

Critical Infrastructure Protection and Resilience Literature Survey: Disaster Risk Mitigation Mechanisms

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1 EXECUTIVE SUMMARY

Defence R&D Canada's Centre for Security Science (CSS) is working in partnership with Public Safety Canada (PS) on a long term objective to develop an integrated national and regional Critical Infrastructure (CI) Dependency model for CI risk analysis and risk mitigation in support of the 2010 National Critical Infrastructure Strategy.¹ To frame discussions and serve as a starting point, CSS has requested that the National Research Council (NRC) Knowledge Management perform an exploratory study of existing scientific, industrial and government (domestic/international) literature on critical infrastructure protection and resilience (CIPR) and related concepts, including, but not limited to, risk mitigation mechanisms.

This report presents a review of the literature on past disasters, lessons learned and disaster risk mitigation strategies. Based on the data collected for this study, the main threats to critical infrastructure were found to be cyber threats, terrorism and disasters. The major disasters since 2003 (i.e. those with high numbers of deaths and/or economic impacts), both internationally and in North America, have predominantly been natural disasters, including earthquakes, hurricanes, floods, wildfires and the like. Despite the fact that cyber and terrorist attacks are major threats to critical infrastructure protection and resilience discussed in the scientific literature, these do not show up as having had a major impact in the past 10 years.

The literature on risk mitigation generally focuses on disaster mitigation at the societal or community level rather than specifically on critical infrastructure. Numerous lessons learned, mechanisms and solutions, ranging from local, disaster-specific solutions to general international frameworks have been developed to mitigate the threats and impacts from disasters. The main international mechanism is the Hyogo Framework for Action (2005-2015) and much of the current mitigation literature focuses on its five core tenets. Lessons learned from many of the major disasters in the past 10 years were reviewed and were found to largely follow the Hyogo Framework for Action including:

- Integrating disaster risk reduction in national and local strategies and policies;
- Identifying, assessing and monitoring risks and enhancing early warning;
- Using knowledge and education to improve resilience;
- Reducing the underlying risks; and
- Improving disaster preparedness for effective response.

As a result of past disasters and their impacts on various segments of society, the areas of business, health and education are beginning to develop their own mitigation strategies. In the field of business, there is an emerging recognition of the need to take risk management more seriously and to consider disaster risks in investment decisions. In the health sector, more facilities are developing concrete emergency preparedness plans and educating medical responders with the specific skills needed for major disasters. In education, recognition of the maxim that education leads to resilience is encouraging the development of more educational programs at all educational levels.

While Canada has an active National Platform for implementing the Hyogo Framework, its internal policies and strategies for risk mitigation lack detail and depth. The United States stands out as one of the few nations (along with New Zealand) that have concrete and specific risk mitigation actions

for critical infrastructure (CI), which can mainly be found in the US CI sector-specific plans. While individual CI owners and operators may have individual plans, these are largely at the business continuity or contingency level and still lack specifics and depth. Challenges in disaster risk mitigation continue to revolve around integrating an overarching climate change mitigation strategy into national mitigation plans as well as relating to a general lack of financial, human and organizational resources at all levels of government. Consultations on the second phase of the Hyogo Framework for Action identified numerous next steps including the need for more specific goals, targets and indicators as well as involvement of stakeholders and partnerships to promote ownership and international commitment to the framework.

2 BACKGROUND

2.1 Context

In 2009, the Canadian federal government, provinces and territories agreed on a National Strategy¹ and Action Plan for Critical Infrastructure². The purpose of this initiative is to strengthen the resilience of Canadian Critical Infrastructure (CI) by building partnerships, implementing hazards risk management approaches, and advancing the timely sharing and protection of information among partners. The strategy recognized that critical infrastructures are at risk from natural, intentional and accidental hazards and that the risk could be exacerbated by the complex system of interdependencies among critical infrastructure, which can lead to cascading effects across borders and sectors. The Action Plan includes the establishment of sector networks and a cross-sector forum as the basis for collaborative work and information sharing. The Centre for Security Science (CSS) is working in partnership with Public Safety Canada (PS) on initiatives to address some of the objectives identified within the strategy and its action plan in order to increase Canadian infrastructure resiliency, develop strong communities and implement an all-hazards risk management approach. The continuity of national governance to maintain public health, safety, security, economic well-being and the confidence during or after any disaster or emergency is one of the initiatives. The development of national and regional interdependency modeling tools and methodologies to understand CI interdependencies and the cascading effect of events is another important initiative.

2.2 Key Issues

To frame discussions and serve as a starting point in the development of a national and regional CI modeling tool, CSS has requested an exploratory study of existing scientific, industrial and government (domestic/international) literature on critical infrastructure protection and resilience (CIPR) and related concepts; including, but not limited to, risk mitigation mechanisms, CI interdependencies as well as modeling and simulation tools. This study will examine the existing body of knowledge and attempt to structure the current state of knowledge of CIPR. It is anticipated that the results of this work will yield a more in depth and enhanced understanding of the concepts, activities and tools associated with CIPR in terms of physical and cyber security systems from both civilian and military perspectives. Additionally, it will help CSS develop advanced capabilities and expertise in the area, as well as highlight gaps, lessons learned and opportunities for next steps in the pursuit of an integrated CIPR strategy.

2.3 Key Questions

1. What are the threats and risks to CI safety and security (previous, current, emerging, and future)?
2. What are the mechanisms (solutions) used or being developed to mitigate the threats to CI safety and security?
3. What are the top 10 North American and top 10 international major disasters that have occurred in the past 10 years and what have their impacts been (e.g. lives, economic, health, education, policies etc.)?
4. What are the lessons learned from these events and what is proposed to be done in the future to mitigate these threats?

5. What are some of the drivers, challenges, lessons learned and gaps associated with these solutions?

3 INTRODUCTION

The cumulative impact of natural, intentional and accidental disasters represents significant losses for society in terms of humans affected, lives lost, economies disrupted and natural ecosystems destroyed. Every year, thousands of schools, hospitals and other critical infrastructure, including roads, transportation routes, electrical and power facilities and communications networks, are damaged or destroyed as a result of major disasters. Since 1992, more than 1.3 million people have lost their lives and total damages have been reported in the range of \$2 trillion. Since 2010, annual economic losses from disasters have exceeded \$100 billion each year.³ With a growing number of disaster databases capturing disaster loss and risk data, these estimates are now being viewed as conservative: the 2013 Global Assessment Report suggests that figures may be as much as 50% higher when smaller disasters are included. In fact, persistent, small scale disasters can have a greater impact on societies than the major, highly visible disasters.³

Economic losses from weather related disasters have been on the rise. Estimated annual losses have ranged from just a few US\$ billion in 1980 to over \$200 billion in 2010, with Hurricane Katrina representing the greatest economic loss. The Americas have experienced the greatest economic losses from weather- and climate-related disasters, accounting for 54.6% of total losses, followed by Asia (27.5%) and Europe (15.9%). Information on informal economies or undocumented economies are not included in these estimates but are very important since some of the hardest hit disaster zones are typically found in developing countries. While recorded economic losses are higher in the developed world, loss of life and losses expressed as a proportion of gross domestic product are higher in developing countries; between 1970-2008, over 95% of deaths from natural disasters occurred in developing countries.⁴ According to the *2013 Global Assessment Report*, the world can expect disaster related losses to double by 2030 if not enough is done to address and mitigate the risk, threats and impacts associated with disasters.

Numerous mechanisms and solutions, ranging from local, disaster-specific solutions to general international frameworks have been developed to mitigate the threats and impacts from disasters. There are a number of definitions of mitigation in the literature⁵⁻⁸ that vary in terms of where they place mitigation within a risk management continuum. In some cases mitigation is considered to be the same as prevention, as in the *Canadian Emergency Management Framework* where mitigation is defined as structural and non-structural actions taken:

...to eliminate or reduce the risks of disasters in order to protect lives, property, the environment, and reduce economic disruption. Prevention/mitigation includes structural mitigative measures (e.g. construction of floodways and dykes) and non-structural mitigative measures (e.g. building codes, land-use planning, and insurance incentives). Prevention and mitigation may be considered independently or one may include the other.⁸

Others define it as the lessening or limiting of the adverse impacts of hazards and related disasters by supporting protection and prevention activities, easing response, and speeding recovery to create better prepared and more resilient communities.^{6,7}

For the purposes of this report, mitigation is considered to be synonymous with disaster risk reduction and can be defined as measures “that eliminate or reduce the impacts and risks of hazards through proactive measures taken before an emergency or disaster occurs.”⁸ Very few reports reviewed for this study, except for the US National Infrastructure Protection Plan, the US National Mitigation Framework, some sections of the US Federal Emergency Management Agency’s Mitigation Assessment Team’s reports and the New Zealand Earthquake Commission report, discuss specific mitigation activities in relation to CI as most reports remain at a high level of strategy development and do not drill down to specific actions or to the individual CI level.

To address the key questions in this study, searches were conducted using the strategies described in section 11. The first search was done to compile a list of the major disasters for 2003-2013, while the second two compiled a body of literature on threat mitigation strategies and lessons from the disasters identified in the first search. The findings in this study are based on roughly 100 sources including articles, reports, websites and statistical databases on world disasters.

This report presents a brief summary of threats and risks to critical infrastructure. It provides an overview of some of the major disasters in the past decade (2003-2013) and some of the lessons learned from them. This is followed by an overview of the main mitigation measures that are discussed in the literature, the international efforts to reduce risks, Canadian and American strategies for disaster mitigation as well as mechanisms that are being developed to reduce risk in the economic/business, medical and educational domains. The report concludes with a section on drivers, challenges and gaps in the field of risk mitigation.

4 THREATS AND RISKS TO CRITICAL INFRASTRUCTURE

The threats and risks to critical infrastructure presented below are based on the consulted literature. Based on analyzed data, 15 threats were identified and were cross-correlated with the 10 Canadian Critical Infrastructure Sectors. Figure 1 highlights that cyber attacks, terrorism and disasters are the most frequently discussed threats to critical infrastructure in the CI modeling and simulation literature. While cyber attacks and terrorism are high on the list, the mitigation strategies that are discussed in this report relate to natural disaster mitigation as this is the most frequently discussed mitigation topic in the risk literature. Similarly, as will be seen below, most major disasters (based on number of deaths and economic impacts) in the past 10 years, both in North America and internationally, have been natural disasters (i.e. weather-related events, earthquakes, etc).

