating the injuries associated with earthquakes to the desired precision of the SNRA (i.e., within an order of magnitude).
- The SNRA project team used the following assumptions to estimate direct economic consequences caused by an earthquake event:
- Indirect losses included in historic records do not significantly bias direct economic loss estimates.
- Correcting for inflation only from 2005-2011 does not significantly bias direct economic estimates. (Published normalized economic losses incorporating population, wealth, and mitigating factors were only available through 2005.)

Potential Mitigating Factors

The following key factors can mitigate the potential consequences caused by earthquakes: population and wealth/assets density, land use, construction type and quality, adherence to building codes in design, level of preparedness and awareness in dealing with disasters, and the potential/extent for liquefaction.

Figure 2: Peak Acceleration With 10 Percent Probability of Exceedance in 50 Years



Additional Relevant Information

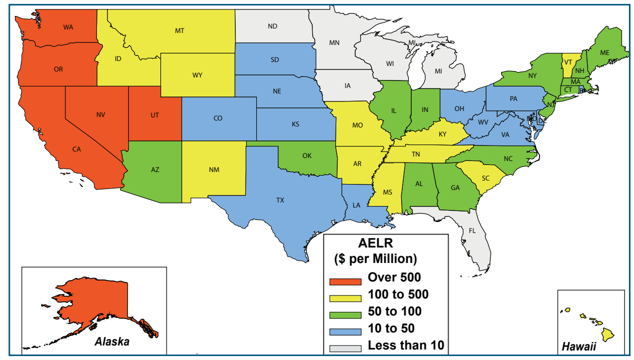
Figure 2 shows, from a national perspective, the probability that ground motion would reach a certain level during an earthquake. The data show peak horizontal ground acceleration (the fastest measured change in speed for a particle at ground level that is moving horizontally due to an earthquake) with a 10 percent probability of exceedance in 50 years. The map was compiled by the USGS Geologic Hazards Team.

As shown in Figure 2, the areas with the highest probability of seismic impacts in the U.S. are in western California, with moderate probability across larger areas of the western U.S., the Midwest, and around Charleston, SC.

In 2008, FEMA estimated average annualized losses from earthquakes for the entire nation by state. The estimated average annualized loss (AAL) addresses risk by estimating the probability of loss occurring in the study area (largely a function of building construction type and quality). By annualizing estimated losses, the AAL factors in historic patterns of frequent, smaller events with infrequent but larger events to provide a balanced presentation of risk. The AAL analysis yielded an estimate of the national AAL of $5.3 billion per year. This estimate does not include lifeline infrastructure losses or indirect (long-term) economic losses, and is therefore, a minimum estimate of the potential losses. Moreover, the estimate represents a long-term average and actual losses in any single year may be much larger or smaller.

The annualized loss ratio (ALR) represents the AAL as a fraction of the replacement value of the local inventory. The ALR gauges the relationship between average AAL and replacement value. This ratio can be used as a measure of vulnerability in the areas and, because it is normalized by replacement value, it can be directly compared across different geographic units such as metropolitan areas or counties.

Figure 3: Hazus-MH Annualized Earthquake Loss Ratios (AELR) by State.



Source: FEMA, April 2008[22]

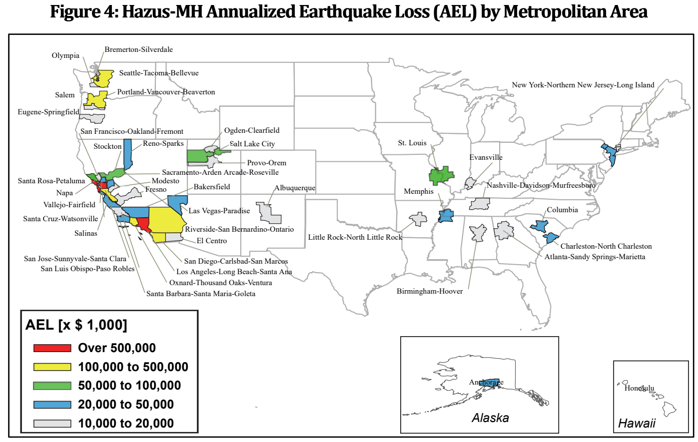
Figure 3 depicts the resulting state ALRs from this study, which helps to illustrate a national perspective of those areas more vulnerable to potential earthquake impacts. The states shown in dark red (Alaska, Washington, Oregon, California, Nevada and Utah) have the highest expected ALRs among all states and therefore have a higher likelihood of experiencing earthquake losses in any given year. Florida, North Dakota, Minnesota, Iowa, Wisconsin and Michigan have the lowest ALRs and are therefore least likely to experience earthquake losses when compared with the rest of the nation.

Figure 4 shows the annualized earthquake losses (AEL) by metropolitan area. Table 3 shows the top 7 metropolitan areas vulnerable to earthquake losses, as ranked using AEL. Of these 7 vulnerable areas, 5 are located in California.

Table 3: Top 7 Metropolitan Areas Vulnerable to Earthquake Losses

Order	Metropolitan Area	AEL ($ Million)
1	Los Angeles-Long Beach-Santa Ana, CA	1,312.3
2	San Francisco-Oakland-Fremont, CA	781.0
3	Riverside-San Bernardino-Ontario, CA	396.5
4	San Jose-Sunnyvale-Santa Clara, CA	276.7
5	Seattle-Tacoma-Bellevue, WA	243.9
6	San Diego-Carlsbad-San Marcos, CA	155.2
7	Portland-Vancouver-Beaverton, OR-WA	137.1

Figure 4: Hazus-MH Annualized Earthquake Loss (AEL) by Metropolitan Area



Source: FEMA, April 2008[22]

[22] FEMA Publication 366: Hazus-MH Estimated Annualized Earthquake Losses for the United States, April 2008.

Table 4: Earthquakes with 2011 damage estimates in excess of $100 million. Year, location, and current year (2011) damage estimates highlighted in blue.

Original Source[24]	Date	Year	City/place name	State	FIPS	Deaths	Event-year property damage	Inflation-only adjustment	Normalized damages with 1% mitigation	Proportional fatalities	Prop. fatalities 1% mitigation
ACC	4/18/1906	1906	San Francisco	CA	6901	3000	524,000,000	8,941,736,986	$104,905,367,626	24062	8896
EM-DAT	6/22/1915	1915	El Centro	CA	6025	6	1,000,000	14,598,047	$131,076,352	33	13
EM-DAT	10/11/1918	1918	Mona Passage	PR	72000	116	29,000,000	261,566,935	$1,943,953,812	331	138
NGDC-s	4/21/1918	1918	San Jacinto/Riverside County	CA	6065	0	200,000	1,803,910	$193,990,095		0
EM-DAT	6/29/1925	1925	Santa Barbara	CA	6083	13	8,000,000	74,247,020	$1,371,950,746	98	44
ACC	3/11/1933	1933	Long Beach	CA	6902	116	39,250,000	495,767,829	$7,565,220,534	737	358
NGDC-s	10/31/1935	1935	Helena	MT	30049	2	6,000,000	70,378,531	$512,380,253	6	3
NGDC-s	10/19/1935	1935	Helena	MT	30049	3	11,250,000	132,000,000	$960,000,000	9	5
EM-DAT	5/19/1940	1940	El Centro/Imperial Valley	CA	6025	9	6,000,000	69,000,000	$392,000,000	12	6
ACC	4/13/1949	1949	Puget Sound/Olympia	WA	53067	8	52,500,000	359,951,841	$3,403,585,667	41	24
NGDC-s	11/18/1949	1949	Terminal Island	CA	6902	0	9,000,000	61,706,030	$414,893,442		0
NGDC-s	8/15/1951	1951	Terminal Island	CA	6902	0	3,000,000	18,982,899	$109,913,608		0
ACC	8/22/1952	1952	Kern County/Bakersfield	CA	6029	2	20,000,000	124,417,934	$662,071,491	6	4
ACC	7/21/1952	1952	Kern County/Bakersfield	CA	6029	14	55,000,000	342,149,318	$1,820,696,601	44	26
EM-DAT	8/18/1959	1959	Hebgen Lake	MT	30031	28	26,000,000	140,472,170	$706,863,603	85	54
NGDC-s	3/28/1964	1964	Prince William Sound/Anchorage	AK	2099	131	540,000,000	2,735,575,437	$11,213,495,628	332	220
ACC	4/29/1965	1965	Seattle	WA	53999	7	20,250,000	100,744,986	$299,194,941	13	9
NGDC-s	10/2/1969	1969	Santa Rosa	CA	6097	1	8,000,000	36,000,000	$120,000,000	2	2
ACC	2/9/1971	1971	San Fernando	CA	6902	65	539,500,000	2,092,109,007	$5,083,948,997	114	81
NGDC-s	10/15/1979	1979	Imperial Valley	CA	6025	0	30,000,000	67,881,448	$129,806,214		0
ACC	10/1/1987	1987	Whittier/Los Angeles	CA	6902	8	354,000,000	542,215,449	$795,888,336	10	9
hybrid	10/18/1989	1989	Loma Prieta/San Francisco	CA	6901	62	5,750,000,000	8,206,000,000	$10,485,000,000	71	60
ACC	6/28/1992	1992	Landers/Yucca Valley	CA	6071	3	100,000,000	129,782,948	$202,144,394	4	3
ACC	4/25/1992	1992	Ferndale/Fortuna/Petrolia	CA	6023	0	66,000,000	85,656,746	$106,971,740		0
ACC	1/17/1994	1994	Northridge/Los Angeles	CA	6902	60	47,350,000,000	58,814,639,537	$78,235,199,499	69	62
ACC	2/28/2001	2001	Seattle/Tacoma/Olympia	WA	53999	1	2,000,000,000	2,189,728,415	$2,378,245,427	1	1
ACC	12/22/2003	2003	Paso Robles/San Simeon	CA	6079	2	300,000,000	316,390,574	$328,283,332	2	2

[24] Original source cited by Vranes and Pielke (2009), *op. cit.*, from which this table was taken.

Flood

A flood occurs within the U.S. resulting in direct economic losses greater than $100 Million.

Data Summary

Table 1 shows the minimum, average, and maximum values for frequencies and consequences of national level floods. Note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[1]	0	3	25
Injuries and Illnesses	Number of Injuries or Illnesses[1]	0	95	4,520
Direct Economic Loss	U.S. Dollars[1]	$104 Million	$740 Million	$16 Billion
Social Displacement	Displaced from Homes ≥ 2 Days[2]	150	29,000	200,000
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	Moderate[4]		
Frequency of Events	Number per Year[5]	0.5	4	10

Table 1

Event Background

Floods are one of the most common hazards in the United States. Their effects can be local, impacting a neighborhood or community, or large, affecting entire river basins and multiple states.[6] For the purpose of the SNRA, a national-level flood is defined as a flood producing direct economic loss in excess of $100 million dollars. Economic loss reported here is a combination of property and crop damage. A 13 year time period, from Jan-1-1993 to Dec-31-2005, was used to estimate the interarrival rates/frequencies and consequences for floods exceeding the $100 million threshold. A full list of aggregated flood events used for this report is located in Table 2. Table 1 reports the maximum, average, and minimum frequency with which such floods occurred in the United States, and the maximum, average and minimum consequences for fatalities, injuries, and direct economic losses associated with floods in the set.

This flood risk summary is based on aggregating flood losses reported by NOAA's National Climactic Data Center (NCDC).[7] Modern flood reporting by NOAA relies on many individual reports that assess damages in a specific area of responsibility. A large scale flood, for example, can result in dozens or hundreds of damage entries that assess damages for specific geographic regions. The reason for this is that damage estimates are recorded by individuals with specific areas of responsibility. As flooding passes down the Mississippi, for example, the affected areas can pass from region to region. To capture the transient and distributed nature of flood events, individual flood loss estimates were aggregated based on proximity and time. Flood damage reports that occur within 100 miles of one another and within plus or minus one calendar day are aggregated into composite flood events. The composite flood events above the $100 million threshold are used for reporting of national level event statistics in Tables 1 and 2 of this report. All hurricanes were removed from flood events to avoid over reporting flooding captured in the hurricane risk summary sheet.

Low, average and high consequence estimates were developed in the following manner. For fatalities, injuries and economic loss, the low estimate is the smallest consequence for events that exceed $100 million. For event frequency, the low estimate is the lowest number of events recorded in a year. The average frequency is the expected number of events in a given year. Similarly, the average for fatalities, injuries/illness, and economic damage are the expected value for each given the occurrence of a national level flood. The maximum frequency is the maximum number of national-level floods recorded in a single year. The maximum for fatalities, injuries/illness, and economic damage is the greatest value produced by a single storm in each consequence category.

It is important to note that the frequency estimates reported here differ from probabilities. The frequency of a national-level flood can be greater than one, while a probability cannot. Additionally, while the average estimates for consequences and frequency are correlated and approximate the average annual loss when multiplied together, the maximum and minimum historical values for consequence and frequency are uncorrelated and do not have meaning when multiplied together.

Economic flood damages were inflated to a 2011 dollar value using average changes in the Consumer Price Index. The historical maximum for fatalities was the Great October Flood of 1998 in West Texas with an estimated 25 deaths. Several floods within the time period exceeded $100 million in economic damages without any reported loss of life or injury. In total, 37 floods exceeding the $100 million threshold are aggregated in the findings of this report. For economic loss, $104 million[8] (5/8/1993: Heavy rain in parts of Oklahoma, Arkansas, and Texas) is the smallest historic loss that meets the $100 million threshold. Twenty three historic events exceeding the economic threshold did not record any fatalities. The greatest gap between flood events occurs between 1998 and 2000. This two year time lapse between national level events results in an interarrival frequency of 0.5, or $1/t_{max}$.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

To estimate social displacement for the SNRA, U.S. flood event data from EM-DAT was used to approximate the number of people forced to leave home for two days or greater. EM-DAT, an Emergency Events Database maintained by the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters with support from USAID,[9] provides estimates of the "total number affected" by disaster events. Data on "total number affected" for U.S. flood events from 1970-2011 listed in EM-DAT as causing $100M or greater in damages are listed in Table 3. This data covers a longer historic time period than the flood data used for the economic analysis and the EM-DAT events listed may not match the events listed in Table 2 exactly due to differences in damage reporting between the two databases.[10] The low, high, and average of the "total affected" data in Table 3 are used as the social displacement estimates for floods in the SNRA.

The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to floods is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA. Note that the low estimate may be biased low due to incomplete reporting of displacement and evacuations in EM-DAT.

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[1] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss are the historical minimum, average, and maximum for each consequence type in the event set. Extremal events for one consequence type may but generally do not correspond to those for other consequence types.
[2] Low, average, and high reported "total affected" for floods causing greater than $100M in economic damage as recorded in the EM-DAT database during the time period 1970-2011. See Social Displacement section in this summary sheet for details.
[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[4] Floods were given a best estimate of 'Moderate'. The experts assessed that flooding of agricultural areas is a typical impact. The severity of the impact depends upon whether there is release of contaminants from urban areas.
[5] Historical lowest, average, and maximum number of events per year (calculated from interarrival times).
[6] FEMA.gov: Flood, March 2011. http://www.fema.gov/hazard/flood/.
[7] NOAA NCDC Storm Events Database, available by ftp from http://www.ncdc.noaa.gov/stormevents/ftp.jsp (current URL: database downloaded by SNRA project team from NCDC for analysis September 2011, URL updated 3/16/2013).

[8] 5/8/1993: Heavy rain in parts of Oklahoma, Arkansas, and Texas.
[9] EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium) [official citation]. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université Catholique de Louvain located in Brussels, Belgium (http://www.emdat.be/frequently-asked-questions), and is supported by the Office of U.S. Foreign Disaster Assistance (OFDA) of USAID (http://transition.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/). See Criteria and Definition, http://www.emdat.be/criteria-and-definition, EMDAT Data Entry Procedures, at http://www.emdat.be/source-entry , and EMDAT Glossary, at http://www.emdat.be/glossary/ for details of criteria, thresholds, and methodology for the EM-DAT database.
[10] The historical flood incidents in Table 4 were paired with corresponding historical incidents in Table 3 for the purpose of determining a unique set of records with all consequence numbers, where available, for the SNRA core data set (Appendix K). However, this identification occurred after 2011, and Table K2 was not included in the SNRA data or documentation reviewed by FEMA and the interagency, or in classified (full) versions of the SNRA Technical Report.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[11] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "moderate." Flooding of agricultural areas is a typical impact of large scale flooding. The severity of the impact depends upon whether there is release of contaminants from urban areas.

Potential Mitigating Factors

Flood risk is typically based on history, combined with a number of factors such as rainfall, river-flow and tidal-surge data, topography, flood control measures, and changes due to building and development.

Assumptions

The SNRA project team used the following assumptions to estimate health and safety consequences for this event:

- Historical flood events from 1993-2005 are representative of current flood risk.[12]
- Aggregations of individual reports for flood deaths/injuries represent the actual deaths/injuries from historic flood events to sufficient precision for purposes of the SNRA. These fatality and injury reports are potentially biased low compared to published reports due to underreporting in the NOAA database.

The SNRA project team used the following assumptions to estimate economic consequences for this event:

- Property and flood loss dominate the direct economic losses, such that business interruptions, medical costs, and loss of spending due to fatalities can be neglected.

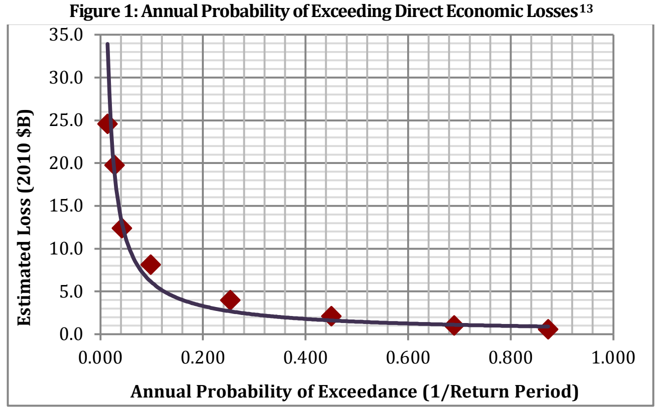
The SNRA project team used the following assumptions to estimate social displacement for this event:

- Numbers displaced by floods sufficiently dominate injuries that EM-DAT's total-affected measure may be considered an approximate measure of social displacement.

Expected Wind Damage Versus Return Period

Results reported in Tables 1 and 2 capture actual flood events. An additional perspective into flood damage is a loss exceedance probability shown in Figure 1. The 13-year range used for consequences in Tables 1 and 2 does not provide record of all possible consequences. Low frequency events have the capacity to eclipse the greatest damage reports from historic events. Figure 1 provides a loss exceedance probability for flood damages in a given year. It is important to note that this loss is an annualized number for the entire country, not specific flood events.

Figure 1: Annual Probability of Exceeding Direct Economic Losses[13]



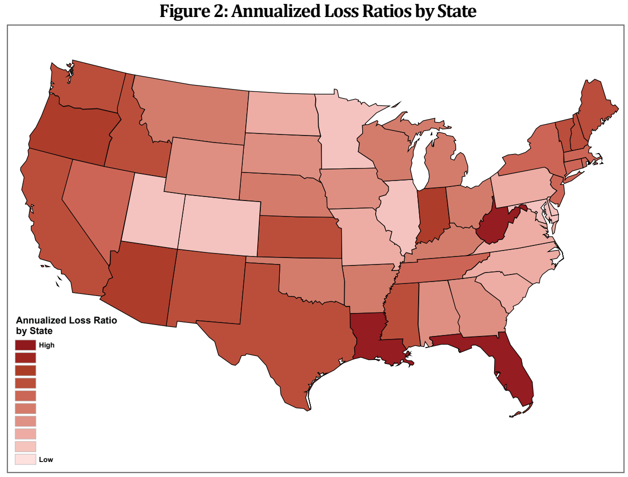
Additional Relevant Information

In 2010, FEMA used default analyses to estimate average annualized losses for flood for the entire nation by state. The estimated average annualized loss (AAL) addresses risk by estimating the probability of the loss occurring in the study area (largely a function of building construction type and quality). By annualizing estimated losses, the AAL factors in historic patterns of frequent, smaller events with infrequent but larger events to provide a balanced presentation of risk. The AAL analysis yielded an estimate of the national AAL of approximately $55 billion per year.

The annualized loss ratio (ALR) represents the AAL as a fraction of the replacement value of the local inventory. The ALR gauges the relationship between AAL and replacement value. This ratio can be used as a measure of vulnerability in the areas and, because it is normalized by replacement value, it can be directly compared across different geographic units such as metropolitan areas or counties.

Figure 2 depicts the resulting state ALRs from this study, which helps to illustrate from a national perspective those areas that are more vulnerable to potential flood impacts. The states shown in dark red (Florida, Louisiana and West Virginia) have the highest expected ALRs among all states and therefore have a higher likelihood of experiencing flood losses in any given year.

Figure 2: Annualized Loss Ratios by State



Source: FEMA, June 2011[14]

[11] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + ½\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: floods were given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[12] Flood event records for 2006 – present are also available from NOAA, but in a different format than the records used for this summary sheet. These records will be included in future analysis.

[13] Modeling done by FEMA HAZUS-MH contract support for the SNRA project team.

[14] FEMA: HAZUS Average Annualized Flood Loss for the Contiguous United States, DRAFT June 2011.

Table 2: Flood Events

Description:	Report Date	Fatalities	Injuries	Econ Loss
Heavy rain in parts of OK, AR, and TX.	5/8/1993	5	0	$103,635,700
Extensive flooding due to 4 to 8 inches of rain in South Central Kansas.	5/8/1993	0	0	$157,000,000
Flooding in OK.	5/8/1993	0	0	$157,000,000
Great Flood of 93.	8/31/1993	0	0	$15,700,000,000
Steady rains in and around Springfield MO.	9/24/1993	1	0	$119,013,850
Flooding in SC and TN.	3/27/1993	3	0	$238,068,000
Heavy rains resulted in flash floods in PA and NY.	8/18/1994	3	6	$111,766,500
Texas flooding.	10/16/1994	15	0	$399,146,400
Flooding in Kern, Los Angeles and San Diego CA.	1/10/1995	0	0	$166,135,000
Flooding from Kern to Tulare CA.	3/1/1995	0	0	$168,072,000
Salinas River flooding in Monterey County CA.	3/10/1995	0	0	$447,000,000
Rain combined with snow melt from unprecedented warm temperatures caused flooding from VA to NY.	1/18/1996	22	1	$475,800,480
Melting snow and rain caused northern Oregon river flooding.	2/6/1996	7	0	$576,000,000
Record breaking rainfall fell over parts of north central and northeast Illinois.	7/17/1996	0	0	$111,888,000
Heavy thunderstorms in PA.	7/19/1996	2	1	$326,160,000
Damages in CA from rain combined with snow melt in the Sierra Nevada.	1/1/1997	3	52	$1,635,600,000
Melting snow and heavy rain in Southern Oregon.	1/1/1997	0	0	$126,900,000
Flooding from excessive rain in KY, OH, and WV.	3/1/1997	10	3	$153,368,520
Record 24 hour rainfall in Jefferson County, KY.	3/1/1997	2	0	$296,100,000
Sheyenne River flooding in ND.	4/8/1997	0	0	$5,428,500,000
Severe flash floods in MN and WI. Milwaukee County, WI was extensively damaged.	6/20/1997	0	6	$141,751,530
Heavy rains resulting in flash floods in multiple counties of CO.	7/28/1997	5	40	$289,162,800
Large hail, strong winds and torrential rain hammered portions of Lakewood and South Denver CO.	8/11/1997	0	0	$180,480,000
A slow moving Nor'easter battered eastern VA.	2/4/1998	0	0	$104,250,000
Powerful Pacific storm fed by an unusually warm El Nino struck southern and central CA.	2/23/1998	5	3	$152,316,200
A slow moving weather system dumped large amounts of rain on AL.	3/8/1998	4	0	$165,389,150
An intense gulf storm dumped up to 14 inches of rain in Houston, Dale, and Geneva counties in AL and southwest Georgia.	3/8/1998	1	1	$543,490,000
Nearly six inches of rain in Calhoun, Franklin, Gadsden, Gulf, Holmes, Jackson, Walton, and Jackson counties of FL.	3/10/1998	0	0	$510,130,000
Agricultural damage due to a large Southern Sierra Nevada snow melt.	6/1/1998	0	0	$139,556,000
Sustained flooding through parts of East Central OH.	6/26/1998	10	0	$281,502,800
A series of slow moving thunderstorms moved through WI.	8/5/1998	2	5	$114,410,900
The Great October Flood in west Texas.	10/17/1998	25	4520	$559,266,500
Flooding from Devils Lake in ND.	8/5/1998	0	0	$136,000,000
Heavy rainfall in Jefferson and Franklin county MO.	5/7/2000	2	0	$132,660,000
Heavy thunderstorms in MN produced record rainfall amounts.	6/19/2000	0	0	$147,840,000
Thunderstorms with near torrential downpours in NJ.	8/12/2000	0	0	$237,996,000
Prior to the formation of tropical storm Leslie, a low pressure system produced massive rainfall in South West FL.	10/3/2000	0	0	$1,254,000,000
Flooding from rapid snow melt and rain.	4/1/2001	3	1	$256,000,000
Severe flash flooding in WV and VA.	7/8/2001	1	0	$280,748,800
High water in Columbia AR.	10/11/2001	0	0	$153,606,400
Flash floods in KY, VA, and WV.	5/2/2002	4	0	$141,233,400
Heavy rainfall caused the Roseau River to overflow the dikes of Roseau.	6/10/2002	0	0	$252,000,000
Heavy rains caused flooding in several counties of MS.	4/6/2003	2	0	$325,683,090
Flooding TN, GA and AL in with the most severe damage in Jefferson County AL.	5/5/2003	3	6	$1,474,800,000
Thunderstorm generated flash floods throughout OH.	7/21/2003	5	0	$288,261,570
A stationary front caused widespread flooding over Southeast Michigan.	5/23/2004	0	0	$120,000,000
Scattered to widespread heavy rains across south-central and southeast WI.	6/1/2004	0	0	$301,860,000
A stalled storm system dumped rain throughout many portions of UT.	1/10/2005	1	6	$348,000,000
Widespread flooding in several CA counties due to heavy rainfall.	12/30/2005	0	0	$476,298,320

Table 3: Social displacement and damage estimates from EM-DAT

Start (DD/MM/YY)	End (DD/MM/YY)	Location	EM-DAT Total Affected	EM-DAT Est. Damage (US$ Million)
09/06/1972	09/06/1972	Rapid City (South Dakota) ...	3,000	120
22/07/1977	22/07/1977	Johnstown (Pennsylvania)	2,700	200
19/02/1980	19/02/1980	South California	106,000	350
06/01/1993	20/01/1993	California, Arizona, Neva ...	6,000	100
28/02/1993	28/02/1993	N/A	5,200	190
24/06/1993	23/08/1993	Oklahoma, Minnesota, Wis ...	31,000	12,000
17/10/1994	23/10/1994	Houston, Galveston (Texas ...	14,070	700
07/05/1995	13/05/1995	Louisiana (New Orleans)	20,000	3,000
28/11/1995	10/12/1995	Washington, Oregon	15,000	100
15/01/1996	21/01/1996	Nevada, Arizona, New Mexi ...	200,000	700
07/02/1996	13/02/1996	Washington, Oregon, Idaho ...	24,900	500
27/12/1996	03/01/1997	Washington, Oregon, Nevad ...	18,100	1,500
01/01/1997	07/02/1997	Nevada, Idaho, California ...	125,000	1,500
17/04/1997	07/05/1997	Grand Forks, Fargo	50,400	5,000
25/07/1997	01/08/1997	Fort Collins (Northern Co ...	424	100
07/03/1998	13/03/1998	S Alabama, N and C Georgi ...	18,000	270
13/06/1998	17/06/1998	Iowa, Indiana, , Illinois ...	1,000	201
24/06/1998	01/07/1998	Kansas, IA, MO, Illinois, ...	14,000	469
23/05/2000	23/05/2000	Franklin, Jefferson, Gasc ...	300	100
12/08/2000	14/08/2000	Morris (Sussex county, Ne ...	175	166
30/06/2002	23/07/2002	New Braunfels, Bandera, U ...	144,000	1,000
05/07/2003	21/07/2003	Carroll, Adams, Cass, How ...	1,200	106
07/01/2005	11/01/2005	La Conchita, Ventura coun ...	508	200

Start (DD/MM/YY)	End (DD/MM/YY)	Location	EM-DAT Total Affected	EM-DAT Est. Damage (US$ Million)
17/02/2005	23/02/2005	Los Angeles, region (Cali ...	150	250
31/12/2005	18/01/2006	Napa, Sonoma, Mendocino, ...	3,600	245
04/04/2006	17/04/2006	Amador, Calaveras, Fresno ...	600	259
25/06/2006	01/07/2006	Maryland, Pennsylvania, N ...	65,000	1,000
16/08/2007	27/08/2007	Illinois, Colorado, Mich ...	2,840	700
24/03/2009	20/04/2009	North Dakota, Minnesota	5,060	166
20/09/2009	21/09/2009	Douglas, Floyd, Carroll, ...	3,000	500

*Note: EM-DAT data from June 2008 Midwest floods is not included because "total affected" estimate (11 million) is a large outlier which could not be independently validated against news reports.

Human Pandemic Outbreak

A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace.[1]

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	140,000	250,000	440,000
Injuries and Illnesses	Number of Injuries or Illnesses	62 Million	77 Million	110 Million
Direct Economic Loss	U.S. Dollars	$84 Billion	$170 Billion	$260 Billion
Social Displacement	Displaced from Homes ≥ 2 Days	0[2]		
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	Low[4]		
Frequency of Events	Number per Year	0.017	0.033	0.1

Event Background

There have been eight naturally caused influenza pandemics (including pandemics subsequently deduced to have been caused by influenza virus) since 1729.[5] Thus the historic frequency is once every 10 to 60 years. New influenza viruses that affect humans can emerge and spread rapidly. Influenza pandemics can occur at any time due in part to the following factors: the quality and scope of epidemiological and laboratory resources to identify and diagnose viruses with pandemic potential – both in the United States and globally; the complex re-assorting of new influenza viruses between animal and humans; potential lack of antibody resistance to new influenza virus strains in the population at large; potential resistance of new influenza virus strains to available antiviral medications; time needed to identify, develop, produce, and distribute an effective pandemic influenza vaccine; and countermeasure resources in the United States and globally to mitigate the transmission of a pandemic virus.

Assumptions

Fatalities and Illnesses

The SNRA project team used the following assumptions to estimate health and safety consequences caused by a pandemic event:

- The scenario is based on a U.S. population of approximately 307 million.
- Likelihood, fatality, and illness best estimates and ranges were provided to the SNRA project team by the U.S. Centers for Disease Control and Prevention. These were derived from expert judgment by CDC subject matter experts, informed by modeling and assumptions similar to those used in U.S. Government pandemic planning scenarios.[6]
- These experts stress that it is impossible to predict the timing or severity of the next pandemic.
- All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).
- The modeled National-level Event is based on assuming a 25% attack rate,[7] and death rates associated with a scenario modeled on a 1968-scale pandemic were it to occur in today's population. Medical technologies to improve survival probabilities in the elderly and health-compromised populations most at risk of dying from influenza have advanced in past decades. However, the larger fraction of these high-risk subpopulations in today's U.S. population – due in large part to these same advances – means that total fatalities from an influenza pandemic of similar virulence could be much higher today than in 1968.[8]

Comparisons to other estimates of health and safety impacts: Large uncertainties dominate any estimate of the human consequences of the next influenza pandemic.

- Severity of virus: Although useful indications of the potential range of impacts may be inferred from records of the historical variability of the influenza virus (see last section), patterns deduced from the historical record have been insufficient in themselves for constructing predictive models for the severity of the next pandemics.[9] Many planning scenarios frequently model experts' best judgment of a 'most representative' scenario, such as the 1968-scale pandemic model used for the SNRA and many other planning scenarios in this country; others model a 1918-scale pandemic as a maximal scenario for planning purposes.[10] Current U.S. Government guidance is to plan to both a 'moderate' 1957/1968-style pandemic and a 'severe' 1918-style pandemic to ensure preparedness for a range of impacts.[11]
- Mitigation measures: In addition to the inherent characteristics of the virus, the actual consequences of a future pandemic will also depend upon the availability, speed of deployment, and effectiveness of medical and non-medical measures to mitigate disease spread and lethality. Despite extensive study in the literature,[12] the extent to which the effects of the next pandemic

[1] Because of the prominence of the Pandemic national-level event among the SNRA natural hazards, the explanatory text of this risk summary sheet was extensively edited from the 2011 version in 2013. Likelihood and consequence estimates are unchanged from the 2011 data. Reversion to a form more closely resembling the original delivered to FEMA in 2011 would be preferable, but the current text was retained for consistency with the final (July 2013) version of the classified Technical Report.

[2] Social displacement was assumed to be zero for the Human Pandemic Outbreak national-level event.

[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[4] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The experts provided a best estimate of 'Moderate' for a pandemic scenario with severe social impacts and a second best estimate of 'Low' for a less severe pandemic scenario (see Environmental Impacts). The SNRA used 'Low' as the best estimate and 'Moderate' as the second best estimate for the Pandemic national-level event, because the final numbers on other consequence scales defined a scenario with social impacts corresponding to the less severe pandemic scenario, rather than the more severe scenario.

[5] Different authors have different lists of which influenza years they consider to have been pandemics, but most modern writers' lists of likely influenza pandemics in the past three centuries include from about 8 to 12 events in total (when the 2009 H1N1 pandemic is included). Serological studies - blood tests to characterize antigens to surface proteins of influenza viruses a person may have been exposed to in his/her lifetime - have been successfully used to determine the serotypes (combinations of particular H and N surface proteins) of influenza outbreaks back to around 1900. However, making a determination of which historical outbreaks before that point were pandemics by the modern virological definition from past writers' observations indicative of a new influenza serotype (e.g. cross-continent spread, patterns of residual immunity from previous outbreaks) involves a great deal of inference and human judgment. Potter CW, A history of influenza. *Journal of Applied Microbiology* 2001 (91) 572-579; Taubenberger et al (2009, April), Pandemic influenza – including a risk assessment of H5N1, *Revue Scientifique et Technique (Rev. Sci. Tech.)* 28(1) 187-202, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2720801/ (accessed March 2013); Patterson, Karl D. (1986), Pandemic Influenza, 1700-1900: A study in historical epidemiology, Rowan & Littlefield, publishers; Dowdle, W. R. (1999), Influenza A virus recycling revisited. *Bulletin of the World Health Organization* 77(10) 820-828; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2557748/ (accessed April 2013); Morens et al (2010, November), Historical thoughts on influenza viral ecosystems, or behold a pale horse, dead dogs, failing fowl, and sick swine. *Influenza and Other Respiratory Viruses* 4(6) 327-337, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3180823/ (accessed May 2013).

[6] E.g. Homeland Security Council (2005, November), National Strategy for Pandemic Influenza; U.S. Department of Health and Human Services (2005, November), HHS Pandemic Influenza Plan; Homeland Security Council (2005), National Planning Scenarios (Scenario 3, Pandemic Influenza).

[7] The attack rate is the percentage of population that becomes clinically ill due to influenza. Clinical illness is defined as a case of influenza that causes some measurable economic impact, such as one-half day of work lost or a visit to a physician's office.

[8] Meltzer MI, Cox NJ, Fukuda K. (1999). The economic impact of pandemic influenza in the United States: priorities for intervention. *Emerging Infectious Diseases* 5(5) 659-671.

Although the SNRA project team is not aware of any longitudinal study looking at the proportion of high-risk populations defined in comparable terms, the scale of this increase is apparent in studies of the U.S. populations covering shorter time periods. One illustration of this is the increase of the overall percentage of the U.S. population at high risk from complications of influenza from 15.5% to 20% in the five year period 1973-1978 displayed in Table 12 of the Office of Technology Assessment's 1981 study of influenza response options. Office of Technology Assessment, U.S. Congress (1981, December), Cost Effectiveness of Influenza Vaccination. NTIS order #PB82-178492, also at http://ota.fas.org/reports/8112.pdf.

[9] Dowdle, W. R. (1999), Influenza A virus recycling revisited. *Bulletin of the World Health Organization* 77(10) 820-828; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2557748/ (accessed April 2013).

For a recent approach from CDC scientists which could be adapted to a quantitative risk assessment of pandemic influenza from historical data in a manner similar to other events in the SNRA, see Reed et al (2013, January), Novel framework for assessing epidemiologic effects of influenza epidemics and pandemics, *Emerging Infectious Diseases* 19(1) 85-91 and its technical appendix. This approach is being studied for a future iteration of the SNRA.

[10] National Infrastructure Simulation & Analysis Center (NISAC), for the Office of Infrastructure Protection, U.S. Department of Homeland Security (2007, October 10), National Population, Economic, and Infrastructure Impacts of Pandemic Influenza with Strategic Recommendations; also the 'high' scenario of the 2005 HHS Pandemic Influenza Plan (p. 18), and the 'high' and conservative fatalities planning factors of the UK Pandemic Influenza Strategy 2011 (pp. 16-17, 20-25) (overall, the UK strategy stresses a range of scenarios similar to HHS recommendations). Department of Health, United Kingdom (2011, November 10), UK Influenza Pandemic Preparedness Strategy 2011, at https://www.gov.uk/government/publications/responding-to-a-uk-flu-pandemic (accessed June 2013); U.S. Department of Health and Human Services (2005, November), HHS Pandemic Influenza Plan, at http://www.flu.gov/planning-preparedness/federal/hhspandemicinfluenzaplan.pdf (accessed April 2013).

[11] HHS Pandemic Influenza Plan, *op cit*; U.S. Centers for Disease Control and Prevention, CDC Resources for Pandemic Flu [web portal], http://www.cdc.gov/flu/pandemic-resources/ (accessed June 2013).

[12] Longini et al (2004, April 1). Containing pandemic influenza with antiviral agents. *American Journal of Epidemiology* 159(7) 623-633; Miller et al (2008, August 1). Prioritization of influenza pandemic vaccination to minimize years of life lost. *Journal of Infectious Diseases* 198(3) 305-311; Perlroth et al (2010, January 15). Health outcomes and costs of community mitigation strategies for an influenza pandemic in the United States. *Emerging Infectious Diseases* 50(2) 165-174; Meltzer et al (1999), *op cit.*; NISAC (2007), *op cit.*; Office of Technology Assessment (1981), *op cit.*; CDC (2011, May 10). Ten Great Public Health Achievements – United States, 2001-2010. *Mortality and Morbidity Weekly Report (MMWR)* 60(19) 619-623; CDC (2011, September 30), Notice to Readers: Revised Estimates of the Public Health Impact of 2009 Pandemic Influenza. *MMWR* 60(38) 1321; Atkins et al (2011, September). Estimating effect of antiviral drug use during pandemic (H1N1) 2009 outbreak, United States. *Emerging Infectious Diseases* 17(9) 1591-1598.

will be mitigated in practice is dominated by open questions (see Potential Mitigating Factors).

Economic Loss

The SNRA project team used the following assumptions to estimate economic consequences caused by a pandemic event:

- All of the estimates are given absent any intervention (i.e., before interventions are applied or attempted).
- The economic impact for the 1968 scenario was taken from Meltzer et al.,[13] and updated from 1995 values to 2010 dollar estimates, using the Consumer Price Index conversion factor (CPI - 1.431 conversion factor).[14] The dollar values provided include estimates for lost productivity due to time off work to either convalesce or to care for a family member who is ill.
- Approximately 83% of the estimated impact for this scenario is associated with the value of lost productivity due to premature death.
- Beyond the inclusion of value of time lost from work, these estimates do not include any valuation for lost economic activity, such as business closing or notable reduction in economic activity.

Comparisons to other estimates of economic impact: In comparison to the 1968 scenario estimate, a 2006 study of the potential economic impact of an influenza pandemic gave an estimate of impact for a "mild" pandemic of 0.8% of global GDP, equivalent in the U.S. to approximately $117.6 billion.[15] This is within the range given in the "Data Summary" for the 1968 scenario.

A Congressional Budget Office (CBO)[16] study of a 1918-type outbreak scenario, assuming 2 million deaths, estimated that such a pandemic would cause the U.S. GDP ($14.7 trillion) to decrease by 4.25% - equivalent to $625 billion. This is above the range included in the Table, but it represents a comparatively less likely worst case scenario. The CBO's "mild" pandemic scenario, equivalent to the 1968 and 1957 pandemics, assumed 100,000 might die, and cause an impact of about 1% of GDP ($147 billion). A detailed Canadian study[17] estimated that a 1918-type pandemic would reduce the Canadian economy by a maximum of 1.1% GDP - equivalent in the U.S. to US$161.7 billion.

Social Displacement

Social displacement was assumed to be zero for the Human Pandemic Outbreak national-level event.[18]

Note that hospitalization is not counted as social displacement for the purposes of the SNRA since it would result in double counting with illnesses. Social distancing, quarantine, large scale telework, and children and family staying home or college students returning home as a result of school closures are also not counted as social displacement because they result in more people staying home rather than leaving home.

Psychological Distress

Psychological consequences for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[19] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The experts provided a best estimate of 'Moderate' for a pandemic scenario with severe social impacts and a second best estimate of 'Low' for a less severe pandemic scenario.
- The SNRA reports the 'Low' environmental impact judgment as the best estimate for the purposes of the SNRA because the social impacts of the final SNRA Pandemic best estimate scenario, as defined by the best estimates on other consequence axes, correspond to the less severe pandemic scenario. The SNRA reports 'Moderate' as the second best judgment because it describes the environmental impacts of a more severe pandemic scenario.
- Experts identified the consequences of a larger pandemic scenario as "Moderate" due to the potential for resources to be pulled from environmental protection activities, thereby allowing impacts to cascade and cause environmental consequences. If the pandemic were large enough, environmental protection could be deemphasized in order to divert resources towards higher priority response efforts and consequences could be increased as service providers are afflicted with the pandemic (e.g., waste disposal efforts could be halted if workers require treatment).

Potential Mitigating Factors

Numerous medical and non-medical measures for mitigating the human consequences of an influenza pandemic, including social distancing, school closing, antiviral medications, antibiotics for secondary bacterial infections, and targeted vaccines, are known and would be expected to be deployed, at least in part. These measures' efficacy for those individuals who directly receive them is clearly indicated by the evidence in the literature. However, there is no consensus in the literature on what proportional or percentage reductions in total national fatalities and illnesses could be expected under the constraints and conditions of an actual pandemic.[20] Estimates of percentage reductions (mitigation effectiveness) in the literature range from 1.6%[21] to 96%[22] for fatalities and 6%[23] to 99%[24] for illnesses respectively.

The appropriate factor for converting the currently unmitigated consequence numbers to mitigated equivalents is not known. However, recent CDC studies of the 2009-10 H1N1 pandemic indicate that any adjustment for mitigation under real-world societal and economic conditions would not substantially shift the numbers reported here.[25]

Additional Relevant Information

New influenza viruses that affect humans can emerge and spread rapidly. Influenza pandemics can occur at any time due in part to the following

[13] Meltzer MI, Cox NJ, Fukuda K. *Emerging Infectious Diseases* 1999;5:659-671.
[14] CPI conversion factors from Bureau Labor Statistics: at: http://www.bls.gov/data/.
[15] McKibinnin WJ and Sidorenko AA. Global macroeconomic consequences of pandemic influenza. Lowry Institute Analyses paper. Lowy Institute for International Policy. Feb. 2006.
[16] Congressional Budget Office (2006, July: updated/corrected from December 2005). A potential influenza pandemic: an update on possible macroeconomic effects and policy issues. At http://www.cbo.gov/publication/17785 (accessed April 2013).
[17] James S and Sargent T. The economic impact of an influenza pandemic. Economic Analysis and Forecasting Division, Department of Finance – Canada. (unpublished paper) May, 2006.
[18] For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. This measure does not capture the significant differences between temporary evacuations and permanent displacement due to property destruction. However, this distinction is less relevant for events with zero displacement on both measures.
[19] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Human Pandemic Outbreak was given a C_{EF} of 1.0.
The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).
[20] E.g. not everyone who is sick can afford going to the doctor or antiviral prescriptions; research and production times needed to mass produce vaccines targeted to the pandemic virus may delay their mass availability until after the pandemic's peak.
[21] CDC (2011, May 10). Ten Great Public Health Achievements – United States, 2001-2010. *Mortality and Morbidity Weekly Report (MMWR)* 60(19) 619-623, at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6019a5.htm?s_cid=mm6019a5_w; CDC (2011, September 30), Notice to Readers: Revised Estimates of the Public Health Impact of 2009 Pandemic Influenza. *MMWR* 60(38) 1321, at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6038a7.htm (accessed June 2013).
[22] Proportion of attack and mortality rates in the Anticipated scenario to rates in the Baseline scenario, figure 3-1, p. 17. National Infrastructure Simulation and Analysis Center (NISAC) (2007, October 10). National Population, Economic, and Infrastructure Impacts of Pandemic Influenza with Strategic Recommendations. Office of Infrastructure Protection, U.S. Department of Homeland Security.
[23] CDC (2011), Ten Great Public Health Achievements, *op cit;* CDC (2011), Revised Estimates, *op cit.*
[24] NISAC (2007), *op cit.*
[25] CDC (2011, May 10, September 30) *op cit.*; Atkins et al (2011, September). Estimating effect of antiviral drug use during pandemic (H1N1) 2009 outbreak, United States. *Emerging Infectious Diseases* 17(9) 1591-1598; at http://wwwnc.cdc.gov/eid/article/17/9/11-0295_article.htm (accessed June 2013).

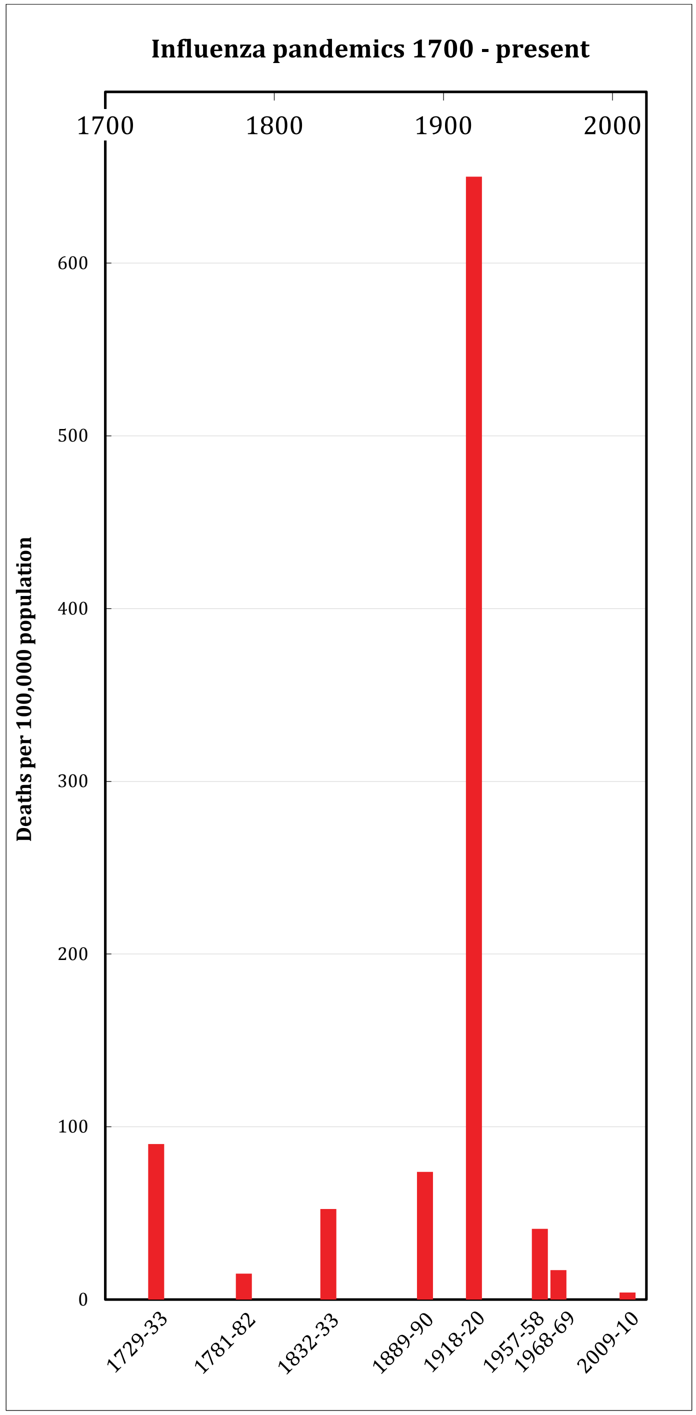
factors: the quality and scope of epidemiological and laboratory resources to identify and diagnose viruses with pandemic potential – both in the United States and globally; the complex re-assorting of new influenza viruses between animal and humans; the potential lack of antibody resistance to new influenza virus strains in the population at large; the potential resistance of new influenza virus strains to available antiviral medications; the time needed to identify, develop, produce, and distribute an effective pandemic influenza vaccine; and the availability of countermeasure resources in the United States and globally to mitigate the transmission of a pandemic virus.

The probability of impact due to a pandemic has two parts: the probability of a pandemic (any type) occurring, and then, once it has occurred, the severity of impact (essentially, the conditional probability that the "mild," "middle," or "worst case" scenario occurs).

- *Probability of a pandemic occurring*: From 1729 through 2009 there have been 8-12 influenza pandemics (including pandemics subsequently deduced to have been caused by influenza virus).[26] They have thus historically occurred with a frequency of once every 10 to 60 years.
- *Probability of severity* (probability of "mild," "middle," or "worst case" occurring once pandemic has started): The 1918 pandemic appears to have caused an exceptionally high case fatality rate. Such a pandemic could, in theory, re-occur but historically has only occurred once in approximately 8-12 pandemics. This historical frequency gives an approximately 10% chance that the next pandemic will be a 1918-type pandemic. Similarly, a "mild" pandemic, such as the 2009 pandemic, has only occurred once in 8-12 pandemics since 1700, and also has an approximate 10% probability of occurring. If one includes both the 1968 and 1957 pandemics as examples of "mild" impact pandemics, then the probability that such a scenario will occur rises to 30%. The probability of a "middle" scenario occurring is the residual after accounting for the probabilities of both "worst case" and "mild" scenarios (range for a "middle": 50% - 80%).

Visualizing the time series of influenza pandemics, 1700-present[27]

Quantitative study of mortality from historical influenza pandemics has focused almost entirely on the twentieth century. However, sufficient data on prior events exist for researchers to depict time series of historical pandemics over longer periods for mortality in selected populations. While differences in base population,[28] health, counting measures, and population age structures prevent precise comparisons, such estimates can be nonetheless arrayed together to get a rough picture of the historical variability of the influenza virus in terms of its effects on the human population (Figure 1).[29] The exceptional scale of the 1918-20 pandemic compared with other pandemics is immediately apparent.



[26] Potter CW, A history of influenza. *J Applied Micro*. 2001:91:572-579; Taubenberger et al (2009, April), Pandemic influenza – including a risk assessment of H5N1, *Revue Scientifique et Technique (Rev. Sci. Tech.)* 28(1) 187-202, at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2720801/ (accessed March 2013); Patterson, Karl D. (1986), Pandemic Influenza, 1700-1900: A study in historical epidemiology, Rowan & Littlefield, publishers; Dowdle, W. R. (1999), Influenza A virus recycling revisited. *Bulletin of the World Health Organization* 77(10) 820-828; at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2557748/(accessed April 2013). Different authors count different events as pandemic or not, but most events on different authors' lists overlap, as does the 8 to 12 total number when the 2009 H1N1 pandemic is included.

[27] This visualization and supporting text were added July 2013.