CIPR Literature Survey: Mitigation Mechanisms

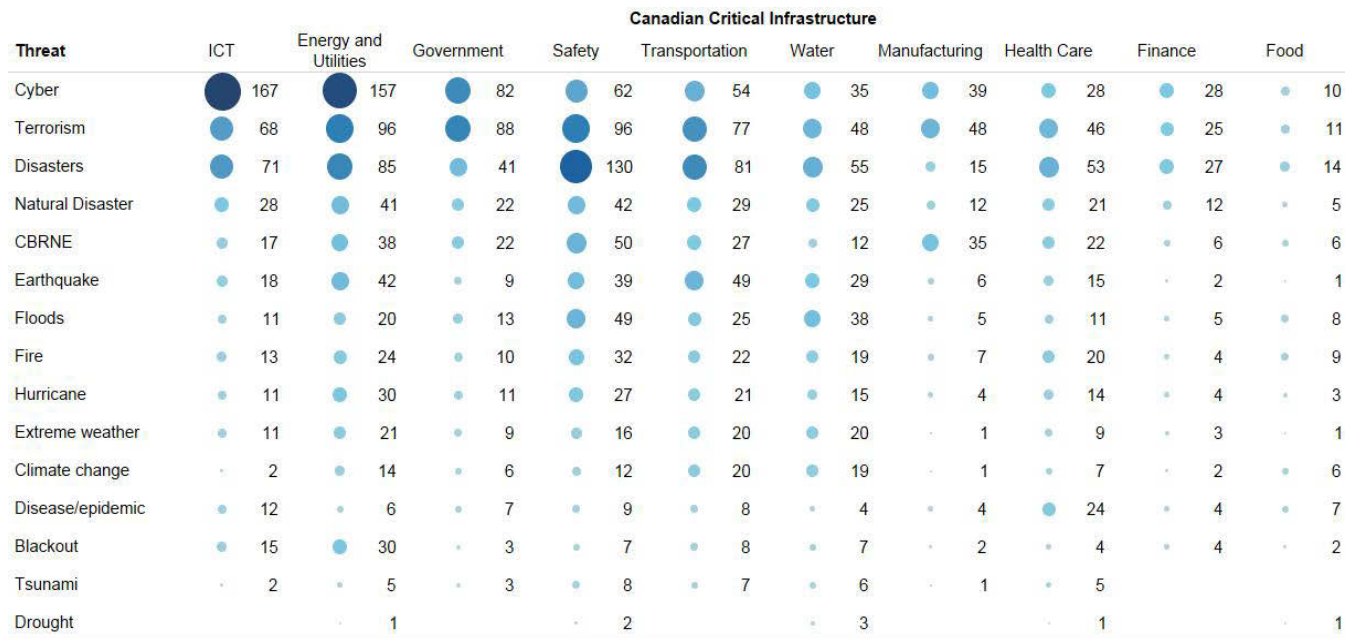


Figure 1. Top Threats on CI Infrastructure, Organized by Canadian CI Sectors, Modeling and Simulation Literature

Figure 2 shows the number of records that discuss each threat by year. Despite the fact that there is a drop in number of records discussing the threats in 2012, most are seeing a steady increase.

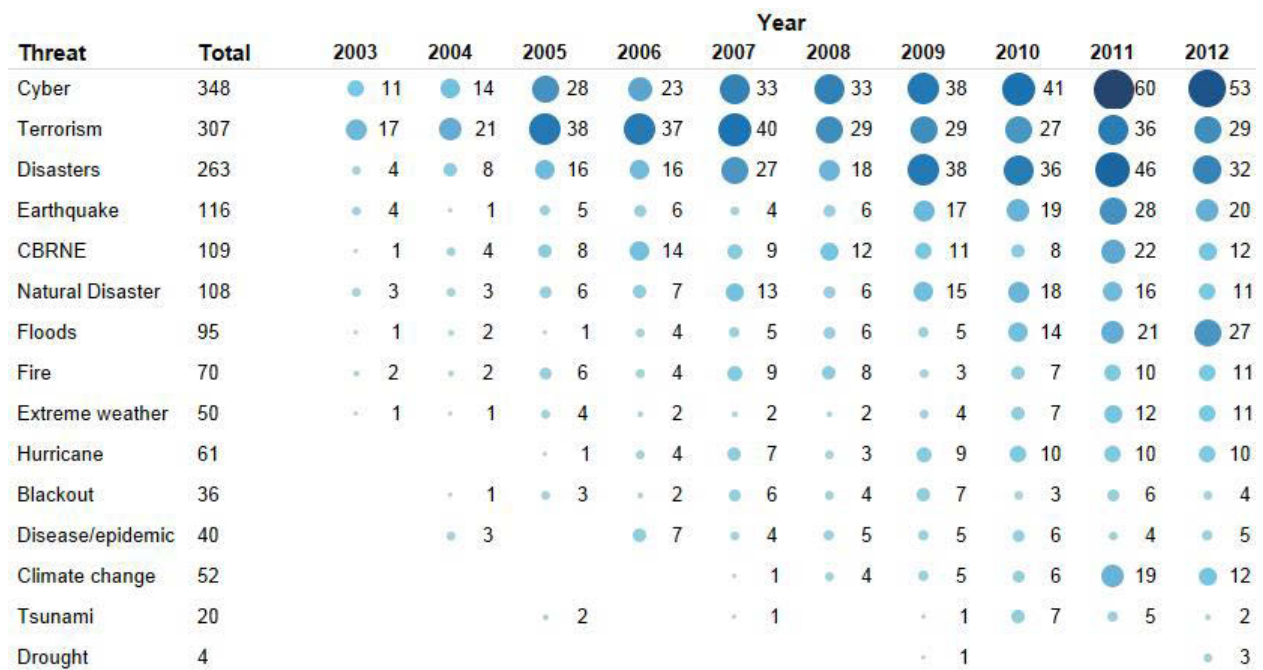


Figure 2. Threats to CI by Year, Modeling and Simulation Literature

CIPR Literature Survey: Mitigation Mechanisms

It is important to note for both of these figures that this data is based on records that discuss critical infrastructure, protection and resilience, modeling and simulation.^a As such the data reflects the threats that are discussed in that sub-field of critical infrastructure protection and resilience.

Despite cyber threats and terrorist attacks being the most discussed threats in the CIPR modeling and simulation literature, the major disasters (based on the number of deaths and overall losses), both in North American and Internationally, that have occurred between 2003-2013 have mostly been natural disasters. Tables 1 and 2 present 17 major, North American and International, disasters between 2003 and 2012, respectively. The information in the following two tables was gathered from a variety of international databases and reports on disasters. It is important to note that figures for deaths and losses vary between databases and as such, the figures are best considered as estimates. For Table 2, an attempt was made to capture a major disaster for each year in both Canada and the US but this was not always possible. Interestingly, the majority (over 60%) of the most costly Canadian disasters is the result of flooding, yet Canada does not consider coastal regions and inland waterways to be part of a critical infrastructure sector. The Canadian data comes primarily from the [Canadian Disasters Database](#) hosted by Public Safety Canada.

Table 1. 17 Major North American Disasters, Deaths, Economic Losses 2003-2013

Country	Year	Disaster	Deaths	Overall Loss (CAN\$)
CAN	2003	Wildfires, Southeastern British Columbia and Southwestern Alberta. July-August	0	492.9 M
CAN	2004	Flooding, Edmonton. July 11	0	13.5 M
US	2005	Hurricane Katrina. August 25-30	1,833	US\$ 129 B
CAN	2005	Flooding, Alberta (High River, Calgary, Red Deer, and other areas). June 8	2	142.1 M
CAN	2006	Flooding, Red Earth, SK. Apr 13	0	19.1 M
CAN	2007	Flooding, Red Earth, SK. Apr 19	0	125.8 M
US	2008	Hurricane Ike	170	US \$ 38 B
CAN	2008	Flooding, Saint John NB. May 30	0	21 M
CAN	2009	Wildfires, Kelowna, Kamloops and Cariboo BC. July 18	1	75 M
CAN	2009	Influenza Pandemic, Across Canada. April 2009-Feb 2010.	425	unknown
US	2010	Deepwater Horizon oil spill, Gulf of Mexico. Apr 20	11	US \$ 42.2 B
CAN	2010	Flooding, Southern Alberta and Saskatchewan. June 17	0	956.4 M
US	2011	1691 Tornadoes	553	9,493 B
CAN	2011	Wildfire, Slave lake and areas. May 1-22	0	700 M
US	2012	Hurricane Sandy, US	117	US \$50 B
CAN	2013	Floods, Alberta, Jun 20	3	3 B

^aThe subset of literature on critical infrastructure modeling and simulation stands as a reasonable proxy for the field of CIPR as modeling and simulation is one of the most discussed topics in the field.

Table 2 presents the 17 major international disasters. In some years, multiple disasters are listed to capture disasters with significantly high fatalities or significantly high losses when these two factors did not coincide. In other cases, additional disasters are listed due to the frequency of reporting in the literature (e.g. the 2011 Christchurch, New Zealand earthquake).