[28] 1729-1890 estimates are for England and Wales;1918-present are for the U.S. (sources below).

[29] The eight pandemics of natural origin are the list of Potter (2001), *op cit.* Note that these eight pandemics will differ from the pandemic lists of many of the sources from which the chart data come, especially those of older sources.

Note that uncertainties reported in the data sources below are suppressed in the Figure for clarity of presentation.

Pre-1918: Estimates for the population of England and Wales, Eichel, Otto R. (1922, December). The long-time cycles of pandemic influenza. *Journal of the American Statistical Association* 18(140) 446-454; available via JSTOR Early Journals Free Content at http://www.jstor.org/stable/2276917 (accessed June 2013). 1729-33 (90/100,000) is the sum of Eichel's lines for 1729 (30-45) and 1733 (45-60); 1781-82, for 1782 (15); 1832-33, for 1833 (45-60); 1889-90 (74/100,000), for 1889 (16) and 1890 (58). The midpoints of the dashed-line uncertainty ranges reported by Eichel were used as 'best estimates' (e.g. 37.5 + 52.5 = 90; 15; 52.5).

1918-20, 1957-58, 1968-69: Historical fatalities, National Institutes of Health, 2011. *Timeline of human flu pandemics* [electronic resource]. National Institute of Allergy and Infectious Diseases, National Institutes of Health, January 14, 2011; at http://www.niaid.nih.gov/topics/flu/research/pandemic/pages/timelinehumanpandemics.aspx (accessed March 2013). U.S. population, for population fatality rate: United States population including Armed Forces abroad, Table I: National Center for Health Statistics (1999). *Vital Statistics of the United States: 1999 Mortality Technical Appendix*. At http://www.cdc.gov/nchs/products/vsus/ta.htm (accessed April 2013).

2009-10: Fatalities (12,470 total), best estimate, Centers for Disease Control (2010, May 4). Updated CDC estimates of 2009 H1N1 influenza cases, hospitalizations and deaths in the United States, April 2009 – April 10, 2010 [electronic resource]; at http://www.cdc.gov/h1n1flu/pdf/CDC_2009_H1N1_Est_PDF_May_4_10_fulltext.pdf (accessed April 2013).

Hurricane

A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[1]	0	26	1,200
Injuries and Illnesses	Number of Injuries or Illnesses[1]	0	650	30,000
Direct Economic Loss	U.S. Dollars[1]	$100 Million	$5.7 Billion	$92 Billion
Social Displacement	Displaced from Homes ≥ 2 Days[2]	140	520,000	5 Million
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	High[4]		
Frequency of Events	Number per Year[5]	0.33	1.9	7

Table 1

Event Background

For the purpose of the SNRA, a national-level hurricane is defined as a hurricane producing direct economic loss in excess of $100 million dollars. Economic damages reported here are a combination of coastal flooding and wind damage generated by hurricanes and tropical storms. A 40 year time period, from 1970 to 2010, was used to estimate the interarrival rates/ frequencies and consequences for hurricanes exceeding the $100 million threshold. While accurate hurricane damages have been recorded since before 1900, mitigation and evacuation strategies have significantly changed since the turn of the 20th century, substantially lowering hurricane consequences. To capture a representative subset for current hurricane consequences, only storms recorded after 1970 were used for this report. Table 1 reports the maximum, average, and minimum frequency with which such hurricanes occurred in the United States, and the maximum, average and minimum consequences for fatalities, injuries, and direct economic losses associated with hurricanes in the set. A list of all hurricanes with accompanying economic consequences and fatalities is shown in Table 2.

Low, average and high estimates were developed in the following manner from the normalized consequence estimates and historic record. For fatalities, injuries and direct economic loss, the low estimate is the smallest consequence for events that exceed $100 million. For event frequency, the low estimate is derived from the greatest time gap, t_{max}, between years with national level events. The average frequency is the expected number of events in a given year. Similarly, the average for fatalities, injuries/illness, and direct economic loss are the expected value for each measure given the occurrence of a national level hurricane. The maximum frequency is the maximum number of national level hurricanes recorded in a single year. The maximum for fatalities, injuries/illness, and direct economic loss is the greatest value produced by a single storm in each consequence category.

It is important to note that the frequency estimates reported here differ from probabilities. The frequency of a national-level hurricane can be greater than one, while a probability cannot. Additionally, while the average estimates for consequences and frequency are correlated and approximate the average annual loss when multiplied together, the maximum and minimum historical values for consequence and frequency are uncorrelated and do not have meaning when multiplied together.

Fatalities

Fatality estimates are based directly on the historic record (Blake, Landsea, & Gibney, August 2011). The historical maximum for fatalities was Katrina in 2005 with an estimated 1,200 deaths.[6] Several storms within the 40 year time period exceeded $100 million in economic damages without causing any loss of life. While several storms have zero recorded fatalities, fatality estimates were not always available for events with less than 25 fatalities. In the case where records were not available, fatality estimates were apportioned as percentages of yearly hurricane fatalities based on economic damages. The average of all national level hurricanes was then used to produce the historical average of 26 fatalities per storm. The table of national level hurricanes, Table 2, contains a total of 2016 fatalities from 78 distinct events.

Injuries and Illnesses

Injury/illness estimates were produced for each hurricane based on a linear model relating fatalities to injuries and illness. The model is derived from Hurricane Andrew in 1992 (CDC, 1993). A model was needed because accurate injury and illness estimates were not readily available for most hurricanes. Fatality, injury and illness statistics are available for regional hospitals and mobile clinics, but these reports do not provide comprehensive estimates for hurricane related injuries. Evacuees can travel hundreds of miles (Faul, Weller, & Jones, September 2011) before receiving medical attention creating a difficult task when accounting for the number of storm related injuries. The CDC, however, has published injury/illness and fatality estimates for 19 parishes during Hurricane Andrew (CDC, 1993) that the SNRA project team used to model a multiplier for estimating total injuries. There were approximately 25 injuries to every fatality within the study group. The multiplier was applied to the fatality estimates to obtain injury/illness estimates for hurricane consequences.

Economic Loss

To provide an accurate assessment for current year planning, historic economic damage estimates have been updated to a 2011 base year. Economic and health & safety consequences, derived directly from historic record, are updated based on changes in populations, building structures, and infrastructure. These damage estimates are published by ICAT and available via the internet.[7] A full description of methods used in economic loss normalization is documented by Pielke (Pielke Jr., Gratz, Landsea, Collins, Saunders, & Musulin, 2008). In total, 78 hurricanes exceeding the $100 million threshold are aggregated in the findings of this report. These estimates potentially contain indirect economic losses. There is not a clear disambiguation for economic loss estimates as there is no readily available record for each loss estimate. Due to this ambiguity, economic loss estimates have the potential to be biased high by as much as 20 percent.

For economic loss, $100 million (1993 Hurricane Emily) is the smallest normalized historic loss that meets the $100 million threshold. Twelve historic events exceeding the economic threshold did not result in any fatalities and, consequently, were not estimated to cause any injuries/illness resulting in a minimum for both fatalities and injuries/illness of zero. The greatest gap occurs between 1985 and 1988. This three year time lapse between national level events results in an interarrival frequency of 0.33, or $1/t_{max}$.

The average economic consequence is $5.7 billion per event. On average, 26 fatalities occur per event with an average of 650 injuries per event. The average time between national level events is approximately six months, resulting in 1.9 events expected per year. An estimate of the average annual loss for each consequence type (e.g., fatalities per year or economic loss per year) can be obtained by multiplying the average frequency by the average consequence in a category. The average annual fatality and economic losses for the set of 78 historic events analyzed are approximately 26 fatalities per year and approximately $5.7 billion per year.

[1] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss are the historical minimum, average, and maximum for each consequence type in the event set. Extremal events for one consequence type may but generally do not correspond to those for other consequence types.
[2] Low, average, and high reported "total affected" for hurricanes causing greater than $100M in economic damage as recorded in the EM-DAT database during the time period 1970-2011. See Social Displacement section in this summary sheet for details.
[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[4] Hurricanes were given a best estimate of 'High', with a second best estimate of 'Moderate'. The experts assessed that hurricanes can cause ecological impacts, beach erosion, nutrient loading, chemical contamination, salt water intrusion into fresh water bodies, and removal of plants leading to erosion. Large areas can experience impacts.
[5] Historical low, average, and maximum number of events per year (calculated from interarrival times).
[6] Note that fatality and economic damage estimates can differ across sources, including official U.S. Government sources, depending upon different definitions of what is counted. The fatality estimate of 1,200 for Hurricane Katrina was the latest official estimate of the National Hurricane Service for fatalities directly caused by the hurricane as of August 2011, as reported in the primary source used for fatality data by the SNRA (Blake and Landsea, p. 5). Counts of all fatalities including indirect fatalities can total 1,833, the current official estimate for all fatalities, or higher.
[7] ICAT damage estimates are available at http://www.icatdamageestimator.com. Accessed September 16, 2011.

Table 2: National Level Hurricane Events from 1970 to 2010

STORM NAME	CURRENT DAMAGE ($ 2011)	Year	Yearly Fatalities[8]	Event Fatalities (Estimated if < 25)
Hermine	$250,000,000	2010	13	12
Hanna	$170,000,000	2008	41	0
Fay	$590,000,000	2008	41	1
Dolly	$1,080,000,000	2008	41	2
Gustav	$4,220,000,000	2008	41	7
Ike	$19,600,000,000	2008	41	31
Ernesto	$550,000,000	2006	0	0
Cindy	$360,000,000	2005	1225	0
Dennis	$2,670,000,000	2005	1225	2
Rita	$11,330,000,000	2005	1225	8
Wilma	$26,210,000,000	2005	1225	16
Katrina	$92,050,000,000	2005	1225	1200
Charley	$120,000,000	2004	60	0
Gaston	$160,000,000	2004	60	0
Jeanne	$9,350,000,000	2004	60	8
Frances	$12,310,000,000	2004	60	11
Charley	$18,520,000,000	2004	60	16
Ivan	$18,480,000,000	2004	60	25
Claudette	$250,000,000	2003	24	1
Isabel	$4,820,000,000	2003	24	22
Isidore	$480,000,000	2002	9	2
Lili	$1,210,000,000	2002	9	6
Gabrielle	$390,000,000	2001	45	2
Allison	$8,330,000,000	2001	45	43
Dennis	$270,000,000	1999	62	2
Irene	$1,430,000,000	1999	62	9
Floyd	$7,700,000,000	1999	62	50
Earl	$150,000,000	1998	23	0
Frances	$970,000,000	1998	23	3
Bonnie	$1,440,000,000	1998	23	4
Georges	$4,100,000,000	1998	23	14
Danny	$200,000,000	1997	4	4
Josephine	$310,000,000	1996	36	1
Bertha	$610,000,000	1996	36	3
Fran	$7,260,000,000	1996	36	32
Jerry	$110,000,000	1995	29	0
Erin	$820,000,000	1995	29	3
Erin	$830,000,000	1995	29	3
Opal	$7,490,000,000	1995	29	23
Beryl	$180,000,000	1994	38	3
Gordon	$1,230,000,000	1994	38	16
Alberto	$1,290,000,000	1994	38	20
Emily	$100,000,000	1993	4	2
Andrew	$66,770,000,000	1992	26	26
Bob	$3,620,000,000	1991	16	16
Marco	$210,000,000	1990	13	13
Jerry	$210,000,000	1989	56	1
Chantal	$280,000,000	1989	56	1
Allison	$1,680,000,000	1989	56	4
Hugo	$18,320,000,000	1989	56	51
Gilbert	$200,000,000	1988	6	5
Bob	$120,000,000	1985	30	0
Danny	$160,000,000	1985	30	0
Gloria	$520,000,000	1985	30	1
Kate	$1,270,000,000	1985	30	2
Gloria	$2,490,000,000	1985	30	6
Elena	$4,340,000,000	1985	30	9
Juan	$4,560,000,000	1985	30	11
Diana	$370,000,000	1984	4	4
Alicia	$9,670,000,000	1983	22	22
Dennis	$140,000,000	1981	0	0
Allen	$2,060,000,000	1980	2	2
David	$980,000,000	1979	22	1
David	$1,570,000,000	1979	22	1
Claudette	$1,710,000,000	1979	22	3
Frederic	$12,640,000,000	1979	22	17
Amelia	$190,000,000	1978	36	36
Belle	$570,000,000	1976	9	9
Eloise	$6,230,000,000	1975	21	21
Subtrop 1 1974	$130,000,000	1974	1	0
Carmen	$1,140,000,000	1974	1	1
Delia	$300,000,000	1973	5	5
Agnes	$20,300,000,000	1972	122	122
Ginger	$190,000,000	1971	8	0
Edith	$310,000,000	1971	8	1
Fern	$480,000,000	1971	8	1
Doria	$2,400,000,000	1971	8	6
Celia	$6,850,000,000	1970	11	11

[8] Fatalities due to all hurricanes in same year.

Social Displacement

To estimate social displacement for the SNRA, U.S. hurricane event data from the international disaster database EM-DAT[9] was used to approximate the number of people forced to leave home for two days or greater. EM-DAT provides estimates of the "total number affected" by disaster events. The national-level hurricane events for which EM-DAT data on "total number affected" was available are listed in Table 3 below. (EM-DAT data was available for approximately one-third of the national-level hurricane events identified from the historic record.) The low, high, and average of the "total affected" data in Table 3 are used as the social displacement estimates for hurricanes in the SNRA.

The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to hurricanes is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA. Note that the low estimate may be biased low due to incomplete reporting of displacement and evacuations in EM-DAT.

Table 3: Social Displacement

Storm Name	Current Damage ($2011)	Category	Year	EMDAT Total Affected
Alberto	$1,290,000,000	TS	1994	20,022
Allison	$8,330,000,000	TS	2001	172,000
Andrew	$66,770,000,000	5	1992	250,055
Bob	$3,620,000,000	2	1991	1,200
Bonnie	$1,440,000,000	2	1998	17,000
Charley	$18,520,000,000	4	2004	30,000
Charley	$120,000,000	1	2004	545
Elena	$4,340,000,000	3	1985	1,000,000
Erin	$830,000,000	1	1995	6,000
Ernesto	$550,000,000	TS	2006	140
Fay	$590,000,000	TS	2008	400
Floyd	$7,700,000,000	2	1999	3,000,010
Fran	$7,260,000,000	3	1996	4,000
Frances	$12,310,000,000	2	2004	5,000,000
Georges	$4,100,000,000	2	1998	5,127
Gustav	$4,220,000,000	2	2008	2,100,000
Hugo	$18,320,000,000	4	1989	25,000
Ike	$19,600,000,000	2	2008	200,000
Isabel	$4,820,000,000	2	2003	225,000
Isidore	$480,000,000	TS	2002	13,200
Jeanne	$9,350,000,000	3	2004	40,000
Katrina	$92,050,000,000	3	2005	500,000
Opal	$7,490,000,000	3	1995	78,000
Rita	$11,330,000,000	3	2005	300,000
Wilma	$26,210,000,000	3	2005	30,000

*Note: EM-DAT estimate for TS Frances (1998) was not included because it only includes injuries, not displacement.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[10] The numerical outputs of

[9] EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium) [official citation]. EM-DAT is maintained by the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université Catholique de Louvain, Brussels, Belgium (http://www.emdat.be/frequently-asked-questions), and is supported by the Office of U.S. Foreign Disaster Assistance (OFDA) of USAID (http://transition.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/). See Criteria and Definition, http://www.emdat.be/criteria-and-definition, EMDAT Data Entry Procedures, at http://www.emdat.be/source-entry , and EMDAT Glossary, at http://www.emdat.be/glossary/ for details of criteria, thresholds, and methodology for the EM-DAT database.

[10] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: hurricanes were given a C_{EF} of 1.0.

this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

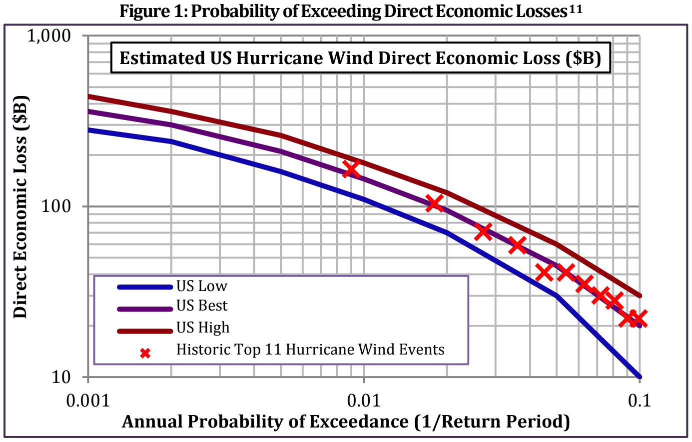
The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "moderate." Hurricanes can cause ecological impacts, beach erosion, nutrient loading, chemical contamination, salt water intrusion into fresh water bodies, and removal of plants leading to erosion. Large areas can experience impacts.

Expected Wind Damage Versus Return Period

The results reported in Tables 1 and 2 capture both wind and coastal flooding. An additional perspective into hurricane damage is the effect of wind damage alone. Figure 1 provides a loss exceedance probability for wind related hurricane damages in addition to damages from the top 11 hurricane wind events.

Figure 1: Probability of Exceeding Direct Economic Losses[11]



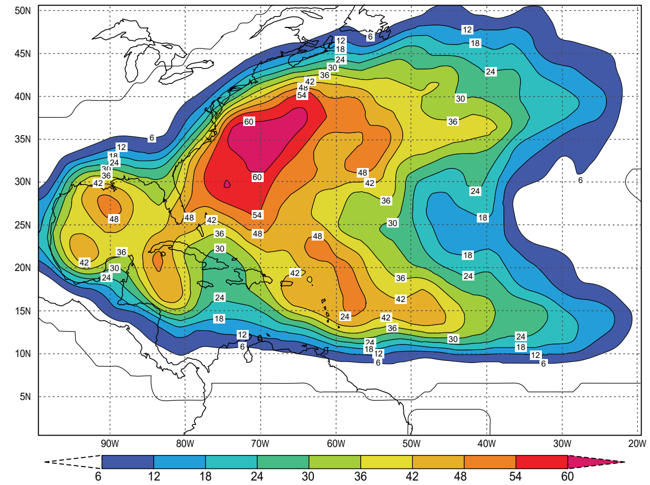
Additional Relevant Information

Figure 2 depicts the likelihood that a tropical storm or hurricane would affect the area sometime during the Atlantic hurricane season. This figure was created by the National Oceanic and Atmospheric Administration's Hurricane Research Division using data from 1944 to 1999 and counting hits when a storm or hurricane was within approximately 100 miles (165 kilometers) of each location.

As shown in Figure 2, the probability of potential impact varies across the U.S. coastline. Portions of the North Carolina Outer Banks have the same probability of occurrence (42 to 48 percent) as South Florida and southern Louisiana. Parts of the southeastern U.S. coastline as well as the Florida panhandle and portions of the Texas coastline have a lower probability of occurrence, in the 24 to 36 percent range. The northeastern U.S. coastline has the lowest probability, in the 12 to 24 percent range. The ranges provided in the "Data Summary" on Page 1 reflect the range of probability from a national perspective.

The probability of storm occurrences will vary significantly based on the return interval for different categories of magnitude. The probability of less intense storms (lower return periods) is higher than more intense storms (higher return periods).

Figure 2: Empirical Probability of a Named Hurricane or Tropical Storm

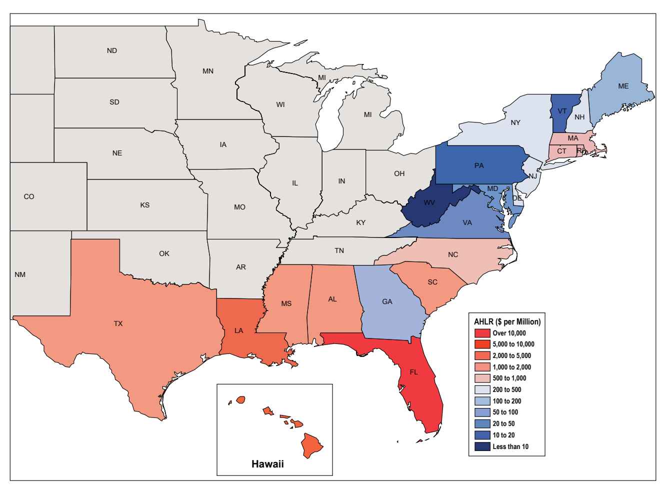


Source: National Oceanic and Atmospheric Administration[12]

In 2007, FEMA estimated average annualized losses for hurricane wind for the nation by state. The estimated average annualized loss (AAL) addresses the key idea of risk: the probability of the loss occurring in the study area (largely a function of building construction type and quality). By annualizing estimated losses, the AAL factors in historic patterns of frequent, smaller events with infrequent but larger events to provide a balanced presentation of the event risk. The AAL analysis, which only considered those 22 states and the District of Columbia that are susceptible to the hurricane wind hazard, yielded an estimate of the national AAL of $11.1 billion per year. This estimate does not include storm surge, lifeline infrastructure losses or indirect (long-term) economic losses, and is therefore a minimum estimate of the potential losses. Moreover, the estimate represents a long-term average and actual losses in any single year may be much larger or smaller. It is important to recognize that the nationwide losses are the result of averaging losses caused by hurricanes occurring in different parts of the nation in different years.

The annualized loss ratio (ALR) represents the AAL as a fraction of the replacement value of the local inventory. The ALR gauges the relationship between average AAL and replacement value. This ratio can be used as a measure of vulnerability in the areas and, because it is normalized by replacement value, it can be directly compared across different geographic units such as metropolitan areas or counties.

Figure 3: Hazus-MH Hurricane Wind Annualized Loss Ratios by State



Source: FEMA, September 2007[13]

Figure 3 shows the resulting state ALRs from this study,[14] which helps to illustrate from a national perspective those areas that are more vulnerable to potential hurricane wind impacts. Based on this data, Florida has the highest expected ALR among all states exposed to hurricane winds and therefore has the highest likelihood of experiencing losses due to hurricane

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

11 Graphical output of modeling done by HAZUS-MH contract support and provided to the SNRA project team.

12 Available through NOAA, National Weather Service, Tropical Cyclone Climatology; at http://www.prh.noaa.gov/cphc/pages/FAQ/Climatology.php (accessed 3/16/2013).

13 Estimated annualized hurricane wind losses for the United States calculated September 2007 using HAZUS-MH, and provided to the SNRA project team by FEMA.

14 FEMA 610: HAZUS-MH Estimated Annualized Hurricane Wind Losses for the United States, draft September 2007 (pre-publication draft, no corresponding publication in FEMA Library).

wind in any given year. Other high potential loss states include Louisiana, Texas, Mississippi, Alabama and South Carolina. Table 4 ranks states according to hurricane wind AAL and ALR.

Table 4: Hazus-MH Annualized Hurricane Loss (AHL) and Annualized Hurricane Loss Ratios (AHLR) Ranking

Order	State	AHL ($ K)	Order	State	AHLR ($ Million)
1	Florida	5,610,000	1	Florida	5,660
2	Texas	1,450,000	2	Louisiana	3,560
3	Louisiana	889,000	3	Hawaii	2,520
4	New York	505,000	4	Mississippi	1,600
5	Massachusetts	430,000	5	Rhode Island	1,510
6	Hawaii	335,000	6	Texas	1,170
7	Alabama	303,000	7	South Carolina	1,160
8	North Carolina	262,000	8	Alabama	1,120
9	South Carolina	247,000	9	Massachusetts	875
10	Mississippi	210,000	10	Connecticut	728
11	New Jersey	194,000	11	North Carolina	622
12	Connecticut	187,000	12	New York	357
13	Georgia	125,000	13	New Hampshire	320
14	Rhode Island	113,000	14	Delaware	310
15	Virginia	72,500	15	New Jersey	307
16	Pennsylvania	34,100	16	Georgia	262
17	Maryland	31,000	17	Maine	224
18	New Hampshire	25,000	18	Virginia	174
19	Maine	17,800	19	Maryland	91
20	Delaware	17,300	20	District of Columbia	45
21	District of Columbia	2,160	21	Vermont	43
22	Vermont	1,560	22	Pennsylvania	42
23	West Virginia	792	23	West Virginia	7

Source: FEMA, September 2007[15]

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Pielke, R. J., Gratz, J., Landsea, C., Collins, D., Saunders, M., & Musulin, R. (2008). Normalized Hurricane Damage in the United States: 1900-2005. *Natural Hazard Review* (9), pp. 29-42.

[15] Estimated Annualized Hurricane Loss (AHL) and Annualized Hurricane Loss Ratios (AHLR) calculated September 2007 using HAZUS-MH, provided to the SNRA project team by FEMA and rounded to three significant figures.

Space Weather

The Sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure.

Data Summary[1]

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	N/A		
Injuries and Illnesses	Number of Injuries or Illnesses	N/A		
Direct Economic Loss	U.S. Dollars	N/A		
Indirect Economic Loss	U.S. Dollars	$4-10 Billion	N/A	$1-2 Trillion
Social Displacement	Displaced from Homes ≥ 2 Days	N/A		
Psychological Distress	Qualitative Bins	See Discussion		
Environmental Impact	Qualitative Bins[2]	None[3]		
Frequency of Events	Number per Year	N/A	One per 100 Years	N/A

Event Background

Space weather events presumably have occurred throughout human history, but were not noticed until human technology advanced to the point of developing systems that would be affected by geomagnetic and electrical disturbances. The connection to solar phenomena was made in 1859 when a solar flare was observed, followed by disruption of telegraph communications. Direct environmental and health effects are minimal as damage occurs mainly through the medium of disruption of technology.

Technologies that can be directly affected by extreme space weather are the electric power, spacecraft, aviation, and GPS-based positioning industries. Within the last 30 years, space weather events have disrupted all of these technologies. Severe storms could result in additional consequences for numerous systems that rely on the electrical grid. As stated in a NRC workshop report, "Impacts would be felt on interdependent infrastructures, with, for example, potable water distribution affected within several hours; perishable foods and medications lost in about 12-24 hours; and immediate or eventual loss of heating/air conditioning, sewage disposal, phone service, transportation, fuel resupply, and so on."[4] The potential effects of a more severe event have been studied but are still subject to considerable uncertainty.

The potential for loss of life is thought to be low. Any deaths would be caused by the loss of electricity and the resulting cascading effects on other critical infrastructures. For example, the loss of electricity could cause mass transit and passenger rail control systems to fail, potentially causing accidents with fatalities. Water shortages may be caused by the failure of electrical pumps to convey water. Power loss at purification plants could lead to acute exposure to toxicants or disease. By extension, firefighters would not have access to water to put out fires and hospitals would not have access to water to take care of at-risk patients. In summary, circumstances beyond a geomagnetic event are necessary to lead to injury, illness, or death. [5]

Assumptions

The analysis conducted in this summary assumes a G5 level or "Extreme" geomagnetic storm on the NOAA Space Weather Scale.

Economic Impacts

The SNRA project team used the following assumptions to estimate economic consequences resulting from a space weather event:

- *Effects on Aviation*: A severe event might force the rerouting of hundreds of flights not just over the pole but also across Canada and the northern U.S. These adverse conditions could last for a week.[6] A National Weather Service (NWS) study estimated the cost of such diversions as approximately $100,000 per flight.[7] In addition, GPS-based air navigation could be disrupted. The Federal Aviation Administration's GPS-based Wide Area Augmentation System (WAAS) was disabled for 30 hours during the severe space weather events of October-November 2003.
- *Effects on Satellites*: Exposure of spacecraft to energetic particles during solar energetic particle events and radiation belt enhancements can cause temporary operational anomalies, damage critical electronics, degrade solar arrays, and blind optical systems such as imagers and star trackers.[8] In January 1994, Telesat's Anik E1 and E2 telecommunications satellites were affected by a space weather event; E2 required 6 months to repair at a cost of $50-70 million. The U.S. Department of Defense has estimated that solar disruptions to government satellites currently cost about $100 million per year.[9] A study by Odenwald and Green[10] estimated total costs due to satellite damage and loss of satellite services at $20-70 billion for a severe event.
- *Effects on GPS services*: Direct estimates of the potential cost of a loss or degradation of GPS services from a severe space weather event were not found. However, the total economic benefit of GPS services to users (i.e., not counting sales of GPS devices) has been estimated at $28-51 billion per year.[11] The percentage of such services that could be lost due to a severe space weather event is unknown.
- *Effects on Electricity Supply*: A very strong space weather event theoretically could cause widespread, lasting damage to our electric power supply system. A widely quoted study by J. Kappenman of Metatech Corp. estimates that power outages would quickly affect almost the entire U.S. east of the Mississippi River plus the Pacific Northwest. Recovery times could be long (months to years) due to the need to replace a significant percentage (approximately 20-55%) of the extremely high voltage transformers in the affected areas. In those areas, approximately 128 gigawatts of generating capacity might be offline for significant periods due to loss of these transformers.[12] At the 2008 NRC workshop on space weather impacts, Mr. Kappenman estimated potential economic losses as $1-2 trillion in the first year, with a potential total duration of 4-10 years.[13] The low estimate of $4-10 billion is the estimated cost of the August 2003 blackout in the Eastern U.S., which was smaller in extent than the estimate for a national-level space weather event and was only hours to days in duration.[14]

Social Displacement

A persistent, widespread power outage could lead to significant social effects. Significant areas might become uninhabitable, particularly in winter. Mr. Kappenman has testified to Congress that over 100 million people could be affected by power outages.[15] Widespread persistent loss of power supply could cause significant psychological impact through job loss and displacement from uninhabitable areas.

The uncertainties in the likelihood of occurrence of such a catastrophic scenario prevented inclusion of quantitative estimates of social displacement in the SNRA.

Psychological Distress

Because defensible estimates for the fatalities, injuries and illnesses, and social displacement upon which the SNRA measure of psychological distress is based could not be determined,[16] estimates for psychological

[1] Defensible quantitative estimates could not be determined for the Space Weather event. See discussion.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[3] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[4] National Research Council, Severe Space Weather Events – Understanding Societal and Economic Impacts Workshop Report, 2008, p. 77.
[5] OECD/International Futures Programme, Geomagnetic Storms, January 2011, p.25.
[6] Sten F. Odenwald and James L. Green, Bracing for a Solar Superstorm, *Scientific American*, July 2008.
[7] NOAA NWS, Intense Space Weather Storms October 19-November 07, 2003, April 2004, p. 17.
[8] National Research Council, Severe Space Weather Events – Understanding Societal and Economic Impacts Workshop Report, 2008, p. 1.
[9] Supra note 1.
[10] Supra note 1.
[11] Nam D. Pham, Ph.D., NDP Consulting, The Economic Benefits of Commercial GPS Use in the U.S. and the Costs of Potential Disruption, June 2011, accessed at http://www.saveourgps.org/pdf/GPS-Report-June-22-2011.pdf.
[12] Kappenman, John, Metatech Corp., Geomagnetic Storms and Their Impacts on the U.S. Power Grid, Jan. 2010, Chapter 4. Prepared for Oak Ridge National Laboratory.
[13] NRC, supra note 3, p. 79.
[14] Electricity Consumers Resource Council, 2004. The economic impacts of the August 2003 blackout. At http://www.elcon.org/Documents/EconomicImpactsOfAugust2003Blackout.pdf.
[15] Testimony of John Kappenman, October 30, 2003, to the Subcommittee on Environment, Technology, and Standards, Committee on Science, U.S. House of Representatives (108th Congress). Hearing title: What is space weather and who should forecast it? GPO Serial No. 108-31, DOCID: f:90161.wais.
[16] Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input. The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

distress are not reported for the space weather event in this iteration of the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as “de minimus” or none. Experts indicated environmental/ecological effects would likely depend on duration of outages. For one day to a few days, the damage would be relatively minimal/de minimus (this is in the scope of typical power outages due to snowstorms, rain, and other natural disasters). If the outage persisted for weeks, then there is the potential for backup systems to fail. If backup systems (such as diesel fuel delivery) failed, then the lack of power to treatment plants and chemical plants could have a massive impact. A space weather event would most likely affect a large geographic area in addition to having the potential for a longer duration.

Potential Mitigating Factors

The consequences of a geomagnetic storm depend largely on the severity of the storm, geographic latitude, ground conductivity, capacity of electrical power transmission networks and length and direction of extra high voltage (EHV) lines contained in these networks. In general, northern latitudes with igneous rock and other high-conductivity ground materials are more vulnerable to the effects of geomagnetic storms. Further, high-capacity electrical transmission systems act as antennae for geomagnetic storms, exacerbating potential consequences. Extra high voltage (EHV) lines that travel east to west over long distances are of particular concern.

Additional Relevant Information

The NOAA Space Weather Prediction Center provides the following estimates for frequency of geomagnetic storms during an average 11–year solar cycle:

GME Event	Average Frequency of Events (Number of Days per Cycle) when Physical Measure (Kp value) was met
G-5 Extreme (Kp=9)	4 Events per Cycle (4 Days per Cycle)
G-4 Severe (Kp=8)	100 Events per Cycle (60 Days per Cycle)
G-3 Strong (Kp=7)	200 Events per Cycle (130 Days per Cycle)
G-2 Moderate (Kp=6)	600 Events per Cycle (360 Days per Cycle)
G-1 Minor (Kp=5)	1700 Events per Cycle (900 Days per Cycle)

The Metatech study estimated that a geomagnetic storm of approximately -5,000 nanoTeslas (nT)/min. intensity, may be expected approximately once every 100 years.[17] For comparison, the 1859 “Carrington Event” was measured at -1760 nT/min, which is three times as intense as the geomagnetic storm responsible for the Quebec power outage in 1989 (-640 nT/min).[18]

The Significant Distress Index is calculated using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + ½\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Space Weather was given a C_{EF} of 1.0.

[17] Kappenman, supra note 7, p. 3-13.

[18] OECD/International Futures Programme, Geomagnetic Storms, January 2011, p.9.

Tsunami

A large tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the United States.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	1	300	1000
Injuries and Illnesses	Number of Injuries or Illnesses	1	300	1000
Direct Economic Loss[1]	U.S. Dollars	$705 Million	$1.53 Billion	$3.32 Billion
Social Displacement	Displaced from Homes for ≥ 2 Days	8,600	14,700	N/A[2]
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	Moderate[4]		
Frequency of Events	Number per Year	0.26%[5]	0.57%[6]	0.92%[7]

Event Background

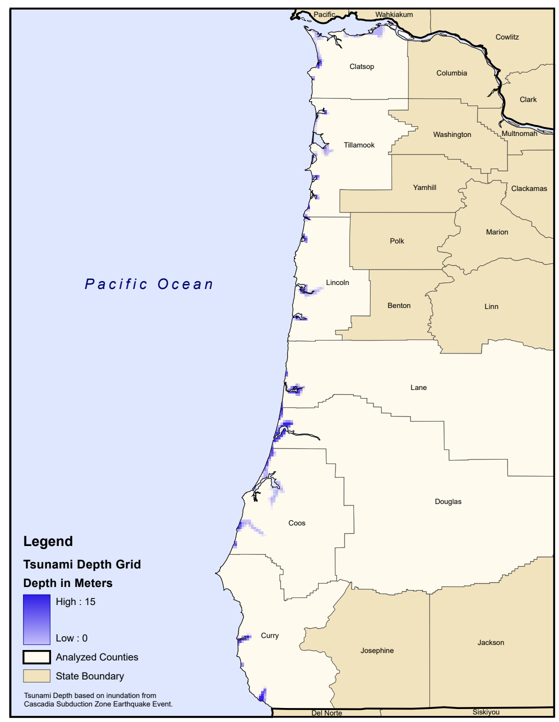
A tsunami event could present a significant risk to the west coast of the United States. The Pacific Northwest is an area of increased risk due to the Cascadian Subduction Zone, which is where the Juan de Fuca Plate meets and is forced under the North American Plate.[8] These subduction zones are associated with volcanism, earthquakes, and orogenic uplift, commonly referred to as mountain building. Earthquakes produced in these areas have the potential to be incredibly powerful, with nine of the ten largest quakes over the last 100 years occurring in these areas, including the 2004 Indian Ocean earthquake and the 2011 Tohoku, Japan, earthquake, both of which caused massive tsunamis. This is the same risk posed to the Pacific Northwest as a result of the Cascadian Subduction Zone.

A report for Seaside, Oregon, involved running more than 25 models including both near field (local) and far field (distant) generated tsunamis with estimated return periods.[9] A modeled 100-year tsunami event showed similar impacts to the 1964 Alaska earthquake, which represented a distant event. The local event looked at Cascadian-type events, which tended to follow a 500-year return period event, although the historical evidence shows that these are rarer than every 500 years. The models generated from this project showed tsunami depths ranging from 22 to 38 meters (72 to 124 feet), although the highest of these depths occurred at the shoreline, with the depths of the land areas seeing highs around 14 to 16 meters (45 to 52 feet). A study was performed to develop a method for Probabilistic Tsunami Hazard Analysis based on traditional Probabilistic Seismic Hazard Analysis.[10] While the study did not focus on the Pacific Northwest, this area was included in the discussion, and the findings showed a maximum expected height from a 975-year return period event would be in the range of 10 to 15 meters.

The Seaside area of the Oregon Coast was chosen to model the risk of such an event because it is typical of many coastal communities in the section of the Pacific Coast from Cape Mendocino to the Strait of Juan de Fuca, and because State agencies and local stakeholders expressed considerable interest in mapping the tsunami threat to this area.[11] Looking at possible events with catastrophic consequences, the Cascadian Subduction Zone is one that has a likelihood of occurring and would result in major damages. Oregon has detailed modeling and analysis of tsunamis that would be generated by an earthquake along this zone, including an inundation boundary that extends the entire length of the coastline.

To perform this scenario analysis, ground digital elevation models (DEM) were used for the entire study area as well as the mapped tsunami inundation line from the State of Oregon GIS Clearinghouse.[12,13] The inundation line was converted to a 3D feature with the DEM as the elevation source. This line was copied and placed parallel to the west, offset by approximately 1,000 meters. This outer line was generalized to remove the inlets and river areas that were represented in the original inundation line feature. The lines were used to create a tin that represented a constant ground surface from the actual inundation line, extending west beyond the coast. This tin was converted into a grid, which allowed for a raster calculation to be performed where the ground surface DEM was subtracted from the inundation grid. The output from the calculation produced the depth grid. Potential losses in the seven coastal counties in Oregon were estimated using HAZUS-MH to model the scenario defined by these modeling inputs.[14] Figure 1 shows the scenario area and the inundation zones.

Figure 1. Tsunami Scenario Location Map[15]



Assumptions

Based on previously conducted research, it is reasonable to assume that modeling a tsunami with the maximum height of 15 meters (approximately 50 feet) is appropriate for analyzing a potential Cascadian event generated tsunami along the Oregon Coast.[16,17] Additionally, the depth damage

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[1] The economic damage numbers reported here include property damage and business interruption costs. The SNRA measure of direct economic damage additionally includes medical costs, and one year's lost demand due to fatalities ($42,500 per fatality): the SNRA project team made the assumption that these contributions would be negligible in comparison to the property damage and business interruption costs, in particular the property damage estimates calculated by HAZUS.

[2] Since variations of scenario parameters in HAZUS did not produce social displacement estimates substantially higher than the best estimate of 14,700, the SNRA does not report a separate high estimate.

[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[4] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.

[5] One-year frequency corresponding to 12% probability within the next 50 years of a 9.0 magnitude earthquake causing a tsunami inundating coastal communities across the U.S. Pacific Northwest and Northern California. 12% was taken as the midpoint of the 10-15% range estimate cited by geologists (see Additional Relevant Information).

[6] One-year frequency corresponding to a 25% probability of a tsunami within 50 years. The SNRA project team averaged the low and high probability estimates reported in the literature to obtain this best estimate.

[7] One-year frequency corresponding to a 37% probability within the next 50 years of an 8.2 magnitude earthquake causing a tsunami impacting a portion of the U.S. Pacific Northwest and/or Northern California (see Additional Relevant Information).

[8] Local Tsunami Hazards in the Pacific Northwest from Cascadia Subduction Zone Earthquakes, http://pubs.usgs.gov/pp/pp1661b/pp1661b.pdf.

[9] Wong, F.L., Venturato, A.J., and Geist, E.L., 2006, Seaside, Oregon, tsunami pilot study—Modernization of FEMA flood hazard maps: GIS Data: USGS Data Series 236: http://pubs.usgs.gov/ds/2006/236/.

[10] Thio, H. K., Ichinose, G. A.; Somerville, P. G.; Polet, J, 2006. Probabilistic Tsunami Hazard Analysis. Presentation, American Geophysical Union Fall Meeting, December 2006; abstract at http://adsabs.harvard.edu/abs/2006AGUFM.S31C..08T. See also Thio et al 2007, Probabilistic tsunami hazard analysis for ports and harbors, Proceedings of the American Society of Civil Engineers, Ports 2007, pp 1-10, abstract http://ascelibrary.org/doi/abs/10.1061/40834%28238%29103; and Thio, H. K., Probabilistic Tsunami Hazard Analysis, presentation, National Tsunami Hazard Mitigation Program 2012 Tsunami Hazard/Risk Analysis Workshop, July 2012, full deck http://nthmp.tsunami.gov/2012tsuhazworkshop/presentations/Thio_presentation.pdf (accessed March 2013).

[11] Wong, *op cit*.

[12] Oregon GIS Data Clearinghouse, http://spatialdata.oregonexplorer.info/GPT9/catalog/main/home.page.

[13] The inundation line matched well with the near field event boundary from the USGS project, and it was determined that this was an acceptable line upon which to base scenario depths.

[14] HAZUS-MH: multihazard loss estimation software. Federal Emergency Management Agency (FEMA), U.S. Department of Homeland Security (1997-2011): http://www.fema.gov/hazus. See FEMA 433 (2004, August), Using HAZUS-MH for Risk Assessment, http://www.fema.gov/pdf/plan/prevent/hazus/fema433.pdf .

[15] Source: GIS Analysis using Hazus-MH and Oregon GIS Data Clearinghouse data. See Discussion.

[16] Thio et al 2006, *op cit*.

functions were adjusted to reflect the velocity losses associated with the tsunami phenomenon. The damage function used assumes a linearly increasing damage from 0 to 100 percent for flood depth, with wave action ranging from 0 feet to 4 feet and 100 percent damage at 4 feet and beyond.

Fatalities and Injuries

The HAZUS-MH flood model used to model the Tsunami scenario does not provide direct estimates of fatalities and injuries. The SNRA project team used the following assumptions to estimate health and safety consequences caused by a tsunami event:

- In terms of fatalities, minimal impact is assumed except:
  - In areas that do not receive the warning in time (may include possible malfunction of warning equipment)
  - In communities not trained in evacuation
  - In flat areas where no evacuation routes exist
  - For persons who do not obey orders or who happen to be in vulnerable areas with no warning systems
- Based on these exceptions, it is reasonable to assume the possible range of fatalities to be between 1 and 1,000 and injuries to be between 1 and 1,000. The timing of a tsunami (impact during day versus night) could potentially impact the ability of the population to receive warnings; therefore, a tsunami at 2 a.m. when people are sleeping could potentially cause more deaths and injuries than a daytime tsunami.
- The population information used for estimating the health and safety consequences is 2000 U.S. Census data.
- Given the effort Oregon has put into training, warning systems, evacuation route planning, as well as other mitigation techniques, professional engineering judgment based on experience suggests that it would be reasonable to expect that approximately 1% of the exposed population would be injured or killed as a result of this event. The result was then split evenly with 50% counted as injured and 50% counted as being killed by the event.
- If a similar scenario were to occur along other areas of the U.S. coastline, higher casualty rates may be more likely because the West Coast (as well as Alaska and Hawaii) is better prepared for tsunami impacts than the East Coast and Gulf Coast (in terms of evacuation plans, drills, and warning systems), and the exceptions listed above would be more likely to be the case in non-West Coast areas.

Economic Loss

The SNRA project team used the following assumptions to estimate economic consequences caused by a tsunami event:

- More than 1,700 buildings were estimated as being destroyed in the modeled event. Building losses would likely exceed $1.5 billion. The event would also cause business disruption, which is estimated to be nearly $13 million. The area incurring the most severe consequences would be Clatsup County, accounting for nearly half of the destroyed buildings and economic losses which would occur.
- If a similar scenario were to occur along other areas of the U.S. coastline, higher economic losses may be expected resulting from the proximity of more development to the coast, lack of warning, and panic.

Social Displacement

The SNRA project team used the following assumptions to estimate social consequences caused by a tsunami event:

- Displacement estimates assume those affected would require accommodations in temporary public shelters. The results estimate that approximately 14,737 persons would seek temporary refuge in public shelters, which was used as the best estimate.
- Range estimates for social displacement were calculated by running the same scenario using inundation level as a variation parameter, decreasing the inundation by 2 feet to estimate the lower bound and increasing the inundation by 2 feet to estimate the higher bound. The lower bound of 8,600 was used as the low estimate.
- Since increasing inundation level did not substantially vary the displacement numbers, the SNRA does not report a high estimate for the tsunami event.[18]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. To reflect empirical findings that the scope and severity of an event is more important than the type of event, the SNRA psychological distress metric is constructed from the fatalities, injuries, and displacement associated with an event as primary inputs, weighted by a secondary factor elicited from subject matter experts for differing psychological impact based on the type of event.[19]

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Moderate." Experts indicated that this is the best estimate, but that consequences could be higher or lower depending on the precise location, barrier channels, and ecosystem impacts.

Potential Mitigating Factors

The consequences caused by a tsunami can be mitigated through several preparedness strategies. Warning and monitoring systems can assist in alerting population areas that may be impacted by a tsunami. Periodically testing these systems will ensure that they are functioning when a tsunami event occurs. Identifying evacuation routes and training communities in how to use them during an event will improve the ability for the population to egress vulnerable areas. Finally, the importance of evacuating during a potential event should be communicated to individuals living or working in vulnerable areas.

Additional Relevant Information

In 1700, a major earthquake occurred along this zone, rupturing a 620-mile section of the fault line. The estimated magnitude was between 8.7 and 9.2 and caused a tsunami that impacted the Oregon coastline and was recorded in Japan. More recently, geologists have studied this fault and concluded there is a 37 percent chance of an 8.2 or larger event in the next 50 years and a 10 to 15 percent chance for a rupture along the entire fault from a 9.0 or larger event.[20,21,22] A tsunami generated from this magnitude event could reach heights of 20 to 30 meters (65 to 100 feet) along the Pacific Northwest coast and have catastrophic results.[23] All oceanic regions of the world can experience tsunamis, but in the Pacific Ocean there is a much more frequent occurrence of large, destructive tsunamis because of the many large earthquakes along the margins of the Pacific Ocean.

It is reasonable to expect that a tsunami impacting the U.S. could potentially experience similar consequences to this scenario, regardless of coastal location. The range of potential loss could be broad depending upon many factors including but not limited to the population density of low-lying coastal areas, presence of agricultural assets such as crops and livestock, and location of nearby drinking water supplies. Long-term impacts could also be experienced and would depend on the level of contamination caused in the area.

[17] Wong, op cit.

[18] Because the inundation boundary line would not likely extend further due to topography as well as other contributing factors, the number or displaced persons is not expected to change from the original scenario calculation even when inundation was assumed to increase by two feet of water.

[19] A Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2}D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics. The familiarity factor, intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences, was assessed as 1.0 for Tsunami on a scale of 1.0 for familiar events to 1.3 for unfamiliar events.
The specificity of the tsunami event to a single geographic scenario precluded comparative judgments of risk on the psychological or other consequence metrics with other events. This limitation will be addressed in a future iteration of the SNRA.

[20] Odds are 1-in-3 that a huge quake will hit Northwest in next 50 years. Oregon State University press release, 24 May 2010, announcing preliminary results later published as reference [22]; at http://oregonstate.edu/ua/ncs/node/13426 (accessed 3/17/2013).

[21] Risk of giant quake off American west coast goes up. *Nature News*, 31 May 2010, citing results later published as reference [22]; at www.nature.com/news/2010/100531/full/news.2010.270.html.

[22] Goldfinger et al, 2012. Turbidite event history – Methods and implications for Holocene paleoseismicity of the Cascadia Subduction Zone. USGS p 1661-F, 7/17/2012: http://pubs.usgs.gov/pp/pp1661f/ (accessed 3/17/13).

[23] Recent findings concluded the Cascadia subduction zone was more hazardous than previously suggested. The feared next major earthquake has some geologists predicting a 10% to 14% probability that the Cascadia Subduction Zone will produce an event of magnitude 9 or higher in the next 50 years; however, the most recent studies suggest that this risk could be as high as 37% for earthquakes of magnitude 8 or higher. Geologists have also determined the Pacific Northwest is not prepared for such a colossal earthquake. The tsunami produced may reach heights of approximately 30 meters (100 ft).

Volcanic Eruption

A large volcano in the Pacific Northwest erupts, impacting the surrounding areas with lava flows and ash, and areas east with smoke and ash.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	340[1]	515[2]	780[3]
Injuries and Illnesses	Number of Injuries or Illnesses	2,000	17,000	150,000
Direct Economic Loss[4]	U.S. Dollars	$4.3 Billion[5]	$8.3 Billion[6]	$16.2 Billion[7]
Social Displacement	Number of Displaced from Homes for ≥ 2 Days	1,300	130,000	2.1 Million
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[8]	High[9]		
Frequency of Events	Number per Unit of Time	1/1000 yrs	1/500 yrs	1/100 yrs

Event Background

This volcanic hazard scenario focuses on community exposure to lahar (large, swift, and saturated debris flows produced by volcanoes) hazards and ashfall associated with Mount Rainier, Washington. Mount Rainier lahar flow affects four counties in the state of Washington: King County, Lewis County, Pierce County, and Thurston County. A majority of the hazard areas are located in Pierce County. Mount Rainier is part of the Cascade Volcano range aligned in a north-south direction that roughly parallels the Pacific Ocean. Mount Rainier is the second highest peak in the conterminous U.S. at 14,410 feet (4,393 meters) and the largest single-peak glacial system in the U.S. Due to the proximity of over 1.5 million people living within the shadow of Mount Rainier, it is considered the most dangerous volcano in the Cascade Range.[10] The most populous city near Mount Rainier is Tacoma. Tacoma is approximately less than one mile from the lahar hazard area boundary.

The lahar hazard areas and debris flow paths used in this scenario are based on the behavior of the Electron Mudflow, a lahar that traveled along the Puyallup River approximately 500 years ago and was due to a slope failure on the west flank of Mount Rainier (Figure 1).[11]

The SNRA project team leveraged data from a 2009 study calculating community vulnerability to possible lahar hazards originating at Mount Rainier.[12]

[1] The 'Low' estimation was calculated by overlaying the Case I Debris Flow GIS boundary on 2000 U.S. Census designated census blocks to determine the affected population. 2010 U.S. Census data was not available during the time of analysis (July 2011).
[2] The 'Best' estimation is the geometric mean of 'Low' and 'High' possible fatalities.
[3] Community Exposure to Lahar Hazards from Mount Rainier, Washington; Nathan J. Wood and Christopher E. Soulard, USGS Scientific Investigations Report 2009-5211, September 16, 2009.
[4] The economic damage numbers reported here includes property damage and business interruption costs, but not lost demand due to fatalities and medical costs due to injuries. The SNRA project team determined that the property damage and business interruption costs dominated the direct economic damages of the scenario used for the volcanic eruption event to the extent that the multipliers for the other two components would have a negligible effect on the reported totals.
[5] The 'Low' estimation was calculated by overlaying the Case I Debris Flow GIS boundary was overlaid on 2000 U.S. Census designated census blocks to determine the affected population. 2010 U.S. Census data was not available during the time of analysis (July 2011).
[6] The 'Best' estimation is the geometric mean of 'low' and 'high' possible economic consequences.
[7] The 'High' estimate for economic consequences was calculated using previously collected data that was developed by overlaying and calculating the union of lahar-hazard zone, community boundaries, and block-level population counts compiled for the 2000 U.S. Census (2010 U.S. Census data was not available during the time of analysis). The economic loss amounts used are based on the total loss of annual sales generated by 3,890 businesses within lahar hazard areas.
[8] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[9] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[10] Mount Rainier National Park: Geologic Resource Evaluation Report; U.S. Department of the Interior, National Park Service; Natural Resource Report NPS/NRPC/GRD/NRR—2005/007, September 2005.
[11] Community Exposure to Lahar Hazards from Mount Rainier, Washington; Nathan J. Wood and Christopher E. Soulard, USGS Scientific Investigations Report 2009-5211, September 16, 2009.
[12] All lahar hazard zone area boundaries used in calculations for this scenario are from the USGS 2009 study.

Ash normally accompanies an eruption of a volcano and is composed of fine particles of fragmented volcanic rock (less than 2 mm diameter).[13] Ashfall is the accumulation of volcanic ash and a typical result of volcanic activity. Ashfall radius is dependent on wind direction, wind strength, and size of ash particles. The negative effects are dependent on the amount of ash accumulation. Ashfall with a thickness of 1/3 inch may cause disruption of ground and air transportation and cause damage to electronics and machinery, while four inches of ash could be sufficient to collapse building roofs. Ash can possibly produce acid rain when mixed with precipitation creating a form of diluted sulfuric acid.[14]

Figure 1 – Reference Map[15]

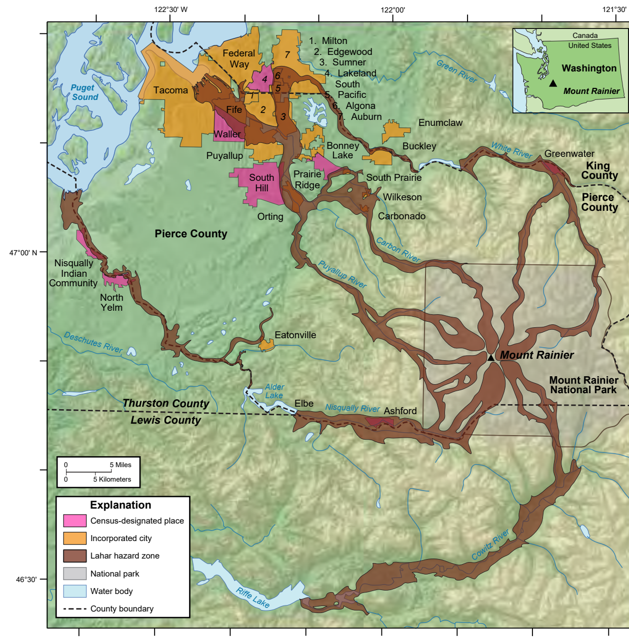


Figure 1. Map showing counties, incorporated cities, and census-designated places within a lahar-hazard zone on and near Mount Rainier, Washington (Hoblitt and others, 1998; Schilling and others, 2008).

Volcanoes commonly repeat past behaviors, therefore historic ashfall and gas patterns were evaluated for Mount Rainier.[16] For this scenario, historic ashfall and gas patterns from Mount St. Helens were used. These patterns caused ash and gas to rise more than 15 miles vertically in 15 minutes. Clouds of ash can extend thousands of miles.[17] Mount St. Helens' heaviest ash deposition occurred in a 60 mile long swath immediately downwind of the volcano and thick ash deposits extended about 195 miles. During the 9 hours of vigorous eruptive activity, about 540 million tons of ash fell over an area of more than 22,000 square miles.[18] If similar ashfall were to occur as a result of Mount Rainier volcanic activity, the ash would reach westerly to Fort Lewis and easterly past the Snoqualmie National Forest.

Some possible negative consequences of ash include, but are not limited to:[19]

- Respiratory effects such as nasal irritation, throat irritation, and airway irritation
- Eye symptoms such as eye irritation, abrasions, discharge, or acute conjunctivitis
- Skin irritation
- Indirect health effects such as reduction of visibility on roadways, increased demand on power leading to electricity loss, and effects on water supply creating possible contamination
- Disruption of ground and air transportation
- Major air routes pass downwind of the Cascade Volcanoes resulting in possible disturbance to flights and flight patterns
- Damage to electronics and machinery possibly affecting economic dynamics
- Crop damage causing agricultural loss

[13] Pierce County Hazard Identification and Risk Assessment: Volcanic; Pierce County Department of Emergency Management; 2010.
[14] The Health Hazards of Volcanic Ash: Guide for the Public. International Volcanic Health Hazard Network (IVHHN), 2003-2011; at http://www.ivhhn.org/index.php?option=com_content&view=article&id=55&Itemid=61 (accessed March 2013).
[15] Ibid.
[16] Hazard Identification and Vulnerability Analysis (HIVA) of Walla Walla, Washington – Volcanic Ash Fall; Walla Walla County Emergency Management Department, October 2003.
[17] Volcanic Ash Fall – A "Hard Rain" of Abrasive Particles: USGS Fact Sheet 027-00; USGS, 2000.
[18] Eruptions of Mount St. Helens: Past, Present, and Future, U.S. Geological Survey Special Interest Publication: Ash Eruption and Fallout; Cascades Volcano Observatory (Robert I. Tilling, Lyn Topinka, and Donald A. Swanson); 1990.
[19] The Health Hazards of Volcanic Ash: Guide for the Public.

- Interruption of telephone, cell, and radio communications

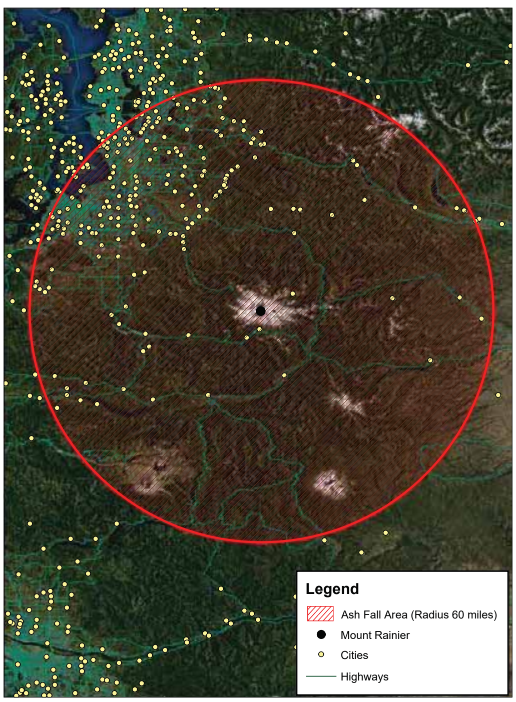
Assumptions

Fatalities and Injuries

The SNRA project team used the following assumptions to estimate health and safety consequences resulting from a volcano event:

- The total population within lahar hazard areas was calculated using a GIS shapefile representing Inundation Zones for Case I Debris Flows.[20] Inundation Zones for Case I Debris Flows are areas that could be affected by cohesive debris flow that originates as enormous avalanches of weak chemically altered rock from the volcano. The Case I Debris Flow GIS boundary shapefile was used in this scenario because the layer covers a larger potentially hazardous area, and therefore includes all possibly vulnerable populations.
- One percent of the total population in lahar hazard areas was used as the amount of possible deaths in the health and safety consequences calculations because the total population is not at risk during Case I Debris Flow activity due to national, regional, state, and local monitoring systems, evaluation routes, and mitigation measures.[21] Further, one percent of the population was used to calculate possible deaths as a result of volcanic activity based on previous data from the 1980 Mount St. Helens eruption. 57 deaths occurred as a result of volcanic activity.[22] The Skamania County 1980 population was 8,289; therefore, 0.6% of the County's population was lost due to volcanic activity. This percentage was increased to 1% for this scenario in the event that a greater percentage of the population was at risk during eruption.
- The methodology used consists of overlaying and calculating the union of lahar-hazard zone, community boundaries, and block-level population counts compiled for the 2000 U.S. Census.[23]
- Possible tourist populations were not considered in any calculations.

Figure 2 – Ashfall Radius



- To calculate injuries and illness amounts, a possible ashfall area with a radius of 60 miles from Mount Rainier (46.852947, -121.760424) was created and is depicted in Figure 2.[24]
- The radius buffer was overlaid on 2000 U.S. Census block data to determine the total population in the ashfall area. The ashfall area was distributed over an eight-county area: Cowlitz County, King County, Kittas County, Lewis County, Pierce County, Skamania County, Thurston County, and Yakima County. The population of the ashfall area was estimated to be approximately 1.5 million. For the 'High' estimate of injuries/illnesses, ten percent of the total population was determined to be vulnerable to injury or illness as a result of ashfall.[25]
- Wind direction and speed were not taken into account during this analysis.
- Existing data did not include specific amounts for injuries and illness due to ashfall: therefore calculations for this scenario were performed using GIS technology.
- Ten percent of the population was used to calculate possible injury or illness as a result of volcanic activity based on previous data from the 1980 Mount St. Helens eruption. For this scenario it was estimated that 250 homes were damaged as a result of volcanic activity based on USGS calculations (USGS reports that more than 200 homes were destroyed).[26] The average household is comprised of an estimated 2.6 persons based on the U.S. Census. This resulted in an estimate that 650 people would be directly affected by the volcanic activity, or 7.3% of the county population. This percentage was increased to 10% for this scenario to include possible persons on transportation routes, working in the surrounding National Park, etc. Due to data limitations, only one radius layer was developed to calculate the "Best" estimation.
- For the 'Low' estimate of injuries/illnesses, the population in the State of Washington U.S. Census tracts immediately surrounding Mt. Rainier was used. Approximately 20,000 people live in the following Census tracts: Census Tract 30.01, Yakima County; Census Tract 701, Pierce County; Census Tract 9720, Lewis County; Census Tract 5238, Kittitas County; and Census Tract 315.02, King County. Ten percent of this population was determined to be vulnerable to injury or illness as a result of ashfall, as discussed above.[27]
- The 'Best' estimate of injuries/illnesses was calculated as the geometric mean of the 'Low' and High' estimates.

Economic Loss

The SNRA project team used the following assumptions to estimate the economic consequences resulting from a volcano event:

- The General Building Stock Dollar Exposure (Replacement Amount) designated by occupancy in census blocks was used to calculate the total dollar exposure of the combined amounts for commercial, industrial, agricultural, religion, government, and educational industries.
- Major transportation routes would be affected by possible volcanic activity. Interstate 5 and State Routes 161 and 167 are within Case I Debris Flow hazard areas, along with 195 major roadway segments. The obstruction of major roadways may have a negative impact on the economy due to supply and delivery delays, restrictions, and cancelations.
- A disruption in port activities resulting from volcanic activity could hinder job security and revenue, thus resulting in an economic loss for the state of Washington. More than 43,000 jobs in Pierce County and more than 113,000 jobs in Washington State are related to the Port activities. Port-related jobs generate $637 million in annual wages in Pierce County and more than $90 million annually in state and local taxes in Washington.[28] The Port of Tacoma is approximately 1 mile from the Case 1 Debris Flow hazard areas and vulnerable to possible volcanic activity.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- The number of homes destroyed in the output ranges of the HAZUS model gave low, best, and high estimates of numbers of persons displaced of 1,300, 130,000, and 2.1 million respectively.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[29] The numerical outputs of

[20] Digital Data for Volcano Hazards from Mount Rainier, Washington Revised 1998: Data to accompany U.S. Geological Survey Open-File Report 98-428; USGS; 2007.
[21] Danger Lurks Deep: The Human Impact of Volcanoes; Joanne Feldman and Robert I. Tilling, Division of Emergency Medicine at the Stanford University School of Medicine in Palo Alto, Calif., GeoTime November 2007.
[22] USGS Cascades Volcano Observatory, Vancouver, Washington Mount St. Helens, Washington "On This Day in 1980" October 6, 1980 http://vulcan.wr.usgs.gov/Volcanoes/MSH/May18/OnThisDay1980/Days/1980October06.html.
[23] "Community Exposure to Lahar Hazards from Mount Rainier, Washington" by Wood and Soulard.
[24] A 60 mile radius was selected based on data from the actual Mt. St. Helens ashfall extents.
[25] Volcanic hazards: a sourcebook on the effects of eruptions: Academic Press; Blong, R.J., 1984, Australia, p. 424.
[26] USGS Cascades Volcano Observatory, Vancouver, Washington Mount St. Helens, Washington.
[27] U.S. Census data obtained from http://factfinder2.census.gov. Accessed on September 18, 2001.
[28] The Economic Impact of the Port of Tacoma; Port of Tacoma as prepared by Martin Associates; May 24, 2005.
[29] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the

this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., as chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "High." A volcanic eruption can cause disruption of aquatic life, eco-systems, etc. over a potentially large area. In addition, there are potential long-term climate change effects if airborne plume is extreme.

Potential Mitigating Factors

The consequences of a volcanic eruption will depend on the severity of the eruption, the sophistication of the monitoring and warning systems, and the level of preparedness (familiarity with evacuation routes, mitigation measures implemented, etc.) of the surrounding population areas that can be potentially affected by fallout from the eruption.

Additional Relevant Information

The average time interval between eruptions of Mount Rainier is estimated at 100 to 1,000 years.[30] For all consequence calculations, the Inundation Zone for Case I Debris Flows used has a frequency of one event per 500 to 1,000 years.[31] These frequencies are based on the last 5,600 years. The annual probability of such a flow originating somewhere on Mount Rainier is thus about 0.1 to 0.2 percent. The debris flow reached the Puget Sound lowland about 600 years ago along the Puyallup River and is considered to be a characteristic Case I flow for purposes of identifying probable inundation areas.[32] The accounts of the most recent Mount Rainier volcanic event range from 1820 to 1870. According to the USGS, there is no immediate indication of renewed activity at Mount Rainier; however, due to the large population surrounding Mount Rainier hazard mitigation actions should be explored.

number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Volcanic Eruption was given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[30] Volcano Hazards from Mount Rainier, Washington, Revised 1998: Open File 98-428; USGS; 1998.

[31] Ibid.

[32] Volcano Hazards from Mount Rainier, Washington, Revised 1998: Open File 98-428; USGS; 1998.

Wildfire

A wildfire occurs within the U.S. resulting in direct economic losses greater than $100 Million.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	0	5	25
Injuries and Illnesses	Number of Injuries or Illnesses	0	63	187
Direct Economic Loss	U.S. Dollars	$104 Million	$900 Million	$2.8 Billion
Social Displacement	Displaced from Homes ≥ 2 Days	770	110,000	640,000
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[1]	High[2]		
Frequency of Events	Number per Year	0.2	0.8	3

Event Background

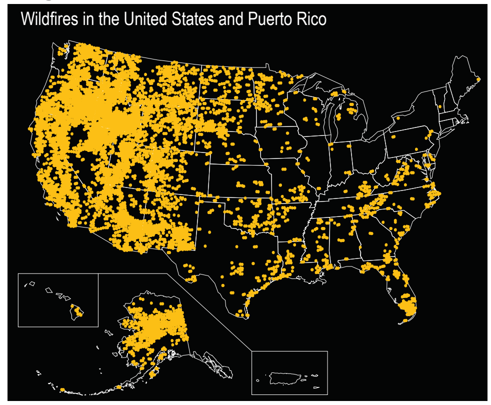
Since 1970, wildfires have destroyed more than 10,000 homes and 20,000 other structures across the nation. Fire suppression has cost government agencies in excess of $20 billion and the insurance industry $6 billion in restitution.[3] Severe wildfire events have the potential to create great economic losses—from hundreds of millions of dollars to the three California wildfires in 1991, 1993, and 2003, each of which caused damages greater than $2 billion.[4]

Wildfires are a frequent event in the United States: some 1,570,000 wildfires were reported for the 20 year period 1990-2009, consuming a total of 94,000,000 acres[5] and 110 human lives.[6] Only a small proportion of these are large enough to overwhelm local fire-fighting capabilities.[7] Although the vast majority of large wildfires occur in sparsely populated regions of the United States—a disproportionate share of the very largest wildfires by acres burned occur in Alaska[8]—it is at the "wildland/urban interface," where the wilderness meets new urban and suburban areas of high population densities, that the wildfires of greatest destructiveness in terms of human life and economic damage occur.[9] Overall, although wildfire frequency has decreased in the last 200 years, the severity of wildfires has increased, and the overall risk to life and property of wildfires in the U.S. is increasing.[10] In particular, the frequency and economic costs of the very largest wildfires considered here show a sharp increase around 1990.[11]

For even the most catastrophic wildfires in the United States, the numbers of dead and injured tend to be relatively small. No wildfire causing human deaths on a catastrophic scale in the United States has occurred since 1918, when a brush fire engulfed 38 towns across Minnesota, killing 450 people.[12] Since then, the largest death tolls have not numbered more than 30 from a single incident—for the majority of massive wildfires in recent decades, potentially affected populations receive sufficient advanced warning that no human deaths occur.

The health risk of wildfires is largely dependent on the population in the impacted area as well as the speed and intensity with which the fire moves through those areas.[13] Wildfires can increase eye and respiratory illnesses related to fire-induced air pollution. Wildfires can also result in direct and indirect deaths caused by direct contact with the wildfire or wildfire product (e.g., smoke or superheated air) or from indirect contact with a wildfire product (e.g., smoke that caused poor visibility resulting in a car crash).[14]

Figure 1. Wildfires Greater than 250 Acres, 1980-2003[15]



Assumptions

The estimates provided above are based on historical examples of major wildfires in the United States. The dataset that was considered comprises all wildfires with reported total economic damage of $100 million or greater (in 2011 dollars) which occurred from 1990 to 2009.[16]

Fatalities and Injuries

The SNRA project team used the following assumptions to estimate health and safety consequences caused by a wildfire event:

- In order to produce the summary figures in the "Data Summary," all "Low," "Best," and "High," estimates for human deaths and injuries are calculated from the dataset of catastrophic wildfires selected according to the economic cutoff of $100M minimum (see Table 1). The set chosen by this economic measure captured the range of the scenarios most catastrophic in numbers of dead and injured for all historical wildfires in the United States since 1990. To compute "Low", "Best", and "High" estimates for fatalities and injuries the historical low, average, and high values of the 1990-2009 dataset were used.
- The best-estimate frequency is the average frequency of occurrence of this set of wildfires in the selected twenty-year period. The low frequency is the inverse of the longest time interval between wildfires in this set (in days, measured from fire begin day); the high frequency is the greatest number of fires which occurred in one year (four, in 2006).

Economic Loss

The SNRA project team used the following assumptions to estimate economic consequences caused by a wildfire event:

- Since total monetary losses appeared more representative of the geographic spread of wildfires and the relative difficulty of fighting them than the number of dead and injured, the former were used to select a set of national-level events having the capability to overwhelm local emergency response efforts.
- All "Low," "Best," and "High," estimates are calculated from historical data of property damage and crop damage, comprising all U.S. wildfires between 1990 and 2009 meeting a cutoff of $100 million dollars total cost adjusted to 2011 dollars (Table 1).[17] As the frequency and severity in economic consequences caused by large wildfires were seen to have sharply increased after 1990, the dataset was restricted to this date range to be more representative of present-day conditions.
- Estimates of total losses for wildfires can vary greatly between sources. One of the reasons for this is that different types of economic cost—the cost of suppressing the fire, private property damage, crop damage, costs incurred for environmental remediation, and the indirect business-interruption costs due

[1] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[3] Zane et al. for National Center for Environmental Health. 2007. Wildfire-related deaths—Texas, March 12-20, 2006. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5630a1.htm.
[4] See Table 1.
[5] As compiled from National Interagency Fire Center, Total Wildland Fires and Acres (1960-2009), http://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html.
[6] As compiled from the SHELDUS database http://webra.cas.sc.edu/hvriapps/sheldus_setup/sheldus_login.aspx.
[7] Brush, Grass, and Forest Fires. Ahrens, Marty, 2010, National Fire Protection Association, pp 11, 15: http://www.nfpa.org/assets/files//PDF/OS.BrushGrassForest.pdf; analysis of SHELDUS database.
[8] National Interagency Fire Center, 1997-2009 Large Fires (100,000+ acres), http://www.nifc.gov/fireInfo/fireInfo_stats_lgFires.html.
[9] Fires in the wildland/urban interface, U.S. Fire Administration 2002, at http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; quoting Ainsworth et al, Natural History of Fire and Flood Cycles, University of California-Santa Barbara 1955, and 'History of fire', National Park Service.
[10] Wildfire hazards – a national threat. Fact sheet 2006-3015, U.S. Geological Survey, Department of the Interior, 2006; available at http://pubs.usgs.gov/fs/2006/3015/2006-3015.pdf.
[11] Analysis of SHELDUS database.
[12] National Interagency Fire Center, Historically significant wildland fires: http://www.nifc.gov/fireInfo/fireInfo_stats_histSigFires.html.
[13] U.S. Climate Change Science Program. 2008. Analyses of the effects of global change on human health and welfare and human systems: A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Gamble J.L. ed, Ebi et al authors, U.S. EPA.
[14] Zane et al. for National Center for Environmental Health. 2007. Wildfire-related deaths—Texas, March 12-20, 2006. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5630a1.htm.
[15] Wildfire Hazards – A National Threat. U.S. Geological Survey fact sheet 2006-3015, Feb 2006, available at http://pubs.usgs.gov/fs/2006/3015/2006-3015.pdf .
[16] As compiled from the SHELDUS database, http://webra.cas.sc.edu/hvriapps/sheldus_setup/sheldus_login.aspx. SHELDUS breaks down wildfire events into separate counties, and sometimes breaks down single wildfires in the same location into separate fires with overlapping date ranges, dividing casualty and damages between them to avoid double counting. Where this was obviously done (fires reported by counties in the same state having the same time range, or reported in the same city with overlapping or continuously adjacent time ranges) the separately reported portions of a single fire event were consolidated into single events.
All wildfires (after consolidation) above the $100 million threshold in 2011 dollars (a CPI multiplier of 1.0464 was used to convert the December 2009 values given in SHELDUS to May 2011) from 1970 follow after these endnotes. As noted in the "Assumptions" section, only the data points from 1990 on were used for analysis.
[17] Available at http://webra.cas.sc.edu/hvriapps/sheldus_setup/sheldus_login.aspx.

to lost economic productivity, economic activity, and tax revenue—are accounted for or missing from cost tallies for different major wildfires, even within the same source. In general, for the type of wildfire considered here, which has a direct impact on human populations, the total damages enumerable as property and crop damage are substantially larger than the pure costs of suppressing the fire, and also tend to be substantially larger than the second-order indirect costs of lost economic activity and demand due to business interruption, injuries and fatalities, and loss of tax revenue base.[18] Hence the total reported property and crop damages used here for calculating economic loss estimates are believed to capture the dominant portion of the total economic losses from this type of wildfire.[19]

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

To estimate social displacement for the SNRA, U.S. wildfire event data from the international disaster database EM-DAT[20] was used to approximate the number of people forced to leave home for two days or greater. EM-DAT's public interface reports estimates for "total number affected" by disaster events: these data are listed in Table 1 for the seven wildfire events in the main historical data set for which it was available.[21] The low, high, and average of the "total affected" data in Table 1 are used as the social displacement estimates for wildfires in the SNRA.

The "total affected" measure includes the number of people needing immediate assistance, which can include displacements and evacuations; the number of people needing immediate assistance for shelter; and the number of people injured. Because EM-DAT includes injuries in the "total affected" measure, there is potential for double-counting between the SNRA injury and displacement estimates for this event. However, displacement due to wildfires is typically significantly greater than the number of injuries, so using EM-DAT's "total affected" measure was judged to provide an estimate of social displacement of sufficient precision for the SNRA.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[22] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The EPA experts identified the best estimate for environmental consequences as "High." Experts made this estimate given the assumption that the wildfire threatens an "urban U.S. setting," as the fire could envelop oil, chemical, or other hazardous storage tanks and cause widespread release of such materials. However, many wildfires would have low longer-term effects on eco-systems and, in fact, provide longer-term benefits including re-seeding of certain plants and assisting the growth of forested areas. Thus, this scenario could quite conceivably be scored as "Low" or "De Minimus (None)" if the wildfire does not occur in an urban U.S. setting.[23]

Potential Mitigating Factors

The primary drivers of increased consequences associated with wildfires appear to be the high proportion of new home construction in high-risk regions adjacent to or intermixed with wildlands,[24] long-term changes in forest management practices,[25] and early effects of climate change.[26] These three trends most converge in California, where the data show that two-thirds of the most catastrophic (by cost) wildfires of the last twenty years have occurred.[27]

Additional Relevant Information

The frequency of catastrophic fires, such as those listed in Table 1, depends upon the threshold used to select which fires will be on the list. The economic cutoff of $100M resulted in a set of major wildfires which have occurred with an average historical frequency of slightly less than once per year in the 1990-2009 time period (0.8 per year to be precise). Wildfires causing 500 million dollars or greater in damages occur about one every other year (0.45/year); the most catastrophic wildfires, causing $2 billion or more in damages, occur about one every four years (0.25/year).

Table 1. U.S. wildfires causing ≥ $100 million in direct economic damages, 1970-2009[28]

Begin	End	Location	State	Name (if any)	Fatal-ities	Injur-ies	Total damage (2011 dollars)	EM-DAT Tot.Aff
9/25/70	9/29/70	LA/San Diego	CA	Laguna Fire	9	770	$1,288,741,000	
8/8/77	8/8/77	Monterey	CA		0	0	$1,182,055,000	
10/20/91	10/20/91	Oakland	CA	Oakland Hills Fire	25	150	$2,803,063,000	
10/26/93	10/31/93	Sacramento	CA		0	89	$514,587,000	
10/27/93	11/4/93	Los Angeles	CA	Old Topanga Fire	6	187	$2,221,587,000	
5/31/98	7/30/98	Central Florida	FL		0	150	$261,731,000	
7/1/98	7/10/98	Central Florida	FL		0	65	$523,462,000	40,124
8/2/98	8/30/98	Chelan	WA		0	0	$123,978,000	
5/4/00	5/31/00	Los Alamos	NM	Cerro Grande	0	0	$1,966,720,000	25,400
9/29/00	9/30/00	Tehama	CA		0	0	$717,197,000	
6/17/03	7/15/03	Pima	AZ	Rodeo-Chediski Fire	0	0	$161,404,000	1,269
10/25/03	11/5/03	San Diego	CA	Cedar Fire	22	157	$2,572,317,000	27,104
3/12/06	3/18/06	Carson	TX		12	8	$107,289,000	
4/11/06	4/13/06	Wheeler	TX		0	2	$103,553,000	
6/24/07	6/30/07	Alpine	CA	Alpine Fire	0	3	$544,127,000	768
10/21/07	10/31/07	San Diego County	CA		10	132	$748,175,000	640,064
11/15/08	11/19/08	Sacramento	CA		0	0	$156,960,000	55,000

[18] Western Forestry Leadership Coalition 2010. The true cost of wildfire in the western U.S. At http://www.wflccenter.org/news_pdf/324_pdf.pdf. The SHELDUS database attempts to provide some consistency between reports by relying on two U.S. Government sources (the National Climactic Data Center and the U.S. Fire Administration (http://webra.cas.sc.edu/hvri/products/sheldusmetadata.aspx#6), and by including property and crop damage estimates only.

[19] Note that the damages to crops and private property considered here to be direct damages – since they represent the property and crops directly damaged or consumed by the wildfire – are usually referred to as 'indirect' costs in studies of the economic damages of wildfires. This is because 'direct' costs are by convention limited to the cost of fire suppression, and all damage caused by the wildfire is considered as 'indirect' or 'additional' costs (see for instance the reference above).

[20] EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université Catholique de Louvain located in Brussels, Belgium (http://www.emdat.be/frequently-asked-questions), and is supported by the Office of U.S. Foreign Disaster Assistance (OFDA) of USAID (http://transition.usaid.gov/our_work/humanitarian_assistance/disaster_assistance/). See Criteria and Definition, http://www.emdat.be/criteria-and-definition, EMDAT Data Entry Procedures, at http://www.emdat.be/source-entry, and EMDAT Glossary, at http://www.emdat.be/glossary/ for details of criteria, thresholds, and methodology for the EM-DAT database.

[21] In addition to these, the Old Topanga fire had an EM-DAT Total Affected count of 130. This was excluded from the SNRA data set as being either a clear undercount (a fire causing $2 B of damages would be expected to destroy hundreds or thousands of homes) or a count of injuries rather than homeless.

[22] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: wildfires were given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

[23] The best and second best estimates were switched by the SNRA project team in October 2011, subsequent to the reporting of the SNRA results to FEMA, in response to stakeholder feedback focusing on the longer-term environmental effects associated with the experts' "Low" judgment.

[24] Fires in the wildland/urban interface, U.S. Fire Administration 2002, at http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; quoting Wildland Fire Preparedness/Education Partnership, Firewise Colorado, February 2001.

[25] Fires in the wildland/urban interface, U.S. Fire Administration 2002, http://www.usfa.dhs.gov/downloads/pdf/tfrs/v2i16.pdf; Westerling et al 2006, Warming and earlier spring increase western U.S. forest wildfire activity, *Science* 313(5789) pp 940-943, http://www.sciencemag.org/content/313/5789/940.full.pdf.

[26] National Academy of Sciences, America's Climate Choices, 2011, p 19, at http://dels.nas.edu/Report/Americas-Climate-Choices/12781; Global Climate Change Impacts in the United States, U.S. Global Change Research Group, p 82, at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf; Ryan et al, The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States, U.S. Department of Agriculture Synthesis and Assessment Product 4.3 (2008), sections 3.1-3.2, at http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf; Westerling et al 2006, Warming and earlier spring increase western U.S. forest wildfire activity, *Science* 313(5789) pp 940-943, at http://www.sciencemag.org/content/313/5789/940.full.pdf.

[27] For wildfires above $100 M reported total cost.

[28] Dataset used for analysis excluded the two fire events before 1990.

Biological Food Contamination

Accidental conditions where introduction of a biological agent (e.g., Salmonella, *E.coli*, botulinum toxin) into the food supply results in 100 hospitalizations or greater and a multi-state response. This event does not include food contamination caused by malicious acts.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Metric	Low	Best	High
Fatalities[1]	0	11	42
Injuries and Illnesses[2]	200	17,000	45,000
Direct Economic Loss (USD)	N/A[3]		
Social Displacement[4,5]	0	400	950
Psychological Distress	See text		
Environmental Impact[6]	Moderate[7]		
Frequency of Events (per Year)[8]	0.2	0.64	1.2

Event Background

The risk data estimated for this summary sheet are applicable to a contamination event (or a series of interconnected events) where a biological agent is accidentally or unintentionally introduced into the U.S. food supply resulting in national level public health consequences and product recalls. This event may include contamination of domestic food products, international food imports, or food products or ingredients that are utilized as a component of a supply chain. Such an incident may span multiple months as the investigation on the disease agent or contaminant is identified through laboratory analysis and traced to the product origin. This assessment only addresses outbreaks that result directly in harm to human health, and does not assess the consequences of crop or animal diseases, such as Foot and Mouth Disease in cattle, which could have catastrophic effects on the Nation. Nor does it address intentional contamination of the food supply by a terrorist; that risk is captured in a different National Level Event.

Data from the CDC's Foodborne Outbreak Online Database (FOOD)[9] were used to identify events that rose to a level of national significance. Data in FOOD come from CDC's national Foodborne Disease Outbreak Surveillance System database. Most foodborne outbreaks are investigated by the state, local, territorial, and tribal health departments where the outbreak occurs. Outbreak information is then reported to CDC by the public health agency that conducted the investigation. CDC is only directly involved in outbreak investigations that involve more than one state, or are particularly large, or when the state or local health department requests assistance. Because of this only multistate outbreaks that resulted in reported hospitalizations of more than 100 persons were considered to be National Level Events. There have been seven such events between 1998 and 2008, the years included in FOOD.

The best-estimate frequency is the average frequency of occurrence of this set of events in the selected eleven year period. The low frequency is the inverse of the longest time interval between outbreaks in this set (5 years); the high frequency is the greatest number of outbreaks which occurred in one year (two, in 2006).

Assumptions

Fatalities and Illnesses

The SNRA project team used the following assumptions to estimate health and safety consequences resulting from an accidental biological food contamination event:

- Outbreaks included in FOOD report a number of illnesses and fatalities. These reported numbers are known to be low because they do not account for underreporting or underdiagnosis. Consequently, the reported numbers were adjusted using the latest multipliers provided by the CDC.[10]
- Fatalities were increased by a factor of two, while illnesses were increased with the following multipliers:

Table 1: Multipliers Used to Adjust Reported Illnesses

Pathogen	Multipliers	
	Underreporting	Underdiagnosis
STEC O157 (*E. Coli*)	1.0	26.1
Salmonella spp., nontyphoidal	1.0	29.3
Listeria Monocytogenes	1.0	2.1

- The "Low," "Best," and "High" values of illnesses and fatalities are populated with the minimum, mean, and maximum of these adjusted values.

Table 2: Reported and Adjusted Values for SNRA Events

Outbreak	Reported Illnesses	Adjusted Illnesses	Reported Fatalities	Adjusted Fatalities
1998 *Lysteria*-Hot Dog	101	212	21	42
2004 *Salmonella*-Roma Tomato	429	12,570	0	0
2006 *E. Coli*-Spinach	238	6,212	5	10
2006 *Salmonella*-Peanut Butter	715	20,950	9	18
2007 *Salmonella*-Pot Pie	401	11,749	3	6
2008 *Salmonella*-Jalapeno/Serrano Peppers	1,535	44,976	2	4
2008 *Salmonella*-Peanut Butter	716	20,979	9	18

Economic Loss

The SNRA project team used the following assumptions to estimate economic consequences resulting from an accidental biological food contamination event:

- For each of the seven outbreaks, the costs of lost productivity due to illness as well as medical costs were calculated using the USDA Economic Research Service's Foodborne Illness Cost Calculator,[11] with the Value of Statistical Life reset to $0.

Table 3: Economic Impact (Adjusted to 2010 USD)

Outbreak	Lost Productivity & Medical Costs	Business Interruption Costs	Total
1998 *Lysteria*-Hot Dog	N/A		
2004 *Salmonella*-Roma Tomato	$4.2 Million		
2006 *E. Coli*-Spinach	$6.0 Million	$61.4 Million[12]	$67.4 Million
2006 *Salmonella*-Peanut Butter	$4.7 Million		
2007 *Salmonella*-Pot Pie	$ 3.6 Million		
2008 *Salmonella* Jalapeno/Serrano Peppers	$11.0 Million		
2008 *Salmonella*-Peanut Butter	$5.7 Million		

Business interruption costs could be determined for only one event. However, its magnitude indicated that the unknown business interruption

[1] Low, average, and high adjusted fatalities of the set of multistate outbreaks with 100 or more reported hospitalizations between 1998 and 2008 from the CDC FOOD database. Reported fatalities were multiplied by a factor of 2 to compensate for underreporting (see text).
[2] Low, average, and high adjusted illnesses from the set of events described in note 1. Reported illnesses were multiplied by the CDC's recommended multipliers (see Table 2 below) to compensate for underdiagnosis and underreporting.
[3] The SNRA project team judged that the single data point calculated (see text) was insufficient to determine a representative range of economic consequence estimates for this event.
[4] The SNRA measure of Social Displacement is the number of people displaced from their homes for two or more days.
[5] Low and best estimates of 0 and 400 respectively reflect expert judgment. The high estimate of 950 is a judgment based on a historic incident where contamination of the water by *E. coli* in the Ontario community of Kashechewan forced the evacuation of the town (see discussion for references).
[6] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[7] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[8] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 1 above.
[9] Centers for Disease Control and Prevention (CDC). Foodborne Outbreak Online Database. Atlanta, Georgia: U.S. Department of Health and Human Services, Center for Disease Control and Prevention. Available from URL: http://wwwn.cdc.gov/foodborneoutbreaks. Accessed 08/17/2011.
[10] Scallan E, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson M-A, Roy SL, et al. Foodborne illness acquired in the United States—major pathogens. *Emerging Infectious Diseases*. Volume 17 Number 1 January 2011. Available from URL: http://www.cdc.gov/EID/content/17/1/7.htm. Accessed on 08/22/2011.
[11] United States Department of Agriculture, Economic Research Service. Foodborne Illness Cost Calculator. Available from URL: http://www.ers.usda.gov/Data/FoodBorneIllness. Accessed on 08/19/2011.
[12] United States Department of Agriculture, Economic Research Service. Consumers' Response to the 2006 Foodborne Illness Outbreak Linked to Spinach. Available from URL: http://www.ers.usda.gov/AmberWaves/March10/Features/OutbreakSpinach.htm. Accessed on 08/19/2011.

cost estimates for other events were likely to dominate total direct costs. As a representative range of total costs could not be determined for additional data points, the SNRA project team elected not to report economic consequences for the Biological Food Contamination event.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Social displacement estimates for the accidental Biological Food Contamination event were provided by staff researchers and subject matter experts at the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[13]
- The low and best estimates of 0 and 400 respectively reflect expert judgment. The high estimate of 950 is a judgment based on a historic incident where contamination of the water by *E. coli* in the Ontario community of Kashechewan forced the evacuation of the town.[14]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[15] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., as chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Moderate." Moderate impacts would most likely result from either waste disposal (e.g., disposing of the contaminated food supply) or dissemination of an infectious agent through some type of accidental application (e.g., pesticide application on crops). In either event, the result could be the introduction of a non-native pathogen into native species, thus causing extinction and permanent change to the ecosystem if disseminated over a wide geographic area. If the agent infects only humans, the environmental/ecological risk would be "Low." There may also be increased environmental/ecological risk if the food production cycle were disrupted. Changing the mechanisms of food production could increase the environmental/ecological risk.

Potential Mitigating Factors

The consequences caused by an accidental introduction of an infectious agent into the food supply can be mitigated through several preparedness strategies. Effective investigative capability, early warning systems and emergency information dissemination are necessary to rapidly detect contamination, locate its source and notify the public of the event and necessary safety measures. Monitoring and warning systems should be regularly tested to ensure that they are functioning properly when an event occurs. Further, a properly prepared and deployed response team could potentially aid in containing the spread of the contamination.

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[13] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[14] Contamination of the water by *E. coli* in the Ontario community of Kashechewan forced the evacuation of the town. Source: Virchez, Jorge, and Ronald Brisbois. 2007. "A Historical and Situtional Summary of Relations between Canada and the First Nations: The case of the Community of Kashechewan in Northern Ontario." *Associacion Mexicana de Estudios sobre Canada*, AC. 87-100. Note that contamination of the food supply is likely to cause minimal displacement.

[15] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + ½\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: accidental Biological Food Contamination was given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

Chemical Substance Release

Accidental conditions where release of a large volume of a chemical acutely toxic to human beings (a toxic inhalation hazard, or TIH) from a chemical plant, storage facility, or transportation mode results in either one or more offsite fatalities, or one or more fatalities (either on- or offsite) with offsite evacuations/shelter-in-place. This event does not include releases caused by malicious acts.

Data Summary[1]

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[2]	1	5	25
Injuries and Illnesses	Number of Injuries or Illnesses[2]	0	57	790
Direct Economic Loss	U.S. Dollars[2]	$43,000	$14 Million	$330 Million
Social Displacement	Displaced from Homes ≥ 2 Days[2]	0	260	5,400
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[3]	Moderate[4]		
Frequency of Events	Number per Year[5]	0.61	1.6	5

Event Background

The dominant risk to human beings from accidental chemical releases is from an accidental release of a highly toxic gas, or toxic inhalation hazard (TIH), in a densely populated area.[6] The 1984 accidental release of toxic methyl isocyanate gas from the Union Carbide chemical plant in the city of Bhopal, India, which killed about 4,000 people immediately and 20,000 in subsequent years, is the primary historical example of the human damage such a release may cause.[7]

Across the United States, accidental releases of chemicals hazardous to human beings occur with a frequency of several times a day.[8] Of these, the largest number of historical (and recurring) accidents causing human death and injury – sometimes in the dozens or hundreds – are caused by fires and explosions from highly flammable chemicals such as propane, liquefied petroleum gas, and ammonium nitrate. However, as these fire and explosion hazards are of a different character and potential magnitude than the hazard posed by a highly toxic gas such as chlorine, hydrogen fluoride (HF), or the Bhopal chemical methyl isocyanate which could potentially kill thousands of people if released in a high population area,[9] they have not been included within the scope of this chemical substance release event analysis for the purpose of the SNRA.

Highly toxic gases may be released while transported by road, rail, or pipeline, or from a fixed facility where they are manufactured, stored, or used for further chemical processing, agricultural chemical production, meat packing, or water treatment. Of the most toxic industrial chemicals, chlorine in particular is used and transported in a total quantity much greater than all the other most toxic industrial chemicals combined: after anhydrous ammonia (which is less toxic),[10] it is the second most commonly used and transported chemical in this country.[11] Chlorine is also normally stored, used, and transported in the United States in volumes large enough to kill thousands of people if released in a densely populated area.[12] Further, like other hazardous chemicals it is routinely transported through the nation's most densely populated areas, in particular Chicago, the central hub of North America's railroad network (one out of every 25 of the nation's major rail accidents—derailments, fires, explosions—occur in Cook County, Illinois alone).[13] An insurance model of a single accidental chlorine railcar breach in the Chicago railyards projected 10,200 fatalities, with several square miles of the city's business district shut down and cordoned off for a week for investigation and recovery efforts.[14] Similarly, FEMA's current National Planning Scenario for a catastrophic release of chlorine from a fixed plant near a medium sized city projects 17,000 dead.[15]

However, these consequence models do not attempt to estimate the likelihood of such an event to occur, which was a particular requirement of the SNRA project. Compared to other types of events (for instance, nuclear plant accidents), few studies linking frequency to consequence estimates have been done for catastrophic chemical accidents. Although the overall national risk to human health and life from catastrophic accidents has been quantitatively modeled in a number of studies of the transportation portion of the chemical sector as a whole, these results could not be used for the SNRA because comparable national-scale estimates could not be found for fixed facilities. Unlike the transportation sector, it does not appear that a national risk assessment attempting to answer these questions for the fixed-facility sector has been attempted since 1974.[16]

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[1] The data reported in this table represent historical U.S. accident data. This data is not representative of either the likelihood or the consequences of a catastrophic, mass-casualty chemical accident of a magnitude which has not yet occurred in the United States. The SNRA project team used historic data because a defensible estimate for the likelihood of a catastrophic accident could not be determined. For additional discussion, see Event Background section below.

[2] Low, best, and high estimates for fatalities, injuries and illnesses, direct economic loss, and number of displaced from homes for at least two days come from the low, average, and high values of the set of events meeting one of the following two threshold criteria: 1) at least one "public" fatality, defined as one fatality other or in addition to an employee fatality, caused by the hazardous material; 2) at least one fatality of any kind caused by the hazardous material, plus a reported evacuation or shelter-in-place order; this set came from the set of all reported toxic inhalation hazard (TIH) incidents reported 1994-2010 to either the EPA's RMP (Risk Management Program) accident database for fixed industrial producers and consumers of listed toxic chemicals above given threshold limits, or to the Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database of road, rail, water, and air transportation accidents. For further details see Assumptions sections below.

[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[4] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.

[5] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 2 above.

[6] See note 11.

[7] [Pastel/Bhopal]. Bibliographic information for all cited references may be found at the end of this section.

[8] [Belke], appendix A. A scrolling newsfeed on the homepage of the Chemical Safety Board at http://www.csb.gov/ lists all the reported chemical accidents which occurred in the United States in the past week. A similar newsfeed with global coverage may be found on the homepage of the Mary Kay O'Connor Process Safety Center, http://process-safety.tamu.edu/.

[9] [Argonne-2000] pp 128, 132; [PHMSA].

[10] [Argonne-2000] pp 128, 132; [PHMSA].

[11] Chlorine gas, like the Bhopal chemical methyl isocyanate and many other industrial chemicals used in the U.S., is a highly toxic gas capable of killing large numbers of people at relatively low concentrations, but is used and transported in much greater quantities than any other. Anhydrous ammonia and flammable chemicals such as propane are used and shipped in comparable total quantities in storage tanks, pipelines, trucks, and railcars comparable to chlorine, under much less stringent safety standards, and are involved in a much higher proportion of fatal accidents. However, they are most frequently shipped in much smaller containers than chlorine, and by toxicity (ammonia) or blast range (propane and other flammables) they have the capability to cause many fewer deaths than chlorine even if transported in similar quantities (which is why their required storage and shipment safety standards are much lower) ([Wharton] pp 69, 129, [DoT-1992] p 7-9, [Argonne-2000] pp 4-5, 19, 67-69, 126-128, 148-150).

[12] Unlike most other chemicals which are most frequently shipped by road and pipelines, the primary hazard chlorine is shipped almost exclusively (85%) by rail, usually in standard 90 ton (18,000 gallon) tanks ([Branscomb] pp 11-12) which are of comparable size to the largest storage tanks (60,000 – 120,000 gallon) used in fixed facilities often cited in catastrophic-release scenarios (as in [FEMA-2006]). Eleven ruptures of chlorine railcars resulting in the loss of most or all contents have occurred in the 42 year period 1965-2007 which included 2.2 million rail shipments of chlorine (for comparison, the 2007 annual rate was 30,000 shipments). [ACC]

[13] 7% of the nation's rail network mileage lies within the highest population density counties, 3000 people per square mile or more ([Vanderbilt] pp 3-5]); 8% of severe rail accidents occur in these counties (the 23 most densely populated) (all derailments, fires, and explosions, 2006-2010, [FRA] database sorted by county, correlated with Census county population data). Half of these (4% of the total) occur in Cook County, IL alone. The population density of Cook County is 5800 people per square mile; the population of Aiken County, South Carolina where the 2005 Graniteville crash resulted in 9 fatalities and 631 injuries was 144 per square mile ([DoT-PHMSA] pp 33, 104). Other references calculating similar proportions include ([DoT-1992] pp 5-15-19, [DoE] pp 68-72).

DoT's most recent review noted

> DOT is aware that there are [toxic inhalation hazard] rail movements along corridors with population densities several times higher than these [four of the major hazmat rail releases of the past decade]. This coupled with the relatively favorable circumstances surrounding the four incidents leads DOT to believe that the mean of the casualties resulting from the releases analyzed is likely not the true mean of the distribution of the population of preventable releases, but rather lies in the lower end of the distribution. DOT believes that absent issuance of the proposed standards a future incident could potentially result in a larger number of casualties than experienced in recent years. ([DoT-PHMSA] p 33)

[14] [RMS] pp 54-59. This estimate of 10,200 dead (and additionally 32,400 injured) models a 90-ton chlorine railcar breach in a switchyard in Chicago, where the areas of greatest rail line and node density are surrounded by densely populated neighborhoods. Although hundreds of thousands of people may be within the zone of a modeled chlorine cloud (see also [FEMA-2006]), most scenarios (including both of these) realistically assume that nearly everyone is indoors at home or at work, or is able to go indoors before they are overcome: such shelter-in-place measures are known from experience to reduce the number of human casualties by ten times or more. Under circumstances where large numbers of people may be gathered for an outdoor event the fatality rate may be much higher: a similarly modeled scenario of a chlorine railcar breach within Washington DC, but set at a time when thousands of people are thronged on the National Mall for a festival or other event, estimated 100,000 fatalities. [Branscomb] p 5 footnote 9.

[15] [FEMA-2006]. This scenario modeled a deliberate release, but the consequences are similar to a catastrophic accidental release: once a large volume of gas escapes to the air, its subsequent behavior no longer depends on the cause of the breach.

[16] Accident data and worst-case scenarios reported by fixed facilities in the United States from 1995-2005 have been most extensively analyzed by [Belke], [Wharton], [Kleindorfer], and other reports from its authors available at this reference's parent site link (http://opim.wharton.upenn.edu/risk/papers.php). They do not attempt to quantitatively estimate the likelihood of the type of low-frequency

This 1974 national risk assessment for catastrophic chemical accidents[17] (performed by UCLA's School of Engineering, also referenced below by its lead author as Simmons et al 1974) was commissioned by the Atomic Energy Commission as one of a set of studies attempting to quantify the risk on a national scale of a number of different hazards (dam failure, airplane accidents, hurricanes, tornadoes, asteroids) for the purpose of comparison with the risk to the nation of civilian nuclear power.[18] However, only the risk of transporting chlorine by rail was treated in a fully quantitative manner: semi-quantitative analyses were used to assess that this risk dominated the national risk of catastrophic accidents from all TIH in the fixed and transportation sectors combined to such an extent, that the chlorine rail accident likelihood and consequence estimates could be taken as a reasonable approximation to the risk of catastrophic mass-casualty accidents from the chemical industry as a whole. Although its quantitative approach was further developed in subsequent and more sophisticated studies of the transportation sector taken in isolation, and similar methods have been applied to individual chemical process plants, no public industry-wide quantitative risk assessment has been attempted in this country since.[19]

For the fixed sector, the only recent national-scale likelihood estimate for a catastrophic chemical accident comes from a 1996 regulatory impact analysis by the EPA. After including its estimated risk reduction consequent to the proposed regulation (which was enacted) fully going into effect, and incorporating its given ranges in uncertainty in its estimates of consequent risk reduction and in its basic assumptions, the EPA study's calculations give a 0.002% (1 in 50,000) to 0.4% (1 in 250) annual likelihood of a Bhopal-scale accident causing on the order of 4,000 fatalities to occur in the United States, with 0.4% being the best as well as high estimate.[20]

For the transportation sector, the National Transportation Risk Assessment done for the Department of Transportation (DoT) by Argonne National Laboratory in 2000 modeled the nation's road and rail network, routing for each of the top six toxic inhalation hazard (TIH) chemicals, accident rates and rupture probabilities for different models of train car, variation of population density along transport routes, and expected distributions of atmospheric conditions relevant to gaseous chemical dispersion to model expected ten-year frequency estimates for accidents along a range from zero to thousands of fatal exposures. The authors estimated the annual likelihood of a catastrophic chemical accident causing thousands of fatalities to be 0.0001% (one in 100,000 years).[21]

Given the frequency of major chemical accidents in the United States, whether during transport (at least five in the last decade[22]) or at fixed facilities,[23] and the routine production, use, and carriage of large volumes of hazardous chemicals in or through large population centers as mentioned earlier, other researchers have assessed the likelihood of a catastrophic release to be much greater than the estimate reported in the DoT study mentioned above. For example, a later (non-quantitative) DoT study of rail hazardous material transport qualitatively compared the frequency of accidents with the frequent proximity of transport to large population centers in this manner, and concluded it was only a matter of time before the two probabilities should overlap with catastrophic results.[24] The recent accidental rupture of the nuclear plant in Fukushima, Japan may also bring to mind the unquantified but possibly substantial risk of an external event such as an earthquake causing similar damage to a chemical plant or storage tank here, with catastrophic results: several very large concentrations of chlorine are stored on earthquake fault lines in California in highly populated counties.[25] (Note that complex, cascading events such as an earthquake triggering a chemical release are not

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high-consequence accidents within the scope of SNRA. They have, however, concluded that the extensively documented historical frequency of high-frequency but lower-consequence accidents has too low a correlation with the likelihood of high-consequence events for extrapolation from historical data to generate meaningful frequency estimates for high-consequence accidents [Elliot].

One partial list of major historical accidents involving chlorine (as well as the flammable liquefied petroleum gas and the explosive ammonium nitrate not considered here) may be found at [UK-HSE]: although worldwide in scope, it is dominated by accidents from fixed facilities which have occurred in the United States. Another list of major chemical accidents may be obtained from the UN Environmental Program's APPELL database [APPELL] by query limited to the United States and sorted by chemical involved. Other good historical sources of comprehensive chemical accident lists include [NICS], [Lees], and for pre-1974 accidents [EPA-1974].