Table 2. 17 Major International Disasters, Deaths, Economic Losses 2003-2013

Year	Disaster	Magnitude ⁹	Fatalities	Overall Losses US\$
2003	HeatWave Europe		70,000	13.8 B
2003	EQ, Bam Iran	6.6	26,796	5 M
2004	Tsunami, Indian Ocean		225,841	11.2 B
2005	EQ, Kashmir, Pakistan	7.6	73,338-88,000	5.2B
2006	EQ, Yogyakarta, Indonesia	6.3	5,778	
2006	Floods, India			3.39 B
2007	Cyclone Sidr, Bangladesh		4,234	
2008	EQ, Wenchuan, Sichuan, China	8.0	87,476 (dead/missing)	84.4 B
2008	Cyclone Nargis, Myanmar		138,366 (dead/missing)	4 B
2009	EQ, Indonesia	7.6	1,195	
2010	EQ/Tsunami, Chile	8.8	520	30 B
2010	EQ, Haiti	7.0	222,570	8 B
2011	EQ/Tsunami, Tohoku, Japan	9.0	19,846	210 B
2011	EQ, Christchurch, New Zealand	5.9	185	15 B
2012	Typhoon Bopha, Phillipines		1,901	
2012	EQ, Italy	N/A		15.8 B
2013	EQ, China	6.6		6.8 B

5 LESSONS FROM MAJOR NORTH AMERICAN AND INTERNATIONAL DISASTERS, 2003-2013.

The following section highlights or summarizes lessons that have been learned from many of these disasters. Additional broad lessons learned that relate to disaster risk reduction but that are not related to a specific individual disaster can be found in the 2012 [Special Report of Intergovernmental Panel on Climate Change \(IPCC\)](#).

5.1 Lessons from Earthquakes/Tsunamis

11 out of the 17 international disasters are earthquakes, many of which resulted in tsunamis. Numerous lessons can be learned from these disastrous events. Highlights of some of the lessons from the Japanese, Chinese, Haitian and New Zealand earthquakes as well as from the 2004 South East Asian tsunami are presented below.

5.1.1 Earthquake – Christchurch (New Zealand)

An earthquake of magnitude 5.9 in the urban and surrounding areas of Christchurch led to significant liquefaction, damages and disruption of critical infrastructure systems. Despite the fact that the earthquake exceeded hazard assessment estimates, many essential services infrastructure continued to

operate. This is largely due to resiliency being built into the design of the city and its critical infrastructure through interdependency planning, mutual assistance agreements between utility providers, extensive insurance coverage and highly trained personnel. Many systems were prepared due to lessons learned from previous earthquakes and seismic protection investments including strengthening infrastructure and building in redundancies and backups. The seismic upgrade programme of one of the power companies, which cost roughly \$40 million, is estimated to have saved up to \$30-50 million.^{10,b}

Key lessons already implemented or enacted by power, gas and water sectors since the earthquake include:

- Restraining heavy equipment (e.g. transformer banks) in substations;
- Removing or strengthening existing buildings;
- Replacing equipment found to perform poorly during previous earthquakes;
- Installing temporary overhead lines to quickly restore power while permanent lines are replaced;
- Using high density polyethylene (HDPE) pipes for all new pressure mains in the water network as they performed best;
- Independent back-up resources relieved interdependencies between critical infrastructures (such as electricity and water networks) and allowed for maintenance of basic functionality;¹⁰
- Adding diversity and redundancy where cost-effective;
- Retrofitting to improve seismic performance of asset;
- Adopting best practices in design, choice of materials and installation;
- Undertaking site-specific liquefaction risk assessments;
- Recognizing critical infrastructure interdependencies (e.g. strengthening electricity supply to other 'lifeline' critical infrastructure).¹¹

Other changes that have resulted from the earthquake include:

- Zoning policies and building regulations were revised, including the abandonment and depopulating of selected areas including the densely built-up central business district; and
- Important changes in the insurance industry including companies' 'incapacity to pay out' and termination of insurance policies.¹²

5.1.2 Earthquake – Tohoku (Japan)

The largest earthquake to have hit Japan in the past century occurred in March 2011 and measured 9.0 on the Richter scale, and resulted in a devastating tsunami. Almost immediately following the first shakes from the earthquake, warnings were sent out across the country and 27 high-speed bullet trains were stopped without a single derailment. Tsunami warnings were also issued 20 minutes ahead of the first wave. While economic losses from this disaster were the highest for the past decade (US\$ 200+

^bIt is assumed that these values are listed in New Zealand dollars since although the report does not specify, it is published in a New Zealand source.

billion), the death toll was relatively low (<20 000) and was significantly lower than the 2004 South East Asian tsunami.^{13,14}

Lessons learned from the 2011 Japanese earthquake include:

- Early warning systems save lives;¹³
- Strict building codes and collective coherence, well rehearsed emergency drills, appropriate application of funding and compliance with official orders creates a collectively prepared community;¹³ and
- Tailored medical relief efforts optimize the effectiveness of medical response and can help prevent deaths. A central body should coordinate the medical effort and communicate up to date information regarding the following recommended steps:
 - Rapid search and rescue.
 - Early care in the field, evacuation centers and primary clinics.
 - Definitive evaluation at disaster base hospitals.
 - Proper evacuation to unaffected areas.¹⁴

5.1.3 Earthquake – Haiti

The 7.0 magnitude earthquake in Haiti in January 2010 resulted in one of the highest death toll disaster in the past decade with response and recovery being hampered by severe underlying vulnerabilities that existed in Haiti, including: systemic poverty, fragile governance and a continual threat of natural disasters.¹⁵The literature that covered lessons learned from the Haitian earthquake typically focused on humanitarian efforts in the recovery phase, but elements of mitigation mechanisms can be seen in the creation of education and disaster planning. Some specific recommendations include:

- Raising awareness at the local level about risk assessment, prevention and mitigation in communities;
- Training communities in skills, such as first-aid, that are applicable across a wide range of hazards;
- Providing opportunities for community members to discuss future city planning as a first step to community participatory rehabilitation;
- Helping at-risk communities safeguard their lives and assets by developing disaster plans or evacuation plans;
- Helping communities develop community contingency action plans;
- Promoting the integration of risk management in long-term planning;
- Working with communities to identify risks and promoting the safe siting of buildings;
- Protection of key infrastructure such as water plant and hospitals; and
- Building model homes in various communities as examples for others to learn from.¹²

5.1.4 Earthquake – Wenchuan (China)

Following the magnitude 8.0 earthquake in Sichuan province in 2008, numerous earthquake-induced geohazards occurred including rock avalanches, landslides, debris flows and earthquake lakes, the latter proving to be the most dangerous. Lessons learned from the Wenchuan earthquake are based on the fact that these geohazards are predicted to occur for many years to come and will occur in a circular sequence as one hazard gradually evolves into the next, due to instabilities caused by the initial earthquake. As such, geohazard risk assessment and prevention are key activities. An overview of two strategies for earthquake geohazards mitigation is presented below.

1. Strategies for disaster emergency response and relief
 - Earthquake-lake investigations and risk analysis of potential for failure.
 - Earthquake-lake monitoring and planning.
 - Addressing risk assessment specifically for threatened inhabited areas.
2. Strategy for reconstruction assistance
 - Promoting post-earthquake geohazards monitoring.
 - Construction site selection.
 - Geohazards control by civil engineering.
 - Ecology protection and engineering-induced geohazards prevention.
 - Resource utilization and earthquake-lake evaluation.^{16,17}

Other disaster impact mitigation strategies emerging from China include:

- Plans to equip 30% of the general population within high risk areas with the capacity to provide basic emergency response;
- Improving training and preparedness of medical staff for disaster relief; and
- Changing policy to include medical response for people with chronic conditions.¹⁸

5.1.5 Earthquake - Indonesian

Following the 2009 earthquake in Indonesia, extensive multidisciplinary scientific study on risk identification called the Last-Mile Project focused on the city of Padang in Western Sumatra and developed [specific recommendations](#) for risk reduction. The recommendations areas, along with selected examples, are listed below.

1. Political Recommendations: Generation and marketing of one single, official “Risk Reduction Plan”.
2. Urban Planning
 - *Hazard*: Designation of identified inundation / hazard zones as well as safe zones within the city.
 - *Urban development*: Relocation of homes and businesses from the highest risk zones.
 - *Shelters*: Designation of official rescue areas – vertical shelters and horizontal shelter areas.

- *Critical Infrastructure*: Relocation or retrofitting of highly exposed critical infrastructures, e. g. bridges, hospitals, etc.
3. Evacuation Strategies: General evacuation directions should be risk reducing
 4. Communication
 - *Education*: Implementation of continuous communication of tsunami risk and education programs.
 - *Warning dissemination*: Development of standardized procedures to receive and disseminate warnings; clear wording of warnings and guidance messages for the people need to be defined and socialized intensively.
 5. Lesson Learned
 - *Recommendations and observations from eyewitness reports*: Individual, private preparation is insufficient – education and organization for e. g. drinking water storage, staple foods, etc. is needed.
 - *Further recommendations and observations from the Last-Mile Project*: Capacity building has to be considered as an everlasting and continual process. New mechanisms and knowledge need to be institutionalized and further developed as well as facilitated and mainstreamed to other imperiled regions.²¹

5.1.6 Tsunami – South East Asian

Previous tsunamis did not affect change as much as the 2004 South East Asian tsunami. This disaster led to much effort and progress in building institutional arrangements, architectures, structures and governance of disaster risk reduction efforts. However the full implementation of these changes continues to be a challenge for Indonesia. Following the 2004 tsunami, the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO), the global governance body for managing tsunami hazards and risks, recommended the development of the Tsunami Warning System known as the Grand Scenario. Presidential Regulation has also created the National Disaster Management Agency known as , Badan Nasional Penanggulangan Bencana, BNPB, in Indonesia.¹⁹

Recommendations for continued improvement in the region include:

- Integration and synthesis between institutional arrangements (e.g. the Disaster Management Law and the Coastal and Small Island Management Law);
- Decentralize disaster management funds from the national to the local level with greater emphasis on pre-disaster investment;
- Finalize the tsunami warning chain (national to local) and early warning process;¹⁹
- Green belts such as dunes, mangroves and dense coastal trees can significantly reduce the force of impact where tsunami water depths do not exceed a few meters;
- Re-plan and re-zone reconstruction following disasters;

- Implement the Build Back Better^c concept;
- Review planning and emergency requirements for low-lying areas, especially for critical facilities; and
- Enhance knowledge and capacity for evacuation (of self and dependents), including knowledge of alternate routes and refuge areas.²⁰

5.2 Lessons from Hurricanes and Cyclones

5.2.1 Hurricane - Katrina and Sandy (US)

The following are a highlight of some of the major lessons learned from Hurricane Katrina.

1. Damage as a result of breaks in levees was due to poor construction and sporadic funding.
2. Local, state and federal leaders should assign a single individual responsible for managing hurricane and flood protection system.
3. Better inter-agency coordination is recommended.
4. Promote top-down government involvement (which is curious, according to McGee, because much of the evidence shows that the disaster was exacerbated by top-down government policies and involvement).²²
5. Explore possibility of mandatory comprehensive private disaster insurance with risk-based rates.
6. Develop pre-existing public programs to insure against losses and to subsidize low-income residents who can't afford insurance rather than have expensive and inefficient post-disaster relief and recovery programs.²³
7. Provide more erosion protection and resistant materials to improve survivability of levees.
8. Make use of redundant protection systems.
9. Redesign the hurricane protection systems (HPS) using a risk based approach.²⁴

The American Society of Civil Engineers (ASCE) identified ten critical actions that they believe are a necessary part of a shift to protect public safety and to prevent similar disastrous consequences of subsequent hurricanes. The high level call-to-actions are listed below. More specific details can be found in the ASCE's 2007 *The New Orleans Hurricane Protection System: What Went Wrong and Why* report.²⁵

1. Understand risk and embrace safety
 - Keep safety at the forefront of public priorities.
 - Quantify the risks.
 - Communicate the risks to the public and decide how much risk is acceptable.
2. Re-evaluate and Fix the Hurricane Protection System
 - Rethink the whole system, including land use in New Orleans.

^c The Build Back Better concept is based on the notion of rebuilding post-disaster in a way that reduces risk and increases resilience in the face of future disasters. <http://practicalaction.org/principles-building-back-better>

- Correct the deficiencies.
- 3. Revamp the Management of the Hurricane Protection System
 - Put someone in charge.
 - Improve inter-agency coordination.
- 4. Demand Engineering Quality
 - Upgrade engineering design procedures.
 - Bring in independent experts.
 - Place safety first.²⁵

Some examples of Hurricane Katrina's impacts on suggested policy changes include but are not limited to the following examples:

- Incorporate risk-based concepts into US Army Corps of Engineers (USACE) design;
- Revise the USACE Levee Design Manual EM 1110-2-1913 to incorporate risk based safety factors;
- Conduct periodic and thorough assessment of USACE projects; and
- Establish a National Levee Safety Program and USACE National Levee Safety Group.²⁴

As a result of lessons learned from Hurricane Katrina, New York hospitals were better prepared to deal with Hurricane Sandy. For example, some NY hospitals had the capacity to manage evacuations by having additional transportation equipment in place, the Department of Health and Human Services deployed more than 1000 disaster medical personnel to assist with response and recovery, and FEMA placed urban search and rescue teams nearby prior to the Hurricane Sandy hitting the city.²⁶

Additional, generic lessons from Hurricane Sandy include the following:

- Update floodplain maps to incorporate new realities of climate change.
- Require states to incorporate climate change into their hazard mitigation planning.²⁷
- Rebuild natural dune systems to lessen the impact of future storms.²⁸
- Future preparedness and response plans need to include meaningful community input to develop a bottom-up strategy.
- Establish an officially trained front-line team organized by government officials capable of responding to emergency situations and should include trained members from vulnerable communities.²⁹
- Corporate decentralized decision making and action is critical to response and recovery efforts for companies.
- Companies need to establish plans with critical personnel outside the affected areas to enable quick response to the impact zone.³⁰

- Coordinate with neighbouring companies to improve effectiveness of response.³⁰ This can also be effective for healthcare facilities in terms of shared equipment, supplies, infrastructure and training.²⁶
- Set up back up resources or plans for major utilities and resources like power and food.³⁰
- Establish an alternative for primary care and chronic illness maintenance prior to disasters to avoid drain on emergency medical services.²⁹
- Establish clear and consistent evacuation policies (in particular for medical facilities as well as nursing homes and assisted living facilities).^{26,29}
- Establish medical facility emergency preparedness plans that include staff assignments, generators, identification of evacuation relocation sites, and preparedness for long term power loss.^{26,29}
- Prepare for the long-term mental health impacts that natural disasters will have on those affected.^{27,28}

Lessons from FEMA's [Mitigation Assessment Team](#) (MAT) review of Hurricane Sandy in New Jersey and New York focuses on disaster-resistant building practices in hurricane-prone regions. They cover the following key areas:

- Climate change and sea level rise;
- Building codes and standards;
- Flood protection;
- Residential construction;
- Critical facilities and key assets; and
- Mechanical, electrical and plumbing systems.³¹

In terms of critical facilities and key assets, the MAT report recommends repairing and/or designing buildings and critical function to be more resistant to flooding with owners being responsible for providing emergency temporary power when needed. It also recommends that healthcare facilities plan for extended complete power loss and develop emergency plans and training exercises as well as procurement of emergency systems and supplies such as headlamps, back-up communication systems with batteries and battery powered lighting. Additional recommendations include increased elevation and protection of essential utilities and ventilation equipment at maintenance and transit facilities, in order to protect them from initial flooding and subsequent seepage.³¹

Over 50 more specific recommendations can be found in the MAT report in section 7.9. Further guidance for critical facility vulnerability assessments and mitigation actions can be found in FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds* and FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and Winds*.³¹

5.2.2 Cyclone – Sidr (Bangladesh)

Few articles discussing lessons from cyclones^d were found. One article from the International Conference of the Production and Operations Management Society (POMS) in 2009 presented the following six recommendations following an examination of successful practices during the 2007 cyclone Sidr in Bangladesh.

- Develop a Comprehensive Disaster Management Programme (CDMP) with the aim of developing a holistic pan government strategy for reducing long term vulnerability of the poor to disasters.
- Create a database of institutional capabilities, early warning information, and an inventory of key relief materials such as water, shelter, drugs etc. to better improve disaster response.
- Establish a Cyclone Preparedness Programme (CPP) that uses sounds and symbols, in addition to text, to transfer knowledge to areas with high levels of illiteracy.
- Training and education are a core part of cyclone preparedness.
- Local levels of engagement between all key stakeholders are necessary for effective disaster preparedness and emergency management.
- Shelters, enforceable building codes, embankments and protective infrastructure (e.g. physical barriers to storm surges).³²

5.3 Lessons from Floods – Alberta (Canada)

In collaboration with a broad group of water practitioners from across Alberta, WaterSMART Water Management Solutions, a local water management consulting company, recently identified six key recommendations for specific actions that can be taken to mitigate the impacts of flooding and droughts. These recommendations include:

1. Anticipate and plan for more extreme weather events, including both flood and drought
 - Conduct a study to analyze the confluence of events that resulted in the 2013 flood.
 - Overlay potential development scenarios on the weather scenarios.
 - Determine the magnitude of potential economic loss from another flood event.
2. Improve operational capacity to deal with a variety of potential extreme weather scenarios through better modeling and data management
 - Improve predictive capacity through increased modeling and data management.
 - Recognize that flood and drought planning are interconnected, and that both should receive an equal amount of attention.
 - Develop a better understanding of the relationship between flooding and groundwater.
 - Re-evaluate the potential for slumps and mudslides during flooding events.

^d Cyclones are the same weather phenomenon as hurricanes but are named differently in the Indian Ocean and southwestern Pacific

- Ensure that data is available and easily accessible so that it can be used in modeling and planning.
 - Build upon work that has already been conducted.
3. Investigate the cost/benefit balance of investing in physical infrastructure such as on and off-stream storage, diversions, and natural infrastructure such as wetlands
 - Conduct cost-benefit and risk analyses to assess the best use of capital funds to support infrastructure spending decisions.
 - Implement the recommendations of the Bow River Project.
 - Utilize more on-stream storage for flood control.
 - Increase the volume of off-stream storage.
 - Incorporate natural infrastructure such as wetlands, riparian areas, natural storage conditions and land cover into flood and drought mitigation planning.
 - Investigate uninhabited areas that could be potentially flooded with the least economic and environmental impact.
 4. Consider flood risks in municipal planning and strengthen building codes for new development in flood plains
 - Reconsider municipal development in flood-prone areas.
 - Connect land use planning to hydrology.
 - Refine zoning and building codes.
 - Encourage the Association of Professional Engineers and Geoscientists of Alberta (APEGA) to revise and update their practice standards to include consideration of risks in a flood event.
 - Make a variety of tools widely available to all Albertans to inform them about a future flood.
 5. Evaluate options for overland flood insurance
 - Give homeowners an option to accept insurance once but not again if they rebuild in flood plain or to relocate.
 - Start investigating whether overland flood insurance should be brought into Alberta.
 6. Manage water resources collaboratively, following the examples of the Bow River Consortium and the Cooperative Stormwater Management Initiative, and ensure Watershed Planning and Advisory Councils (WPACs) across the province have proper authority and funding
 - Support WPACs to work with their memberships to assess flood risk, consequences, and mitigation strategies, and to provide advice to the Government of Alberta.
 - Consider creating a Provincial Water Authority.
 - Support and provide increased capacity to smaller municipalities to respond to natural disasters.³³

More information on each of these recommendations, as well as next steps for Albertan flood mitigation, can be found in the [2013 Great Alberta Flood: Actions to Mitigate, Manage and Control Future Floods](#).

Additional flood mitigation recommendations in response to the 2013 Alberta floods have been developed by the [Institute for Catastrophic Loss Reduction](#), a Canadian not-for-profit multidisciplinary disaster prevention research and communications centre affiliated with the University of Western Ontario. In their report on [Best Practice for Reducing the Risk of Future Damage to Homes from Riverine and Urban Flooding](#) they present 12 key recommendations.

Reducing the risk of riverine flood damage

1. Implement the recommendations of the *Provincial Flood Mitigation Report: Consultations and Recommendations* a.k.a. the [Groeneveld Report](#) on the 2005 Alberta flood.
2. Prohibit new development in the floodway.
3. Owners of homes in the floodway destroyed in the recent flooding should strongly be encouraged not to rebuild, and should be provided compensation for the building and purchase of the land so it can be converted to use not vulnerable to flood damage.
4. Revisit Alberta's 100-year design flood criteria to consider increased protection beyond the floodway like British Columbia's 200-year standard, Saskatchewan's 500-year standard and Manitoba's decision to defend Winnipeg from the 700-year flood.
5. Actively communicate the danger of flood damage to homes, recognizing that flood proofing reduces the cost of recovery from flooding but does not prevent the risk of flood damage.
6. Consider requiring additional flood proofing actions for homes located in areas at risk of flooding including raising the lowest-floor elevation of buildings above the flood elevation with an acceptable safety factor, prohibiting basements where there is a risk of flooding, and prohibiting use of basements for living space.