Because of its reliance on recent historical data, this risk summary sheet for chemical accidents is essentially an update of [EPA-1974]. Along with [Simmons] which was completed in the same year (1974) these appear to have been the last and only attempts to produce a national-scale risk assessment for chemical accidents in the United States. See also [Fullwood] pp 428ff.

[17] [Simmons].

[18] These results were presented in the Nuclear Regulatory Commission's landmark 1975 Reactor Safety Study [WASH-1400], also known as the Rasmussen Report, which developed many of the techniques of probabilistic risk assessment relied upon for risk assessments today. In its quantitative approach, communication of uncertainty estimates, all-hazards scope, and deliberate comparison of different national-level risks by common metrics, chapter 6 of this report reads very similar to the SNRA.

[19] [Simmons] Being also almost 40 years old, it is unclear to what extent industry trends and practices in the years since, the last decade in particular, have rendered its inputs and assumptions out to date (although its growth projections for the chlorine industry, its prediction that this trend and population increases along rail routes would roughly cancel the risk reduction of expected safety improvements with time, and its prediction that accident trends would hence remain constant through 1990 proved accurate). As the first attempt of its kind, it relied on many simplifying assumptions to reduce the problem space and make tractable the large computational problem with its variables of rail traffic modeled across multiple segments, population distribution, weather patterns, railcar accident and rupture rates. Every subsequent quantitative study of hazardous material transportation hazards of a national scope located by the SNRA project team ([DoT-1988], [DoT-1992], [Argonne-2000], [DoE]), although each increasing in sophistication over the one before it, has followed this model. It reported two fatality-vs-frequency curves, one with and one without modeled evacuation: both curves are presented in figures 6-1 and 6-12 of [WASH-1400], but only the lower-fatality evacuation model is represented on the graph here.

[20] [EPA-1996] Chapter 6, pp 6-8 – 6-30. Noting that the Bhopal plant was American-owned and similar to American-owned plants in the U.S., the authors' first estimate comes from the product of the historical frequency of such events worldwide (1 in 50 years of 'the modern industrial era' since the second world war) with the proportional exposure of the United States to chemical risks (50%, as 50% of the world's annual output of chemicals and refined petroleum came from the U.S.), resulting in 1/50 x 1/2 = 0.01 or 1% in the absence of further regulation (page 6-9). This was used as their best estimate because it required the fewest number of assumptions. On an alternate assumption that the U.S. share of fatal hazardous-materials disasters decreases with the number of fatalities (the world's largest mass-casualty accidents rarely occur in the U.S.) the authors estimated the likelihood might be only 15% of this number (0.15%) (pp 6-10 – 6-11). In footnote 9 they note that if the curves on a plot of the U.S.'s share of fatal accidents (y axis) vs. the log of fatalities per accident (x axis, i.e. the numbers on the x-axis represent 101 = 10, 102 = 100, 103 =1000, 104 = 10,000) could be relied upon in the high-casualty region where the curves are projected beyond the last data point, then a 1-2% proportion might be more appropriate than the 15% they cited in the main text (15% represents the high curve for the last data point). Although the authors state that they were not confident that the curve could be projected out this far, for the purposes of reporting their total range of certainty it is used here.

For the estimate of risk reduction consequent to the RMP rule coming into effect, the authors gave the best estimate of risk reduction from both the RMP rule and new OSHA regulations due to come into effect in the same timeframe to be 60% (pp 6-18 – 6-23: because the consequence estimate is essentially a point estimate for a single event, the overall risk reduction in costs from 'Large Magnitude Toxic Events' is here taken to be a reduction in frequency rather than consequences). This factor was used as their best estimate. Two alternate estimates of risk reduction in the authors' sensitivity analysis (pp 6-23 to 6-28) give what the SNRA project team calculated to be 80% and 83% total reductions in risk from the RMP and OSHA rules combined: after reduction to the one significant figure used throughout the authors' analysis in this section, these collapse to a single factor of 80%. Given the chemical industry's changes in a number of practices subsequent to these rules coming into effect, largely because of these rules (see Mitigating Factors), this range of 60-80% of risk reduction since 1996 seems reasonable. Since these are risk reductions, the overall residual risk multiplier after they are taken into account is either (100% - 60%) = 40% or (100% - 80%) = 20%.

Hence after incorporating both sources of uncertainty, the net range of annual likelihood comes to (0.01% to 1%) x (20% to 40%) = 0.002% to 0.4%. The SNRA project team took 0.4% to be the authors' best estimate because each of the factors going into it (1% base and 60% reduction) were the ones the authors selected to calculate their actual cost estimates.

Comparable likelihood estimates for a fixed-site industrial accident (but for the hazardous materials sector generally, including petroleum refining, flammables, and explosives) causing thousands of fatalities have been obtained by a fuller analysis of historical accidents for France [Rocard] and, by a full probabilistic-risk-analysis (but for only particular large concentrations of industry) for the UK (the Canvey Island studies, see for instance [Lees], [Fullwood]). Equipment failure rates which may be used for probabilistic safety analysis of chemical process plants are given in [Lees] and [FEMA-1989].

The International Atomic Energy Agency has published a procedure for conducting a regional or national quantitative risk assessment of fixed chemical sites using generic process plant and storage tank failure rates and specific chemical information [IAEA]. By allocating the number of loading and unloading operations to process plants in proportion to their reported quantities, total national amounts shipped of each chemical, and the distribution between rail and road shipments for each chemical as provided by studies such as [Argonne-2000], sufficient data exist in the public domain from Census block population and geographic population center data, RMP data available through [RTK], and chemical shipment statistics collated by the Department of Transportation and transportation studies such as those cited here to conduct such a national-scale quantitative risk assessment for catastrophic mass-casualty accidents caused by fixed facilities in the United States.

[21] [Argonne-2000] pp 11-12, chapter 5. The summary figure 5.11 and table 5.22 may be found on pp 154, 156. These tabulate estimated fatal exposures for each chemical, as well as for all six TIH chemicals combined, at the 15 minute LC-50 threshold, representing the concentration at which an expected 50% of a normally distributed human population would be dead after fifteen minutes of continuous exposure. To account for the likelihood that most of the population within this area would be partially protected by being indoors (being inside even an ordinary building offers substantial partial protection, which can be enhanced to 90% protection or greater by sealing doors and windows with tape, rolled towels, or anything which will block off routes for air exchange), the authors note that these exposure numbers should be divided by 7 to give estimates for actual fatalities, pp 122-123. Although their reported numbers represent totals from all accidents in a ten-year period, the right hand high-exposure end of the curve may be taken as the approximate predicted frequency of a single event having that many fatal exposures in a ten year period: because of their sharply decreasing probability, an exceptionally high casualty toll in a given ten year period is more likely to be dominated by a single catastrophic event. The six TIH chemicals were estimated by the authors to represent about 90% of the risk from TIH chemicals as a whole, p 8. It is interesting to note how chlorine dominates the high-fatality end of the combined-chemical curve (figure 5.11).

This study is similar to previous studies commissioned by DoT ([DoT-1988], [DoT-1992]).

[22] [DoT-PHMSA] Tables 3, 4, pp 62, 71.

[23] Such as the Magnablend ammonia and allied chemicals plant in Waxahachie, Texas which caught fire in spectacular fashion in October 2011 during the drafting of this sheet. Such accidents are hardly exceptional, however: see note 8.

[24] See note 8.

[25] [Tierney], [Eguchi]. There is some evidence to suggest that the Fukushima accident may not have been an outlier event, or one characteristic only of nuclear facilities: the frequency of accidental chemical releases in Japan markedly spikes in earthquake years: [Wharton] figure 1.A-2, p 42. It is interesting that these three spikes are depicted on the graph as dotted lines as though to indicate that they should be considered outlier events.

As part of the overall industrywide risk-reduction trend discussed in Mitigating Factors below, many of the largest chemical hazards in quake zones have switched or plan to soon switch to alternate or less hazardous chemical production processes. One of the highest profile examples has been Clorox, which maintained a number of bleach production plants in the hills above Los Angeles storing very large quantities of liquefied chlorine gas on-site. The company announced in 2009 that it would be converting all its bleach plants to processes using concentrated bleach as the starting material rather than pure chlorine. [SHG], [CAP-2006], [CAP-2008], [PIRG].

The question of earthquake-caused accidents at fixed facilities storing or using hazardous chemicals has been extensively studied – [Tierney] and [Eguchi] cited above are but two of a large field – but it appears no attempt has been made to quantify the risk of such an event occurring on a national scale.

This summary sheet also does not consider catastrophic chemical release due to a terrorist attack, as that is considered elsewhere. However, it is interesting to note that well before 9/11, 10% of the thousands of chemical accidents occurring in the U.S. every year were attributed to deliberate or intentional human action [EPA-1999].

considered in the SNRA because of the difficulty of quantifying their interdependencies; this is a limitation of the assessment.)[26]

A notable historical counterexample to these expectations of large casualty numbers from an urban chemical accident is the 1979 multiple-railcar multiple-chemical derailment, release, and fire in the Canadian city of Mississauga, a suburb of Toronto. The train accident caused several cars to burst, including a full 90 ton tank of liquefied chlorine gas (the same volume as that of the Chicago train scenario mentioned above), and several tanks of an assortment of flammable and toxic chemicals. Evacuations soon began, and continued for several days while different chemicals came into contact, reacted with each other, and caused new fires, explosions, and clouds of toxic gases, making it an exceptionally difficult disaster for the fire crews to contain. 210,000 people were evacuated from the city – three-quarters of the city's population of 280,000 – and were not permitted to return for a period of three to six days. The entire city was essentially shut down for a week. Extensive federal and provincial resources were mobilized to assist the city's emergency crews, reroute traffic around the city, and coordinate the temporary resettlement and aid to the evacuated population. However, the winds happened to be blowing in the right direction to blow much of the toxic chlorine gas out over Lake Ontario and away from the city center, most of the rest burned up in reactions with the other chemicals, and the remainder, diluted by the water firefighters hosed at the ruptured tank, was frozen into a chlorine-water ice slush in the bottom of the tank by the subfreezing night temperatures of the Canadian winter. This was the worst-case imaginable scenario, a major release of highly toxic gas in a densely populated urban area similar to cities in the United States, causing massive disruption and economic loss to an entire city: yet there were no human fatalities.[27]

Since a distribution of frequency and consequence estimates representing these low-probability, high-consequence mass-casualty events could not be derived for the fixed chemical sector with rigor comparable to the studies producing such estimates for the transportation sector, the SNRA project team elected to rely on recent historical data of more frequent accidents which have occurred in the United States. These came from two publicly available databases of comparable quality and uniformity, the Risk Management Program (RMP) database of accidents reported to the EPA by fixed facilities under the Clean Air Act, and the Pipeline and Hazardous Materials Safety Administration (PHMSA) of the Department of Transportation's database of reported road, rail, air, and water accidents involving hazardous chemicals. Both were restricted to the seventeen year range 1994-2010 covered by the RMP database.[28]

The predicted fatality versus likelihood curves from the 1974 UCLA chlorine risk assessment (Simmons et al 1974), the EPA's 1996 Regulatory Impact Analysis (RIA) for the Risk Management Program for fixed facilities (one data point, plus uncertainties in frequency and consequence[29]), and data for one-year cumulative-year totals for all TIH generated by Argonne National Labs for the 2000 Argonne NTRA are plotted in Figure 1, along with historical fatality curves for 1994-2010 for fatalities directly caused by hazardous materials for all TIH fatal accidents reported to the PHMSA and RMP databases. Note that with the exception of the EPA estimate and the historical data, these lines represent only the best estimates without uncertainty,[30] and they are not strictly comparable. In particular, the Simmons and EPA estimates and the historical data represent the annual frequency or estimated probability that an accident of that magnitude or greater will occur; the Argonne numbers represent the estimated probability that the fatalities from all accidents in a given year will total to that number or greater. As the frequency of high-fatality accidents decreases with greater fatality numbers, a large number for a given year will be more and more likely to represent the effect of one rare large accident dominating the results, and so this curve will approach the estimated frequency of a single accident having that number of fatalities or greater.[31]

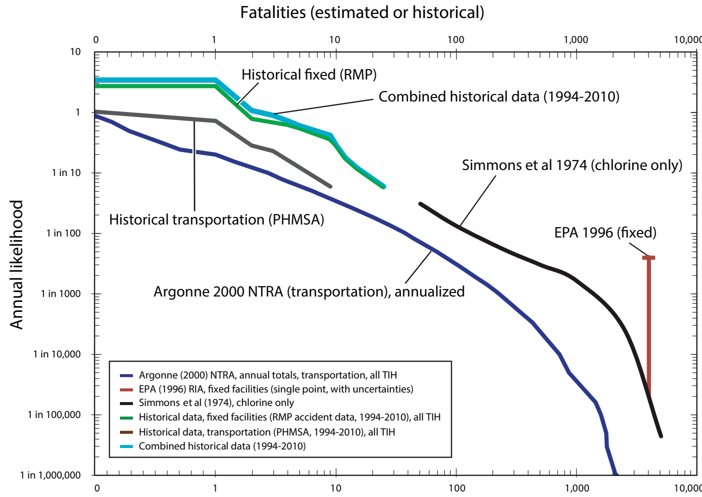

Figure 1

Note: The fatality scale from 0 to 1 is direct, and logarithmic above 1; the likelihood scale is logarithmic along its entire range. Fatalities are per event for historical data, the EPA's 1996 RIA (Regulatory Impact Analysis), Simmons et al (UCLA) 1974; annual yearly totals of all accidents for Argonne's 2000 NTRA (National Transportation Risk Assessment). Uncertainties are depicted only for the EPA point estimate, other curves are best estimate lines. The estimated uncertainty in likelihood and consequence in Argonne 2000 is a factor of 3, in Simmons et al 1974 a factor of 10 for likelihood and 2 for consequence.

The Argonne data represent 1 year totals, and total rail and road fatalities for all TIH (toxic inhalation hazard) chemicals, rather than the 10 year totals for six selected TIH chemicals as reported in the published NTRA: the line above represents actual estimated fatalities (LD-50 exposures divided by 7, see summary sheet text for reference). Historical RMP and PHMSA accident data represent all TIH accidents reported 1994-2010. Simmons et al (1974) calculated fatality estimates from chlorine transportation by rail alone, but estimated that this modality dominated the risk to the general population from fixed and transported chlorine combined: the curve here comes from the lower-fatality estimates of their evacuation model presented in figure 16 (p 53), which corresponds to the lower curve in the Rasmussen Report (WASH-1400) (see references).

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In order to restrict the set of historic events to those which presented the most significant challenge to national preparedness, the SNRA project team selected those events which either 1) caused at least one fatality outside the plant or accident location, or to a member of the public or a public responder; or 2) caused at least one fatality of any kind (public, public responder, or employee), and which also resulted in an evacuation or a shelter-in-place order. These criteria excluded accidents causing fatalities only among workers, if no evacuation or shelter orders were issued. In choosing these criteria, the SNRA project team attempted to select those events which had a serious impact to public health outside the plant or industry where it occurred. These criteria, while imperfect, reflect the difference in public perception between the voluntary acceptance of the risk of occupational hazards by those who choose to work in the chemical

26 [Simmons] also explicitly ruled out treatment of earthquake hazards to chemical plants or storage tanks for similar reasons (p 39).

27 [Mississauga], [City-Mississauga]. The identity of the slush as a semi-frozen mixture of chlorine and water was the assessment of hazardous materials experts on the scene at the time of the accident [City-Mississauga]; chemical interactions between the chlorine and water may have made the composition of the plugging slush more complicated.

For discussion of mass evacuations from chemical accidents in general, see [Cutter-1989], [Cutter-1991], [Sorensen].

28 The EPA's Risk Management Program was established in 1999 to implement new reporting requirements from amendments to the Clean Air Act introduced after the Bhopal disaster. It requires fixed facilities producing, consuming, or storing more than a threshold quantity of a listed hazardous chemical in any single container or set of interconnected containers to report all accidents in the prior five-year period resulting in any loss of life, injury, environmental damage, evacuation or shelter-in-place orders, any economic damage outside the facility, or significant (judged by the reporting company) economic damage to the facility itself. It has been extensively studied and described by [Belke], [Wharton], [Kleindorfer], and in other papers available at the latter publication's parent site (http://opim.wharton.upenn.edu/risk/papers.php.) The EPA provided the SNRA project team with a disk containing the RMP accident databases through July 2011 for direct analysis. This database is also conveniently available on the Web through the Right to Know Network's site [RTK].

The PHMSA transportation database is available online [PHMSA-database].

29 The likelihood (vertical) uncertainty is the range cited above, and represents the product of the uncertainty about the base likelihood of a Bhopal-style accident to occur in the U.S. (to what extent historical frequency data should be modified by an estimate of different conditions in the U.S. than in India) and the uncertainty about how much the net risk of high-consequence chemical accidents would decrease subsequent to the RMP's coming into effect in years following 1996. The consequence (horizontal) uncertainty is the range represented by the estimate of "on the order of 4,000 fatalities", which for the purposes of graphing was taken to mean the range 3,500 – 4,499, the significant-figure uncertainty represented by the use of a single significant figure (this is the range which would be rounded up or down to 4,000).

30 The uncertainty in the Argonne numbers (frequency and consequence) are a factor of 3 ([Argonne-2000] p 5). The uncertainty estimates given by the UCLA Simmons et al (1974) report are a factor of 10 in frequency and a factor of 2 in consequence ([Simmons] pp 3, 41, 43).

31 The Argonne report reported ten-year totals rather than single-year totals: these also (when divided by ten) will approximate the annual estimated probability of a single catastrophic high-fatality accident for fatality levels taken above a sufficiently high selected threshold to reduce to a minimum the likelihood that a high ten-year total could represent two or more medium-sized accidents, rather than be dominated by one very large, very rare accident. In order to allow for this approximation to be valid for a larger range of consequence data, Dan Brown of the original Argonne team kindly calculated single-year totals for the SNRA project team from the original study data and computer program. To extend the scope of the results to the class of chemical hazards the SNRA project team was considering, Dr Brown also extended the calculations to include estimates for all TIH chemicals transported by road and rail, rather than the top six TIH chemicals reported in the original study (which the authors estimated represented 90% of the total TIH hazard, [Argonne-2000] p 8). These data, divided by the factor of seven which the study authors themselves applied (to account for expected mitigating factors such as sheltering-in-place, pp 122-123) to convert their estimates of LC-50 fatal exposures to estimates of actual fatalities, are the data plotted in the graph above. Loading and unloading accidents may be reflected in the historical data, but were excluded from the risk assessment of the Argonne study ([Argonne-2000] pp 9-10).

industry, and the involuntary risk to the general public from chemical accidents.[32]

Assumptions

Frequency, fatality, injury and illness, direct economic loss, and social displacement estimates were determined from the set of all reported toxic inhalation hazard (TIH) incidents from 1994-2010 in two historical accident databases, the EPA RMP database for fixed facilities and the PHMSA database for transportation accidents. The EPA's RMP (Risk Management Program) maintains a database of accident reports from fixed industrial producers and consumers of listed toxic chemicals above given threshold limits. The Department of Transportation's Pipeline and Hazardous Substances Administration (PHMSA)'s database records road, rail, water, and air transportation accidents.

Low, best, and high estimates for fatalities, injuries and illnesses, direct economic loss, and number of displaced from homes for at least two days come from the low, average, and high values of historical incidents in this set meeting threshold criteria for the Chemical Substance Release event. Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents occurring within one year (high) from this set.

Environmental impact estimates were elicited from EPA subject matter experts.

Fatalities and Illnesses/Injuries

The SNRA project team used the following assumptions to estimate health and safety consequences caused by an accidental toxic inhalation hazard (TIH) chemical release event:

- The scope of this national-level event was limited to chemical accidents having the potential to cause a large number of human casualties in the brief timescale characterizing what is commonly considered to be an 'event'. As the class of chemicals having the potential to kill a large number of people in a very short period of time is comprised almost entirely of toxic inhalation hazards which are gaseous under normal conditions, only accidents involving toxic inhalation hazards (TIH) were considered to be within the scope of this event category. This choice effectively excludes accidental spills or releases of chemicals in liquid or solid form, which form the class most likely to cause environmental damage or contamination capable of causing human death and injury over long-term exposure, and also excludes accidents primarily involving chemicals hazardous by their flammable or explosive potential, such as propane, liquefied gas, and ammonium nitrate. Included were accidents caused by chemicals listed as toxic (T) in the RMP database, and classes 2.2 (non-flammable gases, selected because ammonia is classed in this category) and 2.3 (poisonous gases) in the PHMSA database.
- The set of accidents selected were those which either 1) caused at least one fatality outside the plant or accident location, or to a member of the public or a public responder; or 2) caused at least one fatality of any kind, public, public responder, or employee, and which also resulted in an evacuation or a shelter-in-place order. Within this set, no distinction was made between fatalities (onsite, offsite, employee, responder, or public).
- From the PHMSA transportation database, only fatalities and injuries reported as being caused by the hazardous substance were included.
- The databases contained many duplicate reports, largely updates to previous reports of the same accident event: these were eliminated manually once the small threshold set was generated.

Economic Loss

In addition to the generally applicable assumptions of those listed above, the SNRA project team used the following assumptions to estimate economic consequences caused by an accidental chemical release event:

- All economic estimates were inflation-adjusted to 2011 dollars.
- The direct economic damages which fixed facilities are required to report, and update for accuracy, to the RMP database are property damage to equipment or the facility itself, and all known or readily knowable property damage outside the facility. These damages do not include business interruption costs, medical or insurance costs, or litigation or settlement costs not overlapping with the above.[33]
- The direct economic damages carriers are required to report, and update for accuracy, to the PHMSA transportation database are the value of the material (spilled chemical) which was lost, physical damage sustained by the carrier (vehicles or other cargo), damage caused to public or private property, the dollar value of the response cost, and the dollar value of any remediation and clean-up cost. These damages do not include business interruption costs, medical or insurance costs, or litigation or settlement costs not overlapping with the costs listed above.[34]
- The SNRA project team added cost estimates tied to the number of injured or killed. The cost of medical care per injury/illness was taken as $6,600, for consistency with previous DHS risk assessments (including the Integrated Terrorism Risk Assessment conducted by the DHS Science & Technology Directorate to assess the risk of chemical, biological, radiological, and nuclear terrorism).
- The SNRA project team did not attempt to estimate an equivalent dollar value or a value of a statistical life (VSL) to determine an economic cost per fatality. Instead, only the countable direct contribution to the national economy of the average annual spending of one person in a year, which the SNRA project team set at $42,500, was multiplied by the number of fatalities to estimate the loss to the economy from accident fatalities.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

Social displacement estimates for the SNRA chemical accidents event come from the same historical dataset of 1994-2010 historic toxic industrial chemical accidents in the United States used for the other quantitative measures of the accidental chemical substance release event.

- There is historical precedent for very large evacuations due to chemical accidents. After Hurricane Katrina, the evacuation of 210,000 people from Mississauga was the second largest evacuation in history in North America. However, the same historical dataset used for other metrics was used for social displacement to ensure consistency of scope across measures for this event.
- The PHMSA and RMP databases include evacuation estimates. The PHMSA database additionally reports total evacuation time; the RMP database reports the total duration of the chemical substance release itself, which the SNRA project team used as a proxy for evacuation time.[35] Only two events in the historical data set, as reported in these databases, had evacuations lasting 48 hours or more (see Data Table).
- The low, best, and high social displacement estimates represent the low (0), average (260), and high (5,400) of this set.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[36] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field

[32] The concept of 'voluntary' versus 'involuntary' risk is discussed in the introduction to [EPA-1974]; see also [EPA-1983].
[33] [RMP-reqts].
[34] [HMIR].
[35] E.g. the SNRA project team assumed that people would not return to their homes while the toxic substance was still being released, and that they would return shortly thereafter.
[36] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: accidental Chemical Substance Spill or Release was given a C_{EF} of 1.1.
The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (such as chemical or biological agent, contamination extent, persistence and toxicity—both chronic and acute toxicity—or infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Moderate." Experts made this estimate given that the primary set of scenarios considered for this event were releases of toxic gases which could cause large numbers of human casualties. The widespread release of a toxic gas could contaminate tens to hundreds of acres with toxic material, but not on a catastrophic scale compared with other types of disaster.
- The greater likelihood for toxic releases to happen in sparsely populated areas, although decreasing human fatalities, increases the potential for ecological damage.
- Persistence was also judged to be a possible issue. The more persistent the chemical, the greater the impact it will have on the environment. There is also a potential for water contamination (depending on the contamination, and the spread of the contaminant through water), which could elevate a chemical disaster to an environmentally high impact event.

Potential Mitigating Factors

It appears that the risk from chemical accidents has been decreasing in recent years and, should current trends continue, is expected to continue decreasing. The combination of new reporting requirements for fixed facilities in this country introduced in the years 1986-1999 following the Bhopal catastrophe, pressure from local and issue-oriented public policy groups, and sharply increased public and political attention on the potential attractiveness of chemical facilities to terrorist attack following 9/11 has resulted in a significant reduction in the quantities of highly toxic chemicals held by fixed facilities located in the most populated areas nationwide, largely due to the substitution of less toxic intermediates where possible.[37] Although attempts at directly reducing the risk from transportation accidents by regulation and rerouting have been less successful,[38] the decreased end-user need for the most toxic chemicals at fixed facilities has also reduced the quantities being transported, reducing the overall risk from transported toxic chemicals in a similar fashion.[39]

Additional Relevant Information

Although the majority of fatal chemical accidents which have occurred in recent years have occurred in rural areas or small population centers, because road and rail traffic is so routinely routed through urban centers of high population density[40] and because of cities' dependence on water treatment plants which frequently use large amounts of chlorine,[41] some of the risk from the most catastrophic chemical accidents appears to be broadly spread among the American population. However, much of the risk appears to be geographically and socially distributed less evenly. As noted above, Chicago is at particular risk from chemical accidents by rail, and earthquake-prone regions such as California from fixed facilities. The bulk of the nation's chlorine production factories are located on the Gulf Coast:[42] although these factories withstand hurricanes on a regular basis,[43] their location increases that region's risk exposure to at least transportation accidents as their manufactures must be shipped out.[44] A risk factor particular to the fixed chemical sector, having possible social consequence as demonstrated by the government's experience of Hurricane Katrina, is the finding from studies of RMP accident data that fixed chemical facilities rated as 'highest risk' are disproportionally situated in counties having higher minority populations. This correlation persists after other demographic factors, including geographic location and poverty levels, are factored out.[45]

[37] In addition to accidents, the EPA's Risk Management Program requires facilities holding more than a threshold quantity of a listed hazardous chemical in a single container or set of interconnected containers to submit risk assessments including modeling the consequences of the worst-case-possible scenario on surrounding populations. The number of reporting facilities substantially decreased from the first reporting period 1995-2000 to the second 2000-2005, in large part because many sites reduced the amount of chemical on-site or the amounts in any one ruptureable container below the reporting thresholds [Wharton]. Concerns about terrorists targeting chemical plants predate 9/11, and were the primary reason the EPA partially restricted the RMP data from public access [Wharton], [CRS]. Other risk reduction examples include the widespread substitution of sodium hypochlorite (concentrated bleach) for pure liquefied chlorine by water treatment facilities and the consumer bleach manufacturer Clorox, and DuPont's switching a pesticide manufacturing process from a batch production process requiring 40-50,000 pounds of the Bhopal chemical methyl isocyanate to a continuous process consuming the intermediate as it is produced, such that no more than two pounds of the chemical exists on-site at any one time [SHG] pp 3-2 – 3.4. Also see [CAP-2006], [CAP-2008], [PIRG].

[38] [Branscomb] pp 7-9, 41-46 for unsuccessful rerouting attempts by local city councils, recent safety standards on new railcars not yet realized because of low turnover in railcar fleet.

[39] Recent annual shipment rates of chlorine (30,000 rail shipments in 2007) are lower than the historical average (2.2 million over 42 years, average 52,000 annually) [ACC].

[40] See note 13.

[41] [CAP-2007], map p 11. Also [PIRG], [CAP-2006], [CAP-2008], [SHG].

[42] [Branscomb] figure 1, p 12.

[43] [Challener].

[44] [DoT-1988] pp 7 to 8, page 3-12.

[45] [Wharton] pp 98, 119-122; [Elliott-2004]. See also [Cutter-1989].

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Data Table

Commodity Short Name	Date	City	State	Fixed Site or Transport	Source	'Public' Fatalities	Employee Fatalities	Total Hazmat Fatalities	Total Hazmat Injuries	Reported Loss or Damages	CPI	Adjusted (2011$)	SNRA Direct Economic Damage
Ammonia (anhydrous)	12/13/1994	Pensacola	FL	Fixed	RMP	0	4	4	27	$220,200,000	1.49	$327,330,768	$327,678,968
Chlorine	4/11/1996	Alberton	MT	Transport	PHMSA	1	0	1	787	$10,000,000	1.44	$14,438,815	$19,675,515
Ammonia (conc 20% or greater)	8/26/1997	Lancaster	OH	Fixed	RMP	5	0	5	0	$0	1.39	$0	$212,500
Ammonia (anhydrous)	11/3/1997	Sacaton	AZ	Fixed	RMP	0	1	1	1	$50,000	1.39	$69,492	$118,592
Chlorine	2/23/1998	Orlando	FL	Fixed	RMP	9	0	9	1	$0	1.39	$0	$389,100
Ammonia (conc 20% or greater)	4/22/1998	Centralia	KS	Fixed	RMP	12	0	12	0	$0	1.39	$0	$510,000
Ammonia (anhydrous)	10/10/1998	Tacoma	WA	Fixed	RMP	5	0	5	0	$11,400,000	1.36	$15,501,879	$15,714,379
Ammonia (anhydrous)	10/26/1998	Franklinton	LA	Fixed	RMP	25	0	25	0	$0	1.36	$0	$1,062,500
Ammonia (anhydrous)	1/5/2000	Green River	WY	Fixed	RMP	1	0	1	2	$0	1.32	$0	$55,700
Hydrogen chloride (anhydrous) [Hydrochloric acid]	5/17/2000	Jefferson	OK	Fixed	RMP	15	0	15	0	$300	1.32	$395	$637,895
Ammonia (anhydrous)	4/2/2001	Hammond	LA	Fixed	RMP	1	0	1	12	$5,800,000	1.28	$7,419,317	$7,541,017
Chlorine	7/14/2001	Newberg	OR	Fixed	RMP	0	3	3	51	$115,000	1.26	$144,818	$608,918
Ammonia (anhydrous)	10/16/2001	Mesquite	NM	Fixed	RMP	1	0	1	2	$600,000	1.26	$755,570	$811,270
Ammonia (anhydrous)	1/18/2002	Minot	ND	Transport	PHMSA	1	0	1	0	$0	1.26	$0	$42,500
Ammonia (conc 20% or greater)	4/11/2003	Soddy Daisy	TN	Fixed	RMP	0	1	1	0	$6,015,000	1.23	$7,405,805	$7,448,305
Ammonia (anhydrous)	4/21/2003	Lakewood	CO	Fixed	RMP	1	0	1	6	$100	1.23	$123	$82,223
Ammonia (anhydrous)	7/13/2003	Pampa	TX	Fixed	RMP	1	0	1	3	$0	1.20	$0	$62,300
Ammonia (anhydrous)	11/4/2003	Paynesville	MN	Fixed	RMP	1	0	1	1	$0	1.20	$0	$49,100
Vinyl acetate monomer [Acetic acid ethenyl ester]	4/23/2004	Illiopolis	IL	Fixed	RMP	0	5	5	6	$0	1.20	$0	$252,100
Ammonia (anhydrous)	5/25/2004	Seymour	IN	Fixed	RMP	10	0	10	0	$0	1.20	$0	$425,000
Chlorine	6/28/2004	Macdona	TX	Transport	PHMSA	2	1	3	66	$0	1.20	$0	$563,100
Chlorine	1/6/2005	Graniteville	SC	Transport	PHMSA	8	1	9	631	$8,018,600	1.16	$9,301,453	$13,848,553
Carbon dioxide (refrigerated liquid)	1/8/2005	Sanford	FL	Transport	PHMSA	1	1	2	0	$0	1.16	$0	$85,000
Ammonia (anhydrous)	8/28/2006	Ebensburg	PA	Fixed	RMP	10	0	10	4	$0	1.09	$0	$451,400
Titanium tetrachloride	6/27/2007	Westlake	LA	Fixed	RMP	0	1	1	1	$178,000	1.09	$194,485	$243,585
Argon (refrigerated liquid)	5/20/2008	Hollywood	FL	Transport	PHMSA	3	0	3	0	$0	1.05	$0	$127,500
Ammonia (anhydrous)	7/15/2009	Swansea	SC	Transport	PHMSA	1	0	1	7	$700	1.04	$727	$89,427
Ammonia (anhydrous)	11/16/2009	Cincinnati	OH	Fixed	RMP	2	0	2	0	$0	1.04	$0	$85,000

Commodity Short Name	Date	Evacuated (RMP)	Shelter in Place (RMP)	Public Evacuated (PHMSA)	Employees Evacuated (PHMSA)	Evacuated > 48 hours	Environ-mental Damage	Mode of Transportation (PHMSA) or Industry (RMP)	Cause
Ammonia (anhydrous)	12/13/1994	2,000	80			2,000	Yes	Nitrogenous Fertilizer Manufacturing	Equipment Failure
Chlorine	4/11/1996			0	0	0	No	Rail (Transportation)	Derailment
Ammonia (conc 20% or greater)	8/26/1997	0	0			0	No	Farm Supplies Wholesalers	Equipment Failure
Ammonia (anhydrous)	11/3/1997	30	0			0	Yes	Apiculture	Human Error
Chlorine	2/23/1998	0	0			0	No	Sewage Treatment Facilities	Human Error
Ammonia (conc 20% or greater)	4/22/1998	0	0			0	No	Farm Supplies Wholesalers	Equipment Failure
Ammonia (anhydrous)	10/10/1998	0	0			0	No	Refrigerated Warehousing and Storage	Equipment Failure
Ammonia (anhydrous)	10/26/1998	6	0			0	No	Corn Farming	Human Error
Ammonia (anhydrous)	1/5/2000	6	0			0	No	Ice Manufacturing	Equipment Failure
Hydrogen chloride (anhydrous) [Hydrochloric acid]	5/17/2000	0	0			0	No	All Other Basic Organic Chemical Manufacturing	Unknown
Ammonia (anhydrous)	4/2/2001	0	0			0	No	Fluid Milk Manufacturing	Unknown
Chlorine	7/14/2001	2,000	0			0	Yes	Petrochemical Manufacturing	Equipment Failure
Ammonia (anhydrous)	10/16/2001	0	0			0	Yes	Corn Farming	Human Error
Ammonia (anhydrous)	1/18/2002			0	0	0	No	Rail (Transportation)	Derailment
Ammonia (conc 20% or greater)	4/11/2003	26	1,500			0	Yes	Flavoring Syrup & Concentrate Manufacturing	Equipment Failure
Ammonia (anhydrous)	4/21/2003	20	0			0	Yes	Farm Supplies Merchant Wholesalers	Human Error
Ammonia (anhydrous)	7/13/2003	0	0			0	No	Fresh and Frozen Seafood Processing	Equipment Failure
Ammonia (anhydrous)	11/4/2003	0	0			0	No	Other Farm Product Raw Material Merchant Wholesalers	Human Error
Vinyl acetate monomer [Acetic acid ethenyl ester]	4/23/2004	980	0			0	No	Plastics Material and Resin Manufacturing	Unknown
Ammonia (anhydrous)	5/25/2004	8	4			0	No	Farm Supplies Merchant Wholesalers	Equipment Failure
Chlorine	6/28/2004			0	0	0	Yes	Rail (Transportation)	Crash/Derailment
Chlorine	1/6/2005			5,400	0	5,400	Yes	Rail (Transportation)	Derailment
Carbon dioxide (refrigerated liquid)	1/8/2005			0	0	0	No	Highway (Transportation)	Human Error (Loading Accident)
Ammonia (anhydrous)	8/28/2006	0	0			0	No	Animal Slaughtering and Processing	Equipment Failure
Titanium tetrachloride	6/27/2007	0	100			0	No	Inorganic Dye and Pigment Manufacturing	Equipment Failure
Argon (refrigerated liquid)	5/20/2008			0	0	0	No	Water (Transportation)	Equipment Failure (Corrosion)
Ammonia (anhydrous)	7/15/2009			0	5	0	No	Highway (Transportation)	Equipment Failure
Ammonia (anhydrous)	11/16/2009	0	0	0	0	0	No	Farm Supplies Merchant Wholesalers	Unknown

Dam Failure

Accidental conditions where dam failure and inundation results in one fatality or greater. This event does not include releases caused by malicious acts.[1]

Data Summary[2]

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[3]	1	17	170
Injuries and Illnesses	Number of Injuries or Illnesses[4]	0	50	3,000
Direct Economic Loss	U.S. Dollars	N/A[5]		
Social Displacement	Displaced from Homes ≥ 2 Days[6]	1	500	250,000
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[7]	Moderate[8]		
Frequency of Events	Number per Year[9]	0.17	0.54	3

Event Background

A catastrophic dam failure may be caused by extraordinary levels of rainfall or snowmelt, leading to water levels higher than the dam can handle. Dam failures can also be caused by earthquakes, mechanical failure of the dam, and other mechanisms. The most common cause of dam failure is prolonged rainfall that produces flooding.[10]

The scope of this event does not include dam failures caused by intentional attacks, whether kinetic (e.g. explosives) or cyber attacks, which are considered within the Explosives Terrorist Attack and the Cyber Event affecting Physical Infrastructure events respectively. The U.S. Department of Homeland Security is the lead Sector-Specific Agency for managing risks to the Dams Sector due to intentional attack under the National Infrastructure Protection Plan.[11] Scenarios analogous to the levee failure of Hurricane Katrina, where the levees are local to the community suffering destruction and their failure is directly caused by a hurricane which itself directly impacts the community, are also excluded from the scope of this event to avoid double counting with the Hurricane event.

There are 83,000 dams listed in the National Inventory of Dams.[12] People, property, and infrastructure downstream of dams could be subject to a devastating loss of life and damage in the event of sudden and unexpected collapse. The United States Society on Dams, a professional organization devoted to dam engineering, safety, and environmental issues, notes that 17 dams in the U.S. are over 500 feet in height, and there are 16 dams with reservoir capacities over 3 million acre-feet.[13] The number of high-hazard-potential dams (dams whose failure would cause loss of human life) has increased to 13,000, with more than 3,300 high and significant dams located within one mile of a downstream population center and more than 2,400 located within two miles.[14,15]

In addition to single dam failures, there is also the possibility of a failed dam stressing other dams downstream, causing a cascading and escalating catastrophic disaster.

The most significant factor determining the magnitude of life loss from a dam collapse is the speed and extent of population evacuation before the water arrives, which is primarily dependent upon warning time, communications, local emergency planning and preparedness, and whether local road networks allow for the rapid evacuation of downstream populations to higher ground within what may be only minutes.[16,17,18] Deaths on a massive scale may result if an evacuation cannot be quickly implemented to move people above inundation levels.

Assumptions

Although numerous estimates of failure likelihoods and consequences for particular dams may be found in the literature,[19,20,21,22,23,24,25,26,27,28,29] many of which are based upon detailed quantitative modeling,[30,31] the SNRA project team was unable to locate an overall quantitative assessment of national dam risk during the research phase of the SNRA project. The closest example of such an assessment was a quantitative risk assessment of major California dams[32] done for the U.S. Atomic Energy Commission's 1974 WASH-1400 report, a comparative assessment of civilian nuclear power risk relative to other catastrophic risks to the Nation which parallels the SNRA in many respects.[33] Although this dams study pioneered a number of quantitative methods used by subsequent studies, because it was the first of its kind and because of its limited geographic scope the SNRA project team were unable to determine how representative its

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[1] The data and findings for the SNRA Dam Failure event were completed in 2011, but a separate risk summary sheet for the event was not completed (the data were reported as a spreadsheet). This risk summary sheet as a text description for this data was written in 2013 using material written for the main body of the Technical Report.
[2] The data reported in this table represent historical U.S. dam failures reporting one or more human fatality from 1960-2009, compiled by the Dams Sector Office (DHS/NPPD) from U.S. Bureau of Reclamation historical data (Table 1).
[3] Low, best, and high estimates for fatalities come from the low, average, and high values of the set of events meeting threshold criteria.
[4] The high injury estimate is the highest reported injury from a subset of the events in the overall data set for which injury reports were available. The low injury estimate was selected to be zero by the SNRA project team, as the most reasonable assumption consistent with the sparse data available and the pattern observed from fatality counts from the set. The best estimate is the geometric mean of the high estimate and 1 (since a geometric mean cannot be taken of zero). See Injuries discussion for details.
[5] Additional analysis is required to estimate the direct economic impacts of dam failure. Studies of some specific dams have estimated economic impacts in the hundreds of millions to billions of dollars, but may not be representative of the full set of dams in the U.S.. See Economic discussion for details.
[6] See Social Displacement discussion for details.
[7] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[8] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[9] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 2 above.
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results were of the true risk of catastrophic dam failure for the entire Nation in the present day.

For this reason, the SNRA project team elected to use U.S. historical data for its quantitative estimates of likelihood and fatalities for the dam event. The historical data were provided to the SNRA project by the Dams Sector Office of the Office of Infrastructure Protection, DHS/NPPD as part of a prepublication draft report on consequence estimation for dam failures.[34] The threshold selected for the Dam Failure national-level event for the SNRA project was one or more human fatalities. Since this source's data set included all dam failures with one or more fatality from 1960-2009 but only failures causing 25 or more fatalities before 1960, the SNRA project team selected 1960-2009 as the temporal window for its own data set. After consolidation of entries for secondary dam failures caused by the failure of upstream dams, which the SNRA treated as single cascading failure events, 26 historical events remained in the set (see Table 1 below).

Likelihood

Estimates in the literature for the annual probability of failure of a generic dam range from 10^{-5} to 10^{-3}, clustering around 10^{-4}. Given an expected lifetime of 100 years, this corresponds to a generic probability of failure of 10^{-2} for a given dam over its lifetime. As these generic estimates are ultimately based upon extrapolations from historical data, by construction these theoretical estimates are usually in good agreement with estimates derived with historical data sets such as that used by the SNRA.[35,36,37,38,39] Expected failure likelihoods of particular dams vary from one dam to another, depending on size, age, construction, local geological factors, and use.[40,41,42]

Of the historical events in table 2, the low, best, and high estimates for frequency correspond to the inverse of the longest interarrival time (in years) between events in the historical set (low estimate), the average interarrival time (best estimate), and the maximum number of events occurring within the same calendar year (high estimate).

Fatalities and Injuries

Fatality estimates correspond to the low, average, and maximum number of fatalities from events in the set. As a minimum of one fatality was used as the threshold for inclusion in the set, all events had fatalities to count.

Injuries were not reported by the primary data source relied upon for event frequency and fatalities, but were obtained separately for a limited number of events from the set by additional staff research. Of this set, the low number was 2 (Bergeron Pond Dam failure, New Hampshire, 1996) and the high number was 3000 (Canyon Lake Dam, South Dakota, 1972). The SNRA project team made the assumption that zero injuries was a reasonable low assumption. Given the sparseness of injury data, the project team decided to use a geometric mean of the high estimate (3,000) and 1 injury (since a geometric mean cannot be taken of zero) for the best estimate. This approach seemed reasonable given that the arithmetic average of the set of fatalities (17) was on the order of the geometric mean (13) of the same set.

Economic Loss

The SNRA project team could not obtain reasonably defensible estimates of economic damage from dam failure during the research phase of the SNRA project.[43] Studies of specific dam failure scenarios have estimated economic impacts in the hundreds of millions to billions of dollars. Examples include estimates ranging from $400M to $2.9B for failures of the Miller Dam and Mansfield Dam in Austin, Texas;[44] estimates ranging from $78M to $4.5B for dams in northeastern Idaho;[45] and an estimate of approximately $20B for a catastrophic failure of the Hills Creek Dam in Oregon.[46] However, the SNRA project team was unable to determine how representative this limited set of regional scenarios were of the economic risk of dam failure for the Nation as a whole.

Social Displacement

The breaching of a major dam would force an enormous evacuation of downstream residents. Studies of two different dams predicted over 250,000 people would be required to evacuate if there were a catastrophic dam failure at the Hills Creek Dam[47] in Oregon or the Folsom Dam in California.[48] The expectation would be that disruption and displacement in the inundated area would last for an extended period, given the physical destruction of housing and infrastructure. Towns and residential areas scoured by the wall of water would take years to rebuild.

The SNRA project team was not able to collect data over the full range of dam breach events within the historical data set. Because fatalities, the scale for which the SNRA project team was able to determine consequences for each event in the data set by construction, clustered at the minimum of 1 and included very few much larger-consequence events, the SNRA project team assumed a similar pattern for social displacement, assuming a minimal value (1 displaced) for the low estimate of social displacement. As with injuries, the SNRA project team selected the geometric mean of the low and high estimates (500) as the best estimate.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[49] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

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[43] The primary data source did not report economic loss estimates. For an approach relating economic losses to Population At Risk (PAR), see page 13 of Dams Sector (2011, September): Estimating Economic Consequences for Dam Failure Scenarios. Office of Infrastructure Protection, National Protection and Programs Directorate (NPPD), U.S. Department of Homeland Security; http://www.damsafety.org/media/Documents/Security/DamsSectorConsequenceEstimation-EconomicConsequences.pdf (checked April 2013).

[44] Texas Colorado River Floodplain Association, op cit.

[45] Northeastern Idaho Region, 2008. All Hazard Mitigation Plan Regional Summary, p 33.

[46] Goettel, *op cit.*

[47] Oregon Partnership for Disaster Resilience. (2009). Eugene/Springfield Multi-Jurisdictional Natural Hazards Mitigation Plan. Prepared for The Cities of Eugene and Springfield, Oregon. October 2009. Accessed July 19, 2011: http://www.eugene-or.gov/portal/server.pt/gateway/PTARGS_0_2_355923_0_0_18/NHMP09.pdf.

[48] Ayyaswamy, supra note 2. The 250,000 estimate is actually of fatalities, largely in Sacramento, following a catastrophic breach of Folsom Dam. This does not, however, take into account the effects of evacuation: given the distance between the dam and the most populated portion of the city, an instantaneous break would still give 2-3 hours of water travel time for warning and evacuation of this downstream population time (according to an experimental evacuation model provided by Ayyaswamy but not applied to Folsom in the study) assuming no impairment of civil communications or transport. Hence the SNRA project team considered this was unlikely to be a realistic fatality estimate for the most likely Folsom Dam breach scenario. However, since few homes in the path of the water would remain habitable, it was considered to be a reasonable estimate for social displacement, defined as the number of people displaced from their homes for two or more days.

[49] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: dam failures were given a C_{EF} of 1.0.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (such as chemical or biological agent, contamination extent, persistence and toxicity—both chronic and acute toxicity—or infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Moderate." Experts assessed that the water released could impact a significant area, but the duration of impact would likely be short term, with a year or more for recovery.

Table 1. Historical U.S. Dam Failures causing Loss of Life, 1960-2009[1]

Dam	State	Date of Failure	Failure Cause	Dam Height (Feet)	Volume Released (Ac-Ft)	Size Category	Warning Time (Hours)[2]	People at Risk[3]	Loss of Life	Injuries
Electric Light Pond Dam	NY	1/1/1960	n/a	26	n/a	Small	n/a	n/a	1	
Mohegan Park Dam	CT	3/6/1963	Piping during elevated level from rainfall	20	138	Small	0	500	6	6[4]
Little Deer Creek Dam	UT	6/16/1963	Piping during normal weather	86	1,150	Intermediate	0	50	1	
Baldwin Hills Dam	CA	12/14/1963	Piping during normal weather	66	700	Intermediate	1.3	16,500	5	
Swift Dam	MT	6/8/1964	Overtopping	157	34,300	Large	Probably 0	n/a	19	
Cripple Creek Dam No. 3 and domino failure of Dam No. 2	CO	6/17/1965	Rainfall caused failure of No. 3, then overtopping failure of No. 2	n/a	640	Small	0	10	1	
Lee Lake Dam	MA	3/24/1968	Piping during normal weather	25	300	Small	0	80	2	
Virden Creek Dam	IA	7/17/1968	Overtopping	20	1,100	Intermediate	n/a	5,400	1	
Buffalo Creek Coal Waste Dam	WV	2/26/1972	Slumping of dam face during 2-year rainfall	46	404	Intermediate	0	4,000	125	1,000[5]
Lake "O" Hills	AK	4/1/1972	n/a	15	48	NJS[6]	n/a	n/a	1	
Canyon Lake Dam	SD	6/9/1972	Overtopping; 245 total deaths from area-wide flood	30	700 (10,100 flood total)	Intermediate	0	10,750	165	3,000[7]
Lakeside Dam	SC	9/18/1975	Overtopping	n/a	n/a	n/a	n/a	n/a	1	
Bear Wallow Dam	NC	2/22/1976	Rainfall; probable overtopping	36	40	Small	0	8	4	
Teton Dam	ID	6/5/1976	Piping during initial reservoir filling	305	250,000	Large	1.2	25,000	11	800[8]
Laurel Run Dam	PA	7/20/1977	Overtopping	42	450	Intermediate	0	150	40	
Kelly Barnes Dam	GA	11/6/1977	Embankment slope failure during 10-year flood	40	630	Intermediate	0	250	39	
Eastover Mining Co. Dam	KY	12/18/1981	n/a	n/a	77	Small	n/a	100	1	
Lawn Lake Dam + Cascade Lake Dam[9]	CO	7/15/1982	Piping during normal weather; Overtopping resulting from Lawn Lake Dam failure	26; 17	674; 25	Small; NJS	0; some	25; 4,275	3	
D.M.A.D. Dam	UT	6/23/1983	Backcutting from collapse of downstream diversion dam	29	16,000	Intermediate	1+	500	1	
Nix Lake Dam	TX	3/29/1989	Overtopping	23	837	Small	0	6	1	
Evans Dam + Lockwood Dam[10]	NC	9/15/1989	Overtopping; Overtopping resulting from Evans failure	18; 14	72; 32	Small; NJS	n/a; n/a	n/a; n/a	2	
Kendall Lake Dam	SC	10/10/1990	Overtopping	18	690	Small	0	n/a	4	
Timberlake Dam	VA	6/22/1995	Overtopping	33	1,449	Intermediate	0	Road traffic[11]	2	
Bergeron Pond Dam	NH	3/13/1996	Dam not overtopped	36	193	Small	0	50	1	2[12]
Mike Olson Dam (Grand Forks County Comm. No. 1 Dam)	ND	6/12/2000	Undermining of downstream end of spillway conduit	29	263	Small	0	n/a	2	
Ka Loko Dam	HI	3/14/2006	Overtopping	44	1,400	Intermediate	0	7	7	

[1] U.S. Bureau of Reclamation records of historical dam failures 1960-2009, extracted from a longer table compiled by the Dams Sector Office, Office of Infrastructure Protection, DHS/NPPD and provided to the SNRA project team September 2011. The source table corresponds to Table 2 of U.S. Department of Homeland Security (2011, September), Estimating Loss of Life for Dam Failure Scenarios, with the addition of reported injury estimates for a limited number of entries culled from other sources (as noted).
[2] "Warning Time" is defined as the interval between the first issuance of dam failure warnings and the initiation of dam failure. This definition of warning time may differ from that used elsewhere in this [the source] document. Most of the entries in this column are zero, indicating that dam failure warnings were not issued prior to dam failure. In some cases in which no warnings preceded dam failure, none of the people at risk were warned. In other cases, people living close to the dam were not warned, but warnings were issued for areas farther downstream as the dam failure was discovered or the flooding was observed. In some cases, warnings were issued for areas downstream from a dam due to natural flooding not associated with the dam failure; this was not considered a dam failure warning and was therefore assigned a zero in the table. [Footnote in source.]
[3] "People at Risk" is defined as the number of people in the dam failure floodplain immediately prior to the issuance of any flood or dam failure warning. [Footnote in source.]
[4] "Connecticut Dam Breaks, Fear Six Dead." Daily Courier, Connellsville Pennsylvania, from United Press International, March 7, 1963. At http://www3.gendisasters.com/connecticut/18029/norwich-ct-earthen-dam-breaks-mar-1963 (checked April 2013).
[5] "Buffalo Creek" [website]. West Virginia Division of Culture and History, unknown date; at http://www.wvculture.org/history/buffcreek/buff1.html (checked April 2013).
[6] Non-Jurisdictional Size.
[7] Association of State Dam Safety Officials, 2011 (April 1). Dam Failures, Dam Incidents (Near Failures). Datasheet, at http://www.damsafety.org/media/Documents/PRESS/US_FailuresIncidents(1).pdf (pdf date 4/1/11, checked April 2013).
[8] Graham, op cit; p 11.
[9] The entries for the 7/15/1982 failures of Lawn Lake Dam and Cascade Lake Dam were considered a single event (cascading failure) for the purposes of the SNRA. The columns for Failure Cause through People at Risk give each dam's information on a line of its own; the Loss of Life column gives the combined fatalities.
[10] The entries for the 9/15/1989 failures of Evans Dam and Lockwood Dam were considered a single event (cascading failure) for the purposes of the SNRA. The columns for Failure Cause through People at Risk give each dam's information on a line of its own; the Loss of Life column gives the combined fatalities.
[11] A 2-lane and 4-lane road [entry in source].
[12] U.S. Water News (1996, April). Dam break in New Hampshire damages homes, washes out highway. Online Archives, at http://www.uswaternews.com/archives/arcsupply/6newhamp.html (checked April, 2013).