Reducing the risk of urban flood damage

7. Create a provincial urban flood damage reduction strategy that builds on existing guidance for stormwater and sanitary sewage management, which should complement actions to reduce riverine flood damage.
8. Develop a provincial strategy for replacing all combined sewer systems with independent sanitary and storm sewers.
9. Consider increasing expectations for municipal stormwater management systems to focus on the 10-year storm for the minor system.
10. Revise the Alberta Building Code to reduce the risk of urban flood damage.
11. Alberta should work with municipal governments and other stakeholders, including the insurance industry, to promote actions that reduce the risk of urban flooding for existing homes. This may include by-laws, regulations and financial incentives to install backwater valves, disconnect roof leaders, disconnect weeping tiles and ensure lot grading that directs stormwater safely away from buildings.

12. The Province should require local governments to create and disclose information about the state of the sanitary sewer and stormwater systems, and about the state of the of the major storm water management system.³⁴

5.4 Lessons from TORNADOS – (US)

In response to the April and May tornados of 2011 in the US, FEMA's MAT released a report on building performance that included multiple recommendations related to codes and standards, building types, the Enhanced Fujita scale (used to rate the strength of tornados in North America) and post-tornado imagery. The full recommendations can be found in the [Spring 2011 Tornadoes: April 25-28 and May 22. Building Performance Observations, Recommendations, and Technical Guidance](#) report. Specific summary recommendations related to critical facilities and infrastructures include:

- Change building codes to require newly constructed schools, 911 call stations, emergency operations centers and fire, rescue, ambulance and police stations to include a FEMA 361-compliant safe room or International Council Code 500-compliant storm shelter;
- Perform vulnerability assessment and identify best available refuge areas in existing buildings;
- Include safe rooms in the design of new buildings;
- Enhance building design to better withstand tornados;
- Strengthen the facility to remain operational following a tornado or high-wind event;
- Work collaboratively to better understand the risks of wind-displaced materials on communications towers;
- Work collaboratively to better understand the effects of wind-displaced materials on latticed structures;
- Provide alternate electrical sources; and
- Work collaboratively to better understand communications tower performance.³⁵

5.5 Lessons from Oil Spill – Deepwater Horizon Oil Spill (US)

The magnitude and conditions of the Deepwater Horizon disaster were such that much of the experience and known response methods were either impossible to apply or ineffective. New science was needed and rapidly developed on a daily basis in order to make appropriate decisions during the nearly three months it took to shut the spill. Lessons learned from federal science departments most closely involved are presented below and come from the introduction to the [December 2012 issue](#) of the *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, which includes roughly 20 additional scientific articles (not reviewed here) on different scientific aspects of the spill,³⁶ that are partially presented here.

1. The importance of preparedness cannot be overstated.
 - Planning should include scientific and technical advancement and investment in clean up solutions.
 - Devices should be installed on extraction equipment to provide flow rate information (which was vital to the response effort) and redundant mechanisms should be in place in case of failure.

2. Preparedness should include basic understanding of places (at the large marine ecosystem scale e.g. the Gulf of Mexico) that are likely to be affected by a spill.
 - Basic understanding of ecosystem and people dynamics requires a comprehensive and integrated effort, ideally through regional scientific collaboration networks, that should include knowledge on where oil is likely to flow and its impact on species and humans, as well as on ecosystem functioning and services.
 - Achieving this integrated knowledge and sharing it publicly require stable funding and mechanisms to integrate monitoring, research, and communication activities across a region and the nation.
3. There is a need for enhanced capacity to respond to spills and to conduct training and other preparedness activities before another spill occurs.
 - Capacity is needed and includes, trained people, technical knowledge, equipment for oil removal, and protocols and networks that can be activated quickly.
 - Progress is needed on adequate funding for R&D on oil spill response, especially in the Arctic. Such funding should support greater participation from academic and other sectors.
4. Mechanisms are needed for rapid mobilization of more funding for research during a spill to support the broader array of knowledge acquisition that researchers were ready to tackle and that could assist in providing a more complete understanding of the Deepwater Horizon disaster impacts as well as better response to future events.
5. Effective mechanisms are needed to enable rapid two-way communication with the broader scientific community.
 - Solutions include the development of regional scientific collaboration networks that could serve as a starting point and better use of web-based communication tools.
 - A new dialogue within the scientific community and possible new mechanisms are needed to resolve the tensions around the appropriate time to share preliminary findings with the public.
6. The scientific teams (Flow Rate Technical Group (FRTG), Oil Budget, Government-Led Science Team (GLST), Operational Science Advisory Team, and Joint Analysis Group (JAG)) created during the Deepwater Horizon disaster were highly successful in trouble-shooting, designing solutions, analyzing and synthesizing data, and evaluating options. Similar mechanisms should be used for future spills of national significance or other major crises, where interagency, interdisciplinary, broad-based scientific input is needed.
7. Intimate engagement with industry is essential
 - To engage wider participation from the scientific community, it would be advisable to consider establishing legal protocols and agreement with industry that would allow those individuals involved in any future response access to necessary proprietary data.³⁶

The introductory article to the proceedings also provided a list of scientific priorities for future oil spill response preparedness that include:

- Gather adequate environmental baselines for all regions at risk;
- Develop new technologies for rapid precise reconnaissance and sampling to support a timely and robust response effort;

- Support the development of models and decision support tools, such as scenario planning, to enhance response and damage assessment;
- Fill large information gaps regarding biological effects of oil, changing climate, and other simultaneous drivers of variability in coastal and aquatic ecosystems;
- Build coupled ecosystem-scale routine monitoring/research/communications for every large marine ecosystem (LME) in US waters, including the coastal zone, to provide integrated interdisciplinary understanding of how the ecosystem works and is changing, ideally as a partnership with academic institutions in the region;
- Put greater emphasis on social science data collection, including adequate baselines, to understand costs to the region and the nation of oil spill disasters;
- Conduct research on impacts of dispersants and dispersants plus oil on a broad array of species and life stages;
- Develop more efficient methodologies for capturing oil at the surface
- Conduct social science studies to understand public perceptions about seafood safety.³⁶

6 OVERVIEW OF GENERAL MITIGATION MECHANISMS

In response to the growing rate and impact of disasters around the world, global efforts are being made to incorporate lessons learned into comprehensive disaster risk reduction and mitigation mechanisms. The most significant international effort to mitigate the threats and risks of disasters is the [Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters](#), which emerged from the World Conference on Disaster Reduction, 18-22 January 2005, in Kobe, Hyogo, Japan. The Hyogo Framework for Action (HFA) is not a binding agreement but a set of recommendations that can be used on a voluntary basis.⁴ The [five main “Priorities for Action” from the HFA](#) are used as a framework to summarize the mitigation efforts described in the literature since most mechanisms that are discussed fall under one of these priorities.

HFA Priority 1 - Ensure that disaster risk reduction (DRR) is a national and a local priority with a strong institutional basis for implementation³⁷

This priority statement calls for the development of institutional mechanisms (specifically the HFA National Platforms^e) along with legislation, policies, plans with decentralized responsibilities, resources and designated roles across sectors.^{3,4} Other reports, such as the [2009 Global Assessment Report](#), and the [Emergency Management Framework for Canada](#), similarly call for the development of policy and governance frameworks to mitigate risk and to collaboratively work with stakeholders to embed these strategies into various levels of political and public administration and jurisdictions as well as in national budgets.^{4,8,38,39} The HFA also calls for political commitment and community participation in risk mitigation.³ Cosgrave and others elaborate on HFA-style community participation by suggesting that citizens become involved in future city planning and in the development of community disaster, contingency and evacuation plans.³⁹⁻⁴¹ Furthermore, successful mitigation strategies are recognized to be long term efforts that require planning and regular maintenance.^{6,21,40,41}

^e National Platforms developed under Hyogo can be viewed at <http://www.preventionweb.net/english/hyogo/national/list/>

HFA Priority 2 - Identify, assess and monitor disaster risk and enhance early warning

This priority statement calls for regular risk assessment that includes threat and multi-hazard identification, development of indicators on risk and vulnerability as well as risk maps that capture regional and emerging risks, compilation of data and statistical loss information and disaster resilience assessments.^{3,4,6,29,38} Risk assessments should incorporate scientific and technological advancements and should include improved modeling and data management, data sharing, space-based earth observations, climate modeling and forecasting.^{3,33,42} Risk assessments should be shared with the public, particularly through early warning systems and evacuation planning.^{4,6,21} Early warning systems should be people-centered, based on local information systems and integrated into public policy.⁴ Linkages between those who generate early warnings and those who are responsible for disaster response should be strengthened between national and local levels to improve their effectiveness.³⁸

HFA Priority 3 - Use knowledge, innovation and education to build a culture of safety and resilience at all levels

This priority statement calls for countries to increase public awareness of risks and mitigation opportunities through various media, including school curricula, formal and informal education, and training (on a community level) with local authorities and in targeted sectors.^{3,8,21,24,40} Risk reduction and mitigation terminology should be standardized and knowledge should be shared cooperatively through networks that span disciplines and regions. Research should be multi-risk oriented with a national and socio-economic impact view and a focus on applicability.³ A scientific and engineering best practice knowledge base should be developed and used to contribute to cost effective decision making and building community resilience.^{3,6,8,24,38}

HFA Priority 4 - Reduce the underlying risks

This priority statement calls for a variety of specific actions to reduce risks, ranging from integrating climate change adaptation strategies (including sustainable ecosystem/environmental management and food security) to protecting critical public facilities, such as hospitals and utilities, to development of land use planning and building codes, and to using the “Build Back Better”^f principle.^{4,21,24,29,33,38,40,41} Disaster mitigation should also include rural development plans that contain disaster risk reduction (DRR) and recovery schemes and social safety-nets that reduce vulnerability across a diversity of incomes.³⁸ Public private partnerships, insurance and financial risk-sharing mechanisms are also suggested.^{8,33,38}

HFA Priority 5 - Strengthen disaster preparedness for effective response at all levels

This priority statement calls for strengthening of disaster preparedness capacities (which, according to the definition used in this report, includes mitigation) at a policy, technical and institutional level through dialogue, coordination and information exchange between disaster managers and other sectors.^{24,38} Preparedness should be focused on risk reduction with a regional orientation. Preparedness should also be exercised and reviewed and contingency plans and emergency funds should be established.³⁸ Risk should be factored into national budgets and include relief expenditure and reserve

^f The Build Back Better concept is based on the notion of rebuilding post-disaster in a way that reduces risk and increases resilience in the face of future disasters. <http://practicalaction.org/principles-building-back-better>

funding.⁴ Preparedness is supported by broad participation and should increasingly focus on small and vulnerable groups.³⁸

6.1 United Nations Mitigation Mechanisms

A small number of key international efforts focus on risk mitigation, generally labeled as disaster risk reduction (DRR), and are administered or fostered by the United Nations. As was mentioned above, the Hyogo Framework for Action (HFA) is the main mechanism used by many nations around the world. In addition to the HFA and its upcoming update in 2015, there is also the United Nations International Strategy for Disaster Reduction (UNISDR) secretariat and implementation plan as well as a number of good practices and lessons learned that are emerging from the UNISDR “[Making Cities Resilient](#)” campaign.