Radiological Substance Release

Accidental conditions where reactor core damage causes release of radiation. This event does not include releases caused by malicious acts.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high consequences. In addition, low and high consequences are not necessarily correlated with each other between different consequence categories.

Description	Metric	Low	Best	High
Fatalities[1]	Number of Fatalities	0[2]	230[3]	2200[4]
Injuries and Illnesses[5]	Number of Injuries or Illnesses	0[2]	240[3]	2300[4]
Direct Economic Loss	U.S. Dollars	$7.5B[6]	$8.6B[3]	$16B[4]
Indirect Economic Loss	U.S. Dollars	$9.4B[6]	$11B[3]	$23B[4,7]
Social Displacement[8]	Displaced from Homes ≥ 2 days	76,000	147,000	500,000
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[9]	Moderate[10]		
Frequency of Events	Number per Year	6 e-3[11]	9 e-3[3]	1 e-2[12]

Event Background

An accidental radiological release could come from a nuclear power plant accident or public exposure to lost or stolen radioactive sources. Most recorded exposure deaths and illnesses involve patients in medical accidents, workers and scientists working with radiological materials, or releases for criminal purposes (Johnston's Archive, 2010; Mohtadi, 2006; Streeper, Lombardi, & Cantrell, 2008). There have been a few accidental releases of lost material worldwide, but the documented exposures of this type are small and less likely to happen in the United States considering the standards regulating the maintenance and transport of radioactive material. Given the consequences of a large, radiological release from a power plant, this analysis focuses on nuclear power plant accidents.

A national-level power plant accident is defined in this scenario as any accident which damages the reactor core. The risk to the public and environment based on this type of accident is highly dependent on radiation containment and the location of the reactor. Accidents causing a radiological release from spent fuel are not considered in this summary sheet as their fatality and illness risk has been calculated to be more than an order of magnitude less than that of a core damage accident (United States Nuclear Regulatory Commission (T.E. Collins, G. Hubbard), 2001).

Assumptions

Fatalities and Illnesses/Injuries

Health and safety consequences were estimated based on the following assumptions:

- The fatalities and illnesses involved in a nuclear reactor accident are latent cancer fatalities and illnesses, determined as an increase over expected background illnesses and fatalities in an unexposed population. These would occur over the lifetimes of the exposed population with no expected deaths immediately after exposure.
- The fatalities and cancer illnesses were calculated from the dose consequence information in the license renewal applications available on the website of the Nuclear Regulatory Commission (United States Nuclear Regulatory Commission).
- The High and Low consequence values use the largest consequence release events and lowest consequence events available in each report. Some reactors do not report the most likely scenarios, which make the Low consequence values higher than would be expected for the most likely scenario. The most probable low consequence scenario would be quite similar to the accident at Three Mile Island in 1979 in which it was determined that the radiological release would not raise the exposure of the population enough to cause an additional case of cancer above the expected background (Perham, 1980).
- All of the consequence estimates assume that the accident is confined to a single reactor. Damage to multiple reactors could cause higher consequences. Also, the consequences associated with external events could be greater than those for internal events (the basis for consequences in NRC models) due to potential difficulties in evacuation.

Economic Loss

Economic consequences were estimated based on the following assumptions:

- The costs associated with a nuclear power plant accident listed with the license renewal application at the website of the Nuclear Regulatory Commission (United States Nuclear Regulatory Commission) include the offsite costs associated with land remediation and business interruption for areas affected outside of the power plant, the direct costs of decontamination and disposal at the power plant site, and the cost to replace the power that would have been generated at the plant.
- The offsite costs vary depending on the size of the release. The cost of onsite decontamination and disposal as well as the cost of using a different power generator are assumed fixed.
- In determining the overall economic consequences for a radiological release incident, the SNRA project team used an approach to estimating direct, indirect, and induced economic losses. The definitions for direct, indirect, and induced costs are listed in Table 1 below:

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:

- **Decontamination, Disposal, and Physical Destruction:** DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
- **Business Interruption:** Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.

[1] Latent cancer fatalities: deaths resulting from cancer that became active after a latent period following exposure to radiation.
[2] The case with zero fatalities is drawn from the Three Mile Island core meltdown (Perham, 1980). A value of 58 fatalities and 61 illnesses would result from the most frequent, lowest consequence scenarios that were outlined in each of the license renewal reports. Despite choosing the lowest consequence events outlined in the report, some reports only contained somewhat rare, medium consequence events, raising the overall expected fatalities. Therefore, the use of the Three Mile Island accident was selected as a more representative example of the most likely results of core damage accident.
[3] The Best estimates use a simulation of the expected core damage frequencies obtained from the license renewal applications for a number of individual reactors available from the public website of the Nuclear Regulatory Commission (United States Nuclear Regulatory Commission). The data from the license renewal applications is used to perform cost/benefit analyses on reactor upgrades and the baseline data was not developed for use in a general risk assessment. Currently, this is the most recent publicly available data and adequate for order of magnitude estimates of the SNRA. An alternative analysis was also conducted using fatality, injury, and core damage frequency data from NUREG-1150, and the best estimates from this analysis were within the same order of magnitude as the results obtained using data from license renewal applications (United States Nuclear Regulatory Commission, 1990). The expected consequences are weighted by the likelihood of a core damage accident for each reactor using a Crystal Ball simulation. The details are explained in the Additional Relevant Information section.
[4] The High consequence estimates also come from the license renewal applications (United States Nuclear Regulatory Commission). The consequences correspond to the highest consequence scenarios outlined in the report. These usually involve a large, early release and assume that there is not enough time for successful evacuation. The frequency of these events is typically one to two orders of magnitude less than the frequency of any core damage event. Note that the likelihood values in the table do not correspond to the consequences for the High and Low categories.
[5] Latent cancer morbidities.
[6] The Low values of economic damage are determined from the results of the most frequent types of core damage accidents in each report as discussed in Footnote 2. The economic costs are mostly fixed values associated with business interruption and are consistent with the $1B in decontamination costs from the shutdown of Reactor 2 at Three Mile Island (*New York Times*, 1993). The replacement power costs assumed in the model should be applicable here.
[7] The current cost estimates for the Fukushima disaster are in the hundreds of billions of dollars. This includes the damage directly from the earthquake and the tsunami as well as the nuclear power plant disaster (Japanese Ministry of Economy, Trade, and Industry).
[8] The low and best estimates reflect published estimates of displacement from the Three Mile Island incident. The high estimate reflects published estimates of displacement from the Chernobyl incident (see text).
[9] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[10] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event.
[11] This number is the 5th percentile of the core damage frequencies taking into account variability across the different reactors and the uncertainty of a single reactor. Note that this frequency incorporates the uncertainty and variability of the expectation and does not directly correspond to the Low consequence values.
[12] This number is the 95th percentile of the core damage frequencies taking into account variability across the different reactors and the uncertainty of a single reactor. This does not correspond to the High consequence values which have likelihoods one to two orders of magnitude lower than the Best CDF value.

- **Loss in Spending from Fatalities:** This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality.
- **Medical Costs:** Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

Indirect Costs include:

- Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.

Induced Costs include:

- The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

- In order to apply this model to the set of costs available, the offsite, disposal and decontamination, and alternate power generation costs must be binned into the above direct costs categories.
- Because the offsite costs are assumed to mostly be due to business interruption, they are placed in that category. The alternative power generation would also be a business interruption cost. Both of these values are several billion dollars and expected to contain the majority of business interruption costs from the accident.
- Onsite decontamination and disposal should be the primary area where this type of work would need to be conducted, so these costs are directly used for the decontamination, disposal, and physical destruction category.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- For the accidental Radiological Substance Release event, the low and best estimates reflect published estimates of displacement from the Three Mile Island incident. This displacement represented voluntary evacuation by individuals and families rather than a mandatory evacuation order: the SNRA's social displacement metric counts all people displaced from homes for two or more days, whether the displacement was directed or not.[13] The high estimate reflects published estimates of displacement from the Chernobyl incident.[14]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[15] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

[13] Sources for the low and best estimates of displacement due to Accidental Radiological Substance Release are Cutter, Susan, and Kent Barnes. 1982. "Evacuation Behavior and Three Mile Island." *Disasters* 6.2: 116-124.; and Soffer, Yechiel, Dagan Schwartz, Avishay Goldberg, Maxim Henenfeld and Yaron Bar-Dayan. 2008. "Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events." *Prehospital and Disaster Medicine* 23.3: 276-281.

[14] Soffer, Yechiel, Dagan Schwartz, Avishay Goldberg, Maxim Henenfeld and Yaron Bar-Dayan. 2008. "Population Evacuations in Industrial Accidents: A Review of the Literature about Four Major Events." *Prehospital and Disaster Medicine* 23.3: 276-281.

[15] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \tfrac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: accidental Radiological Substance Release was given a C_{EF} of 1.1.

The numerical estimates calculated from this formula are reported in Appendix G. The semi-quantitative risk matrix is discussed in the Findings (Psychological Distress Risk).

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (such as chemical or biological agent, contamination extent, persistence and toxicity—both chronic and acute toxicity—or infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "moderate." Nuclear power plant disruption could cause radioactive airborne releases that could travel for large distances and settle into down-range eco-systems, with possible disruptions. In addition, releases into water bodies may have impacts on aquatic life.

Key Mitigating Factors

The consequences caused by a nuclear release are currently mitigated through several preparedness strategies. Monitoring systems indicate the need for individuals in the designated evacuation zone to evacuate to the recommended safe distance. The monitoring and warning systems are regularly tested to ensure that they are functioning properly when an event occurs. Additionally, evacuation and safe routes are identified and communicated to individuals residing or working in the evacuation zones. Further, a properly prepared and deployed response team could potentially aid in limiting exposure to the radiological substance and reducing the size of the contaminated area.

Additional Relevant Information

The frequencies of radiological releases were determined by Core Damage Frequency (CDF)[16] results provided in license renewal applications, which are available at the website of the Nuclear Regulatory Commission (United States Nuclear Regulatory Commission). Of the 104 active nuclear reactors in the United States, 81 have either completed applications for license renewal or have applications that are currently under review. As part of this license renewal process, each reactor includes an environmental report with a Severe Accident Mitigation Alternatives (SAMA) analysis, which is where the CDFs can be found. Information for reactors that do not have current license renewal applications is not available, but it was assumed that the data available on the 81 reactors with current renewal application is representative of the remaining reactors without current license renewal applications. Therefore, in accordance with this assumption, the mean internal CDFs[17] are drawn from the distribution of the 81 reactors whose information is available.

Regarding the SAMA data in the license renewal applications, it is important to note that data from SAMA analyses are developed and used to perform cost/benefit analyses on reactor upgrades, not to perform general risk assessments. However, SAMA data are the best publicly available data for our purposes and are adequate for the order-of-magnitude estimates of the SNRA. The NRC is currently re-evaluating severe accident consequences using two pilot plants. Preliminary results from this State-of-the-Art Reactor Consequence Analysis (which is still in progress[18]) indicate that selected accident scenarios could reasonably be mitigated, either preventing core damage or delaying/reducing the radiation release. For scenarios assumed to proceed without mitigation, accidents progress more slowly and result in smaller and more delayed radiological releases than previously predicted (e.g. in NUREG-1150) (Gauntt, 2008).

Furthermore, each of the reactor license renewal applications includes the CDFs associated with internal events, which are accidents arising from plant activities, such as worker error or parts malfunctions. Uncertainty

[16] **Core Damage Frequency (CDF)** - An expression of the likelihood that, given the way a reactor is designed and operated, an accident could cause the fuel in the reactor to be damaged (United States Nuclear Regulatory Commission, 2011).

[17] **Individual Plant Examination for External Events (IPEEE)** - While the "individual plant examination" takes into account events that could challenge the design from things that could go awry internally (in the sense that equipment might fail because components do not work as expected), the "individual plant examination for external events" considers challenges such as earthquakes, internal fires, and high winds (United States Nuclear Regulatory Commission, 2011).

[18] As of August 2011.

around these CDFs was collected for 15 license renewal applications, which report 5th and 95th percentiles along with mean CDFs. For example, in Reactor 1 this value is 2.10 for the ratio of the 95th percentile to the mean and 0.462 for the 5th percentile to the mean, and in Reactor 2 the ratio of the 95th percentile to the mean is 1.40, and the ratio of the 5th percentile to the mean is 0.687. However, uncertainty was collected in only 15 of the 81 CDFs (not all reports included these values), and the functions associated with the Monte Carlo runs that underlie the uncertainty are not reported. Therefore, to address this lack of information and assign uncertainty to all CDFs for all the reactors, the 15 available reports on uncertainty are used to calculate 15 separate ratios of the 95th percentile to mean and of the 5th percentile to mean. Also, it was assumed that the distributions of the 5th-mean and 95th-mean ratios for the available 15 cases would be representative of all reactors. Crystal Ball was used to find a statistical best fit for the distributions of these ratios. Then to assign uncertainty to all CDFs, the 15 reference values were used for their corresponding reactors and drew randomly from the best fit 95th-mean and 5th-mean distributions for all other reactors, multiplying their CDFs by the randomly assigned ratios in order to derive 5th and 95th percentile values for the CDFs. These distributions were chosen independently for each of the reactors, and it was assumed that the uncertainty for each of the reactors is independent: the model does not simulate a systematic dependency among the reactors' uncertainties, which could push all of the reactors' CDFs in the same direction (high or low).

The frequency of core damage caused by external events (fire, earthquake, flood, plane crash, etc.) is included in some – but not all – of the applications. For the reactors where external CDFs are readily available, they have been included directly in the frequency calculation. In the examples examined, external CDFs including fire, seismic events, and high winds are frequencies that share the same order of magnitude as the internal CDFs. For example, for two given reactors, the internal CDFs are 1.79e-5 for Reactor 1 and 1.15e-5 for Reactor 2. The external CDF values are 5.01e-5 for Reactor 1 and 5.20e-5 for Reactor 2. For reactors without external CDFs, a lognormal distribution based on the selection of 18 known external CDF/internal CDF ratios is used to calculate the variation in external factors. (The lognormal distribution was chosen based on a Crystal Ball best fit.)

The other frequency of interest is the Large, Early Release Frequency (LERF).[19] For example, in Reactor 1 the CDF of 1.79e-5 corresponds to a LERF of 6.50e-7. Similarly in Reactor 2, the CDF of 1.15e-5 corresponds to a LERF of 9.43e-7. Any event with core damage is assumed to cross the threshold of national significance and influence national preparedness goals. Therefore, the CDF is the frequency listed in the risk characteristics table above, which will include all large, early release events. Based on the data from 16 reactors, the frequency of a large, early release is between one and two orders of magnitude lower than the frequency of a more general core damage event.

The results of the analysis using license renewal applications were compared to an alternative analysis that was conducted using fatality, injury, and core damage frequency data from NUREG-1150 (United States Nuclear Regulatory Commission, 1990.). The average of the core damage frequencies taken from NUREG-1150 was multiplied by 104 (the number of active nuclear reactors in the United States) and the fatalities and dose rates taken from NUREG-1150 were used to determine the comparability of the results of the two data sources. The best estimates from the NUREG-1150 analysis were within the same order of magnitude as the results obtained using data from license renewal applications.

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[19] **Large, Early Release Frequency (LERF)** - The frequency of those accidents leading to significant, unmitigated releases from containment in a time frame prior to effective evacuation of the close-in population such that there is a potential for early health effects. Such accidents generally include un-scrubbed releases associated with early containment failure at or shortly after vessel breach, containment bypass events, or loss of containment (United States Nuclear Regulatory Commission, 2002).

Cyber Event affecting Data (Data as Target)

A cyber event[1] occurs which seriously compromises the integrity or availability of data (the information contained in a computer system) or data processes, resulting in economic losses of $1 billion or greater.

Data Summary

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	Not determined		
Injuries and Illnesses	Number of Injuries or Illnesses	Not determined		
Total Economic Loss	U.S. Dollars	Not determined		
Social Displacement	Number of Displaced from Homes for ≥ 2 Days	0		
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[2]	None[3]		
Frequency of Events	Number per Year	See classified data table		

Event Background

This category includes cyber attacks that focus on compromising data or data processes as the primary result. Such attacks could take many forms and be perpetrated in order to achieve many goals. Some examples might include the altering of records in a healthcare or financial system or an attack which causes the internet, communications networks, or data processes to cease.

While frequency information about the type of data/data processes attacks included in this category is difficult to locate in open source material, there are several observations that can assist in setting the context.

A 2010 Verizon report analyzing 141 data breach cases from 2009 (worked by either the Verizon Investigative Response Team or the U.S. Secret Service) estimated the total number of data records compromised across these cases to exceed 143 million.[4] Consistent with previous years, most of the losses in 2009 came from only a few of the 141 breaches. The average number of records lost per breach was 1,381,183, the median only 1,082, and the standard deviation 11,283,151.[5]

In the case of denial-of-service events, according to a 2010 CSIS-McAfee survey of 200 critical infrastructure executives from the energy, oil/gas, and water sectors in 14 countries, nearly 80 percent of the respondents reported facing a large-scale denial-of-service attack in 2010 (up from just over half in 2009), with a quarter reporting daily or weekly denial-of-service attacks on a large scale.[6]

Additionally, one in four of the CSIS-McAfee respondents said they had been the victim of extortion through attack or threat of attack to IT networks in the past two years—an increase from one in five respondents from the previous year.[7]

Consequences for the types of attacks in this event category are difficult to quantify, as they depend on the particular system attacked, the vulnerability and resilience of the network, specific data backup provisions, and other factors. A sample of several historical data/data processes-related cyber attacks is presented in the "Additional Relevant Information" section below. In addition, details on the Wall Street "Flash Crash" are included in the list, in order to provide context on the potential magnitude of consequences produced by events in this category.

[1] The Cyber Attack against Data national-level event was renamed Cyber Event affecting Data in 2013 to address stakeholder concerns.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and *de minimus* (none) categories.
[3] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[4] Verizon RISK Team, 2010 Data Breach Investigations Report (2010): 7.
[5] Ibid.: 40.
[6] McAfee and the Center for Strategic and International Studies, *In the Dark: Crucial Industries Confront Cyberattacks* (April 2011): 6.
[7] Ibid.

Assumptions

Likelihood

Frequency estimates were elicited from the Intelligence Community (IC) by the SNRA project team in July-August 2011.[8] Only attacks resulting in $1 billion in losses or greater were considered. The frequency estimates for this event are classified, but are provided in the data tables of the classified SNRA Technical Report.

Frequency estimates were based on the following assumptions regarding the scope of events in this category.

- **General Scope:** This category includes cyber attacks that focus on compromising data or data processes as the primary result. Although events in this category almost always have indirect effects that "go beyond the computer," only events in which these types of effects are a function of modern reliance on computer systems—rather than the primary objective of the attack—were considered.
- **Actor Types:** Given the goal of capturing the full range of national-level possibilities within each type of incident, events in which cyber attacks are intentionally caused by any type of human actor, including, e.g., hackers, activists, states, terrorists, malicious insiders, or criminals, were considered. Unintentional human-caused events (such as unintentional breaches or accidents) or non-human-caused events (such as those caused by natural disasters or equipment malfunctions) were not considered.
- **Weapon Types:** All types of cyber weapons, including but not limited to malicious software, botnets, distributed denial-of-service attacks, etc., were considered.
- **Target Types:** Any type of civilian target was considered. Note that for the purposes of the SNRA—which is intended to inform civilian capability development—direct attacks on defense systems were not considered. Additionally, state- and non-state- sponsored espionage was not considered.
- **Time Period:** The SNRA focuses on estimating risk within the next five years, in support of the overall need to focus on future-oriented core capability development.
- **National-level Threshold:** As stated above, the SNRA is designed to assess the risks of those events and incidents which create consequences that rise to a strategic, national-level of impact. Thus, small-scale attacks, which occur on a daily basis, were not considered. Instead, only high-impact events, which could produce a national level of awareness due to major consequences related to life safety, economic damage, psychological damage, social displacement, or environmental damage were considered.

Fatalities, Injuries and Illnesses, Economic Damage

Defensible estimates could not be obtained on these consequence measures. Additional analysis will be needed to quantify the human health and economic impacts of the Cyber Event affecting Data event.

Psychological Distress

Since the SNRA measure of psychological distress is tied to fatality and illness/injury estimates, psychological distress estimates were not reported in the SNRA for the Cyber Event affecting Data national-level event.[9]

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

[8] IC participants in the Cyber Event affecting Data frequency elicitation included subject matter experts from multiple agencies. The frequency estimates (see classified SNRA Technical Report) reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.
[9] The SNRA measures psychological distress by a Significant Distress Index calculated from fatality, illness/injury, and social displacement estimates using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is anexpert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: experts assessed a C_{EF} of 1.0 for the Cyber Event affecting Data national-level event.
Although the SNRA determined null social displacement estimates for the Cyber Event affecting Data, scenarios which could credibly threaten human health and safety without forcing people to flee their homes remained part of the event scope and so the SNRA project team could not assume zero estimates for fatalities and illnesses/injuries as well.

- As the Cyber Event affecting Data national-level event is restricted to cyber events not directly causing impacts on the physical world, the SNRA project team assessed the low, best, and high estimates for social displacement to be zero.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "de minimus" or none.

Potential Mitigating Factors

The risk of this type of cyber attack can be mitigated through several preparedness strategies. Practices such as employing advanced authentication measures, the use of encryption technologies, and the monitoring of network use for anomaly detection would help to prevent, more quickly identify, and facilitate a timely response to cyber attacks.[10] In addition, organizations can employ tailored strategies that increase resilience to cyber attacks on data. These could include strategies such as employing back-up systems and developing plans for maintaining operations without the use of computer systems.

Additional Relevant Information

A sample list of several historical data/data processes related to cyber attacks is presented below. Details on the Wall Street "Flash Crash" are included in the list, in order to provide context on the potential magnitude of consequences produced by events in this category.

Attacks on Data and the Potential Magnitude of Compromised Data Integrity or Accessibility[11]
Seattle Hospital Denial of Access. Cyber criminals in 2007 compromised the networks of a Seattle hospital, causing system malfunctions including the crash of the Intensive Care Unit Network.
Wall Street "Flash Crash." In Wall Street's May 2010 "flash crash," complex automated trades created enough market volatility to hemorrhage approximately 1 trillion dollars in only minutes, with some stocks dropping more than 90 percent in value. While the volatility was unintentional and the stocks recovered, the crash illustrates the potential consequences of sophisticated cyber attacks against a financial system that relies increasingly on automated high-frequency trading.[12]

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[10] See McAfee and the Center for Strategic and International Studies: 24.
[11] This list was provided to the participants in the frequency elicitation, to encourage consideration of potential consequences of a cyber attack against data.
[12] Quoted in full from David Pett, "High-Frequency Swaps, Dark Pools Under Scrutiny," *National Post's Financial Post & FP Investing* (8 May 2010) and Kara Scannell and Tom Lauricella, "Flash Crash Is Pinned On One Trade," *The Wall Street Journal* (2 October 2010) as cited in Lord and Sharp: 1:25.

Cyber Event affecting Physical Infrastructure (Vector)

A cyber event[1] in which cyber means are used as a vector to achieve effects which are "beyond the computer" (i.e., kinetic or other effects), resulting in one or more fatalities or economic losses of $100 million or more.

Data Summary

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities	Not determined		
Injuries and Illnesses	Number of Injuries or Illnesses	Not determined		
Total Economic Loss	U.S. Dollars	Not determined		
Social Displacement	Displaced from Homes ≥ 2 Days	0	400	Not determined
Psychological Distress	Qualitative Bins	See text		
Environmental Impact	Qualitative Bins[2]	None[3]		
Frequency of Events	Number per Year	See classified data table		

Event Background

This category encompasses cyber attacks that directly produce national-level effects outside the virtual world. These types of events could involve a variety of targets, such as large-scale assets in a variety of critical infrastructure sectors. Examples might include the electric grid, a dam, or the water system.

The threat of this type of event has seen increased prominence recently, as the extent of the Stuxnet infections have come to light. According to a 2010 CSIS-McAfee survey of 200 critical infrastructure executives from the energy, oil/gas, and water sectors in 14 countries, around 40 percent of respondents found Stuxnet on their computers.[4] While three-quarters of respondents who found Stuxnet were confident it has been removed from their systems, the potential for widespread sabotage through the introduction of malware into SCADA systems was clearly demonstrated.[5] The 2007 "Aurora" tests conducted at Idaho National Labs further confirmed the proposition that hackers could gain remote access to a control system and, in that case, remotely change the operating cycle of a generator, sending it out of control.[6]

More than 40 percent of the executives interviewed in the CSIS-McAfee survey reported they expected a major cyber attack within 12 months—i.e., an attack that would cause severe loss of services for at least 24 hours, a loss of life or personal injury, or the failure of a company.[7] It should be noted, however, that the types of attacks cited in the study—though important for individual companies—would not necessarily produce consequences that would rise to the threshold for a national-level event.

Consequences for the types of attacks in this event category are sector dependent and difficult to quantify. Approximately 85% of critical infrastructure is believed to be owned and operated by the private sector, and system vulnerability and resilience is highly sector-dependent and localized.[8] A sample of historical attacks on the SCADA systems of critical infrastructure assets, along with a list of unintentional or non-cyber related failures within critical infrastructure sectors is included in the "Additional Relevant Information" section below.

Assumptions

Likelihood

Frequency estimates were elicited from the Intelligence Community (IC) by the SNRA project team in July-August 2011.[9] Only attacks resulting in one or more fatalities, or $100 million in losses or greater were considered. The frequency estimates for this event are classified, but are provided in the data tables of the classified SNRA Technical Report.

Frequency estimates were based on the following assumptions regarding the scope of events in this category:

- **General Scope:** This event encompasses cyber attacks that directly produce national-level effects outside the virtual world. While the attacks in this category may involve the manipulation of data as a means to an end, an event whose *direct* result is only compromised data (such as intellectual property theft or altered healthcare records) was not considered.
- **Actor Types:** Given the goal of capturing the full range of national-level possibilities within each type of incident, events in which cyber attacks are intentionally caused by *any* type of human actor, including, e.g., hackers, activists, states, terrorists, malicious insiders, or criminals, were considered. Unintentional human-caused events (such as unintentional breaches or accidents) or non-human-caused events (such as those caused by natural disasters or equipment malfunctions) were not considered.
- **Weapon Types:** All types of cyber weapons, including but not limited to malicious software, botnets, distributed denial-of-service attacks, etc., were considered.
- **Target Types:** Any type of civilian target was considered. Note that for the purposes of the SNRA—which is intended to inform civilian capability development—direct attacks on defense systems were not considered. Additionally, state- and non-state- sponsored espionage was not considered.
- **Time Period:** The SNRA focuses on estimating risk within the next five years, in support of the overall need to focus on future-oriented core capability development.
- **National-level Threshold:** As stated above, the SNRA is designed to assess the risks of those events and incidents which create consequences that rise to a strategic, national-level of impact. Thus, small-scale attacks, which occur on a daily basis, were not considered. Instead, only high-impact events, which could produce a national level of awareness due to major consequences related to life safety, economic damage, psychological damage, social displacement, or environmental damage were considered.

Fatalities, Injuries and Illnesses, Economic Damage

Defensible estimates could not be obtained on these consequence measures. Additional analysis will be needed to quantify the human health and economic impacts of the Cyber Event affecting Physical Infrastructure event.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Low and best estimates of social displacement estimates for the Cyber Event affecting Physical Infrastructure national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[10] The low estimate of 0 reflects assessed judgment of START subject matter experts. The best estimate of 400 comes from a case study of an evacuation of an U.S. Army base due to a large but accidental power outage: this historical event was considered a reasonable proxy for displacement due to an intentional power outage following a cyber attack on the electrical grid.[11]
- No high estimate was determined. However, START subject matter experts noted that a cyber event causing a prolonged power outage over a large area

[1] The Cyber Attack against Physical Infrastructure national-level event was renamed Cyber Event affecting Physical Infrastructure in 2013 to address stakeholder concerns.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[3] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[4] McAfee and the Center for Strategic and International Studies, *In the Dark: Crucial Industries Confront Cyberattacks* (April 2011): 8.
[5] Ibid.
[6] James A. Lewis, "The Electrical Grid as a Target for Cyber Attack," Center for Strategic and International Studies (March 2010).
[7] McAfee and the Center for Strategic and International Studies: 10.
[8] According to the Office of Infrastructure Protection, Department of Homeland Security. http://www.dhs.gov/files/partnerships/editorial_0206.shtm.

[9] IC participants in the Cyber Event affecting Physical Infrastructure frequency elicitation included subject matter experts from multiple agencies. The frequency estimates (see classified SNRA Technical Report) reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.
[10] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.
[11] Reed, Charlie and Grant Okubo. "Flooding, power outages force evacuations at Yokota." *Stars and Stripes* (July 6, 2010). http://www.stripes.com/news/pacific/japan/flooding-power-outages-force-evacuations-at-yokota-1.110071.

could result in several thousand people evacuating, regardless of the outage cause.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[12] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impacts

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g. chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "de minimus" or none. Experts indicated, however, that this depends on the duration of the event. If the consequences of the event (e.g., power outages) occur for longer than a few days, then backup systems for sewage plants, chemical facilities, etc. could fail and result in more severe environmental consequences.

Potential Mitigating Factors

The risk of this type of cyber attack can be mitigated through preparedness strategies that act on both cyber systems and the actual target itself. Cyber strategies include practices such as the use of encryption technologies and the monitoring of network use for anomaly detection.[13] Target specific strategies include the range of measures that are typically employed to manage the risk to critical infrastructure systems. These will vary from sector to sector, but, in general, strategies to increase resilience will likely assist in mitigating the consequences from this type of cyber attack, as well as other threats and hazards.

Additional Relevant Information

A sample of historical attacks on the SCADA systems of critical infrastructure assets is presented below, in order to provide context for the type of consequences that might reasonably be considered within this event category. Because many, if not all, of these attacks did not produce national-level consequences, a second list of unintentional or non-cyber related failures within the critical infrastructure sectors is presented, in order to provide context on the potential magnitude of consequences produced by events in this category.

Targeted and Nontargeted Attacks on Critical Infrastructure Control Systems[14]
Worcester air traffic communications. In March 1997, a teenager in Worcester, Massachusetts, disabled part of the telephone network using a dial-up modem connected to the system. This disabled phone service to the airport control tower, airport security, the airport fire department, the weather service, and the carriers that use the airport. Also, the tower's main radio transmitter and another transmitter that activates runway lights were shut down, as well as a printer that controllers use to monitor flight progress. The attack also disrupted phone service to 600 homes in a nearby town.
Maroochy Shire sewage spill. In the spring of 2000, a former employee of an Australian organization that develops manufacturing software applied for a job with the local government, but was rejected. Over a 2-month period, this individual reportedly used a radio transmitter on as many as 46 occasions to remotely break into the controls of a sewage treatment system. He altered electronic data for particular sewerage pumping stations and caused malfunctions in their operations, ultimately releasing about 264,000 gallons of raw sewage into nearby rivers and parks.
Los Angeles traffic lights. According to several published reports, in August 2006, two Los Angeles city employees hacked into computers controlling the city's traffic lights and disrupted signal lights at four intersections, causing substantial backups and delays. The attacks were launched prior to an anticipated labor protest by the employees.
CSX train signaling system. In August 2003, the Sobig computer virus was blamed for shutting down train signaling systems throughout the East Coast of the United States. The virus infected the computer system at CSX Corporation's Jacksonville, Florida, headquarters, shutting down signaling, dispatching, and other systems. According to an Amtrak spokesman, 10 Amtrak trains were affected. Train service was either shut down or delayed up to 6 hours.
Davis-Besse power plant. The Nuclear Regulatory Commission confirmed that in January 2003, the Microsoft SQL Server worm known as Slammer infected a private computer network at the idled Davis-Besse nuclear power plant in Oak Harbor, Ohio, disabling a safety monitoring system for nearly 5 hours. In addition, the plant's process computer failed, and it took about 6 hours for it to become available again.
Zotob worm. In August 2005, a round of Internet worm infections knocked 13 of DaimlerChrysler's U.S. automobile manufacturing plants offline for almost an hour, leaving workers idle as infected Microsoft Windows systems were patched. Zotob and its variations also caused computer outages at heavy-equipment maker Caterpillar Inc., aircraft maker Boeing, and several large U.S. news organizations.
Harrisburg, Pennsylvania, water system. In October 2006, a foreign hacker penetrated security at a water filtering plant. The intruder planted malicious software that was capable of affecting the plant's water treatment operations. The infection occurred through the Internet and did not seem to be an attack that directly targeted the control system.
Lodz, Poland, tram system. In early 2008, a 14-year old boy jerry-rigged an infrared transmitter that allowed him to hack into the switching network of the Lodz, Poland, city tram system and cause four trams to derail, injuring at least a dozen riders.
Siberian hydro-electric plant. In Russia in the summer of 2009, maintenance personnel for a Siberian hydro-electric plant remotely logged on to the plant's control network and set the turbines to operate beyond safe parameters. One of the turbines was ejected from its moorings damaging additional turbines, leading to the generator room being flooded and causing a transformer explosion. The turbine room was destroyed and 75 workers were killed.

[12] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2}D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: experts assessed a C_{EF} of 1.0 for the Cyber Event affecting Physical Infrastructure event.
As fatality and injury/illness estimates were not determined, psychological distress estimates could not be calculated for this event.

[13] See McAfee and the Center for Strategic and International Studies: 24.

[14] The first seven entries in this table are quoted in whole from Government Accountability Office, Critical Infrastructure Protection: Multiple Efforts to Secure Control Systems Are Under Way, but Challenges Remain (September 2007): 15–17.

The Potential Magnitude of Critical Infrastructure Failures[15,16] *(provided for context to encourage participants to consider potential consequences of a cyber attack)*
Northeast power blackout. In August 2003, failure of the alarm processor in the control system of FirstEnergy, an Ohio-based electric utility, prevented control room operators from having adequate situational awareness of critical operational changes to the electrical grid. This problem was compounded when the state estimating program at the Midwest Independent System Operator failed due to incomplete information on the electric grid. When several key transmission lines in northern Ohio tripped due to contact with trees, they initiated a cascading failure of 508 generating units at 265 power plants across eight states and a Canadian province.
Taum Sauk Water Storage Dam failure. In December 2005, the Taum Sauk Water Storage Dam, approximately 100 miles south of St. Louis, Missouri, suffered a catastrophic failure, releasing a billion gallons of water. According to the dam's operator, the incident may have occurred because the gauges at the dam read differently than the gauges at the dam's remote monitoring station.
Bellingham, Washington, gasoline pipeline failure. In June 1999, 237,000 gallons of gasoline leaked from a 16-inch pipeline and ignited an hour and a half later, causing three deaths, eight injuries, and extensive property damage. The pipeline failure was exacerbated by poorly performing control systems that limited the ability of the pipeline controllers to see and react to the situation.
Browns Ferry power plant. In August 2006, two circulation pumps at Unit 3 of the Browns Ferry, Alabama, nuclear power plant failed, forcing the unit to be shut down manually. The failure of the pumps was traced to excessive traffic on the control system network, possibly caused by the failure of another control system device.

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U.S. Department of Homeland Security (2011, August). Information Technology Sector Baseline Risk Assessment; at http://www.dhs.gov/xlibrary/assets/nipp_it_baseline_risk_assessment.pdf (checked April 2013).

[15] This list was provided to the participants in the frequency elicitation, to encourage consideration of potential consequences of a cyber attack against physical infrastructure.
[16] The entries in this table are quoted in whole from Government Accountability Office: 16–17.

Aircraft-as-a-Weapon

A hostile non-state actor(s) crashes a commercial or general aviation aircraft into a physical target within the U.S.

Data Summary

Description	Low	Best	High
Fatalities	See FOUO data sheet		
Injuries and Illnesses			
Direct Economic Loss	See FOUO data sheet		
Indirect Economic Loss			
Social Displacement[1]	0	50,000	1 Million
Psychological Distress	See text		
Environmental Impact[2]	Low		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

Terrorists have long viewed aviation as a target for attack and exploitation. Successful attacks in the air domain can inflict mass casualties and grave economic damage, and attract significant public attention. Historically, large passenger aircraft have been at the greatest risk to terrorism, whether bombings, taking of hostages, traditional hijacking, and attack using human-portable surface-to-air missiles. Aircraft have also been used as weapons against targets on the ground, most notably but not limited to the attacks of September 11, 2001.[3]

For this incident, the SNRA only considered the risk of aircraft being used as a kinetic mode of attack (e.g. a 9/11 style attack) rather than the risk of an improvised explosive device (IED) being detonated on an aircraft. The latter risk is considered under the explosives incident category in the SNRA.

Assumptions

Likelihood

Frequency estimates used for the Aircraft as a Weapon and Explosives Terrorism Attack events in the SNRA were elicited from DHS subject matter experts in late 2009 - early 2010 by the DHS/NPPD Office of Risk Management & Analysis (RMA) for the RAPID 2010 assessment.[4] These estimates are classified, but are provided in the data tables of the classified SNRA Technical Report.

Fatalities and Injuries

The SNRA project team used the following to estimate health and safety consequences resulting from an aircraft-as-a-weapon attack:

- Historical events: the SNRA project team analyzed a set of ten historical events in which aircraft intentionally or unintentionally crashed into buildings or crowds of people. A detailed listing of these events is found in Table 1 under "Additional Relevant Information." The analysis does not take into account possible higher-consequences events that have not yet occurred, but rather assumes maximum fatalities and injured counts from the 9/11 attacks in New York.

Economic Loss

Total economic loss to the U.S. economy was estimated using indirect and induced costs to the U.S. economy given inputs of several direct economic costs, including business interruption costs, lost demand from fatalities, medical costs and decontamination, disposal, and property damage (DDP) costs.

The SNRA project team used the following assumptions to estimate the direct economic costs resulting from an aircraft-as-a-weapon attack:

- Business Interruption and DDP Costs: The SNRA project team randomly sampled business interruption and DDP cost values from scenarios corresponding to the SNRA fatality estimates, using economic consequence models for aircraft-as-a-weapon attacks previously developed for use with the RAPID 2010 computational risk modeling tool. Note that these scenarios only consider aircraft used against commercial facilities.
- Medical Costs: The numbers of injured were based on the set of events listed above. To account for the distribution of injuries and corresponding medical costs from single events, the SNRA project team multiplied total injuries from the events in the historical data set by a uniform distribution over $13,490 to $122,802, the distribution used by the RAPID assessment for medical costs associated with Explosives/Kinetic/ Incendiary (E/K/I) injuries,[5] by repeated random sampling from each distribution.
- Lost Demand from Fatalities: To estimate the costs of lost demand from deaths, the SNRA project team multiplied the number of deaths listed in Table 1 by $42,500, a value used by prior DHS assessments.[6]

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- The SNRA project team selected 0 as the low estimate of social displacement, for consistency with the scope of the Aircraft as a Weapon national-level event as defined by the range of fatalities in Table 1: it is possible that an attack on a non-residential district resulting in only two fatalities would not cause extensive enough damage to force people from their homes for two or more days.
- The best and high social displacement estimates were provided by staff researchers and subject matter experts at the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[7] The best estimate of 50,000 reflects expert judgment. The high estimate of 1 million reflects literature estimates of the number of people displaced from Lower Manhattan after the 9/11 attacks.[8]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[9] The numerical outputs of

[1] The SNRA measure of social displacement was defined as the number of people forced to leave home for a period of two days or longer.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and *de minimus* (none) categories. Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[3] U.S. Department of Homeland Security (2007, March 26). *National Strategy for Aviation Security.* At http://www.dhs.gov/publication/national-strategy-aviation-security.
[4] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.
RAPID has a different event structure breakdown than the SNRA, but its construction from event trees for multiple granular attack modes, for each of which frequencies were elicited separately, permitted the previously elicited frequencies to be separated and re-mapped to the SNRA event set.

[5] Medical costs from E/K/I injuries taken as a class are comparatively well studied and were used as a proxy for medical costs in the Aircraft as a Weapon attack SNRA event.
[6] RAPID 2010, the 2008 Bioterrorism Risk Assessment (BTRA 2008) (the BTRA as a whole is classified Secret, but its economic methodology appendix is U//FOUO).
[7] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.
[8] Sources for the Aircraft as a Weapon displacement estimates include: Fritsch, Jane (September 12, 2001), "A Day of Terror – The Response: Rescue Workers Rush In, and Many Do Not Return", *New York Times*; and "Boats evacuated one million New Yorkers after WTC attack,"; at http://www.marinelog.com/DOCS/NEWSMM/MMISep19.html. The high estimate may count residents as well as non-resident workers evacuating from Lower Manhattan, and thus may be an overestimate of displacement.
[9] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2}\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.
The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events,

this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "Low." Experts indicated that one airplane could cause tens of acres of environmental impact of a limited duration but the identified event would likely occur in an urban environment. Consequences could be elevated to "Medium" depending on the target (e.g., a chemical plant).

Potential Mitigating Factors

The frequency estimates related to this event depend on the ability of potential terrorists to gain access to an airplane through either hostile takeover or other means using illicit documents, or a legal process.

The nature of the consequences is related to the size of the airplane and the ability to direct it to a desired target.

Additional Relevant Information

Table 1 lists the events analyzed and includes total fatalities and injuries for each event.

was provided by subject matter experts for each national-level event included in the SNRA: the Aircraft as a Weapon terrorist attack event was given a C_{EF} of 1.2.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Table 1. List of Analyzed Events

#	Event	Date	Fatalities	Injuries
1	Ramstein Air Show Disaster (Ramstein, Germany)	8/28/1988	70[10]	1,500[11]
2	Flight 1862 Crash (Amsterdam, Netherlands)	10/4/1992	47[12]	26[13]
3	Air France Concorde Crash (Paris, France)	7/25/2000	113[14]	6[15]
4	September 11th Attacks (New York, NY, USA)	9/11/2001	2,753[16]	5,124[17]
5	Small Plane Hits the Pirelli Tower (Milan, Italy)	4/18/2002	3[18]	30[19]
6	Small Plane Crashes in Park (San Dimas, CA, USA)	7/4/2002	4[20]	9[21]
7	Ukraine Air Show Disaster (Lviv, Ukraine)	7/27/2002	77[22]	241[23]
8	Military Plane Crashes into Building (Tehran, Iran)	12/6/2005	115[24]	90[25]
9	Small Plane Hits Apartment Complex (New York, NY, USA)	10/11/2006	2[26]	3[27]
10	Suicide Attack on IRS Building (Austin, TX, USA)	2/18/2010	2[28]	13[29]

(Table in its entirety is UNCLASSIFIED)

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Armed Assault

A hostile, non-state actor(s) uses assault tactics to conduct strikes on vulnerable target(s) within the U.S., resulting in at least one fatality or injury.

Data Summary

Description	Low	Best	High
Fatalities	See FOUO data sheet		
Injuries and Illnesses			
Direct Economic Loss	See FOUO data sheet		
Indirect Economic Loss			
Total Economic Loss			
Social Displacement[1]	0	2,000	N/A
Psychological Distress	See text		
Environmental Impact[2]	*De minimus*[3]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Discussion

For the SNRA, the health and safety consequences of a hostile, non-state actor(s) using assault tactics to conduct strikes on vulnerable target(s) was estimated using historical data from the Global Terrorism Database (GTD).[4] To capture the range of terrorist attacks with small arms including large-scale assault/siege-type attacks like the 2008 complex attack in Mumbai, India, historical incidents of successful armed assault and explosives attacks, involving the use of firearms but excluding biological and chemical weapons were included in the data set used to determine fatality and injury estimates. Direct economic damage estimates for incidents of corresponding scope to this historical incident set were calculated using the DHS RAPID 2010 risk modeling engine.[5]

New data about the frequency of successful armed assault attacks in the United States were elicited from Intelligence Community subject matter experts for the SNRA project. An overview of the elicitation process is given in Appendix B: additional details and results may be found in Appendix B of the classified SNRA Technical Report.

Assumptions

Likelihood

Frequency estimates were elicited from the Intelligence Community (IC) by the SNRA project team in July-August 2011.[6] These estimates are classified, but are provided in the data tables of the classified SNRA Technical Report.

Health and Safety

Health and safety information was calculated using historical data from the Global Terrorism Database (GTD). The GTD is an open-source database including information on terrorist events around the world (including domestic, transnational, and international incidents) from 1970 through 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and - when identifiable - the group or individual responsible.[7]

In order to identify events in the GTD database that were most comparable to the definition of a complex attack presented above, the following search criteria were used:

- Attack Type: Armed Assault or Bombing/Explosion
- Weapon Type: Require Firearms; Exclude biological, chemical, radiological, nuclear
- Terrorism Criteria: Require Criteria I,[8] II,[9] and III be met[10]
- Exclude ambiguous cases[11]
- Exclude unsuccessful attacks[12]

Events that produced zero injuries and zero deaths were removed from the resulting set, in order to better meet the "national-level" threshold. All events involving vehicle borne explosives were also removed, in order to order to best fit the definition of the event above. The highest injury-producing event (10,000 injured in Peru) was considered an outlier and removed. In addition, incidents that were part of multi-incident events were aggregated to produce more comprehensive injury/death totals. The resulting set included 10,161 events, which were then used to calculate the minimum, maximum, and mean, which are presented as low, best, and high estimates in the table above.

Economic Loss

Total economic loss to the U.S. economy was estimated using IMPLAN, software for input-output economic modeling. IMPLAN calculates indirect and induced costs to the U.S. economy given inputs of certain direct economic costs. These include business interruption costs, lost demand from fatalities, medical costs, and decontamination, disposal, and property damage (DDP) costs.

Direct economic costs were calculated by the SNRA project team using the following assumptions:

- Business Interruption Costs: The SNRA project team used the business interruption numbers from the DHS RAPID 2010[13] Explosives/ Kinetic/ Incendiary (E/K/I) models for government sector buildings, commercial sector buildings, and national monuments and icons as targets. These densely-populated targets were chosen to best fit the definition of complex attack, as described above. The total costs for business interruption is also a function of the number of targets affected. The SNRA project team chose to use a uniform distribution over 1 to 5 targets. The minimum of 1 was chosen to be sufficient for the definition of complex attack, and the maximum of 5 was based on the number of geographically distinct targets in the 2008 Mumbai attacks. The use of a uniform distribution over this range reflects agnosticism about the relative frequencies between the minimum and maximum—the GTD does not provide information on the number of targets in an event, so the SNRA project team could not create a histogram to inform any judgment on the shape of the distribution between the minimum and maximum.
- Lost Demand from Fatalities: The cost of per fatality loss of demand was based on assumptions from RAPID 2010 and the 2008 Biological Terrorism

[1] The SNRA measure of social displacement was defined as the number of people forced to leave home for a period of two days or longer.
[2] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[3] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[4] The Global Terrorism Database (GTD) is an open-source database including information on terrorism events around the world (including domestic, transnational, and international incidents) from 1970 to 2010. For each GTD incident, information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and – when identifiable – the group or individual responsible. National Consortium for the Study of Terrorism and Responses to Terrorism (START) (2011, July). Global Terrorism Database [Data file]: at http://www.start.umd.edu/gtd.
[5] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.
[6] IC participants in the Armed Assault frequency elicitation included subject matter experts from multiple agencies. The frequency estimates reflect the opinion of the group and have not been formally vetted by any of the agencies which participated.

[7] National Consortium for the Study of Terrorism and Responses to Terrorism (START). (2011). Global Terrorism Database [Data file]. Retrieved from: http://www.start.umd.edu/gtd. The GTD is currently the most comprehensive unclassified database on terrorist events in the world, containing information on over 98,000 terrorist attacks with at least 45 to more than 120 variables for each incident. Over 3,500,000 news articles and 25,000 news sources were reviewed to collect incident data from 1998 to 2010 alone. The GTD Database is supervised by an advisory panel of 12 terrorism research experts.
[8] Criterion I states: "The act must be aimed at attaining a political, economic, religious, or social goal."
[9] Criterion II states: "There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims."
[10] Criterion III states: "The action must be outside the context of legitimate warfare activities, i.e. the act must be outside the parameters permitted by international humanitarian law (particularly the admonition against deliberately targeting civilians or non-combatants)."
[11] According to the GTD: "In certain cases there may be some uncertainty whether an incident meets all of the criteria for inclusion." These "ambiguous cases, where there is a strong possibility, but not certainty, that an incident represents an act of terrorism," were excluded.
[12] According to the GTD: "Success of a terrorist strike is defined according to the tangible effects of the attack. For example, in a typical successful bombing, the bomb detonates and destroys property and/or kills individuals, whereas an unsuccessful bombing is one in which the bomb is discovered and defused or detonates early and kills the perpetrators. Success is not judged in terms of the larger goals of the perpetrators. For example, a bomb that exploded in a building would be counted as a success even if it did not, for example, succeed in bringing the building down or inducing government repression."
[13] RAPID has a different event structure breakdown than the SNRA, but its construction from event trees for multiple granular attack modes, for each of which frequencies were elicited separately, permitted the previously elicited frequencies to be separated and re-mapped to the SNRA event set.

Risk Assessment (BTRA). The number of deaths was based on the analysis of events from the GTD database, as described above.

- Medical Costs: The range of medical mitigation costs was based on assumptions for the RAPID 2010 E/K/I incident set. The number of injured was based on the analysis of events from the GTD database, as described above.
- DDP Costs: The SNRA project team used the DDP cost assumptions for an E/K/I man-portable IED from RAPID 2010 for targets including commercial sector buildings, government sector buildings, national monuments and icons, and airports.[14]
  - These costs were then multiplied by a uniform distribution to model DDP costs of an attack equivalent to 0–5 explosions (each equivalent to 65 lbs. TNT), to capture the complex nature of the attack. A minimum of 0 was chosen to be inclusive of events that do not include explosives.
  - The choice of the upper bound was more difficult, as reporting is inconsistent on the number of explosions that occurred during the 2008 Mumbai attack. Furthermore, RAPID 2010 only models the DDP effects of a man-portable IED, not that of a grenade or firearms, which were also used in the Mumbai attack and could be considered inside the scope of a complex attack as defined for this event. The SNRA project team made the analytic assumption that 5 IED equivalents would be the most appropriate upper bound for modeling a comparable event using the RAPID engine.