The UN General Assembly adopted the *International Strategy for Disaster Reduction* in 1999 and established the UNISDR secretariat to ensure its implementation. UNISDR also coordinates and supports the implementation of the *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters*.⁴³

The Hyogo Framework for Action was adopted by 168 governments and has the goal of integrating DRR into sustainable development policies and strengthening of institutions, mechanisms, and capacities that build resilience to hazards. HFA also has the goal of systematically incorporating risk reduction approaches into the design and implementation of emergency preparedness, response, and recovery programs.⁴ In addition to the five priorities reviewed above, the HFA includes four cross-cutting issues: multi-hazard approach; gender perspectives and cultural diversity; community and volunteers participation; and capacity building & technology transfer that underpin the priorities. The HFA provides critical tasks for specific actors such as states, regional organizations and institutions, and international organizations.³⁷

The [Global Platform for DRR](#) is the main forum that raises awareness, reiterates commitments, and shares experience on implementation of the HFA among stakeholders.⁴⁴ One of the main tools to support the application of the HFA is the HFA Monitoring Service on [PreventionWeb](#), which allows countries to monitor their own progress in DRR. Core indicators are measured for the five priorities and are reported biennially with detailed analysis in the *Global Assessment Reports*. The [2009 Global Assessment Report](#) (GAR) included a 20-point plan for national risk reduction, including actions such as:

- Accelerate efforts to avoid dangerous climate change;
- Focus development policy on addressing the underlying risk drivers;
- Adopt an approach supportive of local initiatives;
- Build on existing systems for public administration to incorporate innovations into the governance of disaster risk reduction; and
- Invest to reduce risk.³⁸

Progress is measured and reported to biennial sessions of the Global Platform for DRR as well as regional platforms.⁴

In 2013, the UNISDR presented a summary of reports from 2007-2013 on the implementation of the HFA. An overview of progress to date on each of the five priorities for action (based on a cumulative scoring system) from the UNISDR [2013 Global Assessment Report](#) can be seen in Figure 3 below. The

findings show that the main progress in meeting the HFA priorities for action was mainly qualitative to date and focused on policies, legislation and planning. These initial steps reflect a shift from crisis management to proactive risk reduction and safety. This progress is considered as a crucial first step that lays the foundation for more quantitatively measurable achievements in the future. The 2013 [summary of implementation report](#) provides a review of each of the five priorities and their associated indicators and identifies key accomplishments and challenges as well as an overview of implementation on a regional level.⁴⁵

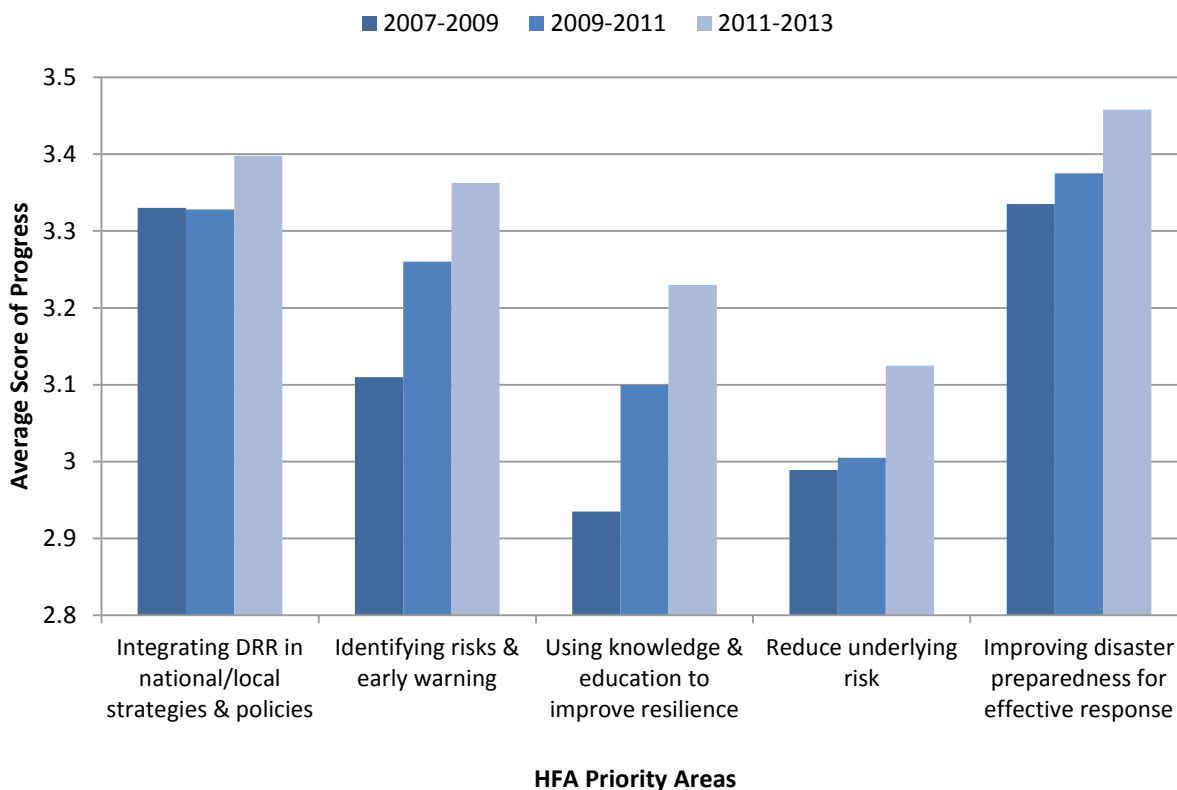


Figure 3. Summary of HFA progress to date, 2007-2013(Source: UNISDR, 2013 Global Assessment Report¹²)

Consultations on a post-2015 HFA, also known as HFA2, took place during the [Fourth Session of the Global Platform for Disaster Risk Reduction](#) (19-23 May, 2013, Geneva Switzerland). The results of the consultations showed a consensus on the need to continue to implement the HFA and to build on the achievements therein.⁴⁶

Some key messages from the consultations include the following:

- Build on the existing HFA and introduce the innovations necessary to address the challenges of increasing risk over the next 30 years;
- Design a clear set of principles and commitments that recognize that the reduction of disaster risk is a legal obligation;
- Address the need to govern disaster risk reduction and resilience through strong coordination, enabled local action and appropriate financial instruments;
- Enhance understanding of risk through evidence, assessments, education and public awareness;

- Leverage benefits of integrated approaches including providing guidance on integrating disaster risk reduction and climate change adaptation in sustainable development; and
- Draw on the practical experience and good practice of countries and organizations in the areas identified in the reviews and consultations to date.³

Other coordinated efforts of the United Nations include the [UN Plan of Action on Disaster Risk Reduction for Resilience](#), which sets out three commitments in line with the HFA to support accelerated risk reduction and resilience building.⁴⁷ The [Global Framework for Climate Services](#), which is managed by the World Meteorological Organization and emerged from the World Climate Conference-3, prioritizes agriculture and food security, disaster risk reduction, health and water.⁴⁸ The UNISDR 2010 [Making Cities Resilient: My City is Getting Ready](#) campaign provides a ten-point check list in line with the HFA that guides local government in making their cities more resilient through capital investments, infrastructure upgrades, retrofitting, and urban renovation and renewal.

A UNISDR study of good practices and lessons learned from the [Making Cities Resilient](#) campaign presented 14 case studies that highlight the impact that local governments can have on risk reduction in such areas as policy, risk assessment and recovery, building structures, water resource management, and local capacity building with varied stakeholders for a range of hazard types. The report identified four key roles for local governments in DRR including:

1. To play a central role in coordinating and sustaining a multi-level, multi-stakeholder platform to promote disaster risk reduction in the region or for a specific hazard;
2. To effectively engage local communities and citizens with disaster risk reduction activities and link their concerns with government priorities;
3. To strengthen their own institutional capacities and implement practical disaster risk reduction actions by themselves;
4. To devise and implement innovative tools and techniques for disaster risk reduction, which can be replicated elsewhere or scaled up nationwide.³⁹

6.2 Canadian Mitigation Mechanisms

In Canada, federal emergency management policy is based on four components: prevention/mitigation, preparedness, response and recovery. The overarching legislation that covers emergency management is the 2007 *Emergency Management Act*.⁴⁹

Since 2007, Canada has developed a number of additional mechanisms to mitigate threats to Canadian safety and security. The [National Disaster Mitigation Strategy](#)⁵⁰ (NDMS), established in 2008, has set out a number of goals and principles.