Based on these assumptions, a Monte Carlo simulation was run, and for each trial the total direct economic loss was calculated. Low, best, and high estimates of direct economic cost represent the trials at the 5th percentile, mean, and 95th percentile of the resulting distribution.

The low, best, and high estimates of direct economic loss were used as inputs to IMPLAN to calculate low, best, and high estimates of indirect and total economic loss.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- For the Armed Assault national-level event, the low and best social displacement estimates of 0 and 2,000 respectively reflect subject matter expert judgments provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[15]
- A high estimate was not determined for this event.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[16] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "*de minimus*." Environmental impacts would be minimal.

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[14] The airport target was not used for the business interruption modeling. While the SNRA project team assumed that DDP costs for a man-portable IED attack at an airport would be representative of DDP costs in a complex attack, the team did not assume that the knock-on implications for business interruption would be similarly representative. The team also noted that all DDP costs for a man-portable IED attack at an airport were within the range already created by DDP values for government buildings, commercial buildings, and monuments. Therefore, the airport DDP numbers only served to add more numbers to sample from. These may or may not have had a significant effect on the mean; however, they did not alter the bounds on the range that the project team sampled from.

[15] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[16] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: the Armed Assault terrorist attack event was given a C_{EF} of 1.1.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Biological Terrorism Attack (non-food)

A hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target directed at a concentration of people within the U.S.

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Total Economic Loss	See classified data sheet		
Social Displacement	0	1,800	N/A
Psychological Distress	See classified data sheet		
Environmental Impact	Low[1]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

The SNRA considered the risk from a non-food biological attack in which a hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target with a concentration of people within the United States. Frequency estimates for this event only include data for successful attacks (e.g., detonation of a device or release of an agent). Examples of failed attacks not included in the SNRA include interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to the United States, or failure of the dissemination device.

Biological agents can be isolated from sources in nature, acquired from laboratories or a state bioweapons stockpile, or synthesized or genetically manipulated in a laboratory. Potential dissemination mechanisms of a biological agent by terrorists include aerosol dissemination from sprayers or other devices outdoors or through the ventilation system of a building, subway, or airplane, human carriers, insects or other animal vectors, or physical distribution through the U.S. Mail or other means. Biological agents include transmissible agents that spread from person to person (e.g. smallpox, Ebola) or agents that may cause adverse effects in exposed individuals but which do not make these individuals contagious (e.g. anthrax, botulinium toxin).[2]

Unlike a nuclear or chemical attack, a biological attack may go undetected for hours, days, or potentially weeks (depending on the agent) until humans, animals, or plants show symptoms of disease. If there are no immediate signs of the attack as with the anthrax letters, a biological attack will probably first be detected by local health care workers observing a pattern of unusual illness, or by early warning systems that detect airborne pathogens. There may be uncertainties about crucial facts such as the exact location or extent of the initial release, the type of biological agent used, and likelihood of additional releases. The exact infectious dose (the number of organisms needed to make one sick, referred to as dose response) and the long-term health consequences for those who survive exposure are key scientific knowledge gaps for many biological agents: while approximate ranges and prognoses for humans have been extrapolated from animal studies, they comprise additional uncertainties which may complicate the public health response to a biological attack.[3]

This National-Level Event focuses on non-food biological attacks. Note that the risks of intentional biological food contamination are considered in a separate National-Level Event in the SNRA and should not be considered for this event.

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[4] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the biological (non-food) terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for biological attacks on targets other than food and agriculture targets for the SNRA project to correspond to the scope of the SNRA biological (non-food) terrorism attack event.

SNRA analysis for this national-level event adopted the definition of a terrorist attack from the Homeland Security Act of 2002, which is any activity that:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources;
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States;
- Appears to be intended to intimidate or coerce a civilian population;
- Appears to be intended to influence the policy of a government by intimidation or coercion; or
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

In addition to this general definition, SNRA analysis considered the following categories of actors:

- International Terrorist Organizations: Terrorist organizations that operate both inside and outside of the U.S. that are not sponsored by a nation (e.g., al-Qaeda);
- State-Sponsored Terrorist Organizations: Terrorist organizations that operate inside and/or outside of the U.S. that are sponsored by a nation; sponsorship is defined as the provision of technical assistance, equipment, or chemical by a state program (e.g., Hezbollah);
- Domestic Terrorist Organizations: Terrorist organizations that operate only within the U.S. that are not sponsored by a nation (e.g., Animal Liberation Front and Rajneesh);
- Small Groups/Individuals Terrorist Organizations: Small groups (i.e., 2 to 3 members) or individuals that operate only within the U.S. that are not sponsored by a nation (e.g., the Unabomber and Timothy McVeigh).

Biological agents can be classified into different categories and disseminated in different modes (e.g., wet or dry aerosol). The SNRA considers the following categories of biological agents:

- Traditional Biological Agents: Includes bacterial, viral, toxin, and prion agents; these agents are most often considered in biological agent assessments;
- Enhanced Biological Agents: Refers to traditional agents that have been modified to increase the hazard associated with the agent, such as bacterial agents enhanced to be antibiotic resistant;
- Emerging Biological Agents: Includes organisms that were not previously considered significantly pathogenic but are currently recognized for that potential. The Severe Acute Respiratory Syndrome (SARS) is an example of such an agent.[5]

Frequency estimates for this National-level Event only include data for successful attacks, e.g., detonation of a device or release of an agent. Failed attacks are not considered during this assessment process. Examples of failed attacks include interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to United States, or failure of the dissemination device.

The SNRA project team used the definitions of direct, indirect, and induced economic costs given in Table 1 for economic loss estimates of this national-level event.

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:

- **Decontamination, Disposal, and Physical Destruction**: DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
- **Business Interruption**: Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.

[1] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[2] National Academies and U.S. Department of Homeland Security (2004). Biological attack: human pathogens, biotoxins, and agricultural threats. Retrieved from http://www.dhs.gov/biological-attack-fact-sheet via http://www.ready.gov.
[3] Ibid.
[4] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).
[5] Bush, George W. (2001, January 31). Homeland Security Presidential Directive/HSPD-18 – Medical Countermeasures against Weapons of Mass Destruction: at http://fas.org/irp/offdocs/nspd/hspd-18.html. HSPD-18, the mandate for the Integrated CBRN Terrorism Risk Assessment (ITRA 2011) which the Biological Attack (non-food) national-level event leverages for its frequency, fatality, illness, and economic consequences data, defined the traditional/enhanced/emerging/advanced agent classification used in characterizing biological terrorism agents.

• **Loss in Spending from Fatalities**: This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality. • **Medical Costs**: Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.
Indirect Costs include: • Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include: • The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Low and best estimates of social displacement for the Biological Terrorism Attack (non-food) national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[6]
- The low estimate of 0 reflects assessed judgment of START subject matter experts. The best estimate of 1,800 represents the number of people evacuated in a historical outbreak of tuberculosis in East Timor in 1999, used as a proxy estimate for a small-scale but deliberate dissemination of a contagious agent.[7]
- A high estimate for social displacement was not determined for this event.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[8] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental consequences as "Low." The environmental impact will vary on agent or persistence, but the highest potential would be an increase in animal disease. However, this potential is low given the focus on human diseases. Additionally, the disposal of contaminated waste could result in a higher risk for environmental consequences.

Potential Mitigating Factors

Viable human-health surveillance techniques, to include DHS Bio-Watch detection systems where available, should be employed in order to minimize the time window between attack and start of treatment. Emergency notification systems should be operational, with special care taken to provide the most accurate and current information to hospitals that they may take steps to mitigate surge capacity problems and diagnose patients effectively. The appropriate Prevention/Deterrence, Preparedness, Emergency Assessment/Diagnosis, Emergency Management/Response, Hazard Mitigation, Evacuation/Shelter, Victim Care, Investigation/Apprehension and Recovery/Mediation mission areas should be activated to ensure a comprehensive, integrated response and minimize the impact of an attack.

Weather can have an ameliorating effect on biological agents as humidity, wind currents and ultraviolet radiation may decrease their potency. Therefore, agents are often most harmful when released in enclosed spaces.

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[6] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[7] (Source: Connolly, Maire, 1999. "Communicable Disease Surveillance and Control in East Timor." World Health Organization.) Subject matter experts consulted for the SNRA noted that this estimate is arbitrary given the large range of potential biological attack scenarios; the high estimate could be significantly higher than the best estimate provided if there is a need to decontaminate a large area.

[8] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + \frac{1}{2}\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Biological Terrorism Attack (non-food) was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Chemical Terrorism Attack (non-food)

A hostile non-state actor(s) acquires, weaponizes, and releases a chemical agent against an outdoor, indoor, or water target directed at a concentration of people, using an aerosol, ingestion, or dermal route of exposure.

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Direct Economic Loss	See classified data sheet		
Indirect Economic Loss	See classified data sheet		
Social Displacement	0	100,000	700,000
Psychological Distress	See classified data sheet		
Environmental Impact[1]	Moderate[2]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

The Department of Homeland Security (DHS) and Federal Bureau of Investigations (FBI) define a chemical attack as follows:[3]

> A chemical attack is the spreading of chemicals with the intent to do harm. The Chemical Weapons Convention defines a chemical weapon as "any toxic chemical or its precursor that can cause death, injury, temporary incapacitation, or sensory irritation through its chemical action." A variety of chemicals could be used in an attack, to include toxic commercial and industrial chemicals and warfare agents developed for military use. The chemical could be used in various forms or states—such as gas, liquid, or solid. The toxicity of chemicals varies greatly; some are acutely toxic (causing immediate symptoms) in small doses, others are not toxic at all. Chemicals in liquid or vapor form generally create greater exposure than chemicals in solid form.

Chemical agents can be disseminated in various modes. Potential delivery mechanisms of a chemical agent by terrorists include building ventilation systems, misting or aerosolizing devices, passive release (container of chemical left open), explosives, improvised devices combining readily available chemicals to produce a dangerous chemical, or sabotage of industrial facilities or vehicles containing chemicals.[4]

This National-level Event focuses on non-food chemical attacks. Note that the risks of intentional chemical food contamination are considered in a separate National-level Event in the SNRA and should not be considered for this event.

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[5] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the chemical (non-food) terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for chemical attacks on non-food targets for the SNRA project, separate from attacks on food and beverage[6] targets, to correspond to the event structure of the SNRA.

The SNRA leveraged data for the classified risk summary sheet that assumed terrorist attack to include the following:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources.
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States.
- Appears to be intended to intimidate or coerce a civilian population.
- Appears to be intended to influence the policy of a government by intimidation or coercion.
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

The SNRA only includes data for successful attacks for this national-level event (e.g., detonation of a device or release of an agent). Failed attacks (e.g., interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to United States, or failure of the dissemination device) are not considered during this assessment process.

The analysis used broad definitions of organizations that may initiate or represent potential chemical terrorism threats to the U.S., the categories of chemical agents that could be used for an attack, and the targets that may be selected for a chemical attack. The adopted criteria for general categories representing chemical terrorist threats to the U.S. are as follows:

- The International Terrorist Organization category is composed of terrorist organizations that operate both inside and outside of the U.S. that are not sponsored by a nation (e.g., al-Qaeda).
- The State-Sponsored Terrorist Organization category is composed of terrorist organizations that operate inside and/or outside of the U.S. that are sponsored by a nation. Sponsorship is defined as the provision of technical assistance, equipment, or chemical by a state program (e.g., Hezbollah).
- The Domestic Terrorist Organization category is composed of terrorist organizations that operate only within the U.S. that are not sponsored by a nation (e.g., Animal Liberation Front and Rajneesh).
- The Small Groups/Individuals Terrorist Organization category is composed of small groups (i.e., 2 to 3 members) or individuals that operate only within the U.S. that are not sponsored by a nation (e.g., the Unabomber and Timothy McVeigh).

Chemical agents can be acquired from a variety of different sources and disseminated in various modes. The analysis uses data that classifies chemical agents into the following categories:

- Toxic Industrial Materials (TIMs) and Toxic Industrial Chemicals (TICs): Includes toxic substances in solid, liquid, or gaseous form that are used or stored for use for military or commercial purposes. Chlorine is an example of this type of agent.
- Traditional Chemical Warfare Agents (CWAs): Encompasses the range of blood, blister, choking, nerve, and psychotropic agents historically developed for military use. Examples include: sulfur mustard, VX, and sarin.[7]

The SNRA project team used the definitions of direct, indirect, and induced economic costs given in Table 1 to estimate the economic losses for this national-level event.

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include: • **Decontamination, Disposal, and Physical Destruction**: DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors. • **Business Interruption**: Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event. • **Loss in Spending from Fatalities**: This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality. • **Medical Costs**: Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.
Indirect Costs include: • Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include: • The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the

[1] Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[3] "Potential Terrorist Attack Methods: Joint Special Assessment", DHS & FBI, 23 April 2008, p. 15 (Reference is UNCLASSIFIED//FOR OFFICIAL USE ONLY: Extracted information is UNCLASSIFIED).
[4] National Academies and U.S. Department of Homeland Security (2004). Chemical attack: warfare agents, industrial chemicals, and toxins. Retrieved from http://www.dhs.gov/chemical-attack-fact-sheet via http://www.ready.gov.
[5] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).
[6] Water systems such as city and building water supplies are included in the non-food event; attacks using bottled water as a vector are included in the chemical-biological food contamination event.

[7] National Academies, DHS (2004), Chemical attack fact sheet, *op. cit*.

commercial air transport sector.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Social displacement estimates for the Chemical Terrorism Attack (non-food) national-level event were provided by staff researchers and subject matter experts at the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[8]
- The low estimate of 0 reflects assessed judgment of START subject matter experts. The best and high estimates of 100,000 and 700,000 respectively represent estimated evacuation and dispersal numbers in two modeled chemical attack scenarios in the literature: an attack with a blister agent aimed at a large gathering such as a football game (best), and a terrorist attack against a petroleum plant using explosives to cause a catastrophic release of toxic industrial chemicals (high).[9]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[10] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "Moderate." Experts indicated that the consequences will most likely be localized as effects will require direct exposure to the chemical. Aquatic runoff could disseminate certain chemicals and increase the impact on the environment. Defining variables that will determine whether or not the consequences are increased or decreased include toxicity, spread, and the persistence of the chemical agent used in the attack.

[8] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[9] Bea, Keith. 2005. "National Preparedness System: Issues in the 109th Congress." CRS Report for Congress. March 10, 2005.

[10] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2}\,D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Chemical Terrorism Attack (non-food) was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Potential Mitigating Factors

Hazardous Material (HazMat) Teams should be prepared to quickly dispatch to the target site and detect/identify the chemical agent deployed in the attack. This will determine the response steps necessary to mitigate consequences from a particular chemical agent. The hazard should be isolated and cordoned in order to prevent spreading the agent by fleeing victims. Additionally, the evacuation effort should include populations downwind from the explosion (chemical agent dependent) and emphasize at-risk or special populations in order to enhance mitigation efforts. Planners should note the importance of effective communication during the response effort to inform the public about evacuation routes, contaminated areas, and potential victims who may have experienced exposure to the chemical agent.

Additional Relevant Information

The severity of an attack is related to the toxicity of the chemical and its concentration when it reaches people. Many variables affect the concentration of a chemical, including the volatility of the chemical and environmental conditions.

The release of toxic chemicals in closed spaces, such as subways, airports, and financial centers, could deliver doses high enough to injure or kill a large number of people. A volatile chemical will disperse to fill the space. The smaller the space, the greater the concentration of the chemical.

In an open area, a toxic chemical cloud (plume) would become less concentrated as it spreads and would have to be released in large quantities to produce many casualties. The area affected would depend upon such factors as the type and amount of chemical agent, the means of dispersal, the local topography, and the local weather conditions. A toxic cloud would spread roughly with the speed and direction of the wind. For a highly toxic chemical, lethal or immediately life-threatening results could be seen close to the release point of the agent where its concentration is highest. However, the concentration of the chemical, and consequently its human health risk, would be greatly diminished at distances far from the source.[11]

[11] National Academies and U.S. Department of Homeland Security (2004), *op. cit.*

Chemical/Biological Food Contamination Terrorism Attack

A hostile non-state actor(s) acquires, weaponizes, and disperses a biological or chemical agent into food supplies within the U.S. supply chain.

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Direct Economic Loss	See classified data sheet		
Indirect Economic Loss	See classified data sheet		
Social Displacement	0	N/A	N/A
Psychological Distress	See classified data sheet		
Environmental Impact[1]	Low[2]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

The SNRA considered biological and chemical attacks on the food supply chain in this event.

A terrorist attack on the Nation's food supply chain using chemical or biological agents may initially be indistinguishable from an unintentional food contamination. Depending on the type of agent used in the attack, it could take several days for individuals to show symptoms and possibly weeks before public health, food, and medical authorities suspect terrorism as the source.[3] In 1984 members of the Rajneeshees, a religious community in an accelerating political dispute with the Oregon county where they had established their commune, deliberately contaminated salad bars at eight county restaurants with *Salmonella* bacteria, infecting or sickening 751 people and hospitalizing 45.[4] However, deliberate contamination was not identified until a year later, when the commune collapsed and criminal investigations into its other activities uncovered its clandestine biological laboratories.[5,6]

Chemical and biological weapons differ in potential toxicity, specificity, speed of action, duration of effect, controllability, and residual effects. Children, the elderly, pregnant women, and immune-compromised individuals are particularly susceptible to the adverse effects of a chemical/biological food contamination.[7,8]

This National-level Event focuses on chemical and biological attacks targeting food supplies within the U.S. supply chain. Note that the risks of chemical and biological attacks aimed at non-food targets are considered in separate National-level Events in the SNRA and should not be considered for this event.

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[9] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the chemical/biological food contamination terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for chemical and biological attacks on food and beverage targets to permit analysis of chemical-biological food attacks as a national-level event in the SNRA distinct from attacks on non-food targets.

The SNRA leveraged data for the classified risk summary sheet that assumed terrorist attack to include the following:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources;
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States;
- Appears to be intended to intimidate or coerce a civilian population;
- Appears to be intended to influence the policy of a government by intimidation or coercion; or
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

The SNRA only includes data for successful attacks for this national-level event, e.g., detonation of a device or release of an agent. Failed attacks are not considered during this analysis (e.g., interdiction during the fabrication and assembly of the dissemination device, interdiction during travel to United States, or failure of the dissemination device).

The analysis used broad definitions of organizations that may initiate or represent potential chemical or biological terrorism threats to the U.S. supply chain, the categories of chemical agents that could be used for an attack, and the targets that may be selected for a chemical attack. The adopted criteria for general categories representing chemical/biological food terrorist threats to the U.S. are as follows:

- The International Terrorist Organization category is composed of terrorist organizations that operate both inside and outside of the U.S. that are not sponsored by a nation (e.g., al-Qaeda).
- The State-Sponsored Terrorist Organization category is composed of terrorist organizations that operate inside and/or outside of the U.S. that are sponsored by a nation. Sponsorship is defined as the provision of technical assistance, equipment, or chemical by a state program (e.g., Hezbollah).
- The Domestic Terrorist Organization category is composed of terrorist organizations that operate only within the U.S. that are not sponsored by a nation (e.g., Animal Liberation Front and Rajneesh).
- The Small Groups/Individuals Terrorist Organization category is composed of small groups (i.e., 2 to 3 members) or individuals that operate only within the U.S. that are not sponsored by a nation (e.g., the Unabomber and Timothy McVeigh).

The SNRA project team used the following assumptions identified in Table 1 to estimate the economic losses for this national-level event.

Table 1: Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:

- **Decontamination, Disposal, and Physical Destruction**: DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
- **Business Interruption**: Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.
- **Loss in Spending from Fatalities**: This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality.
- **Medical Costs**: Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

[1] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rakings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.

[3] Federal Emergency Management Agency (August 2008), Food and Agricultural Incident Annex, p. 2, at http://www.fema.gov/pdf/emergency/nrf/nrf_FoodAgricultureIncidentAnnex.pdf (retrieved January 2015).

[4] This was to test a plan to poison the county water supply on Election Day, to suppress voter turnout and enable the group to take over the county board by electing their own candidates. Török et al (1997, August 6). A large community outbreak of Salmonellosis caused by intentional contamination of restaurant salad bars. *Journal of the American Medical Association (JAMA)* 278(5) 389-395; at http://www.cdc.gov/phlp/docs/forensic_epidemiology/Additional%20Materials/Articles/Torok%20et%20al.pdf (retrieved May 2014). Although unsuccessful in identifying deliberate action as the cause of the poisoning, CDC and FBI investigations following the incident may have deterred the group from carrying out their planned Election Day attack in November. Sobel et al (2002, March 9). Threat of a biological attack on the US food supply: the CDC perspective. *Lancet* 359(9309) 874-880.

[5] Török et al, *op cit.*

[6] Carus, W. Seth (2001, February). Bioterrorism and biocrimes: the illicit use of biological agents since 1900. Pages 50-58. National Defense University; at http://www.ndu.edu/centercounter/full_doc.pdf (retrieved March 2013). Agents experimented with included *Salmonella typhimurium*, the variant which was used in the salad bar attacks, *Salmonella typhi* which causes hepatitis and typhoid fever, *Giardia*, HIV, and multiple chemical and pharmaceutical poisons. *Giardia lamblia* was to be introduced into the county water supply via dead rats and beavers, which carry the parasite (p. 54).

[7] United Nations (1970). Chemical and Bacteriological (Biological) Weapons and the Effects of Their Possible Use, p. 12. Report of the Secretary-General, UN Publication no. E.69.I.24. Reprinted by Ballantine Books, 1970.

[8] FEMA (2008), *op. cit.*

[9] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

Indirect Costs include: • Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include: • The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Subject matter experts from the National Consortium for the Study of Terrorism and Responses to Terrorism (START)[10] judged that although a terrorist chemical or biological attack against the food chain could sicken or kill many people, it was unlikely to force people to evacuate or leave their homes. Note that deaths and unplanned hospital stays are not considered social displacement for the purposes of the SNRA.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[11] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "low." Experts indicated that this hazard is directed towards humans leading the environmental consequences to be minimal. If the agent is introduced into an agricultural setting, there could be consequences for the local ecosystem.

  Waste disposal is one of the primary concerns and depending on the volume of material this could lead to more significant environmental consequences.

Potential Mitigating Factors

Population exposure can be limited with fast and accurate identification of the agent and vehicle (water, milk, lettuce, etc.) utilized to target the food supply system. A prepared public communications plan will assist in further limiting the spread, while also mitigating the economic losses associated with falsely identifying the food supply contaminant.

Additional References

Khan et al (2001). Precautions against biological and chemical terrorism directed at food and water supplies. *Public Health Review* 116 (January-February 2001) 3-14.

Mohtadi et al (2009). Risk analysis of chemical, biological, or radionuclear threats: implications for food security. *Risk Analysis* 29(9) 1317-1335.

World Health Organization (2008, May). Terrorist threats to food: Guidance for establishing and strengthening prevention and response systems. At http://www.who.int/foodsafety/publications/fs_management/terrorism/en/ (checked April 2013).

[10] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[11] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Chemical/Biological Food Contamination Terrorism Attack was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Explosives Terrorism Attack

A hostile non-state actor(s) deploys a man-portable improvised explosive device (IED), vessel IED, or VBIED (Vehicle-borne IED) in the U.S. against a concentration of people, and/or structures such as critical commercial or government facilities, transportation targets, or critical infrastructure sites, etc., resulting in at least one fatality or injury.

Data Summary

Description	Low	Best	High
Fatalities[1]	See FOUO data sheet		
Injuries and Illnesses[2]			
Direct Economic Loss	See FOUO data sheet		
Indirect Economic Loss[3]			
Social Displacement	0	5,000	N/A
Psychological Distress	See text		
Environmental Impact[4]	Low[5]		
Frequency of Events[6]	See classified data sheet		

(UNCLASSIFIED)

Event Background[7]

An improvised explosive device (IED) attack is the use of a "homemade" bomb and/or destructive device to destroy, incapacitate, harass, or distract. IEDs are used by criminals, vandals, terrorists, suicide bombers, and insurgents. Because they are improvised, IEDs can come in many forms, ranging from a small pipe bomb to a sophisticated device capable of causing massive damage and loss of life. IEDs can be carried or delivered in a vehicle; carried, placed, or thrown by a person; delivered in a package; or concealed on the roadside. The term IED came into common usage during the Iraq War that began in 2003.

IEDs consist of a variety of components that include an initiator, switch, main charge, power source, and a container. IEDs may be surrounded by or packed with additional materials or "enhancements" such as nails, glass, or metal fragments designed to increase the amount of shrapnel propelled by the explosion. Enhancements may also include other elements such as hazardous materials. An IED can be initiated by a variety of methods depending on the intended target.

Many commonly available materials, such as fertilizer, gunpowder, and hydrogen peroxide, can be used as explosive materials in IEDs (see Table 1). Explosives must contain a fuel and an oxidizer, which provides the oxygen needed to sustain the reaction. A common example is ANFO, a mixture of ammonium nitrate, which acts as the oxidizer, and fuel oil (the fuel source). Concern about the use of explosives created from liquid components that can be transported in a stable form and mixed at the site of attack is the reason that in 2006 the U.S. Department of Homeland Security restricted the amount of liquids that passengers can carry on commercial aircraft.

[1] Minimum, mean, and maximum values from GTD. See Discussion for search parameters.
[2] Minimum, mean, and maximum values from GTD. See Discussion for search parameters.
[3] Based on IMPLAN analysis and updated with information from GTD. See Discussion for details.
[4] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[5] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[6] 5th percentile, mean, and 95th percentile of residual threat values from RAPID 2010. See Discussion for details.
[7] This section is substantially adapted from National Academies and U.S. Department of Homeland Security (2004), IED attack: improvised explosive devices. Retrieved from http://www.dhs.gov/ied-attack-fact-sheet.

Table 1. Examples of explosives

	Common uses	Common form	Known IED use
High explosives (HE)			
Ammonium nitrate and fuel oil (ANFO)	Mining and blasting[8]	Solid	Oklahoma City bombing
Triacetone Triperoixide (TATP)	No common uses; mixed from other materials	Crystalline solid	2005 bombings in London
Semtex, C-4	Primarily military	Plastic solid	Irish Republican Army bombings
Ethylene glycol dinitrate (EGDN)	Component of low-freezing dynamite	Liquid	Millennium Bomber, intended for Los Angeles airport, 1999
Urea nitrate	Fertilizer	Crystalline solid	World Trade Center 1993
Low explosive			
Smokeless powder	Ammunition	Solid	Olympic Park bombings

The extent of damage caused by an IED depends on its size, construction, and placement, and whether it incorporates a high explosive or propellant. Table 2 predicts the damage radius based on the volume or weight of explosive (TNT equivalent) and the type of bomb. Vehicle bombs, also known as vehicle-borne IEDs, can carry significantly more explosive material, and therefore do more damage.

Table 2. Damage radius

Threat description	Explosive Capacity (High Explosives Only)	Building Evacuation distance	Outdoor evacuation distance
Small package/letter	1 lb	40 ft	900 ft
Pipe bomb	5 lb	70 ft	1,200 ft
FedEx package	10 lb	90 ft	1,080 ft
Vest/container bombs	20 lb	110 ft	1,700 ft
Parcel package	50 lb	150 ft	1,850 ft
Compact car	500 lb	320 ft	1,900 ft
Full size car/minivan	1,000 lb	400 ft	2,400 ft
Van/SUV/pickup truck	4,000 lb	640 ft	3,800 ft
Delivery truck	10,000 lb	860 ft	5,100 ft

An explosion in or near a building or public transportation venue may blow out windows; destroy walls; and shut down building systems such as power, ventilation, fire suppression, water/sewage, and others. Exit routes may be disrupted or destroyed, and smoke and dust may travel upward through stairways and elevator shafts, making navigation difficult. Building failure may result in the release of hazardous materials used within a building, such as radioactive material from medical devices, or incorporated within the structure of a building, such as asbestos insulation. An IED attack may cause disruptions in municipal services such as electricity, water, communications, and transportation, which may continue for days to weeks after the attack. Individuals and businesses should have a plan for addressing these interruptions.

A known bomber tactic is to use a distraction, such as gunfire, small bombs, or other surprises, to attract bystanders to a window, a doorway, or outside, and then to detonate a second destructive device at the gathering point. In an attack, there may be bombings at multiple locations. Rescue efforts can be hampered by the need to respond to more than one site.

The explosion of a bomb can cause secondary explosions if gasoline, natural gas, or other flammable material is ignited. Secondary hazards that result can include fire with possibly toxic smoke, disruption of electric power, ruptured natural gas lines and water mains, and debris. There can be loss of traffic control in the area of the blast with possible traffic accidents involving fleeing citizens.

Explosions create a high-pressure blast that sends debris flying and lifts people off the ground. The type of injuries and the number of people hurt will vary depending on: the physical environment and the size of the blast;

[8] Ammonium nitrate (without fuel oil) is used as fertilizer.

the amount of shielding between victims and the blast; fires, or structural damage that result from the explosion; and whether the explosion occurs in a closed space or an open area. Injuries common to explosions include:

- **Overpressure damage** to the lungs, ears, abdomen, and other pressure-sensitive organs. Blast lung injury, a condition caused by the extreme pressure of a HE explosion, is the leading cause of illness and death for initial survivors of an explosion.
- **Fragmentation injuries** caused by projectiles thrown by the blast – material from the bomb, shrapnel, or flying debris that penetrates the body and causes damage.
- **Impact injuries** caused when the blast throws a victim into another object, i.e. fractures, amputation, and trauma to the head and neck.
- **Thermal injuries** caused by burns to the skin, mouth, sinus, and lungs.
- Other injuries including exposure to toxic substances, crush injuries, and aggravation of pre-existing conditions (asthma, congestive heart failure, etc.).

Some health effects caused by IEDs, including eye injuries and abdominal injuries, may not be apparent initially, but can cause symptoms and even fatalities hours to months after the event. Psychological effects in attack survivors, first responders, and others are not unusual in the aftermath of a high-casualty event. While most symptoms diminish with time, in some cases assistance and guidance from mental health professionals may be required.

Methodology and Assumptions

Likelihood

Frequency estimates used for the Aircraft as a Weapon and Explosives Terrorism Attack events in the SNRA were elicited from DHS subject matter experts in late 2009 - early 2010 by the DHS/NPPD Office of Risk Management & Analysis (RMA) for the RAPID 2010 assessment.[9] These estimates are classified, but are provided in the data tables of the classified SNRA Technical Report.

Health and Safety

Health and safety consequence estimates were calculated from the Global Terrorism Database (GTD). The GTD is an open-source database including information on terrorist events around the world (including domestic, transnational, and international incidents) from 1970 through 2010. The GTD is currently the most comprehensive unclassified data base on terrorist events in the world, containing information on over 98,000 terrorist attacks with at least 45 to more than 120 variables for each incident. Over 3,500,000 news articles and 25,000 news sources were reviewed to collect incident data from 1998 to 2010 alone. The GTD Database is supervised by an advisory panel of 12 terrorism research experts.

In order to identify events in the GTD that were most comparable to the definition of the Explosive National-level Event the following search criteria were used:

- Attack Type: Bombing/Explosion
- Weapon Type: Explosives/Bombs/Dynamite OR Incendiary
- Require Criteria I[10], II[11], III[12] be met, with ambiguous cases[13] excluded
- Exclude unsuccessful attacks[14]
- Target Type: limited to Airports and Airlines, Business, Government (Diplomatic), Government (General), Military, Other, Telecommunication, Tourists, Transportation, Unknown, Utilities

In addition to the search criteria listed above, events in the GTD that killed 0 persons AND wounded 0 persons were excluded for the purpose of estimating Health and Safety consequences. The minimum, mean, and maximum values of the number of fatalities and injuries associated with the incidents that met the GTD search criteria were gathered to populate the risk characteristics table above.

Economic

The SNRA Project team used the GTD to calculate economic consequences for an explosives event:

- Total economic loss to the U.S. economy was estimated using indirect and induced costs to the U.S. economy given inputs of several direct economic costs, namely, business interruption costs, lost demand from fatalities, medical costs, and decontamination, disposal, and property damage (DDP) costs.
- To estimate these direct costs, injury and fatality information from the GTD was combined with estimates from previous assessments. For some events, the GTD records "Property Damage" which includes any reported direct costs of the event. While these values were not directly used in the modeling process, they were compared to other assessments' estimates for the purpose of validation.
- Business Interruption and DDP Costs: Assumptions for Man-Portable IED, Vessel IED, and VBIED weapon types against all target classes were used.
- Lost Demand from Fatalities: Data on the number of fatalities per incident was gathered from the GTD and combined with the assumption of a $42,500 per fatality cost.
- Medical Costs: Data on the number of injuries per incident was gathered from the GTD and combined with the RAPID assumption of a U ($13,490, $122,802)[15] per injury cost.

For comparison, total economic loss to the U.S. economy resulting from the 1993 bombing at the World Trade Center has been estimated at $1 billion.[16] Economic loss resulting from the 1995 bombing in Oklahoma City has been estimated at $414 million. This figure includes $234 million in physical loss, $54 million in loss of income from worker fatalities and injuries, $67 million in business interruption losses, and $59 million in resources reallocated to recovery efforts.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Low and best estimates of social displacement for the Explosives Terrorism Attack national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[17]
- The low estimate of 0 reflects assessed judgment of START subject matter experts. The best estimate of 5,000 reflects subject matter expert judgment based on an evacuation radius of several blocks from a deliberately set improvised explosive device (IED).
- A high estimate for social displacement was not determined for this event.

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based

[9] In order to leverage previous DHS risk assessments, likelihood estimates were calculated using the Risk Assessment Process for Informed Decision Making (RAPID) 2010. Specific weapon types were identified that were most comparable to the definition of the Explosive National-level Event.
RAPID is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.
RAPID has a different event structure breakdown than the SNRA. However, its construction from event trees for multiple granular attack modes, for each of which frequencies were elicited separately, permitted the previously elicited frequencies to be separated and re-mapped to the SNRA event set.
Likelihood estimates in the classified version of this summary sheet were calculated using residual threat values from RAPID 2010 for the weapon types corresponding to the SNRA Explosives Terrorism Attack national-level event (see event definition). Residual threat is estimate of the likelihood of a successful attack. It is a weighted average that incorporates adversary preferences among the different attack scenarios as well as the ability of DHS and non-DHS programs to detect and interdict these attacks.
[10] Criteria I states: "The act must be aimed at attaining a political, economic, religious, or social goal."
[11] Criteria II states: "There must be evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) than the immediate victims."
[12] Criteria III states: "The action must be outside the context of legitimate warfare activities, i.e. the act must be outside the parameters permitted by international humanitarian law (particularly the admonition against deliberately targeting civilians or non-combatants)."
[13] According to the GTD: "In certain cases there may be some uncertainty whether an incident meets all of the criteria for inclusion." These "ambiguous cases, where there is a strong possibility, but not certainty, that an incident represents an act of terrorism," have been excluded.
[14] According to the GTD: "Success of a terrorist strike is defined according to the tangible effects of the attack. For example, in a typical successful bombing, the bomb detonates and destroys property and/or kills individuals, whereas an unsuccessful bombing is one in which the bomb is discovered and defused or detonates early and kills the perpetrators. Success is not judged in terms of the larger goals of the perpetrators. For example, a bomb that exploded in a building would be counted as a success even if it did not, for example, succeed in bringing the building down or inducing government repression."
[15] A uniform distribution over the interval [13,490, 122,802].
[16] U.S. House of Representatives (March 10, 1993) WORLD TRADE CENTER BOMBING. Congressional Record. [Online] http://www.fas.org/irp/congress/1993_cr/h930310-terror.htm.
[17] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

on the type of event, but as a secondary input.[18] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as "Low." Experts explained that the overall environmental consequences are low, but that they could become more severe if a water treatment plant or chemical plant were targeted.

Additional References

FBI Bomb Data Center (1999). *1998 Bombing Incidents*. General Information Bulletin 98-1, Federal Bureau of Investigation, U.S. Department of Justice.

North et al (1999, August 23). Psychiatric disorders among survivors of the Oklahoma City bombing. *Journal of the American Medical Association* 282(8) 755-762.

Verger et al (2004, August). The psychological impact of terrorism: an epidemiologic study of posttraumatic stress disorder and associated factors in victims of the 1995-1996 bombings in France. *American Journal of Psychiatry* 161(8) 1384-1389.

[18] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2} D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Explosives Terrorist Attack was given a C_{EF} of 1.2.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Nuclear Terrorism Attack

A hostile non-state actor(s) acquires an improvised nuclear weapon through manufacture from fissile material, purchase, or theft, and detonates it within a major U.S. population center.

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Direct Economic Loss	See classified data sheet		
Indirect Economic Loss	See classified data sheet		
Social Displacement	330,000	2 million	3 million
Psychological Distress	See text		
Environmental Impact[1]	High[2]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

The Department of Homeland Security (DHS) and Federal Bureau of Investigations (FBI) define a nuclear attack as follows:

> A nuclear weapon is a device with explosive power resulting from the release of energy unleashed by the splitting of nuclei of a heavy chemical element, such as plutonium or uranium (fission), or by the fusing of nuclei from a light element, such as hydrogen (fusion). Fusion (thermonuclear) bombs can be significantly more powerful than fission bombs, but are at this point believed to be beyond the capability of terrorists to construct.[3]

A successful nuclear attack would cause substantial fatalities, injuries, and infrastructure damage from the heat and blast of the explosion, and significant radiological consequences from both the initial nuclear radiation and the radioactive fallout that settles after the initial event. A nuclear detonation in a modern urban area would impact the medical system more than any disaster previously experienced by the Nation.[4] An electromagnetic pulse from the explosion could also disrupt telecommunications and power distribution. Significant economic, social, psychological, and environmental impacts would be expected.[5]

Nuclear explosions are classified by yield, or the amount of energy they produce, relative to how many tons of TNT would be needed to produce an equivalent explosive yield. Strategic nuclear weapon systems held by state actors deliver weapons with yields in the multi-hundred kilotons to megaton (1,000 kiloton) range. Generally, when considering nuclear explosion scenarios perpetrated by terrorists, experts assume a low-yield nuclear device detonated at ground level, where low yield in this context ranges from factions of a kiloton (kT) to 10 kT.[6] This is still orders of magnitude greater than conventional explosives which may be used in a terrorist attack: for comparison, the 1995 Oklahoma City bombing was equivalent to 2 tons of TNT, or 0.002 kilotons.[7]

There are two general types of nuclear weapons a terrorist may acquire and use: illicitly acquired weapons produced by nation-states and improvised nuclear devices (INDs).

- The former are designed, constructed, and usually tested using the resources of a sovereign state. They are typically reliable, high-yield weapons designed for a delivery vehicle, such as an aircraft or missile.
- An IND, by contrast, would be a crude nuclear device built from components of a stolen weapon or from scratch using nuclear material. The primary obstacle to terrorists attempting to construct a viable IND is obtaining the weapons-grade fissile material – plutonium, highly enriched uranium, or a stolen state-manufactured weapon – needed to produce a nuclear explosion.
- Crude nuclear weapons are typically heavy, ranging from a few hundred pounds to several tons. Smaller, specially designed systems such as the so-called suitcase nuclear weapons are much lighter but more technically difficult to produce.[8]

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[9] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the nuclear terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for successful terrorist attacks corresponding to the five CBRN national-level events in the SNRA.

The SNRA leveraged data for the classified risk summary sheet that assumed terrorist attack to include the following:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources;
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States;
- Appears to be intended to intimidate or coerce a civilian population;
- Appears to be intended to influence the policy of a government by intimidation or coercion;
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

Nine U.S. cities were considered in calculating the probabilities and consequences of the attack. The cities were chosen to sample a variety of locations and population densities and included New York, Washington, Houston, and Miami. Impacts of the attack were evaluated for four yields across the nine cities and were evaluated 12 times throughout the year to sample atmospheric conditions at detonation.

The SNRA project team used the following assumptions identified in Table 1 to estimate the economic losses for this national-level event.

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:
• **Decontamination, Disposal, and Physical Destruction:** DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
• **Business Interruption:** Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.
• **Loss in Spending from Fatalities:** This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality.
• **Medical Costs:** Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.
Indirect Costs include:
• Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include:
• The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

[1] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'best' estimate.
[3] "Potential Terrorist Attack Methods: Joint Special Assessment", DHS & FBI, 23 April 2008, p. 36. (Reference is (UNCLASSIFIED//FOR OFFICIAL USE ONLY): Extracted information is UNCLASSIFIED.)
[4] National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats.(2010, June), *Planning Guidance for Response to a Nuclear Detonation* (2nd ed), p. 81.
[5] National Academies, U.S. Department of Homeland Security (2005). Nuclear attack. Fact sheet for the public (series, Communicating in a Crisis). Retrieved from http://www.dhs.gov/xlibrary/assets/prep_nuclear_fact_sheet.pdf via http://www.ready.gov (checked April 2015).
[6] It should be noted that if a state-built weapon were available to terrorists, the presumption of low yield may no longer hold. NSS (2010) *op cit.*, p. 15.
[7] National Academies, DHS (2005), Nuclear attack public fact sheet, *op cit.*; p. 16, NSS 2010, *op cit.*
[8] National Academies, DHS (2005), Nuclear attack public fact sheet, *op cit.*
[9] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Social displacement estimates for the Nuclear Terrorism Attack national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[10]
- The low, best, and high social displacement estimates of 330,000, 2 million, and 3 million for the Nuclear Terrorism Attack event reflect judgments from START subject matter experts, based on published evacuation/shelter-in-place estimates for a detonated 10 kiloton improvised nuclear device.[11]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[12] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures.
- Experts identified the best estimate for environmental consequences as “High.” Experts indicated that the environmental consequences would be high due to the size and effect of the fallout and the persistence of the material. The relative toxicity may be moderate, since isotopes could be remediated. Ultimately, the long-term impact to the environment could be more moderate, but the impact would be high for in the short and intermediate term (1 year or more).

Additional Relevant Information

The consequences of a nuclear attack would be determined by the following effects of a detonation:

- *Air blast:* As with a conventional explosive, a nuclear detonation produces a shock wave, or air blast wave.
- *Heat:* The second effect would be extreme heat, a fireball, with temperatures reaching to millions of degrees.
- *Initial radiation:* The initial radiation is produced in the first minute following detonation.
- *Ground shock:* Ground shocks roughly equivalent to a large localized earthquake would also occur. This could cause additional damage to buildings, communications, roads, utilities and other critical infrastructure.
- *Secondary radiation:* Secondary radiation exposure from fallout would occur primarily downwind from the blast, but changing weather conditions could spread radioactivity and enlarge the affected area.

A failed detonation is potentially hazardous to the extent that it results in a fizzle yield, which occurs if the fissile material mechanically disassembles before a significant yield is generated. Even a fizzle yield, however, can produce a fairly large explosion that could disperse radioactive material widely.

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[10] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[11] Davis, Tracy C. 2007. "Stages of Emergency: Cold War Nuclear Civil Defense." Duke University Press.; Meade C, Molander R.C. Considering the Effects of a Catastrophic Terrorist Attack. Santa Monica, CA: RAND Center for Terrorism Risk Management Policy; 2006. http://www.rand.org/pubs/technical_reports/2006/RAND_TR391.pdf; National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats. Planning Guidance for Response to a Nuclear Detonation. 2nd Edition; 2010. http://www.remm.nlm.gov/PlanningGuidanceNuclearDetonation.pdf.

[12] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Nuclear Terrorism Attack was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

Radiological Dispersal Device Attack

A hostile non-state actor(s) acquires radiological materials and disperses them through explosive or other means or creates a radiation exposure device (RED).

Data Summary

Description	Low	Best	High
Fatalities	See classified data sheet		
Injuries and Illnesses	See classified data sheet		
Direct Economic Loss	See classified data sheet		
Indirect Economic Loss	See classified data sheet		
Social Displacement	25,000	50,000	100,000
Psychological Distress	See text		
Environmental Impact[1]	Low[2]		
Frequency of Events	See classified data sheet		

(UNCLASSIFIED)

Event Background

Radiological devices used for terrorism may include radiological dispersal devices (RDD) and radiological exposure devices (RED). The principal type of RDD is a "dirty bomb" that combines a conventional explosive with radioactive material. A second type involves radioactive material dispersed in air or water by other mechanical means, such as a water spray truck, a crop duster, or manually spread. An RED may comprise a powerful radioactive source hidden in a public place, such as a trash receptacle in a busy train or subway station, to expose passers-by to a potentially significant dose of radiation.[3]

It is very difficult to design an RDD that would deliver radiation doses high enough to cause immediate health effects or fatalities in a large number of people. Most injuries from a dirty bomb would probably occur from the heat, debris, and force of the conventional explosion used to disperse the radioactive material, affecting individuals close to the site of the explosion. At the low radiation levels expected from an RDD, the immediate health effects from radiation exposure would likely be minimal.[4] Subsequent decontamination of the affected area could involve considerable time and expense. A dirty bomb could have significant psychological and economic effects.[5]

Most radiological devices would have very localized effects, ranging from less than a city block to several square miles. Factors determining the area of contamination would include the amount and type of radioactive material, the means of dispersal, the physical and chemical form of the radioactive material (for example, material dispersed in the form of fine particles may be carried by the wind over a relatively large area), local topography and location of buildings, and local weather conditions.[6]

Preparedness and effectiveness of response teams will play a significant role in mitigating the consequences caused by an RDD attack. Early identification of a radiological attack is important in determining whether or not to evacuate the area or shelter in place and the size of the area requiring cordoning.

There is evidence indicating terrorist organizations have expressed interest in using RDDs, though experts disagree as to how attractive they are as a tactic due to the limited number of expected casualties and the challenges associated with acquiring and handling radiological material. However, others assert that the resulting psychological and economic consequences may be enough for terrorists to risk the difficulties in pursuing this as a method for attack.[7]

Assumptions

The SNRA leveraged classified data from the DHS/S&T 2011 Integrated Terrorism Risk Assessment (ITRA)[8] for quantitative frequency, fatality, illness/injury, and economic loss estimates for the radiological terrorism attack event. The data relies heavily on the Intelligence Community (IC) and other technical experts to develop scenarios and estimate the likelihoods of those scenarios for analysis. The DHS Science and Technology Directorate (S&T) extracted ITRA data for successful terrorist attacks corresponding to the five CBRN national-level events in the SNRA.

The SNRA leveraged data for the classified risk summary sheet that assumed the qualifiers for terrorist attack to include the following:

- Involves an act that is dangerous to human life or potentially destructive of critical infrastructure or key resources;
- Involves an act that is a violation of the criminal laws of the United States or any State or other subdivision of the United States;
- Appears to be intended to intimidate or coerce a civilian population;
- Appears to be intended to influence the policy of a government by intimidation or coercion;
- Appears to be intended to affect the conduct of government by mass destruction, assassination, or kidnapping.

The analysis only included data for successful attacks for this national-level event, e.g. detonation of the device or successful spread into the food or water system. Failed attacks were not included in this analysis (e.g., interdiction during the fabrication and assembly of the dispersal device, interdiction during travel to United States, or failure of the dispersal device).

The analysis used broad definitions of organizations that may initiate or represent potential radiological terrorism threats to the U.S., the categories of radionuclides that could be used for an attack, and the targets that may be selected for a radiological attack. The adopted criteria for general categories representing radiological terrorist threats to the U.S. are as follows:

- The International Terrorist Organization category is composed of terrorist organizations that operate both inside and outside of the U.S. that are not sponsored by a nation (e.g., al-Qaeda).
- The Domestic Terrorist Organization category is composed of terrorist organizations that operate only within the U.S. that are not sponsored by a nation (e.g., Animal Liberation Front and Rajneesh).
- The Small Groups/Individuals Terrorist Organization category is composed of small groups (i.e., 2 to 3 members) or individuals that operate only within the U.S. that are not sponsored by a nation (e.g., the Unabomber and Timothy McVeigh).

The SNRA project team used the following assumptions identified in Table 1 to estimate the economic losses for this national-level event.

Table 1. Definitions for Direct, Indirect, and Induced Costs

Direct Costs include:

- **Decontamination, Disposal, and Physical Destruction**: DDP costs covered the repair, replacement and environmental clean-up which are considered expenditures by the government. It was assumed the government would recoup this spending through tax increases, causing a reduction of household spending of that same amount. However, this spending would be received as income by some sectors, such as waste management and environmental consulting services. The increase in spending into the waste management and environmental consulting services is treated as increase in annual output for these sectors.
- **Business Interruption**: Business interruption impacts considered losses due to decreased output at the target area, along with other increases and decreases to related sectors due to behavioral changes resulting from the event.
- **Loss in Spending from Fatalities**: This SNRA project team estimated a loss of spending of $42,500 for each fatality. In addition, $6,000 is included in increased output for mortuary services for each fatality.
- **Medical Costs**: Costs of medical mitigation were considered to be borne through private spending and insurance companies, while the hospital sector received an offsetting increase in output.

[1] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.
[2] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.
[3] U.S. Environmental Protection Agency (2006, October). OSC Radiological Response Guidelines. Office of Solid Waste and Emergency Response, Office of Air and Radiation, U.S. EPA; at http://www.uscg.mil/hq/nsfweb/foscr/ASTFOSCRSeminar/References/EnvResponsePapersFactSheets/OSCRadResponseGuidelines.pdf (retrieved April 2013).
[4] National Academies and U.S. Department of Homeland Security (2005). Radiological attack: dirty bombs and other devices. Retrieved from http://www.dhs.gov/radiological-attack-fact-sheet via http://www.ready.gov.
[5] EPA (2006) OSC Radiological Response Guidelines, *op. cit.*.
[6] Ibid.
[7] Dana A. Shea, "Radiological Dispersal Devices: Select Issues in Consequence Management," Congressional Research Service for the Library of Congress (December 7, 2004).
[8] DHS Directorate of Science & Technology (2011), Integrated CBRN Terrorism Risk Assessment (reference is SECRET//NOFORN).

Indirect Costs include:
• Costs incurred by the suppliers and vendors in the associated expenditure sectors for the industries impacted by the direct costs above.
Induced Costs include:
• The induced costs are those incurred due to reduced spending by households with members employed in any of the directly or indirectly affected industries. Induced costs can also include substitution effects or likely transfers of economic activity from one set of sectors to another set, such as avoidance of air or other travel or altered transportation mode preferences to other sectors following an attack on the commercial air transport sector.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

- Social displacement estimates for the Radiological Terrorism Attack national-level event were provided by the National Consortium for the Study of Terrorism and Responses to Terrorism (START).[9]
- The low, best, and high social displacement estimates of 25,000, 50,000, and 100,000 for the Radiological Terrorism Attack event reflect judgments from START subject matter experts, based on published evacuation/shelter-in-place estimates for radiological dispersal device (RDD) attack scenarios.[10]

Psychological Distress

Psychological consequences for the SNRA focus on *significant distress* and *prolonged distress*, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. An index for significant distress was created that reflected empirical findings that the scope and severity of an event is more important than the type of event. The equation for this index uses the fatalities, injuries, and displacement associated with an event as primary inputs; a factor elicited from subject matter experts weights the index for differing psychological impact based on the type of event, but as a secondary input.[11] The numerical outputs of this index formula were used to assign events to bins of a risk matrix for a semi-quantitative analysis of psychological risk in the SNRA.

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental consequences for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental consequence category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agents, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).
- EPA defined environmental consequence as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- The environmental assessment included effects resulting from terrorism threats, but did not include human health effects or effects in urban areas because these effects are already reflected in other consequence measures
- Experts identified the best estimate for environmental consequences as "Low." Experts indicated that the environmental impact would be limited because: fallout would be restricted to an urban area, toxicity from likely materials would be relatively low, and the dispersion area could be relatively limited as well. Environmental consequences could be elevated to "Medium" depending on the specific scenario.

Potential Mitigating Factors

Though the effects of an RDD attack will vary by the size of the detonation device, the means of dispersal, weather conditions, and the selected radionuclide, the preparedness level and effectiveness of response teams will play a significant role in mitigating the consequences caused by an RDD attack. Those closest to the detonation site would likely sustain injuries from the explosion, but as the radioactive material spreads it becomes less concentrated and harmful.[12] Early identification of a radiological attack is important in determining whether or not to evacuate the area or shelter in place and the size of the area requiring cordoning. Additionally, the evacuation effort should include populations downwind from the explosion and also consider the needs of at-risk and special populations. Planners should note the importance of effective communication during the response effort to inform the public about evacuation routes and areas that are potentially contaminated.

In general, protection from radiation is afforded by utilizing the following principles:

- Minimizing the time exposed to radioactive materials;
- Maximizing the distance from the source of radiation; and
- Shielding from external exposure and inhaling radioactive material.[13]

[9] START is a Department of Homeland Security University Center of Excellence that focuses on social and behavioral aspects of terrorism, natural disasters, and technological accidents, and the social, behavioral, cultural and economic factors influencing responses to and recovery from catastrophes.

[10] Worcester, Maxim. "International Terrorism and the Threat of a Dirty Bomb." Institute Fur Strategies, Politik, Sicherheits, und Wirtschaftsberatung, Berlin.

[11] The Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\,Fat + Inj + \frac{1}{2}D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is the expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human consequence metrics.

The Event Familiarity Factor is intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological consequences. This factor, ranging from 1.0 for familiar events to 1.3 for unfamiliar events, was provided by subject matter experts for each national-level event included in the SNRA: Radiological Terrorism Attack was given a C_{EF} of 1.3.

The numerical psychological distress estimates for this event and the complete semi-quantitative risk matrix may be found in Appendix G and the Findings sections, respectively, of the full SNRA Technical Report.

[12] "Dirty Bombs: Backgrounder", United States Nuclear Regulatory Commission, May 2007.

[13] Ibid.

APPENDIX K: SNRA DATA SET

Table K.1: SNRA Data Summary

National-Level Event	Frequency			Fatalities			Injuries/Illnesses			Direct Economic Cost ($M)			Social Displacement			Psychological Distress			EFF*	Environmental	
	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High		Best	2nd Best
Aircraft as a Weapon													0	50,000	1,000,000				1.2	Low	Moderate
Armed Assault													0	2,000					1.1	De minimus	De minimus
Explosives Terrorism Attack													0	5,000					1.2	Low	Moderate
Biological Food Contamination	0.20	0.64	1.2	0	11	42	200	17,000	45,000				0	400	950	200	17,000	46,000	1	Moderate	Low
Chemical Substance Spill or Release	0.61	1.6	5	1	5	25	0	60	790	0.04	14	330	0	255	5,400	6	230	4,000	1.1	Moderate	High
Dam Failure	0.17	0.54	3	1	17	170	0	50	3,000				1	500	250,000	6	390	130,000	1	Moderate	Moderate
Radiological Substance Release	0.0062	0.0093	0.014	0	230	2,200	0	240	2,300	7,500	8,600	16,000	76,000	150,000	500,000	42,000	82,000	290,000	1.1	Moderate	High
Animal Disease Outbreak	0.04	0.1	0.1	0	0	0	0	0	0	2,300	15,200	69,000	0	1,000			500		1	Low	Moderate
Earthquake	0.11	0.27	2	0	370	8,900	0	8,700	210,000	107	8,700	105,000	160	27,000	2,000,000	90	27,000	1,400,000	1.1	Moderate	High
Flood	0.5	4	10	0	3	25	0	95	4,500	104	740	16,000	150	29,000	200,000	75	15,000	100,000	1	Moderate	Moderate
Human Pandemic Outbreak	0.017	0.033	0.10	140,000	250,000	440,000	62,000,000	77,000,000	110,000,000	84,000	170,000	260,000	0	0	0	63,000,000	78,000,000	110,000,000	1	Low	Moderate
Hurricane	0.33	1.9	7	0	26	1,200	0	650	30,000	100	5,700	92,000	430	520,000	5,000,000	220	260,000	2,500,000	1	Moderate	High
Space Weather		0.01																	1	De minimus	Moderate
Tsunami	0.0024	0.005	0.0074	1	300	1,000	1	300	1,000	700	1,500	3,300	8,600	15,000		4,300	9,200	13,000	1	Moderate	High
Volcanic Eruption	0.001	0.002	0.01	340	520	780	2,000	17,000	150,000	4,300	10,000	16,000	1,300	130,000	2,100,000	4,400	85,000	1,200,000	1	High	Moderate
Wildfire	0.2	0.8	3	0	5	25	0	63	190	100	900	2,800	770	110,000	640,000	390	55,000	320,000	1	Low	High
Biological Terrorism Attack (non-food)													0	1,800					1.3	Low	Low
Chemical Terrorism Attack (non-food)													0	100,000	700,000				1.3	Moderate	High
CB Food Contamination Terrorism Attack													0						1.3	Low	Moderate
Nuclear Terrorism Attack													330,000	2,000,000	3,000,000				1.3	High	High
Radiological Terrorism Attack													25,000	50,000	100,000				1.3	Low	Moderate
Cyber Event affecting Data													0	0	0				1	De minimus	De minimus
Cyber Event affecting Phys. Infrastructure													0	400					1	De minimus	Low

* Event Familiarity Factor (See Appendix G)

Cell color key	
(dark gray)	Data are classified
(light gray)	Data are For Official Use Only
(tan)	No data
(yellow)	Not reported in quantitative charts

Table K.2: SNRA Core Data

Record Type	Event Group	NLE	Place	State	Event Start	Comments/Identifiers	SNRA Fatalities	SNRA Inj/Ill	SNRA Displaced	EFF	SNRA Psych.Distress	SNRA Direct Economic Damage	Event End	Observation Period Start	Observation Period End	Observation Period (years)	Incident Likelihood	Source
Scenario	Natural	Animal Disease					0	0	1,000	1.0	500	$15,200,000,000					0.1	See RSS
Scenario	Natural	Human Pandemic					250,000	77,000,000	0	1.0	78,250,000	$170,000,000,000					0.033	See RSS
Scenario	Natural	Tsunami					300	300	14,700	1.0	9,150	$1,530,000,000					0.0057	See RSS
Scenario	Natural	Volcanic Eruption					515	17,000	130,000	1.0	84,575	$8,300,000,000					0.002	See RSS
Incident	Natural	Earthquake	San Francisco	CA	4/18/1906	Assumption 1% annual mitigation	8,896	209,056		1.1	278,890	$104,905,367,626		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	El Centro	CA	6/22/1915	Assumption 1% annual mitigation	13	306		1.1	408	$131,076,352		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	San Jacinto/Riverside County	CA	4/21/1918	Assumption 1% annual mitigation	0	0		1.1	0	$193,990,095		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Mona Passage	PR	10/11/1918	Assumption 1% annual mitigation	138	3,243		1.1	4,326	$1,943,953,812		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Santa Barbara	CA	6/29/1925	Assumption 1% annual mitigation	44	1,034		1.1	1,379	$1,371,950,746		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Long Beach	CA	3/11/1933	Assumption 1% annual mitigation	358	8,413		1.1	11,223	$7,565,220,534		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Helena	MT	10/19/1935	Assumption 1% annual mitigation	5	118		1.1	157	$960,000,000		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Helena	MT	10/31/1935	Assumption 1% annual mitigation	3	71		1.1	94	$512,380,253		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	El Centro/Imperial Valley	CA	5/19/1940	Assumption 1% annual mitigation	6	141		1.1	188	$392,000,000		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Puget Sound/Olympia	WA	4/13/1949	Assumption 1% annual mitigation	24	564		1.1	752	$3,403,585,667		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Terminal Island	CA	11/18/1949	Assumption 1% annual mitigation	0	0		1.1	0	$414,893,442		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Terminal Island	CA	8/15/1951	Assumption 1% annual mitigation	0	0		1.1	0	$109,913,608		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Kern County/Bakersfield	CA	7/21/1952	Assumption 1% annual mitigation	26	611		1.1	815	$1,820,696,601		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Kern County/Bakersfield	CA	8/22/1952	Assumption 1% annual mitigation	4	94		1.1	125	$662,071,491		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Hebgen Lake	MT	8/18/1959	Assumption 1% annual mitigation	54	1,269		1.1	1,693	$706,863,603		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Prince William Sound/Anchorage	AK	3/28/1964	Assumption 1% annual mitigation	220	5,170		1.1	6,897	$11,213,495,628		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Seattle	WA	4/29/1965	Assumption 1% annual mitigation	9	212		1.1	282	$299,194,941		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Santa Rosa	CA	10/2/1969	Assumption 1% annual mitigation	2	47		1.1	63	$120,000,000		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	San Fernando	CA	2/9/1971	Assumption 1% annual mitigation	81	1,904		1.1	2,539	$5,083,948,997		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Imperial Valley	CA	10/15/1979	Assumption 1% annual mitigation	0	0		1.1	0	$129,806,214		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Whittier/Los Angeles	CA	10/1/1987	Assumption 1% annual mitigation	9	212	9,000	1.1	5,232	$795,888,336		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Loma Prieta/San Francisco	CA	10/18/1989	Assumption 1% annual mitigation	60	1,410	32,500	1.1	19,756	$10,485,000,000		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Ferndale/Fortuna/Petrolia	CA	4/25/1992	Assumption 1% annual mitigation	0	0		1.1	0	$106,971,740		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Landers/Yucca Valley	CA	6/28/1992	Assumption 1% annual mitigation	3	71	750	1.1	507	$202,144,394		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Northridge/Los Angeles	CA	1/17/1994	Assumption 1% annual mitigation	62	1,457	120,000	1.1	67,944	$78,235,199,499		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Seattle/Tacoma/Olympia	WA	2/28/2001	Assumption 1% annual mitigation	1	24	400	1.1	251	$2,378,245,427		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Earthquake	Paso Robles/San Simeon	CA	12/22/2003	Assumption 1% annual mitigation	2	47	160	1.1	151	$328,283,332		1/1/1906	7/15/2011	105.53	0.0095	See RSS
Incident	Natural	Flood			3/27/1993	Flooding in SC and TN.	3	0		1.0	15	$238,068,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/8/1993	Heavy rain in parts of OK, AR, and TX.	5	0		1.0	25	$103,635,700		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/8/1993	Extensive flooding, South Central Kansas.	0	0		1.0	0	$157,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/8/1993	Flooding in OK.	0	0	31,000	1.0	15,500	$157,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/31/1993	Great Flood of 93.	0	0		1.0	0	$15,700,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			9/24/1993	Steady rains in and around Springfield MO.	1	0		1.0	5	$119,013,850		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/18/1994	Heavy rains, flash floods in PA and NY.	3	6		1.0	21	$111,766,500		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			10/16/1994	Texas flooding.	15	0	14,070	1.0	7,110	$399,146,400		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/10/1995	Flooding, Kern, Los Angeles, San Diego CA.	0	0		1.0	0	$166,135,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/1/1995	Flooding from Kern to Tulare CA.	0	0		1.0	0	$168,072,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/10/1995	Salinas River flooding in Monterey County CA.	0	0		1.0	0	$447,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/18/1996	Rain, snow melt caused flooding from VA to NY.	22	1		1.0	111	$475,800,480		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			2/6/1996	Northern Oregon river flooding.	7	0	24,900	1.0	12,485	$576,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/17/1996	Record breaking rainfall over Illinois.	0	0		1.0	0	$111,888,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/19/1996	Heavy thunderstorms in PA.	2	1		1.0	11	$326,160,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/1/1997	Melting snow, heavy rain in Southern Oregon.	0	0	18,100	1.0	9,050	$126,900,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/1/1997	Damages in CA from Sierra Nevada rain, snow melt.	3	52	125,000	1.0	62,567	$1,635,600,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/1/1997	Flooding from excessive rain in KY, OH, and WV.	10	3		1.0	53	$153,368,520		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/1/1997	Record 24 hour rainfall in Jefferson County, KY.	2	0		1.0	10	$296,100,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			4/8/1997	Sheyenne River flooding in ND.	0	0	50,400	1.0	25,200	$5,428,500,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/20/1997	Flash floods in MN and WI.	0	6		1.0	6	$141,751,530		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/28/1997	Heavy rains, flash floods in CO.	5	40	424	1.0	277	$289,162,800		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/11/1997	Hail, wind, torrential rain Lakewood, Denver CO.	0	0		1.0	0	$180,480,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			2/4/1998	Slow moving Nor'easter battered eastern VA.	0	0		1.0	0	$104,250,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			2/23/1998	Powerful Pacific storm, southern and central CA.	5	3		1.0	28	$152,316,200		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/8/1998	Slow moving system dumped much rain on AL.	4	0	18,000	1.0	9,020	$165,389,150		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/8/1998	Gulf storm dumped up to 14 inches of rain, AL, GA.	1	1		1.0	6	$543,490,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			3/10/1998	Nearly six inches of rain, multiple counties FL.	0	0		1.0	0	$510,130,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/1/1998	Agricultural damage from Sierra Nevada snow melt.	0	0		1.0	0	$139,556,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/26/1998	Sustained flooding, parts of East Central OH.	10	0	14,000	1.0	7,050	$281,502,800		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/5/1998	Slow moving thunderstorms moved through WI.	2	5		1.0	15	$114,410,900		1/1/1993	12/31/2005	13.00	0.0769	See RSS

Record Type	Event Group	NLE	Place	State	Event Start	Comments/Identifiers	SNRA Fatalities	SNRA Inj/Ill	SNRA Displaced	EFF	SNRA Psych.Distress	SNRA Direct Economic Damage	Event End	Observation Period Start	Observation Period End	Observation Period (years)	Incident Likelihood	Source
Incident	Natural	Flood			8/5/1998	Flooding from Devils Lake in ND.	0	0		1.0	0	$136,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			10/17/1998	The Great October Flood in west Texas.	25	4,520		1.0	4,645	$559,266,500		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/7/2000	Heavy rainfall, Jefferson and Franklin county MO.	2	0	300	1.0	160	$132,660,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/19/2000	Heavy thunderstorms in MN, record rainfall amounts.	0	0		1.0	0	$147,840,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			8/12/2000	Thunderstorms, near torrential downpours, NJ.	0	0	175	1.0	88	$237,996,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			10/3/2000	Massive rainfall in South West FL.	0	0		1.0	0	$1,254,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			4/1/2001	Flooding from rapid snow melt and rain.	3	1		1.0	16	$256,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/8/2001	Severe flash flooding in WV and VA.	1	0		1.0	5	$280,748,800		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			10/11/2001	High water in Columbia AR.	0	0		1.0	0	$153,606,400		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/2/2002	Flash floods in KY, VA, and WV.	4	0		1.0	20	$141,233,400		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/10/2002	Heavy rainfall, Roseau River overflowed dikes.	0	0		1.0	0	$252,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			4/6/2003	Heavy rains, flooding, several counties MS.	2	0		1.0	10	$325,683,090		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/5/2003	Flooding TN, GA and AL.	3	6		1.0	21	$1,474,800,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			7/21/2003	Thunderstorm, flash floods throughout OH.	5	0	1,200	1.0	625	$288,261,570		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			5/23/2004	Stationary front, flooding SE Michigan.	0	0		1.0	0	$120,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			6/1/2004	Heavy rains, southern WI.	0	0		1.0	0	$301,860,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			1/10/2005	Stalled storm system dumped rain throughout UT.	1	6		1.0	11	$348,000,000		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Flood			12/30/2005	Widespread flooding, several CA counties.	0	0	3,600	1.0	1,800	$476,298,320		1/1/1993	12/31/2005	13.00	0.0769	See RSS
Incident	Natural	Hurricane			1970	Celia	11	275		1.0	330	$6,850,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1971	Doria	6	150		1.0	180	$2,400,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1971	Edith	1	25		1.0	30	$310,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1971	Fern	1	25		1.0	30	$480,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1971	Ginger	0	0		1.0	0	$190,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1972	Agnes	122	3,050		1.0	3,660	$20,300,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1973	Delia	5	125		1.0	150	$300,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1974	Carmen	1	25		1.0	30	$1,140,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1974	Subtropical Storm 1 1974	0	0		1.0	0	$130,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1975	Eloise	21	525		1.0	630	$6,230,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1976	Belle	9	225		1.0	270	$570,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1978	Amelia	36	900		1.0	1,080	$190,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1979	Claudette	3	75		1.0	90	$1,710,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1979	David	1	25		1.0	30	$980,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1979	David	1	25		1.0	30	$1,570,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1979	Frederic	17	425		1.0	510	$12,640,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1980	Allen	2	50		1.0	60	$2,060,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1981	Dennis	0	0		1.0	0	$140,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1983	Alicia	22	550		1.0	660	$9,670,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1984	Diana	4	100		1.0	120	$370,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Bob	0	0		1.0	0	$120,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Danny	0	0		1.0	0	$160,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Elena	9	225	1,000,000	1.0	500,270	$4,340,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Gloria	1	25		1.0	30	$520,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Gloria	6	150		1.0	180	$2,490,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Juan	11	275		1.0	330	$4,560,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1985	Kate	2	50		1.0	60	$1,270,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1988	Gilbert	5	125		1.0	150	$200,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1989	Allison	4	100		1.0	120	$1,680,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1989	Chantal	1	25		1.0	30	$280,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1989	Hugo	51	1,275	25,000	1.0	14,030	$18,320,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1989	Jerry	1	25		1.0	30	$210,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1990	Marco	13	325		1.0	390	$210,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1991	Bob	16	400	1,200	1.0	1,080	$3,620,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1992	Andrew	26	650	250,055	1.0	125,808	$66,770,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1993	Emily	2	50		1.0	60	$100,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1994	Alberto	20	500	20,022	1.0	10,611	$1,290,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1994	Beryl	3	75		1.0	90	$180,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1994	Gordon	16	400		1.0	480	$1,230,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1995	Erin	3	75	6,000	1.0	3,090	$820,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1995	Erin	3	75		1.0	90	$830,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1995	Jerry	0	0		1.0	0	$110,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1995	Opal	23	575	78,000	1.0	39,690	$7,490,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1996	Bertha	3	75		1.0	90	$610,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1996	Fran	32	800	4,000	1.0	2,960	$7,260,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1996	Josephine	1	25		1.0	30	$310,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1997	Danny	4	100		1.0	120	$200,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1998	Bonnie	4	100	17,000	1.0	8,620	$1,440,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS

Record Type	Event Group	NLE	Place	State	Event Start	Comments/Identifiers	SNRA Fatalities	SNRA Inj/Ill	SNRA Displaced	EFF	SNRA Psych.Distress	SNRA Direct Economic Damage	Event End	Observation Period Start	Observation Period End	Observation Period (years)	Incident Likelihood	Source
Incident	Natural	Hurricane			1998	Earl	0	0		1.0	0	$150,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1998	Frances	3	75		1.0	90	$970,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1998	Georges	14	350	5,127	1.0	2,984	$4,100,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1999	Dennis	2	50		1.0	60	$270,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1999	Floyd	50	1,250	3,000,010	1.0	1,501,505	$7,700,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			1999	Irene	9	225		1.0	270	$1,430,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2001	Allison	43	1,075	172,000	1.0	87,290	$8,330,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2001	Gabrielle	2	50		1.0	60	$390,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2002	Isidore	2	50	13,200	1.0	6,660	$480,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2002	Lili	6	150		1.0	180	$1,210,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2003	Claudette	1	25		1.0	30	$250,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2003	Isabel	22	550	225,000	1.0	113,160	$4,820,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Charley	0	0	545	1.0	273	$120,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Charley	16	400	30,000	1.0	15,480	$18,520,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Frances	11	275	5,000,000	1.0	2,500,330	$12,310,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Gaston	0	0		1.0	0	$160,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Ivan	25	625		1.0	750	$18,480,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2004	Jeanne	8	200	40,000	1.0	20,240	$9,350,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Cindy	0	0		1.0	0	$360,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Dennis	2	50		1.0	60	$2,670,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Katrina	1,200	30,000	500,000	1.0	286,000	$92,050,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Rita	8	200	300,000	1.0	150,240	$11,330,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2005	Wilma	16	400	30,000	1.0	15,480	$26,210,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2006	Ernesto	0	0	140	1.0	70	$550,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Dolly	2	50		1.0	60	$1,080,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Fay	1	25	400	1.0	230	$590,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Gustav	7	175	2,100,000	1.0	1,050,210	$4,220,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Hanna	0	0		1.0	0	$170,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2008	Ike	31	775	200,000	1.0	100,930	$19,600,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Hurricane			2010	Hermine	12	300		1.0	360	$250,000,000		1/1/1970	12/31/2010	41.00	0.0244	See RSS
Incident	Natural	Wildfire	Oakland	CA	10/20/1991	Oakland Hills Fire	25	150		1.0	275	$2,803,063,000	10/20/1991	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Sacramento	CA	10/26/1993		0	89		1.0	89	$514,587,000	10/31/1993	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Los Angeles	CA	10/27/1993	Old Topanga Fire	6	187		1.0	217	$2,221,587,000	11/4/1993	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Central Florida	FL	5/31/1998		0	150		1.0	150	$261,731,000	7/30/1998	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Central Florida	FL	7/1/1998		0	65	40,124	1.0	20,127	$523,462,000	7/10/1998	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Chelan	WA	8/2/1998		0	0		1.0	0	$123,978,000	8/30/1998	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Los Alamos	NM	5/4/2000	Cerro Grande	0	0	25,400	1.0	12,700	$1,966,720,000	5/31/2000	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Tehama	CA	9/29/2000		0	0		1.0	0	$717,197,000	9/30/2000	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Pima	AZ	6/17/2003	Rodeo-Chediski Fire	0	0	1,269	1.0	635	$161,404,000	7/15/2003	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	San Diego	CA	10/25/2003	Cedar Fire	22	157	27,104	1.0	13,819	$2,572,317,000	11/5/2003	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Carson	TX	3/12/2006		12	8		1.0	68	$107,289,000	3/18/2006	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Wheeler	TX	4/11/2006		0	2		1.0	2	$103,553,000	4/13/2006	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Alpine	CA	6/24/2007	Alpine Fire	0	3	768	1.0	387	$544,127,000	6/30/2007	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	San Diego County	CA	10/21/2007		10	132	640,064	1.0	320,214	$748,175,000	10/31/2007	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Natural	Wildfire	Sacramento	CA	11/15/2008		0	0	55,000	1.0	27,500	$156,960,000	11/19/2008	1/1/1990	12/31/2009	20.00	0.0500	See RSS
Incident	Accidental	Food Contamination			1998	1998 Lysteria-Hot Dog	42	212		1.0	422			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2004	2004 Salmonella-Roma Tomato	0	12,570		1.0	12,570			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2006	2006 E. Coli-Spinach	10	6,212		1.0	6,262	$67,400,000		1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2006	2006 Salmonella-Peanut Butter	18	20,950		1.0	21,040			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2007	2007 Salmonella-Pot Pie	6	11,749		1.0	11,779			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2008	2008 Salmonella- Jalapeno/Serrano Peppers	4	44,976		1.0	44,996			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Food Contamination			2008	2008 Salmonella-Peanut Butter	18	20,979		1.0	21,069			1/1/1998	12/31/2008	11.00	0.0909	See RSS
Incident	Accidental	Chemical Accident	Pensacola	FL	12/13/1994	Fertilizer Manufacturing, Ammonia	4	27	2,000	1.1	1,152	$327,678,968		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Alberton	MT	4/11/1996	Rail Transport, Chlorine	1	787	0	1.1	871	$19,675,515		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Lancaster	OH	8/26/1997	Farm Supplies, Ammonia	5	0	0	1.1	28	$212,500		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Sacaton	AZ	11/3/1997	Apiculture, Ammonia	1	1	0	1.1	7	$118,592		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Orlando	FL	2/23/1998	Sewage Treatment, Chlorine	9	1	0	1.1	51	$389,100		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Centralia	KS	4/22/1998	Farm Supplies Wholesaler, Ammonia	12	0	0	1.1	66	$510,000		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Tacoma	WA	10/10/1998	Refrigerated Warehouse, Ammonia	5	0	0	1.1	28	$15,714,379		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Franklinton	LA	10/26/1998	Corn Farming, Ammonia	25	0	0	1.1	138	$1,062,500		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Green River	WY	1/5/2000	Ice Manufacturing, Ammonia	1	2	0	1.1	8	$55,700		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Jefferson	OK	5/17/2000	Chemical Manufacturing, HCl	15	0	0	1.1	83	$637,895		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Hammond	LA	4/2/2001	Milk Manufacturing, Ammonia	1	12	0	1.1	19	$7,541,017		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Newberg	OR	7/14/2001	Petrochemical Manufacturing, Chlorine	3	51	0	1.1	73	$608,918		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Mesquite	NM	10/16/2001	Corn Farming, Ammonia	1	2	0	1.1	8	$811,270		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Minot	ND	1/18/2002	Rail Transport, Ammonia	1	0	0	1.1	6	$42,500		1/1/1994	12/31/2010	17.00	0.0588	See RSS

Record Type	Event Group	NLE	Place	State	Event Start	Comments/Identifiers	SNRA Fatalities	SNRA Inj/Ill	SNRA Displaced	EFF	SNRA Psych.Distress	SNRA Direct Economic Damage	Event End	Observation Period Start	Observation Period End	Observation Period (years)	Incident Likelihood	Source
Incident	Accidental	Chemical Accident	Soddy Daisy	TN	4/11/2003	Syrup Manufacturing, Ammonia	1	0	0	1.1	6	$7,448,305		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Lakewood	CO	4/21/2003	Farm Supplies Wholesaler, Ammonia	1	6	0	1.1	12	$82,223		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Pampa	TX	7/13/2003	Seafood Processing, Ammonia	1	3	0	1.1	9	$62,300		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Paynesville	MN	11/4/2003	Farm Raw Material Wholesaler, Ammonia	1	1	0	1.1	7	$49,100		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Illiopolis	IL	4/23/2004	Plastic Manufacturing, Vinyl acetate monomer	5	6	0	1.1	34	$252,100		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Seymour	IN	5/25/2004	Farm Supplies Wholesaler, Ammonia	10	0	0	1.1	55	$425,000		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Macdona	TX	6/28/2004	Rail Transport, Chlorine	3	66	0	1.1	89	$563,100		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Graniteville	SC	1/6/2005	Rail Transport, Chlorine	9	631	5,400	1.1	3,714	$13,848,553		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Sanford	FL	1/8/2005	Highway Transport, CO2 (refrigerated liquid)	2	0	0	1.1	11	$85,000		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Ebensburg	PA	8/28/2006	Animal Slaughtering, Ammonia	10	4	0	1.1	59	$451,400		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Westlake	LA	6/27/2007	Pigment Manufacturing, Titanium tetrachloride	1	1	0	1.1	7	$243,585		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Hollywood	FL	5/20/2008	Water Transport, Argon (refrigerated liquid)	3	0	0	1.1	17	$127,500		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Swansea	SC	7/15/2009	Highway Transport, Ammonia	1	7	0	1.1	13	$89,427		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Chemical Accident	Cincinnati	OH	11/16/2009	Farm Supplies Wholesaler, Ammonia	2	0	0	1.1	11	$85,000		1/1/1994	12/31/2010	17.00	0.0588	See RSS
Incident	Accidental	Dam Failure		NY	1/1/1960	Electric Light Pond Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		CT	3/6/1963	Mohegan Park Dam	6	6		1.0	36			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		UT	6/16/1963	Little Deer Creek Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		CA	12/14/1963	Baldwin Hills Dam	5			1.0	25			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		MT	6/8/1964	Swift Dam	19			1.0	95			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		CO	6/17/1965	Cripple Creek Dam No. 3, domino failure Dam No. 2	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		MA	3/24/1968	Lee Lake Dam	2			1.0	10			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		IA	7/17/1968	Virden Creek Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		WV	2/26/1972	Buffalo Creek Coal Waste Dam	125	1,000		1.0	1,625			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		AK	4/1/1972	Lake "O" Hills	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		SD	6/9/1972	Canyon Lake Dam	165	3,000		1.0	3,825			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		SC	9/18/1975	Lakeside Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		NC	2/22/1976	Bear Wallow Dam	4			1.0	20			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		ID	6/5/1976	Teton Dam	11	800		1.0	855			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		PA	7/20/1977	Laurel Run Dam	40			1.0	200			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		GA	11/6/1977	Kelly Barnes Dam	39			1.0	195			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		KY	12/18/1981	Eastover Mining Co. Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		CO	7/15/1982	Lawn Lake Dam + Cascade Lake Dam	3			1.0	15			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		UT	6/23/1983	D.M.A.D. Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		TX	3/29/1989	Nix Lake Dam	1			1.0	5			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		NC	9/15/1989	Evans Dam + Lockwood Dam	2			1.0	10			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		SC	10/10/1990	Kendall Lake Dam	4			1.0	20			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		VA	6/22/1995	Timberlake Dam	2			1.0	10			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		NH	3/13/1996	Bergeron Pond Dam	1	2		1.0	7			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		ND	6/12/2000	Mike Olson Dam (Grand Forks Co. Comm. No.1 Dam)	2			1.0	10			1/1/1960	12/31/2009	50.00	0.0200	See RSS
Incident	Accidental	Dam Failure		HI	3/14/2006	Ka Loko Dam	7			1.0	35			1/1/1960	12/31/2009	50.00	0.0200	See RSS

Animal Disease, Human Pandemic, Tsunami, and Volcanic Eruption represent single scenarios: they are represented by the best estimate of their annual frequency and associated consequences. The remaining data in this table consist of the raw data from which the quantitative estimates for the remaining natural and accidental hazards were derived, as presented in the corresponding risk summary sheets. Accidental Radiological Substance Release is not included in this table.

For each incident, a point likelihood is calculated as 1/(event observation period) – that is, if the observation period from which the source data were reported covered the 18.5 years from 1/1/1970 to 7/1/1988, the point frequency for the incident would be 1/18.5 = 0.054. This is done to permit aggregation, subdivision, selection of different thresholds, and other manipulations on the source data.

EFF = Event Familiarity Factor, used in the SNRA Psychological Distress metric (Appendix G).

See RSS = See event Risk Summary Sheet (Appendix J) for data sources.

Blanks indicate no data, not zero.

APPENDIX L: TORNADOES

The Tornado National-level Event was added to the SNRA data set in calendar year 2012, subsequent to the communication of the 2011 SNRA data and findings to FEMA which informed the National Preparedness Goal.

Tornadoes

On average, there are 1,300 tornadoes that strike the United States each year, of which an average of 140 (or approximately 10%) are significant (rated as EF2 or higher on the enhanced Fujita scale (EF scale)).[1] Tornadoes are more common in the United States than in any other country because of the interactions between cold fronts coming from Canada that collide with warm fronts that hit the central United States via the Gulf of Mexico. This collision generally centers over the central and southeastern portions of the United States, and there is a higher frequency of tornadoes that strike these regions. Nevertheless, tornadoes occurred in all 50 states, the District of Columbia,[2] and Puerto Rico between 1996 and 2011.

For the purposes of the SNRA, only tornado events that resulted in $100 million or more in direct economic damage were analyzed. It is common for more than one tornado to spawn from a storm cell, so tornadoes that met a temporal and spatial threshold were aggregated into tornado events. Data from 1996 to 2011 was used to aggregate tornadoes into tornado events in the SNRA because it provided the most complete record of fatalities, injuries and direct economic consequences. Using the aggregation methodology, there were 46 tornado events analyzed for the SNRA that occurred from 1996-2011, of which 44 were outbreaks that included more than one tornado.

There are several important trends to note when considering tornado events. First, technology has played an increasingly important role in preparing for, mitigating, and responding to tornadoes. Through radar advancements, scientists have lengthened the average lead time before a storm. Tornado warnings can then be disseminated via multiple methods, including radio, television, the Internet, social media and mobile devices. Nevertheless, despite better communication and detection capabilities, tornadoes still pose a significant threat to the United States. One trend noted in the research is the geographic shift of tornado prevalence toward the Southeastern states. This is important because the mid-Southeastern states (such as Alabama, Arkansas, Mississippi, and Tennessee)[3] are more densely populated than traditional tornado alley areas like the rural regions of Oklahoma or Texas. The increased population density, and in particular mobile home density, could result in an increase in fatalities, injuries and economic consequences in the future.[4]

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[1] This is based on the number of tornadoes per year from 1996 – 2011. All calculations are taken from the NOAA National Weather Storm Service Storm Prediction Center (SPC) database. NOAA NWS SPC (2012). *SPC Tornado, Hail, and Wind Database Format Specification.* Retrieved June 22, 2012 from http://www.spc.noaa.gov/wcm/#data.

[2] On September 24, 2001, a tornado originated in Virginia and passed through Washington, DC.

[3] Parisi, T. (2008, February 8). *Deadly Storms Underscore New Research Finding*. Retrieved September 12, 2012, from NIU News: Media Relations and Internal Communications: http://www.niu.edu/PubAffairs/RELEASES/2008/feb/tornado.shtml.

[4] Dixon, P.G., Mercer, A.E., Choi, J. & Allen, J.S. (2011, April). Tornado Risk Analysis: Is Dixie Alley an Extension of Tornado Alley? *Bulletin of the American Meteorological Society*, 92, 433-441.

Tornado

A tornado event (either a single tornado or a cluster of tornadoes that form during a single storm system) occurs in the United States resulting in direct economic losses of or greater than $100 Million. The methodology for determining clusters can be found below.

Data Summary[1,2]

Description	Metric	Low	Best	High
Fatalities	Number of Fatalities[3]	0	22	316
Injuries	Number of Injuries or Illnesses[3]	0	247	3125
Direct Economic Loss	U.S. Dollars[3]	$103 Million[4]	$450 Million	$4.7 Billion
Frequency of Events	Number per Unit of Time[5]	0.63 per Annum	2.9 per Annum	7 per Annum

Event Description

The most destructive and deadly tornadoes occur from supercells – which are rotating thunderstorms with a well-defined radar circulation called a mesocyclone (supercells can also produce damaging hail, severe non-tornadic winds, unusually frequent lightning, and flash floods).[6] Although tornadoes appear throughout the world, the continental United States is subjected to more tornado events than any other country. On average, there are 1,300 tornadoes that hit the United States each year, of which an average of 140 (or approximately 10%) are significant (rated as EF2 or higher on the enhanced Fujita scale).[7] Tornadoes are more common in the United States than in any other country because of the interactions between cold fronts coming from Canada that collide with warm fronts that hit the central United States via the Gulf of Mexico. This collision generally centers over the central and southeastern portions of the United States, and there is a higher frequency of tornadoes that strike these regions. Nevertheless, tornadoes occurred in all 50 states, the District of Columbia[8] and Puerto Rico between 1996 and 2011.

For the purposes of the Strategic National Risk Assessment, the SNRA team analyzed tornado events that resulted in $100 million or more in economic damage. From 1996 to 2011, there were 46 tornado events that met this criterion. Of these 46 events, 44 were outbreaks that included more than one tornado. These outbreaks were determined using a clustering method to aggregate the fatality, injury and economic consequences of tornadoes that occurred within one day and 150 miles of at least one other tornado.

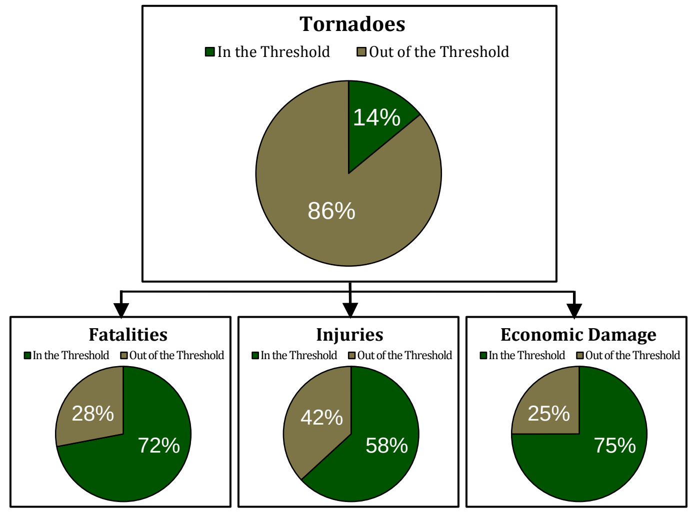
The economic threshold highlights 46 events during the time frame. Figure 1 outlines data on the tornado events that met the criteria of the $100 million threshold.

Methodology

Note that the tornadoes captured by this threshold represent only 14% of all tornadoes in the data set. However, those 14% of tornadoes are responsible for 72% of all fatalities, 58% of all injuries and 75% of all economic damage from all tornadoes during the 1996 – 2011 timeframe (see Figure 1).

When appropriate (i.e., when temporal and spatial criteria were met) individual tornadoes were clustered into multi-tornadic outbreak events. This was done because DHS is responsible for responding to a single destructive event, without separating out damage that comes from different tornadoes. The SNRA team chose to cluster tornadoes using spatial and temporal clustering, as this facilitated analysis on the aggregated total of fatalities, injuries and economic damage caused by tornadoes in a storm system, not just an individual storm. Through the use of this threshold, the SNRA team was able to capture the most damaging and dangerous storms from the data set.

Figure 1. Percentage of tornadoes in the data set that meet the threshold and the proportion of associated consequences within and outside of the threshold



In order to cluster the tornadoes, the team created a model that clusters tornado events if certain criteria are met. The data set has been programmed to cluster tornadoes if they meet the following two conditions: 1) the events fall within a one day window[9,10] and 2) the events are located within 150 miles of another event.[11]

It is important to note that the SNRA team elected to not make the Enhanced Fujita (EF) Scale (formerly known as the Fujita (F) Scale) rating a threshold for clustering. A powerful storm (EF4 – EF5) could hit a forest or a field, causing relatively little damage. At the same time, a weak storm (EF0 – EF2) could cause significant economic damage or loss of life if it struck a densely populated area. Due to the inconsistency, the SNRA team felt it was important to include all tornadoes regardless of the EF scale rankings in the data set.

During this risk assessment, temporally and spatially associated events were identified as “tornado clusters.” There are two main reasons why the SNRA team created a model to cluster tornadoes as opposed to relying on external sources:

- A specific definition of a tornado cluster (also referred to as a tornado outbreak) is not available for guidance in the meteorological literature. There is an ongoing debate in the field regarding the definition of an outbreak, as storm systems can spawn tornadoes over a broad array of time and space.[12] Without a concrete definition, the SNRA team determined that it needed to create the clustering model internally.
- Since the historical data in the data set is arranged by individual tornadoes, and it does not group tornadoes by storm system, the entire data set had to be clustered before tornado clusters could be identified. Without the historical data on storm cells and their production of tornadoes, the decision was made to infer when tornadoes were associated with one another through the time and distance conditions.

The specific spatial and temporal parameters in the clustering algorithm were calibrated using publically available news and weather reports published on days of tornado outbreaks. Before clustering the data, the SNRA team checked its main data source, the National Weather Service’s (NWS) Storm Prediction Center (SPC) database, for consistency. Several adjustments were incorporated in the SNRA data set:

[1] The data reported in this table represent historical U.S. tornado data. The SNRA project team used historical data from the Storm Prediction Center (SPC) online database. The SPC is a division of the National Weather Service (NWS), which is a part of the National Oceanographic and Atmospheric Administration (NOAA).
[2] Social displacement, psychological distress, and environmental impacts of tornado outbreaks were not assessed for the Tornado event. Expert elicitations and research for these metrics were completed during the main project phase of the SNRA (summer-fall 2011) before the tornado event was added in 2012. These measures will be assessed in the next iteration of the SNRA.
[3] Low, best, and high estimates for fatalities, injuries and illnesses, and direct economic loss come from the low, average, and high values of the set of events meeting a $100 million threshold of direct economic cost. This set came from the National Weather Service's Storm Prediction Center database on tornadoes ranging from 1996 - 2011. For further details see Assumptions sections below.
[4] This is the low estimate when the $100 million threshold is applied.
[5] Frequency estimates correspond to the inverse of the number of years of the longest interval between accident events (low), the mean frequency of the accident events (best), and the greatest number of accidents within one year (high) of the set described in note 3 above.
[6] (Edwards, The Online Tornado FAQ, 2012)
[7] This is based on number of tornadoes per year from 1996 – 2011. All calculations are taken from the SPC database.
[8] On September 24, 2001, a tornado originated in Virginia and passed through Washington DC. The individual entry for DC was removed during data consolidation. The tornado ID number is 11594 (entry in the NOAA SPC database is 2001 – 451).

[9] All units of time have been converted to central standard time (CST).
[10] The day window accounts for a 47 hour and 59 minute span of time. For example, a day window would associate a tornado that struck at 00:00 on January 1, 2011 and one that struck at 23:59 on January 2, 2011.
[11] An event was spatially associated with a previous event if it comes within 150 miles of the path taken by the previous event.
[12] Available definitions that are spatially precise may be nebulous in time, or vice versa. Moreover, many historical attempts to define the term “tornado outbreak” have failed to account for the spatial outliers, far removed from tornado clusters but within the same time domain. (Edwards, Thompson, Crosble, & Hart, 2004)

- The database contained multiple reports for the same tornado. This occurred when a single tornado would cross state lines. The reports were consolidated to reflect an accurate picture of the path and damage of the single tornado. The partial reports were eliminated prior to running the data through the clustering model.
- In 1996, NOAA began to track the economic damage caused by a storm by millions of dollars. Previously, the data had been semi-quantitatively binned by the order of magnitude of the losses. In order to ensure accuracy and consistency, the SNRA team decided to use data from 1996 – 2011.
- The SNRA team combined the Property Damage field and the Crop Damage field to create a Total Damage Field. This historic data was used as an estimate of Total Direct Economic Losses. However, it does not include losses due to business interruptions, medical costs, or loss in spending due to fatalities. These other types of direct economic impacts due to tornadoes were assumed to be small relative to property and crop losses.

To create the clustering model, a program was written by the SNRA team using MATLAB. The base of the program was previous work that was done to support research into clusters of floods for the SNRA. The following parameters were built into the model and used to define the criteria for each cluster:

- **Spatial** – Distance window of 150 miles from any point along the tornado path[13]
- **Temporal** – Time window of 1 day
- Year span: 1996 – 2011

The steps performed by the clustering algorithm proceeded as follows:

- Step 1: The areas of each tornado are calculated by finding all points within 150 miles from starting point A, ending point B, and midpoint C.[14]
- Step 2: Starting with a single tornado, the algorithm clusters any matching tornadoes with the original tornado based on whether the matching tornadoes meet the spatial and temporal criteria.
- Step 3: The algorithm loops over the newly identified tornado cluster (the original tornado and matching tornadoes) to find any other tornadoes that now match any portion of the cluster based on the spatial and temporal criteria.
- Step 4: New clusters are created as the data loops over the data set.
- Step 5: The data loop continues until all tornadoes are sorted into a cluster.[15]
- Step 6: The clusters are analyzed by the SNRA team.

The final data set that was put into the clustering model included individual tornadoes that occurred in the United States[16] from 1996 to 2011. The SNRA team analyzed 20,755 tornadoes that occurred during this timeframe. Using the clustering methodology, the final number of tornado clusters was 4,597. Of these clusters, 2,206 clusters represented more than one tornado while the remainders were individual tornadoes that did not cluster with any other tornadoes in the data set. Once the clusters were formed, they were extracted and analyzed in Microsoft Excel using advanced database tools. In Microsoft Excel, the $100 million threshold was applied. Of the 2,206 clusters established, 46 clusters were analyzed as SNRA level events (see the above Data Summary, Table 1 and Figure 1 for analysis).

Assumptions

The SNRA team used the following assumptions to estimate consequences caused by a tornado event:

- For the purposes of this assessment, tornado clusters are determined through spatial and temporal clustering. The distance threshold is 150 miles and the time threshold is one day. All economic estimates were inflation-adjusted to 2011 dollars.
- The decision to analyze tornado events from 1996 to 2011 was made because the historical data consistently measured the direct economic costs of tornadoes from 1996 to the present.[19]

Table 1. Results for Tornado Events Resulting in $100 Million or More in Economic Damage

Number of Events	46
Number of Tornadoes	2813
Number of Fatalities	1025
Number of Injuries	11,367
Total Economic Damage	$20.7 billion[17]
Proportion of Tornadoes Above the Threshold from the Entire Data Set	14%
Proportion of Fatalities Represented From Entire Data Set	72%
Proportion of Injuries Represented From Entire Data Set	58%
Proportion of Economic Damage Represented From Entire Data Set	75%
Number of Outbreaks (More than One Tornado per Event)	44
Number of Individual Storms	2
Average Number of Storms per Outbreak	64[18]

- The direct economic damages include losses to both property and crops.[20]
- Social displacement, psychological distress, and environmental impacts will be assessed in the next iteration of the SNRA.[21]

Event Background

Individual Storms:

Single tornadoes have the potential to cause a large loss of life. On May 22, 2011, the deadliest single tornado to strike the United States since 1947 tore through Joplin, MO (population 50,000). The tornado was rated as a strong EF5, and there was extensive loss of life, injuries, economic loss and psychological consequences. NOAA's SPC registered 158 fatalities and 1,150 injuries that were directly related to the single tornado. The final economic cost of the Joplin tornado was found to be $2.8 billion.[22,23] As a result of the tornado, the governor of Missouri issued a State of Emergency due to the loss of critical infrastructure in the city and the need to rapidly deploy federal, state and local resources in response to the disaster. The Joplin tornado was the most significant tornado in a tornado outbreak which spanned May 20 to May 26, 2011. This storm system crossed the Midwest and into the Ohio River Valley, spawning 188 tornadoes across 21 states, in total. This outbreak caused 173 fatalities, 1,545 injuries and $2.84 billion worth of damage.[24]

The Joplin Tornado is also significant because of the damage done to critical infrastructure. City officials as well as local, state and federal emergency managers had to work to restore basic utilities and healthcare capabilities to the city while also clearing debris.[25] FEMA reported that it had provided an estimated $174 million in federal assistance provided through various programs to aid the recovery.[26]

The Joplin Tornado was the most significant tornado to strike the United States from 1996 – 2011, but it is worth noting that severe storms (defined as EF4 – EF5) are rare. Out of 20,755 individual storms analyzed by the SNRA team from 1996 – 2011, there were only 112 other severe tornadoes (0.54% of the total number of tornadoes).[27] These 112 severe storms were responsible for a significant share of damage. From 1996 to 2011, severe storms resulted in 45% of the total amount of damage. They were also responsible for 52% of the total number of fatalities and 41% of the total number of injuries. This suggests that even though the frequency per year is low, the risk of severe storms is high.

However, even significant storms (rated EF2 to EF3) are responsible for a large portion of the damage from tornadoes, mainly because there are significantly more EF2 and EF3 storms. From 1996 to 2011, 10% of all tornadoes were rated as EF2 to 3 (compared to 0.54% of severe storms at EF4 to 5). The 2,144 EF2 and EF3 tornadoes were responsible for 37% of the total amount of damage. The significant storms caused 43% of the total number of fatalities and 48% of the total number of injuries. Even though the majority of tornadoes are weak (there were 18,499 EF0 and EF1

[13] To judge the distance, the SNRA project team used several data fields from the SPC database. First, using the starting and ending latitude and longitude, one can establish the exact origin and termination points of the tornado. For the purposes of the analysis, the algorithm uses the midpoint C of a straight line between the starting point A and terminating point B. If two tornadoes were within 150 miles AND one day of each other at points A, B, or C, they would be clustered.
[14] The average path length of a tornado in the data set is 3 miles and the average maximum width is 113 yards. Due to the short average path length and width, the starting, ending and midpoint were assumed to be sufficient points of measurement from which the 150 mile distance is determined.
[15] Note that a single tornado can be its own cluster if no other tornadoes in the data set meet the spatial and temporal criteria.
[16] Geographically, the data set spanned all 50 U.S. states as well as Puerto Rico and the District of Columbia.
[17] The economic damage of the tornadoes in the threshold totaled $20,721,128,120.
[18] The average number is found by dividing the total number of tornadoes that were part of an outbreak (2811) by the number of outbreaks (44).
[19] Prior to 1996, the SPC database used a logarithmic scale to provide a range of estimated loss. According to the information sheet that accompanies the database, it was "a categorization of tornado damage by dollar amount (0 or blank-unknown; 1<$50, 2=$50-$500, 3=$500-$5,000, 4=$5,000-$50,000; 5=$50,000-$500,000, 6=$500,000-$5,000,000, 7=$5,000,000-$50,000,000, 8=$50,000,000-$500,000,000, 9=$5,000,000,000.)" (NOAA NWS SPC, 2012)
[20] The SPC began separating crop and property damage in 2007. Where available, the fields have been combined to reflect the direct economic damages.
[21] The Tornado national-level event was added to the SNRA in calendar year 2012, subsequent to the main project phase of the SNRA in summer-fall 2011 when the expert elicitations and research for the social displacement, psychological distress, and environmental impact measures were completed. These measures will be assessed for all events in the next iteration of the SNRA.
[22] (Storm Prediction Center Warning Coordination Meteorologist, 2011)
[23] (The Associated Press, 2012)
[24] (Storm Prediction Center Warning Coordination Meteorologist, 2011)
[25] (State Emergency Management Agency, 2011)
[26] (FEMA, 2011)
[27] From 1996 – 2011, there were 99 EF 4 tornadoes (or 0.48% of the data set) and 13 EF 5 tornadoes (or 0.06% of the data set).

tornadoes, or 89% of all tornadoes in the data set), the majority of the damage from tornadoes comes from significant and severe storms.

Tornado Clusters:

While powerful storms like the Joplin tornado do pose a significant threat, they very rarely appear alone.[28] By clustering tornadoes, the SNRA team was able to gain a clearer picture of the regional impact of storm systems that hit vulnerable areas. This clustering method illuminated information from serious outbreaks, such as the outbreak that occurred from April 22 – 28, 2011. In April 2011, the United States was hit by an unprecedented number of tornadoes. There were 752[29] tornadoes reported during the month of April alone, and this significantly outpaced the previous record of 540[30] tornadoes in May 2003. From April 22 – 28, there were 382 tornadoes that struck 21 states, resulting in 316 fatalities, 3125 injuries and $4.7 billion in damage. The most significant and deadly tornadoes struck Alabama, Mississippi and Tennessee from April 26 – April 28. Of the 316 fatalities, 234 were in Alabama, 32 were in Tennessee, 31 were in Mississippi, 15 were in Georgia, and 4 were in Virginia.