The goal of the NDMS is: *“To protect lives and maintain resilient, sustainable communities by fostering disaster risk reduction as a way of life.”* The principles embedded in the strategy reflect the essence of what the NDMS aims to achieve and how it should be developed. These principles are as listed:

- *Preserve Life* – Protect lives through prevention.
- *Safeguard Communities*– Enhance economic and social viability by reducing disaster impacts.
- *Fairness* – Consider equity and consistency in implementation.

- *Sustainable* – Balance long-term economic, social and environmental considerations.
- *Flexible* – Be responsive to regional, local, national and international perspectives.
- *Shared* – Ensure shared ownership and accountability through partnership and collaboration.

The strategy establishes ongoing national disaster mitigation program activity areas. Implementation of program activities are structured around four key elements.

- Leadership and Coordination (Federal/Provincial/Territorial (FPT)): Senior officials responsible for Emergency Management will work collaboratively with all stakeholders to promote and facilitate disaster mitigation initiatives within their own jurisdictions.
- Public Awareness, Education and Outreach: Through the NDMS, FPT partners will work with multiple stakeholders to enhance public awareness of risks and mitigation opportunities.
- Knowledge and Research: Apply and promote scientific and engineering best practices in order to build a knowledge base for sustainable, cost-effective mitigation decisions that contribute to community resiliency.
- FPT Cost-Shared Mitigation Investments: Develop and leverage new and existing mitigation strategies and initiatives.

Unfortunately, according to a 2013 article by The Canadian Press which gained access to internal federal briefing notes through the Access to Information Act, it has been recognized that “...the Strategy has yet to be supported with a program for implementation, and has received consistent criticism for recognizing the importance of mitigation, but not providing financial support,” indicating that the strategy is still a work in progress.⁵¹

In 2009, as part of its HFA commitment, Canada formed the [National Platform for Disaster Risk Reduction](#). The goal of the platform is to build networks to bring together interdisciplinary stakeholders working on risk reduction and to foster participation through the Platform’s Annual Roundtable. In 2011, Canada updated its 2007 Emergency Management Framework which previously espoused an all-hazards approach to emergency management including the four core components of prevention/mitigation, preparedness, response and recovery. The new framework explains that traditionally Canada focused on preparedness and response, but that modern hazards require the government to deal with risks, hazards and vulnerabilities through prevention and mitigation as well as recovery measures. It goes on to recognize that investment in prevention and mitigation can prevent disasters or significantly reduce the social, economic and environmental costs and damages when events do occur.⁸

The Public Safety Canada website for [emergency management](#) lists the following examples of mitigation measures.

- Hazard mapping.
- Adoption and enforcement of land use and zoning practices.
- Implementing and enforcing building codes.
- Flood plain mapping.
- Reinforced tornado safe rooms.

- Burying of electrical cables to prevent ice build-up.
- Raising homes in flood-prone areas.
- Disaster mitigation public awareness programs.
- Insurance programs.⁵²

Finally and more recently, Public Safety Canada published the [All Hazards Risk Assessment Methodology Guidelines 2012-2013](#) (AHRA). This methodology is a broader risk assessment approach designed for federal institutions and departments to assess risks of federal interest and includes strategies for disaster mitigation. Interestingly, the AHRA specifically identifies critical infrastructure risk assessment as beyond the scope of the federal AHRA methodology and explains that CI risk assessment is covered in the [National Strategy for Critical Infrastructure](#) and [Action Plan for Critical Infrastructure](#). Furthermore, it notes, alignment of these risk assessment activities is a possibility that may be explored in the future.⁴⁹

The [National Strategy for Critical Infrastructure](#) is quite high level and identifies three main objectives including building partnerships, implementing an all-hazards risk management approach and advancing the timely sharing and protection of information among partners. The document also provides some limited details on the mitigation of risk to CI. The [Action Plan for Critical Infrastructure](#), published in conjunction with the national strategy, only directly mentions mitigation as being part of the sector-specific work plans that should be developed. The Plan recommends a risk-based analysis of all-hazards and identification of interdependencies within CI, as well as an evaluation of the effectiveness of mitigation efforts.² The CI Strategy and Action Plan, like the *National Disaster Mitigation Strategy*, have also been criticized for being under-developed and ineffective.⁵³

6.3 United States Mitigation Mechanisms

The two primary federal agencies that manage United States' (US) mitigation strategies for the nation and its critical infrastructure are the Department of Homeland Security and the Federal Emergency Management Agency (FEMA). The most comprehensive mechanism for mitigating threats to critical infrastructure can be found in the *US National Infrastructure Protection Plan* (NIPP), first written in 2006 and updated in 2009 and 2013 which is administered by the Department of Homeland Security. The 2013 version, called [Partnering for Critical Infrastructure Security and Resilience](#) proposes "A Nation in which physical and cyber critical infrastructure remain secure and resilient, with vulnerabilities reduced, consequences minimized, threats identified and disrupted, and response and recovery hastened."⁵⁴

This vision is intended to be accomplished through the following five goals.

- Assess and analyze threats to, vulnerabilities of, and consequences to critical infrastructure to inform risk management activities.
- Secure critical infrastructure against human, physical and cyber threats through sustainable efforts to reduce risk, while accounting for the costs and benefits of security investments.
- Enhance critical infrastructure resilience by minimizing the adverse consequences of incidents through advance planning and mitigation efforts, as well as effective response to save lives and ensure the rapid recovery of essential services.

- Share actionable and relevant information across the critical infrastructure community to build awareness and enable risk-informed decision making.
- Promote learning and adaptation during and after exercises and incidents.

Each of the [16 US CI sectors](#) defined by the Department of Homeland Security has a Sector-Specific Agency (SSA) assigned to it that is responsible for developing and implementing a Sector-Specific Plan (SSP) which details the application of the NIPP. While new plans will be established in alignment with the 2013 NIPP update, the current SSP's can be found on the Department of Homeland Security [Sector Specific Plans website](#). Ten of the SSP include a list of risk mitigation activities (RMA). An RMA, according to the NIPP Measurement and Reporting Office, is “a program, tool, initiative, project, major task, or some other undertaking that directly or indirectly leads to a reduction in risk.”⁵⁵

The US SSP's are the only source that could be found during the entire literature search that has concrete and specific actions for mitigating risk for individual critical infrastructure. While there may be plans or strategies in other countries that are specifically developed for CI players (usually private sector), these are quite generic in their approach, possibly because central/governmental agencies lack jurisdiction in this regard. For instance, the UK [2013 Sector Resilience Plans](#) (as well as earlier plans) only provide high level summary of efforts such as conducting risk assessments; reviewing and updating policies, business continuity plans and lessons learned from past events; working on maintaining capabilities in the event of disruption, etc.⁵⁶ Similarly the 2010 Australian [Critical Infrastructure Resilience Strategy](#) lacks specific mechanisms to reduce the impact of disasters on CI. While individual companies that manage CI may be taking actions to mitigate risks (as will be seen in the lessons learned section below⁶), this search did not find many systematic or integrated efforts to reduce risks to specific CI from a comprehensive federal perspective elsewhere in the world at this point in time.

Addressing emergency management, including mitigation, on a broader societal level, the Federal Emergency Management Agency (FEMA) mission is to:

*Support our citizens and first responders to ensure that as a nation we work together to build, sustain and improve our capability to prepare for, protect against, respond to, recover from and mitigate all hazards.*⁵⁷

As part of the [National Planning Frameworks](#), FEMA has created five documents to cover each of the preparedness mission areas (prevention, protection, mitigation, response and recovery). The [National Mitigation Framework](#) focuses on creating resilience by addressing risk and creating a culture of preparedness. In line with the [Disaster Mitigation Act of 2000](#), which shifts hazard mitigation from post-disaster to a pre-disaster focus⁵⁸ and delineates responsibilities for state, local and tribal mitigation planning,⁵⁹ the [National Mitigation Framework](#) discusses seven core capabilities required for entities involved in mitigation.

- *Threats and Hazard Identification* - Gather required data in a timely and accurate manner in order to effectively identify threats and hazards.
- *Risk and Disaster Resilience Assessment* - Perform credible risk assessments using scientifically valid and widely used risk assessment techniques.

⁶ Other examples can be found at <http://ccap.org/electric-utilities-and-climate-resilience-in-the-toronto-region/>

- *Planning* - Incorporate the findings from assessment of risk and disaster resilience into the planning process.
- *Community Resilience* - Recognize the interdependent nature of the economy, health and social services, housing infrastructure, and natural and cultural resources within a community.
- *Public Information and Warning* - Warn people of the risks in their community and the actions they can take to mitigate those risks.
- *Long-Term Vulnerability Reduction* - Adopt and enforce a suitable building code to ensure resilient construction.
- *Operational Coordination* - Capitalize on opportunities for mitigation actions following disasters and incidents.⁶⁰

FEMA's [Plan-Prepare-Mitigate](#) website provides a great number of resources for hazard mitigation for protecting homes, communities, business and the nation as a whole. FEMA also administers three Hazard Mitigation Assistance grant programs which fund eligible mitigation activities that reduce disaster losses and protect life and property from future disaster damages including:

- Hazard Mitigation Grant Program (HMGP) - HMGP assists in implementing long-term hazard mitigation measures following Presidential disaster declarations. Funding is available to implement projects in accordance with State, Tribal, and local priorities;
- Pre-Disaster Mitigation (PDM) - PDM provides funds on an annual basis for hazard mitigation planning and the implementation of mitigation projects prior to a disaster. The goal of the PDM program is to reduce overall risk to the population and structures, while at the same time, also reducing reliance on Federal funding from actual disaster declarations; and
- Flood Mitigation Assistance (FMA)- FMA provides funds on an annual basis so that measures can be taken to reduce or eliminate risk of flood damage to buildings insured under the National Flood Insurance Program (NFIP).⁶¹

The Disaster Mitigation Act 2000 provides the legal basis for FEMA to require State, local and aboriginal governments to establish mitigation plans as a condition for receiving mitigation grant assistance.⁶²

Finally, FEMA also runs the Mitigation Assessment Team (MAT) program which assembles and deploys teams of investigators after disasters to:

- Inspect buildings and related infrastructure;
- Conduct forensic engineering analyses to determine causes of structural failure and success;
- Recommend actions that state and local governments, the construction industry, and building code organizations can take to reduce future damages and protect lives and property in hazard areas.⁶³

The MAT program has produced numerous reports with disaster-resistant construction recommendations, some of which were reviewed above in the lessons learned section.