This outbreak ranks with the 1974 Super Tornado Outbreak [as the most severe outbreak to strike the United States since 1950, when the data was consistently measured] and resulted in more deaths than the 1965 Palm Sunday Outbreak.[31] According to the service assessment released by the NWS:

> The deadliest part of the outbreak was the afternoon and evening of April 27, when a total of 122 tornadoes resulted in 313 deaths across central and northern Mississippi, central and northern Alabama, eastern Tennessee, southwestern Virginia, and northern Georgia… there were 15 violent (Enhanced Fujita Scale 4 or 5) tornadoes reported. Eight of the tornadoes had path lengths in excess of 50 miles.[32]

The service assessment conducted in-depth research into why the fatality numbers were so high during this outbreak. Contributing factors to the high number of casualties included:

- A large number of rare, long-track, violent tornadoes
- Tornado tracks intersecting densely populated areas
- Damage to warning dissemination sources
- Individuals in the affected areas who did not respond to warnings until confirmed by more than one communication source
- People in the paths of the storms who waited for visual confirmation before taking protective action
- The rapid pace of the storms, which moved at 45-70 mph, giving people who waited for secondary confirmation a smaller window of time in which to take shelter
- Residences that did not have adequate storm shelters[33]

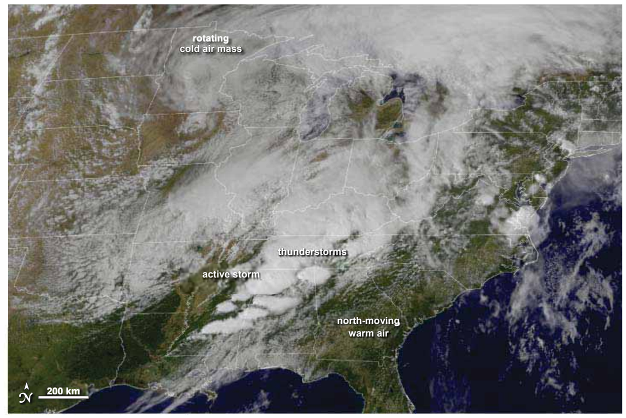
The large number of severe tornadoes played a crucial role in the high fatality rate. As Kevin Simmons and Daniel Sutter explain,

> …insuring residents receive a warning and take shelter in an interior bathroom or closet will not prevent fatalities because these rooms often fail to protect residents from an EF4 or EF5 tornado. In addition, the longer a tornado remains on the ground, more structures and people are placed at risk. To address this threat, engineers have developed safe rooms and underground shelters capable of protecting residents from even the strongest tornadoes. When a significant event occurs, there is enhanced interest and some political pressure to increase the use of shelters. However, violent tornadoes are just too rare to make hardening millions of homes in tornado-prone states cost effective.[34]

According to the data clustered by the SNRA model, there were 12 EF4 tornadoes and 4 EF5 tornadoes during the outbreak, or 4% of the 382 tornadoes in the outbreak.[35] These violent tornadoes were responsible for 277 fatalities (or 88% of fatalities), 2675 injuries (or 86% of injuries), and $4.2 billion in damage (or 90% of damage).

The prevalence of severe storms during this outbreak led to widespread damage. The combination of high fatalities along with the damage to critical infrastructure such as the electricity grid prompted governors in several states (Alabama, Arkansas, Kentucky, Mississippi, Missouri, Tennessee and Oklahoma) to declare a State of Emergency.

Figure 2 - The Southern U.S. on 27 April 2011 (NASA Earth Observatory, 2011)



Additional Relevant Information

The Enhanced Fujita (EF) Scale:

In 2007, NOAA began to classify tornado damage using the Enhanced Fujita scale (EF scale). The previous Fujita (F) scale "did not include damage indicators (DIs) and did not provide a method to correlate construction quality with the observed variability in damage resulting from similar wind speeds. Therefore, in 2004 the EF Scale ratings were adopted and provide a more rigorous and defensible metric for the severity of tornadoes."[36] The EF scale allows for a

> ...more precise and robust way to assess tornado damage than the original [Fujita scale]. It classifies F0-F5 damage as calibrated by engineers and meteorologists across 28 different types of damage indicators (mainly various kinds of buildings, but also a few other structures as well as trees). The idea is that … a tornado scale needs to take into account the typical strengths and weaknesses of different types of construction. This is because the same wind does different things to different kinds of structures. In the EF scale, there are different, customized standards for assigning any given F rating to a well built, well anchored wood-frame house compared to a garage, school, skyscraper, unanchored house, barn, factory, utility pole or other type of structure.[37]

Table 4 – Fujita Scale Conversion (Mitigation Assessment Team Report, 2012)

Fujita Scale Converted to EF Scale			
F0	45–78	EF0	65–85
F1	79–117	EF1	86–110
F2	118–161	EF2	111–135
F3	162–209	EF3	136–165
F4	210–261	EF4	166–200
F5	262–317	EF5	Over 200
mph = miles per hour; EF = Enhanced Fujita			

At this point in time, NOAA has not gone back to reassess the previous Fujita scale classifications for tornadoes, making the assumption that the Fujita scale data is aligned as closely as possible with the EF scale. The SNRA team agreed with this assertion.

Geographic Shifts in Tornado Prevalence

"Tornado Alley" has long been a colloquial term to describe the most tornado prone regions in the United States, which can "shift dramatically across the space between the Rocky and Appalachian Mountains."[38] Tornadoes have occurred in every state as well as the District of Columbia and Puerto Rico since 1996, and during the 1996 – 2011 timeframe, there were on average 406 tornadoes per state. The District of Columbia had the lowest number of tornadoes with only one tornado reportedly passing through DC, while Texas had the highest proportion of tornadoes with 2,282. This is in large part due to its juxtaposition between the Great Plains and the Gulf of Mexico, as well as its large geographic size.

Meteorologists are researching an eastward shift in the number of tornadoes.[39] Walker Ashley, a meteorologist at Northern Illinois University, notes that the increased number of tornadoes in the mid-south states (particularly Alabama, Tennessee, Mississippi and Arkansas) from 1996 into the 2000s pose a threat to residents of those states. He argues that

[28] In fact, as noted above, the Joplin tornado appeared as part of a cluster. The SNRA project team chose to highlight it because of its infamy and its severe consequences.
[29] Based on data from the SPC database. NOAA released the tornado count of 751 tornadoes for the month of April 2011 in its Special Report, but there was a discrepancy between the number of tornadoes (752 in SPC database and 751 in the special report). Therefore, the SNRA team used the SPC database figures. (National Climatic Data Center, 2011)
[30] Based on data from the SPC database. NOAA released the tornado count of 542 tornadoes for the month of May 2003 in its Special Report, but there was a discrepancy between the number of tornadoes (540 in SPC database and 542 in the special report). Therefore, the SNRA team used the SPC database figures. (National Climatic Data Center, 2011)
[31] (National Weather Service, 2011)
[32] (National Weather Service, 2011)
[33] (National Weather Service, 2011)
[34] (Simmons & Sutter, 2012)
[35] There were 382 tornadoes clustered in this outbreak. 4% of the storms were violent (EF4 – EF5).
[36] (Mitigation Assessment Team Report, 2012)
[37] (Edwards, Thompson, Crosble, & Hart, 2004)
[38] (Dixon, Mercer, Choi, & Allen, 2011)
[39] This eastward shift into the mid-southern states is subjectively defined as "Dixie Alley." See Dixon, Mercer, Choi, & Allen, 2011.

"while the 'tornado alley' region of the Great Plains boasts the most frequent occurrence of tornadoes, most tornado fatalities occur in the nation's mid-South region, which includes parts of Arkansas, Tennessee, Alabama and Mississippi."[40] There are a number of factors that make the mid-southern states vulnerable to tornadoes:[41]

- Mobile home density. The NIU meteorologist Walker Ashley noted 44 percent of all fatalities during tornadoes occur in mobile homes, compared to 25 percent in permanent houses. The southeast United States has the highest percentage of mobile-home stock compared with any other region east of the Continental Divide. "Mobile homes make up 30 to 40 percent of the housing stock in some counties in the deep South," Ashley said. "By far, mobile homes are the most vulnerable structures in a tornadic situation."
- Nighttime tornadoes. The southeast United States has a higher likelihood of killer nighttime tornadoes. Most states within this region have greater percentages of tornado fatalities occurring at night than other states. "I just completed another study that shows tornadoes from the midnight to sunrise period are 2.5 times as likely to kill as daytime events," Ashley said. Further, nocturnal tornadoes are more difficult to spot, and people are more likely to be asleep when warnings are issued.
- Forested areas. Whereas regions within the Great Plains by definition are lacking in tree cover, the mid-South region is more forested, leading to reduced visibility both for the public and spotters.[42]
- Early season storms. Storms that occur before the national peak in the severe storm season, which spans May and June, may catch people off guard during a tornado event.
- Complacency. In contrast to other parts of the country, the South lacks a focused "tornado season," which can lead to complacency. "In the South, people think tornado alley is where you get tornadoes," Ashley said. "That sort of perception also leads to complacency, which in turn leads to higher fatality rates." He points out that Oklahoma is known worldwide for the frequency of its tornadoes. Yet the state has fewer fatalities than Arkansas, Alabama and Mississippi.[43]

Advanced Warning Systems

Technology has played an increasingly important role in preparing for, mitigating to, and responding to tornado disasters. The increased use of radar has caused a surge in the number of tornadoes identified by the NWS. Today, the Doppler radar is widely used, and NOAA estimates that it provides on average an 11 minute lead time on tornado formation and can predict with a high level of accuracy where a tornado will strike.[44] Scientists are currently developing the next generation of weather radars by "adapting phased array technology, currently used on Navy ships, for use in weather forecasting. Phased array technology is expected to lengthen the average lead time for tornado warnings from 12 minutes to 20 minutes."[45]

According to the NWS, there are several steps of identification before information is disseminated to the public. When there are favorable conditions "for severe weather to develop, a severe thunderstorm or tornado **WATCH** is issued. Weather Service personnel use information from weather radar, spotters, and other sources to issue severe thunderstorm and tornado **WARNINGS** for areas where severe weather is imminent."[46] Once the conditions justify the issuance of a tornado watch or a tornado warning, information is disseminated to "local radio and television stations and are broadcast over local NOAA Weather Radio stations serving the warned areas. These warnings are also relayed to local emergency management and public safety officials who can activate local warning systems to alert communities."[47]

Due to the advancement in technology, affected individuals may receive tornado watch and warning information via the radio, television, cellular phones, internet and/or social media sites. The modernization of warning dissemination is taking place in both the public sector (with FEMA and NWS leading the initiative for tornadoes) and the private sector (with local news and media outlets enhancing dissemination capabilities).[48]

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[40] (Parisi, 2008)
[41] The following factors are based on analysis done prior to 2008.
[42] Storm spotters play an important role in identifying tornadoes. Over 30 years ago, the National Weather Service (NWS) developed SKYWARN, a program that "encourages communities to develop a network of trained storm spotters who provide detailed reports of dangerous weather conditions to their local emergency management agency and to the NWS." (National Weather Service, 2012)
[43] (Parisi, 2008)
[44] (NOAA National Severe Storms Laboratory, 2012)
[45] (NOAA National Severe Storms Laboratory, 2012)
[46] (National Weather Service, 2012)
[47] (National Weather Service, 2012)
[48] (Coleman, Knupp, Spann, Elliott, & Peters, 2011)

APPENDIX M: DATA SOURCES IN THE CLASSIFIED SNRA

The 2011 SNRA natural hazard and technological hazard data was derived completely from unclassified data, with substantial reliance on historical records. Data within the assessment which addresses only natural hazards and technological hazards has been treated as unclassified. The following paragraphs describe the derivation of the For Official Use Only and classified SNRA data which may be found in the full (classified) SNRA Technical Report.

Consequences

For the adversarial/human-caused events, some consequence estimates were unclassified but marked For Official Use Only (U//FOUO) in accordance with DHS practice, while other consequence estimates were classified by derivation.

- For the conventional attack events (Armed Assault, Explosives, and Aircraft as a Weapon) fatality and injury/illness estimates were derived from unclassified historical data, as detailed in the corresponding risk summary sheets (Appendix J). Following DHS practice these analyst-calculated estimates were marked as (U//FOUO). Direct economic consequence estimates were calculated from (U//FOUO) models and data using the Risk Assessment Process for Informed Decision-Making (RAPID) engine.[1]
- Fatality, injury/illness, and economic consequence data for the CBRN events were uniformly obtained from the DHS Directorate of Science & Technology (S&T) 2011 Integrated Terrorism Risk Assessment (ITRA). While these estimates are unclassified in their original form, the CBRN data provided by S&T to the SNRA team utilized weighted average consequences, which incorporate frequencies (the modelled relative likelihood that an attack, given occurrence, will result in consequences of a given magnitude). This calculation elevated the CBRN consequence estimates provided to the SNRA project to the SECRET//NOFORN classification level of the incorporated frequency data.

Social displacement and environmental impact estimates were unclassified for all events.

Frequency

Quantitative estimates of the frequency with which an adversarial/human-caused event may be initiated and successfully executed were used as measures of the likelihood of SNRA events.

Due to the short timeline imposed by the PPD-8 Implementation Plan, the 2011 SNRA project team made a concerted effort to rely on previously conducted analyses wherever possible. Appropriate prior analysis had been accomplished for many of the adversarial/human-caused events. For these events, all frequency and consequence data derive directly from previously conducted analysis.

Five SNRA adversarial/human-caused events are discussed as a unit below because the data within the SNRA was uniformly obtained from the DHS/ Science & Technology (S&T) 2011 Integrated Terrorism Risk Assessment (ITRA).

[1] The Risk Assessment Process for Informed Decision Making (RAPID) 2010 is a strategic level, DHS-wide process to assess risk and inform strategic planning priorities developed by the DHS Office of Risk Management & Analysis (National Protection & Programs Directorate). The RAPID engine is a suite of computational tools for calculating human and economic measures of risk and the relative effectiveness of different DHS programs in risk reduction. Like the SNRA it is a quantitative tool for calculating and comparing risks in the homeland security mission space with each other, but unlike the SNRA it is designed for additionally calculating the comparative effectiveness of different governmental programs in buying down risk.

SNRA Chemical, Biological, Radiological, and Nuclear Terrorism Attack Events
Events Covered • Biological Terrorism Attack (non-food) • Chemical/Biological Food Contamination Terrorism Attack • Chemical Terrorism Attack (non-food) • Nuclear Terrorism Attack • Radiological Terrorism Attack
Data Source DHS/Science & Technology (S&T) 2011 Integrated Terrorism Risk Assessment (ITRA)
Data Gathering Process[2] The Integrated CBRN Terrorism Risk Assessment elicitations were conducted throughout May and June 2010. Experts were formally elicited on five topics: absolute frequency of CBR initiation, relative frequency of CBR selection, absolute frequency of IND acquisition, frequency of CBRN interdictions, and CTRA and BTRA terrorist organization category capabilities. From this data, absolute frequency of acquisition for CBRN and the absolute frequency of attack with CBRN were calculated. Elicitation methods used were based on the approach described in NUREG-1150.[3] Elicitation experts followed the below steps in obtaining probabilities from intelligence analysts: 1. Pre-elicitation meeting: The group discussed the purpose and approach and scope of the planned elicitations 2. Intelink Terrorism Risk Assessment Frequency of Initiation Intellipedia discussion: Elicitees continued on-line discussion of event definitions and scope, to ensure shared definitions 3. Dissemination of elicitation materials: Elicitation materials were shared electronically to allow the group to review the elicitation process and event definitions 4. Study period/ individual formal elicitation meetings: Individual elicitations were conducted 5. Group review meeting: The full panel reviewed the final results and confirmed or updated responses 6. Dissemination of group review meeting follow-up document and reconciliation responses: The final results were circulated amongst the group for documentation purposes Resultant probabilities were based on analysts' knowledge of the field and prior exposure to intelligence reporting, but probabilities were not expressly linked to specific reporting. Probability distributions resulting from the elicitations were classified as SECRET//NOFORN.
Participating Organizations A combined panel of CBRN experts was convened for elicitation purposes, including analysts from: • National Counterterrorism Center • Defense Intelligence Agency • National Security Agency • Office of the Director of National Intelligence (ODNI) • DHS Office of Intelligence & Analysis Experts who were selected generally had significant expertise in at least one of the four CBRN terrorism threat areas, along with knowledge of the other threat areas.

[2] This process description is a summation of material contained in the DHS Science & Technology Directorate's 2011 Integrated CBRN Terrorism Risk Assessment, Chapter 3: Technical Approach (p. 3-149 – 3-155). (Reference is SECRET//NOFORN; Extracted information is UNCLASSIFIED.)

[3] NUREG-1150 is an elicitation methodology developed by the Nuclear Regulatory Commission (NRC) in 1991to formalize the process by which subject matter experts may provide probabilistic assessments in areas where data is sparse.

Two of the adversarial/human-caused events had previously been assessed within the DHS National Protection and Programs Directorate's (NPPD) Risk Assessment Process for Informed Decision-making (RAPID), which provided a quantitative assessment of strategic risk facing the nation. These events are discussed as a unit below.

SNRA Explosives and Aircraft-as-a-Weapon Events
Events Covered • Explosives Terrorism Attack • Aircraft as a Weapon
Data Source NPPD RAPID (2010)
Data Gathering Process The RAPID elicitations were conducted between October 2009 and January 2010. Eleven experts participated in the elicitation process. Following a modified NUREG-1150 expert elicitation process, RAPID II was able to obtain likelihood probabilities for the terrorism incident sets. Elicitation experts followed the below steps in obtaining probabilities from intelligence analysts: **1.** Identification of issues: Elicitation topics were identified in alignment with the analytic fault trees provided **2.** Selection of experts: RAPID team members identified appropriate experts within the intelligence community **3.** Individual elicitations performed: Using R Project, the RAPID team worked with experts to interactively create probability distributions which represent the likelihood that an adversary will initiate an attack, and, if initiated, the relative likelihood of different types of attacks **4.** Review by experts: Experts reviewed anonymous inputs of all participating experts, with the opportunity to make adjustments The resultant probability distributions identified the likelihood with which particular attack types would be initiated and the likelihood that a particular target class would be selected. Resultant probabilities were based on analysts' knowledge of the field and prior exposure to intelligence reporting, but probabilities were not expressly linked to specific reporting. Probability distributions resulting from the elicitations were classified as SECRET//NOFORN.
Participating Organizations All eleven experts were from the DHS Office of Intelligence & Analysis (I&A) or a DHS operational component. Experts were selected based on their knowledge of the research area.

Finally, the SNRA team conducted original subject matter elicitations for two adversarial/human-caused events. These elicitations were conducted separately but are treated as a unit here because the same elicitation protocol was used.

SNRA Armed Assault and Cyber Events
Events Covered • Armed Assault • Cyber Attack against Data • Cyber Attack against Physical Infrastructure
Data Source Original frequency elicitations conducted in August 2011 to support the SNRA
Data Gathering Process Following a modified NUREG-1150 expert elicitation process, SNRA was able to obtain likelihood probabilities for the terrorism incident sets. Elicitation experts followed the below steps in obtaining probabilities from intelligence analysts: **1.** Selection of experts: The SNRA team worked with staff within the ODNI to identify appropriate participants **2.** Identification of issues: On the day of the elicitation, the experts discussed and agreed upon the definition of the events. Note that for cyber, the broad categories of attacks against data and attacks against physical systems had been previously constructed **3.** Group elicitations performed: Using a binning structure, each member of the group provided their probability estimate. Some information was collected via an in-person group discussion, while some information was received in electronic form after the meeting **4.** Review by experts: Following the elicitation, the SNRA team compiled the inputs and provided final outcomes to participants for review and comment The resultant probability distributions identified the likelihood with which each event types would be initiated and the likelihood that a particular target class would be selected. Resultant probabilities were based on analysts' knowledge of the field and prior exposure to intelligence reporting, but probabilities were not expressly linked to specific reporting. Probability distributions resulting from the elicitations were classified as SECRET//NOFORN.
Participating Organizations Armed Assault • National Counterterrorism Center • Department of Homeland Security Intelligence & Analysis • Federal Bureau of Investigation Cyber Attacks (Infrastructure and Data) • Office of the Director for National Intelligence • Central Intelligence Agency • Federal Bureau of Investigation • National Security Agency • National Security Staff • Department of Homeland Security Cyber Security and Communications

Derivative Classification Sources for SNRA Data

The following references are derivative classification sources for the classified data of the 2011 SNRA, as noted in the data tables provided in Appendices B through D of the full (classified) SNRA Technical Report.

Armed Assault SME: Subject matter expert elicitation session with representatives from the DHS Office of Intelligence & Analysis (I&A), Federal Bureau of Investigation (FBI), and National Security Staff (NSS) (2011, July 26). Classification level of discussion was SECRET; Derived from: Multiple Sources; Declassify on: 20360726.

Cyber SME: Subject matter expert elicitation session with representatives from DHS National Protection and Programs Directorate Office of Cyber Security and Communications (CS&C), Office of the Director of National Intelligence (ODNI), Central Intelligence Agency (CIA), Federal Bureau of Investigation (FBI), National Security Staff (NSS), and National Security Agency (NSA) (2011, July 25). Classification level of discussion was SECRET; Derived from: Multiple Sources; Declassify on: 20360725.

ITRA: Email correspondence from Program Manager, Integrated CBRN Terrorism Risk Assessment (ITRA), DHS Science & Technology Directorate (2011, September 28). Data file: '(SNF) 20110926 Uncertainty (U).zip'. Extracted information is SECRET//NOFORN; Derived from: Multiple Sources; Declassify on: 25X2.

ITRA – Nuclear Econ Update: Email correspondence from Battelle Memorial Institute Support Contractor, Integrated CBRN Terrorism Risk Assessment (ITRA) Program, DHS Science & Technology Directorate (2012, July 20). Data file: '(U) Histogram Bins Rad and Bio_files are SNF.zip'. Extracted information is SECRET//NOFORN; Derived from: Multiple Sources; Declassify on: 20370720.

RAPID: DHS Office of Risk Management & Analysis (RMA) Risk Assessment Process for Informed Decision-making (RAPID) Database. Accessed July 12, 2011. Extracted information is SECRET//NOFORN; Derived from: Multiple Sources; Declassify on: 20360712.

Additional detail is given in Appendix I of the classified SNRA Technical Report. Derivative classifications for narrative statements are noted as footnotes in the body of the classified SNRA Technical Report.

APPENDIX N: COMPARATIVE RISK TABLE – LINEAR SHADING

As Table 1 is presented with logarithmic shading (proportional to powers of ten), the visual distinction between best estimate risks in or bounding the top order of magnitude (those marked by 'X') may not be visually clear. For this reason, Table 1 is replicated below, but with the intensity of shading represented on a linear scale.

Table N.1: Comparative Risk in the SNRA - Natural Hazard and Accidental Events

National-Level Event	Best Estimate Risk: Fatality	Injury/Illness	Direct Economic	Social Displacement	Psychological Distress	Environmental
Animal Disease			X			
Earthquake			X			
Flood			X	X		X
Human Pandemic Outbreak	X	X	X		X	
Hurricane			X	X	X	X
Wildfire			X	X		
Biological Food Contamination						
Chemical Substance Spill or Release						X
Dam Failure						
Radiological Substance Release						
Insufficient quantitative data to support comparisons to other events						
Space Weather						
Tsunami						
Volcanic Eruption						
Cyber Event affecting Data						
Cyber Event affecting Physical Infrastructure						
Risk estimates are classified						
Aircraft as a Weapon	See classified SNRA results					
Armed Assault						
Biological Terrorism Attack (non-food)						
Chemical/Biological Food Contamination Terrorism Attack						
Chemical Terrorism Attack (non-food)						
Explosives Terrorism Attack						
Nuclear Terrorism Attack						
Radiological Terrorism Attack						

How to read this table:

Best estimate risk is assessed to fall within or bound the top order of magnitude of fatality, injury/illness, direct economic, social displacement, or psychological distress risk or the highest risk bin (Figure 8) of best estimate environmental risk among the natural and accidental hazard events in the SNRA. The relative magnitude (on a linear scale) of the quantitatively based best estimate risks is indicated by background coloring in each cell.

Insufficient quantitative risk data to support comparisons with other events.

In this approach, the relative risk on each consequence axis is considered in isolation, rather than combined. Relative weightings between different consequence measures are subjective value judgments that may vary by decision context and decision maker.

The best estimate of risk for each SNRA event is used to identify highest-magnitude risks. However, there is considerable uncertainty, varying data quality, and substantial overlap in the risk estimates of the SNRA events, making it difficult to generate a rank-ordered list of events based solely on the SNRA risk results.

APPENDIX O: SNRA 2011 PUBLIC FINDINGS REPORT

The Strategic National Risk Assessment in Support of PPD 8: A Comprehensive Risk-Based Approach toward a Secure and Resilient Nation

December 2011

Overview

The Strategic National Risk Assessment (SNRA) was executed in support of Presidential Policy Directive 8 (PPD-8), which calls for creation of a National Preparedness Goal, a National Preparedness System, and a National Preparedness Report. Specifically, national preparedness is to be based on core capabilities that support "strengthening the security and resilience of the United States through systematic preparation for the threats that pose the greatest risk[1] to the security of the Nation, including acts of terrorism, cyber attacks, pandemics, and catastrophic natural disasters."

As part of the effort to develop the National Preparedness Goal and identify core capabilities, the Secretary of Homeland Security led an effort to conduct a strategic national risk assessment to help identify the types of incidents that pose the greatest threat to the Nation's homeland security. Representatives from the offices of the Director of National Intelligence and the Attorney General, as well as other members of the Federal interagency, supported this effort. The assessment was used:

- To identify high risk factors that supported development of the core capabilities and capability targets in the National Preparedness Goal;
- To support the development of collaborative thinking about strategic needs across prevention, protection, mitigation, response, and recovery requirements, and;
- To promote the ability for all levels of Government to share common understanding and awareness of National threats and hazards and resulting risks so that they are ready to act and can do so independently but collaboratively.

The subsequent pages provide an overview of the unclassified findings and the analytic approach used to conduct the SNRA. It should be emphasized, however, that although the initial version of the SNRA is a significant step toward the establishment of a new homeland security risk baseline, it contains data limitations and assumptions that will require additional study, review, and revision as the National Preparedness System is developed. These limitations are discussed below, and future iterations of the assessment are expected to reflect an enhanced methodology and improved data sets.

Strategic National Risk Assessment Scope

To inform homeland security preparedness and resilience activities, the SNRA evaluated the risk from known threats and hazards that have the potential to significantly impact the Nation's homeland security. These threats and hazards were grouped into a series of national-level events with the potential to test the Nation's preparedness.

[1] The DHS Lexicon defines risk as the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences. Accessed at: http://www.dhs.gov/xlibrary/assets/dhs-risk-lexicon-2010.pdf

SNRA participants – including Federal agencies, DHS Components, and the intelligence community, among others – developed a list of national-level events (see Table 1) for assessment in the initial SNRA. The events are grouped into three categories: 1) natural hazards; 2) technological/ accidental hazards; and 3) adversarial, human-caused threats/hazards. For the purposes of the assessment, DHS identified thresholds of consequence necessary to create a national-level event. These thresholds were informed by subject matter expertise and available data. For some events, economic consequences were used as thresholds, while for others, fatalities or injuries/illnesses were deemed more appropriate as the threshold to determine a national-level incident. In no case, however, were economic and casualty thresholds treated as equivalent to one another (i.e., dollar values were not assigned to fatalities). Event descriptions in Table 1 that do not explicitly identify a threshold signify that no minimum consequence threshold was employed. This allows the assessment to include events for which the psychological impact of an event could cause it to become a national-level event even though it may result in a low number of casualties or a small economic loss. Only events that have a distinct beginning and end and those with an explicit nexus to homeland security missions were included. This approach excluded:

- Chronic societal concerns, such as immigration and border violations, and those that are generally not related to homeland security national preparedness, such as cancer or car accidents, and;
- Political, economic, environmental, and societal trends that may contribute to a changing risk environment but are not explicitly homeland security national-level events (e.g., demographic shifts, economic trends). These trends will be important to include in future iterations of a national risk assessment, however.

Table 1: SNRA National-Level Events

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
Natural	Animal Disease Outbreak	An unintentional introduction of the foot-and-mouth disease virus into the domestic livestock population in a U.S. state
	Earthquake	An earthquake occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Flood	A flood occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Human Pandemic Outbreak	A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace
	Hurricane	A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million
	Space Weather	The sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure
	Tsunami	A tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the U.S.

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
	Volcanic Eruption	A volcano in the Pacific Northwest erupts impacting the surrounding areas with lava flows and ash and areas east with smoke and ash
	Wildfire	A wildfire occurs within the U.S. resulting in direct economic losses greater than $100 Million
Technological/ Accidental	Biological Food Contamination	Accidental conditions where introduction of a biological agent (e.g., *Salmonella*, *E. coli*, botulinum toxin) into the food supply results in 100 hospitalizations or greater and a multi-state response
	Chemical Substance Spill or Release	Accidental conditions where a release of a large volume of a chemical acutely toxic to human beings (a toxic inhalation hazard, or TIH) from a chemical plant, storage facility, or transportation mode results in either one or more offsite fatalities, or one or more fatalities (either on- or offsite) with offsite evacuations/shelter-in-place
	Dam Failure	Accidental conditions where dam failure and inundation results in one fatality or greater
	Radiological Substance Release	Accidental conditions where reactor core damage causes release of radiation
Adversarial/ Human-Caused	Aircraft as a Weapon	A hostile non-state actor(s) crashes a commercial or general aviation aircraft into a physical target within the U.S.
	Armed Assault	A hostile non-state actor(s) uses assault tactics to conduct strikes on vulnerable target(s) within the U.S. resulting in at least one fatality or injury
	Biological Terrorism Attack (non-food)	A hostile non-state actor(s) acquires, weaponizes, and releases a biological agent against an outdoor, indoor, or water target, directed at a concentration of people within the U.S.
	Chemical/Biological Food Contamination Terrorism Attack	A hostile non-state actor(s) acquires, weaponizes, and disperses a biological or chemical agent into food supplies within the U.S. supply chain
	Chemical Terrorism Attack (non-food)	A hostile non-state actor(s) acquires, weaponizes, and releases a chemical agent against an outdoor, indoor, or water target, directed at a concentration of people using an aerosol, ingestion, or dermal route of exposure
	Cyber Attack against Data	A cyber attack which seriously compromises the integrity or availability of data (the information contained in a computer system) or data processes resulting in economic losses of a Billion dollars or greater

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
	Cyber Attack against Physical Infrastructure	An incident in which a cyber attack is used as a vector to achieve effects which are "beyond the computer" (i.e., kinetic or other effects) resulting in one fatality or greater or economic losses of $100 Million or greater
	Explosives Terrorism Attack	A hostile non-state actor(s) deploys a man-portable improvised explosive device (IED), Vehicle-borne IED, or Vessel IED in the U.S. against a concentration of people, and/or structures such as critical commercial or government facilities, transportation targets, or critical infrastructure sites, etc., resulting in at least one fatality or injury
	Nuclear Terrorism Attack	A hostile non-state actor(s) acquires an improvised nuclear weapon through manufacture from fissile material, purchase, or theft and detonates it within a major U.S. population center
	Radiological Terrorism Attack	A hostile non-state actor(s) acquires radiological materials and disperses them through explosive or other means (e.g., a radiological dispersal device or RDD) or creates a radiation exposure device (RED)

The SNRA participants identified the events listed in Table 1 as those with the potential to pose the greatest risk to the security of the Nation and formed the analytic basis of the SNRA. In some cases, tornados may also become national-level events that pose significant risk. Table 1 is not a complete list of risks that exist and will be reconsidered in future iterations of the assessment. Additional threats and hazards, such as droughts, heat waves, winter storms, rain storms, and different types of technological/accidental or human-caused hazards, can also pose a risk to jurisdictions across the country and should be considered, as appropriate, in preparedness planning. Non-influenza diseases with pandemic potential and other animal diseases should also be considered. In addition, assessment participants identified a number of events for possible inclusion in future iterations of the SNRA, including electric grid failure, plant disease outbreak, and transportation system failure.

Overarching Themes to an All-Hazards Approach

The results of the SNRA are largely classified and include a comparison of risks for potential incidents in terms of the likelihood (calculated as a frequency—i.e. number of events per year) and consequences of threats and hazards, as well as an analysis of the uncertainty associated with those incidents.[2] The assessment finds that a wide range of threats and hazards pose a significant risk to the Nation, affirming the need for an all-threats/hazards, capability-based approach to preparedness planning. Overarching themes include:

- Natural hazards, including hurricanes, earthquakes, tornadoes, wildfires, and floods, present a significant and varied risk across the country.
- A virulent strain of pandemic influenza could kill hundreds of thousands of Americans, affect millions more, and result in economic loss. Additional human and animal infectious diseases, including those previously undiscovered, may present significant risks.

[2] The full results of the SNRA are classified.

- Technological and accidental hazards, such as dam failures or chemical substance spills or releases, have the potential to cause extensive fatalities and have severe economic impacts, and the likelihood of occurrence may increase due to aging infrastructure.
- Terrorist organizations or affiliates may seek to acquire, build, and use weapons of mass destruction. Conventional terrorist attacks, including those by “lone actors” employing explosives and armed attacks, present a continued risk to the Nation.
- Cyber attacks can have their own catastrophic consequences and can also initiate other hazards, such as power grid failures or financial system failures, which amplify the potential impact of cyber incidents.

These findings supported the development of the core capabilities, as well as the establishment of capability targets for the Goal. In addition to the above findings articulated in the National Preparedness Goal, the SNRA found that:

- Many events have the potential to occur more than once every 10 years, meaning that the Nation’s preparedness will likely be tested in this decade.
- Although historic events provide a useful perspective on homeland security risks, the changing nature of society and the risk landscape means that the Nation must also be prepared for new hazards and threats or for events that result in greater consequences than have occurred in the past.
- Within an all-hazards preparedness context, particular events that present risk to the Nation—such as nuclear attacks or chemical releases—require additional specialized response activities.
- Some events, such as explosives attacks or earthquakes, generally cause more localized consequences, while other events, such as human pandemics, may cause consequences that are dispersed throughout the Nation, thus creating different types of impacts for preparedness planners to consider.

Analytic Approach

The SNRA drew data and information from a variety of sources, including existing Government models and assessments, historical records, structured analysis, and judgments of experts from different disciplines. The information was used to assess the risk of identified incidents as a function of frequency[3] and consequence—specifically, *With what frequency is it estimated that an event will occur, and what are the consequences of the incident(s) if it does occur*?

The SNRA examined the consequences associated with six categories of harm: loss of life, injuries and illnesses, direct economic costs, social displacement, psychological distress, and environmental impact. This multi-faceted view of potential consequences draws attention to the broad and often interdependent effects of incidents that require whole of community preparation and cooperation across the homeland security enterprise. For instance, community resilience relates to both mitigating human and economic consequences and addressing the psychological and social distress caused by the incident within the community. Similarly, other types of resilience involve withstanding environmental and infrastructure degradations to ensure that essential services continue to be delivered.

The SNRA relied on the best available quantitative estimates of frequency and consequence from existing Government assessments, peer-reviewed literature, and expert judgment. Where sufficient

[3] Frequency was used in the SNRA to capture likelihood because some events have the potential to occur more than once a year.

quantitative information was not available—such as data related to the frequency of high-consequence space weather—events were assessed qualitatively. The estimates of the frequency and consequences for each of the events considered were compared where appropriate. No effort was made to create a single "risk judgment" for any event type because it was deemed infeasible to aggregate all consequence types into a single metric. Instead, the assessment treated consequence categories separately (i.e., economic consequences are reported separately from fatality consequences). This allowed stakeholders to apply their own expert judgments to the findings and decide how those findings should inform core capability targets in the Goal.

All sources and estimates were documented to promote credibility, defensibility, and transparency within the assessment. Uncertainty in frequency and consequences was explicitly included in the analysis by representing low and high bounds in addition to best estimates. Examples of sources of uncertainty include incomplete knowledge of adversary capabilities and intent, variability in possible event severity and location, and lack of historical precedence.

Because the assessment was performed at a strategic national level, it provided the ability to draw rough comparisons of the assessed events—within an order of magnitude—to view the broad differences in risk across events. Given the uncertainty inherent in assessing risks at a national level and the lack of information about some of the events included—many of which are likely to occur very infrequently—the assessment was designed to avoid false precision. Instead, the assessment identifies only those differences in risk that are still significant despite the associated uncertainties.

Limitations

The analysis of available information—even if that analysis is imprecise and contains a wide degree of uncertainty—supports better decision making, as long as key limitations and assumptions are noted. Participants designed the SNRA to capture the best information the Nation has about homeland security risks to support the development of the National Preparedness Goal while recognizing the limitations of conducting such analysis in a shortened time frame.

- This is a strategic national risk assessment. As such, it does not present a full view of the risk facing local communities. To complement preparedness planning, it is necessary to consider national and regional risks, many of which differ from region to region.
- Given PPD-8's emphasis on contingency events with defined beginning and endpoints (e.g. hurricanes, terrorist attacks), the current SNRA does not explicitly assess persistent, steady-state risks like border violations, illegal immigration, drug trafficking, and intellectual property violations, which are important considerations for DHS and the homeland security enterprise.
- Information about the frequency and consequences of the events included in the SNRA is at varying stages of maturity, with additional work required in some areas to ensure that event data can be appropriately compared. Where substantial additional research is warranted, events are discussed qualitatively and are not compared with other events.
- The SNRA methodology does not explicitly model the dynamic nature of some of the included hazards. For example, terrorists' evolving tactics in response to changes in defensive posture are not included.
- Experts consulted about psychological consequences emphasized caution in the application of the SNRA's measure of psychological distress, and stressed the need for additional research. The Department of Homeland Security and its partner organizations leveraged previously funded social and behavioral research to better understand how to anticipate,

prepare for, counteract, and mitigate the effects of terrorist acts, natural disasters, and technological accidents. Additional research is required to further explore psychosocial factors that enable resilience in individuals, organizations, and communities and at the societal level.

- For national-level events where historic data was used as the basis of analysis, the risk from low-likelihood, high-consequence incidents may not be adequately captured. This is particularly true for technological/accidental hazards. Further study is needed to better characterize these risks at the national strategic level.

Impacts and Future Uses

The SNRA was executed in support of PPD-8 implementation and has served as an integral part of the development of the National Preparedness Goal, assisting in integrating and coordinating identification of the core capabilities and establishing a risk-informed foundation for the National Preparedness System. Participants mapped the core capabilities identified in the Goal to the events assessed in the SNRA to identify any additional core capabilities that may need to be included. In addition, the SNRA can be used to inform discussions on priorities for capability investment decisions. Finally, the SNRA results will be used to drive other preparedness priorities at the national level.

In addition, conducting a Strategic National Risk Assessment will support the National Preparedness System by providing a consolidated list of “national level events” for consideration and augmentation for Threat and Hazard Identification and Risk Assessment processes at multiple jurisdiction levels.

Conclusion

Although the development of the SNRA is an important first step, further analysis through the execution of regional- and community-level risk assessments will help communities better understand their risks and form a foundation for their own security and resilience. The Nation’s preparedness is dependent on a whole-of-community understanding of risk and comprehensive consequences at and across all levels of government. In conjunction with Federal, state, local, tribal, and territorial partners, the SNRA will be expanded and enhanced and will ultimately serve as a unifying national risk profile to facilitate preparedness efforts.

APPENDIX P: PRESIDENTIAL POLICY DIRECTIVE 8: NATIONAL PREPAREDNESS

March 30, 2011
PRESIDENTIAL POLICY DIRECTIVE/PPD-8
SUBJECT: National Preparedness

This directive is aimed at strengthening the security and resilience of the United States through systematic preparation for the threats that pose the greatest risk to the security of the Nation, including acts of terrorism, cyber attacks, pandemics, and catastrophic natural disasters. Our national preparedness is the shared responsibility of all levels of government, the private and nonprofit sectors, and individual citizens. Everyone can contribute to safeguarding the Nation from harm. As such, while this directive is intended to galvanize action by the Federal Government, it is also aimed at facilitating an integrated, all-of-Nation, capabilities-based approach to preparedness.

Therefore, I hereby direct the development of a national preparedness goal that identifies the core capabilities necessary for preparedness and a national preparedness system to guide activities that will enable the Nation to achieve the goal. The system will allow the Nation to track the progress of our ability to build and improve the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from those threats that pose the greatest risk to the security of the Nation.

The Assistant to the President for Homeland Security and Counterterrorism shall coordinate the interagency development of an implementation plan for completing the national preparedness goal and national preparedness system. The implementation plan shall be submitted to me within 60 days from the date of this directive, and shall assign departmental responsibilities and delivery timelines for the development of the national planning frameworks and associated interagency operational plans described below.

National Preparedness Goal

Within 180 days from the date of this directive, the Secretary of Homeland Security shall develop and submit the national preparedness goal to me, through the Assistant to the President for Homeland Security and Counterterrorism. The Secretary shall coordinate this effort with other executive departments and agencies, and consult with State, local, tribal, and territorial governments, the private and nonprofit sectors, and the public.

The national preparedness goal shall be informed by the risk of specific threats and vulnerabilities – taking into account regional variations – and include concrete, measurable, and prioritized objectives to mitigate that risk. The national preparedness goal shall define the core capabilities necessary to prepare for the specific types of incidents that pose the greatest risk to the security of the Nation, and shall emphasize actions aimed at achieving an integrated, layered, and all-of-Nation preparedness approach that optimizes the use of available resources. The national preparedness goal shall reflect the policy direction outlined in the National Security Strategy (May 2010), applicable Presidential Policy Directives, Homeland Security Presidential Directives, National Security Presidential Directives, and national strategies, as well as guidance from the Interagency Policy Committee process. The goal shall be reviewed regularly to evaluate consistency with these policies, evolving conditions, and the National Incident Management System.

National Preparedness System

The national preparedness system shall be an integrated set of guidance, programs, and processes that will enable the Nation to meet the national preparedness goal. Within 240 days from the date of this directive, the Secretary of Homeland Security shall develop and submit a description of the national preparedness system to me, through the Assistant to the President for Homeland Security and Counterterrorism. The Secretary shall coordinate this effort with other executive departments and agencies, and consult with State, local, tribal, and territorial governments, the private and nonprofit sectors, and the public.

The national preparedness system shall be designed to help guide the domestic efforts of all levels of government, the private and nonprofit sectors, and the public to build and sustain the capabilities outlined in the national preparedness goal. The national preparedness system shall include guidance for planning, organization, equipment, training, and exercises to build and maintain domestic capabilities. It shall provide an all-of-Nation approach for building and sustaining a cycle of preparedness activities over time.

The national preparedness system shall include a series of integrated national planning frameworks, covering prevention, protection, mitigation, response, and recovery. The frameworks shall be built upon scalable, flexible, and adaptable coordinating structures to align key roles and responsibilities to deliver the necessary capabilities. The frameworks shall be coordinated under a unified system with a common terminology and approach, built around basic plans that support the all-hazards approach to preparedness and functional or incident annexes to describe any unique requirements for particular threats or scenarios, as needed. Each framework shall describe how actions taken in the framework are coordinated with relevant actions described in the other frameworks across the preparedness spectrum.

The national preparedness system shall include an interagency operational plan to support each national planning framework. Each interagency operational plan shall include a more detailed concept of operations; description of critical tasks and responsibilities; detailed resource, personnel, and sourcing requirements; and specific provisions for the rapid integration of resources and personnel.

All executive departments and agencies with roles in the national planning frameworks shall develop department-level operational plans to support the interagency operational plans, as needed. Each national planning framework shall include guidance to support corresponding planning for State, local, tribal, and territorial governments.

The national preparedness system shall include resource guidance, such as arrangements enabling the ability to share personnel. It shall provide equipment guidance aimed at nationwide interoperability; and shall provide guidance for national training and exercise programs, to facilitate our ability to build and sustain the capabilities defined in the national preparedness goal and evaluate progress toward meeting the goal.

The national preparedness system shall include recommendations and guidance to support preparedness planning for businesses, communities, families, and individuals.

The national preparedness system shall include a comprehensive approach to assess national preparedness that uses consistent methodology to measure the operational readiness of national capabilities at the time of assessment, with clear, objective and quantifiable performance measures, against the target capability levels identified in the national preparedness goal.

Building and Sustaining Preparedness

The Secretary of Homeland Security shall coordinate a comprehensive campaign to build and sustain national preparedness, including public outreach and community-based and private-sector programs to enhance national resilience, the provision of Federal financial assistance, preparedness efforts by the Federal Government, and national research and development efforts.

National Preparedness Report

Within 1 year from the date of this directive, the Secretary of Homeland Security shall submit the first national preparedness report based on the national preparedness goal to me, through the Assistant to the President for Homeland Security and Counterterrorism. The Secretary shall coordinate this effort with other executive departments and agencies and consult with State, local, tribal, and territorial governments, the private and nonprofit sectors, and the public. The Secretary shall submit the report annually in sufficient time to allow it to inform the preparation of my Administration's budget.

Roles and Responsibilities

The Assistant to the President for Homeland Security and Counterterrorism shall periodically review progress toward achieving the national preparedness goal.

The Secretary of Homeland Security is responsible for coordinating the domestic all-hazards preparedness efforts of all executive departments and agencies, in consultation with State, local, tribal, and territorial governments, nongovernmental organizations, private-sector partners, and the general public; and for developing the national preparedness goal.

The heads of all executive departments and agencies with roles in prevention, protection, mitigation, response, and recovery are responsible for national preparedness efforts, including department-specific operational plans, as needed, consistent with their statutory roles and responsibilities.

Nothing in this directive is intended to alter or impede the ability to carry out the authorities of executive departments and agencies to perform their responsibilities under law and consistent with applicable legal authorities and other Presidential guidance. This directive shall be implemented consistent with relevant authorities, including the Post-Katrina Emergency Management Reform Act of 2006 and its assignment of responsibilities with respect to the Administrator of the Federal Emergency Management Agency.

Nothing in this directive is intended to interfere with the authority of the Attorney General or Director of the Federal Bureau of Investigation with regard to the direction, conduct, control, planning, organization, equipment, training, exercises, or other activities concerning domestic counterterrorism, intelligence, and law enforcement activities.

Nothing in this directive shall limit the authority of the Secretary of Defense with regard to the command and control, planning, organization, equipment, training, exercises, employment, or other activities of Department of Defense forces, or the allocation of Department of Defense resources.

If resolution on a particular matter called for in this directive cannot be reached between or among executive departments and agencies, the matter shall be referred to me through the Assistant to the President for Homeland Security and Counterterrorism.

This directive replaces Homeland Security Presidential Directive (HSPD)-8 (National Preparedness), issued December 17, 2003, and HSPD-8 Annex I (National Planning), issued December 4, 2007, which are hereby rescinded, except for paragraph 44 of HSPD-8 Annex I.

Individual plans developed under HSPD-8 and Annex I remain in effect until rescinded or otherwise replaced.

Definitions

For the purposes of this directive:

(a) The term "national preparedness" refers to the actions taken to plan, organize, equip, train, and exercise to build and sustain the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from those threats that pose the greatest risk to the security of the Nation.

(b) The term "security" refers to the protection of the Nation and its people, vital interests, and way of life.

(c) The term "resilience" refers to the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies.

(d) The term "prevention" refers to those capabilities necessary to avoid, prevent, or stop a threatened or actual act of terrorism. Prevention capabilities include, but are not limited to, information sharing and warning; domestic counterterrorism; and preventing the acquisition or use of weapons of mass destruction (WMD). For purposes of the prevention framework called for in this directive, the term "prevention" refers to preventing imminent threats.

(e) The term "protection" refers to those capabilities necessary to secure the homeland against acts of terrorism and manmade or natural disasters. Protection capabilities include, but are not limited to, defense against WMD threats; defense of agriculture and food; critical infrastructure protection; protection of key leadership and events; border security; maritime security; transportation security; immigration security; and cybersecurity.

(f) The term "mitigation" refers to those capabilities necessary to reduce loss of life and property by lessening the impact of disasters. Mitigation capabilities include, but are not limited to, community-wide risk reduction projects; efforts to improve the resilience of critical infrastructure and key resource lifelines; risk reduction for specific vulnerabilities from natural hazards or acts of terrorism; and initiatives to reduce future risks after a disaster has occurred.

(g) The term "response" refers to those capabilities necessary to save lives, protect property and the environment, and meet basic human needs after an incident has occurred.

(h) The term "recovery" refers to those capabilities necessary to assist communities affected by an incident to recover effectively, including, but not limited to, rebuilding infrastructure systems; providing adequate interim and long-term housing for survivors; restoring health, social, and community services; promoting economic development; and restoring natural and cultural resources.

BARACK OBAMA

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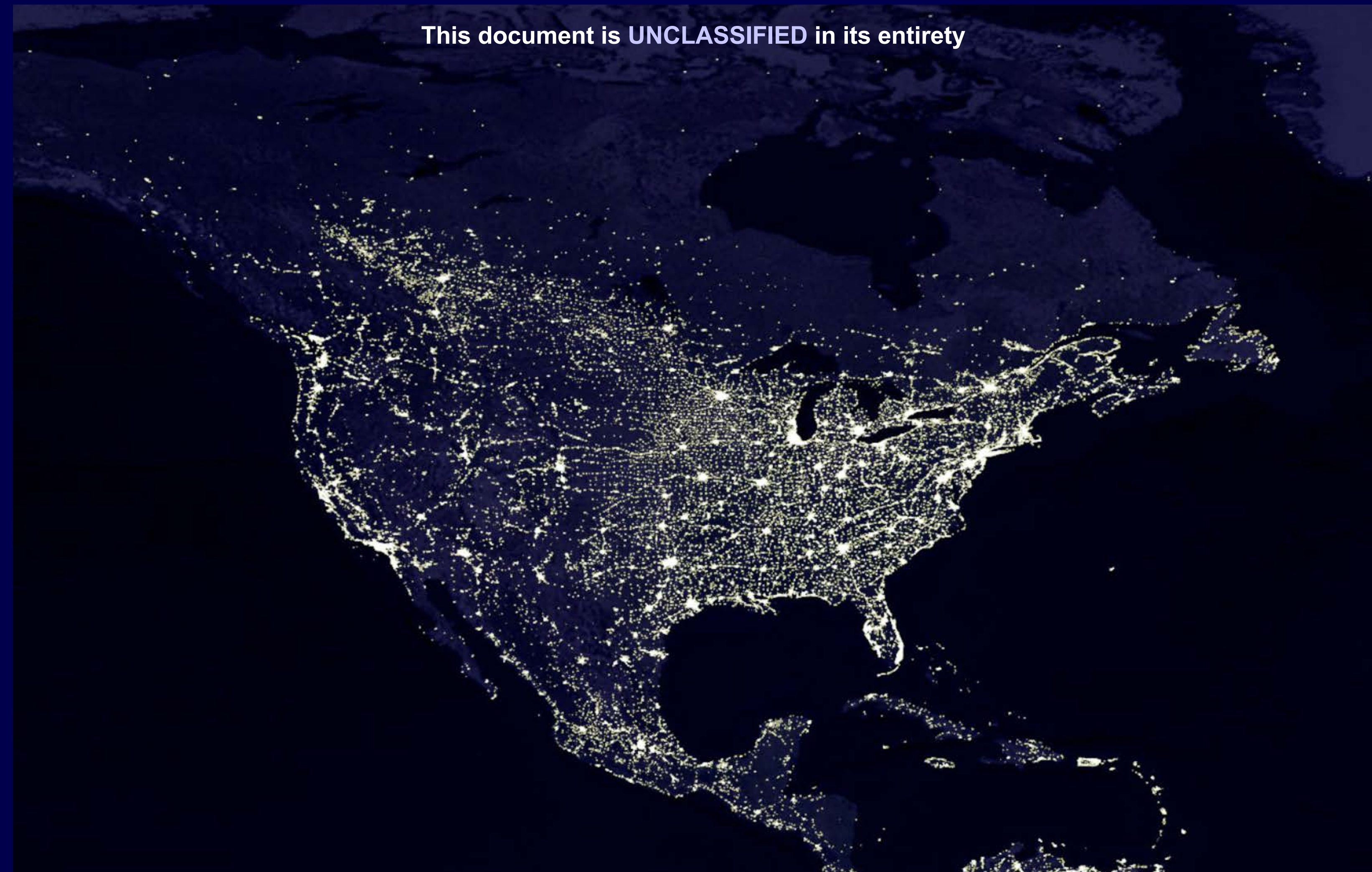

Strategic National Risk Assessment 2011

Unclassified Documentation of Findings

Findings September 2011
Documentation May 2015

Homeland Security

Strategic National Risk Assessment 2011

Unclassified Documentation