7 EMERGING MITIGATION STRATEGIES IN BUSINESS, HEALTH AND EDUCATION

The increasing impact of major disasters along with the international and domestic focus on disaster risk reduction through preparation and risk mitigation is beginning to have an impact on many sectors within society, including the business, health and education sectors. This section will review some recent developments in each of these areas that were found as a result of the broad search on mitigation strategies.

7.1 Business Sector

Business is affected by disasters around the world through direct losses and impacts on their supply chains that affect their profitability. Businesses are further impacted when critical infrastructure such as power and transportation networks are affected by disasters. A 2011 poll of 1,000 senior global executives by PriceWaterhouseCoopers (PwC) showed that 29% of respondents had been financially affected by the 2011 Great Japan Earthquake and nuclear disaster and 24% of those affected were currently taking action to strengthen their risk management strategies. In another 2011 poll by the UK Trade & Investment (UKTI) department, 90% of businesses claimed to have suffered weather-related disasters over the past three years and 53% were investing in risk management activities. These findings are in line with the 2011 *Global Risk Management Survey* by Aon Benfield (a reinsurance intermediary) which identified disaster risk as the 16th most important out of the top 50 risks to business and as the sixth most important driver to strengthening risk management practices.¹²

In addition to an increased business awareness of the need for risk management and disaster mitigation, regulators and investors are increasingly demanding that businesses disclose hidden risks, including those related to disasters. Yet businesses are still struggling to actually include disaster risk considerations in their investment plans and activities and to implement real change in corporate risk management. Of all the countries reporting progress on HFA, only half claim to be actively engaging with business on disaster risk management. One role model in this area is Canada, which has 20 private sector bodies participating in its National Platform for Disaster Risk Reduction.¹²

In many best cases, businesses are addressing disaster risk through business continuity planning.¹² For instance, Canada has a [Guide to Business Continuity Planning](#) on the Public Safety Canada website.⁶⁴ Business continuity plans are often recommended as a key component of societal resilience, as they put strategies in place for continuing basic and critical functions in the event of a disaster.^{65,66} Alternatively, businesses are addressing risk management at the supply chain level by requiring key suppliers to provide disaster related risk assessment or to meet specific risk management standards. However, the UN [2013 Global Assessment of Report on Disaster Risk Reduction](#) (GAR13) explains that contingency planning and supply chain management are not enough and recommends that businesses should examine how risks are incorporated into their activities through investment decisions, thereby shifting risk management prioritization to a more senior level in the corporation.¹²

Companies that are beginning to make this shift are finding that investment in disaster risk management promotes resilience, competitiveness and sustainability. With this shift there are also initiatives to increase the accessibility of risk information, an increase in investors' use of risk disclosure and transparency and new opportunities for partnership with the public sector in disaster risk modeling,

estimation and management. New collaborations, tools and platforms are increasingly being developed to support this shift, such as the following:¹²

- PricewaterhouseCoopers and UNISDR are working collaboratively on a public-private sector initiative with 14 global businesses. The initiative will develop good practices to assess and address pre- and post-disaster risks and has created a Disaster Risk Management Framework tool to explore business risks,⁶⁷
- The G20/OECD has developed the [Methodological Framework on Disaster Risk Assessment and Risk Financing](#) which helps finance ministries develop strategies that include strengthened risk assessments and risk financing;³ and
- GAR13 is developing a new probabilistic multi-hazard global risk model which will provide new information and metrics for risk sensitive investment planning for business, government, analysts and forecasters.

As more and more applications and platforms are developed, businesses will increasingly be able to move beyond business continuity planning into integrated disaster risk management, and insurance markets will be better positioned to develop appropriate pricing that encourages risk-sensitive investment.¹²

Another UNISDR-private sector initiative is the [Disaster Risk Reduction Private Sector Partnerships](#) (DRR-SPS) whose signatories agree to foster business DRR through the following five activities.

1. Promote and develop public-private partnerships for disaster risk reduction to analyze the root causes of continued non-resilient activity.
2. Leverage sectoral private sector expertise and strengths to advance disaster risk reduction and mitigation activities, including enhanced resilience and effective response.
3. Foster a collaborative exchange and dissemination of data: Share information on assessment, monitoring, prediction, forecasting and early warning purposes and action between the public and private sectors.
4. Support national and local risk assessments and socio-economic cost-benefit analyses and capacity-building, and demonstrate opportunities where resilience building and disaster risk reduction is a sound economic strategy, with attractive returns and competitive advantages.
5. Support the development and strengthening of national and local laws, regulations, policies and programmes that enhance disaster risk reduction and improve resilience.

14 case studies in the application of these core activities are captured in the 2013 UNISDR [Business and Disaster Risk Reduction: Good Practices and Case Studies](#) report.³⁰

7.2 Health Sector

The *US Healthcare and Public Health (HPH) Critical Infrastructure Sector-Specific Plan* developed by the Department of Homeland Security identifies key Risk Mitigation Activities (RMAs) that are largely focused on service continuity and has established programs that improve the sector's ability to deliver continued healthcare during and following disasters. HPH mitigation activities also provide protection to its workforce through improved health surveillance and protection of its critical physical assets including

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hospitals, biosafety labs and locations where medical supplies are stock-piled. Programs are also under development to mitigate risks to medical cybersecurity.⁶⁸

Table 3 below lists RMAs linked to the main goals of the *2010 HPH Sector-Specific Plan*⁶⁸

Table 3. US Healthcare and Public Health (HPH) Risk Mitigation Activities (RMAs)

Goal	Category	Mitigation Activity
Service Continuity	Supply Chain Continuity	Mitigate the threat of disruptions in the supply of drugs, biological products, medical devices, and other critical supplies.
	Supporting Services Continuity	Mitigate risks to the sector of disruptions in supporting services, including water, power, transportation, telecommunications, and waste management
Physical Asset Protection	Biosafety Level (BSL) 3 and 4 Facility Protection	Mitigate risks posed to Biosafety Level 3 and 4 facilities that use select agents so that harmful biological agents and toxins are secured and laboratory services are available for response.
	Research Facility Protection	Mitigate risks posed by all hazards to the sector's critical research facilities

In 2008 the American Medical Association Center for Public Health Preparedness and Disaster Response created an educational framework and competency set for health professionals and emergency responders from which educators develop learning objectives and curricula to fit the needs of all health professionals in a disaster. The resultant framework identified seven core learning domains, 19 core competencies, and 73 specific competencies targeted at three broad health personnel categories. The competencies were greatly influenced by the lessons learned following the health system response to Hurricane Katrina. The authors highlight that preparedness is a process and that competencies should be continually reviewed and refined over time.^{69,h} The competency set was approved by the National Disaster Life Support Education Consortium, whose goal is to improve the science of medical disaster education and management and is responsible for reviewing and critiquing the content of the [National Disaster Life Support](#) (NDLS)ⁱ educational and training courses.⁷⁰ A recent online survey of American medical schools found that very few respondents (31%) incorporated disaster medicine in their core curriculum and even fewer (27.5%) have incorporated competency-based training in their disaster medicine curricula.⁷¹

In Canada, the [Centre for Excellence in Emergency Preparedness](#) (CEEP) has a national mandate to address health care issues related to emergency preparedness. CEEP defines standards of care for emergency preparedness; provides resources to health care professionals and institutions, emergency providers and decision makers and funders of health emergency preparedness; promotes planning between agencies, research and dissemination of emergency preparedness knowledge and research;

^h Please see reference 69 for original competencies for health professionals. Updated (2012) competencies for disaster medicine and public health can be found at <https://www.amrms.com/ssl/nap/images/Hettler%20-%20Disaster%20Medicine%20Competencies%20Pres%20and%20Handout.pdf>

ⁱ NDLS was established in 2003 by a consortium of the Georgia Health Sciences University, the University of Georgia, the University of Texas Southwestern Medical Center at Dallas and the Texas A&M School of Public Health to provide training programs to prepare health professionals and emergency response personnel for disasters with mass casualties.

and works with various stakeholders to improve comprehensive health emergency preparedness plans. Numerous resources can be found on the CEEP website, ranging from hospital risk and readiness assessments to incident response protocols and management systems.⁷²

7.3 Education Sector

A number of plans or strategies exist to help mitigate disasters in educational facilities ranging from the K-8 setting, through high schools and all the way to higher education institutions. Some of the strategies focus on hazard mitigation planning and training at an administrative level, whereas others focus on integrating emergency preparedness in the earliest educational curricula.

In 2006-2007, the United Nations sponsored a world campaign called [Disaster Risk Reduction Begins in Schools](#), which focused on mobilizing individuals, communities and governments to include disaster risk reduction in school curricula in high risk countries and on building or retrofitting school facilities to withstand natural disasters.⁷³ In 2008, UNISDR published a guidance document called [Disaster Prevention for Schools: Guidance for Education Sector Decision Makers](#) which includes teaching and learning disaster prevention/preparedness as well as educational materials and teacher training information.⁷⁴ As reviewed above, the call for disaster risk education as a strategy to mitigate the impacts of disasters is a key priority of the HFA and there is no shortage of material on this effort in the educational context. A random sampling of some more recent international documents that focus on DRR in educational settings, either in relation to curricula or physical asset protection, from the PreventionWeb website includes:

- UNICEF, UNISDR, [Children and Disasters: Building Resilience through Education](#), 2011;
- International Federation of Red Cross and Red Crescent Societies (IFRC), [Public Awareness and Public Education for Disaster Risk Reduction: A Guide](#), 2011;
- Consortium for Disaster Education (CDE), [A Framework of School-based Disaster Preparedness](#), 2012; and
- Save the Children International (SCI), UNICEF, [Comprehensive School Safety: A Toolkit for Development and Humanitarian Actors in the Education Sector](#), 2012.

A recent Master's thesis from the Naval Postgraduate School argued that effective disaster reduction, prevention and preparedness is also critical at the K-12 curriculum level since education leads to resilience.⁷⁵ In the US, the American Red Cross has developed the *Masters of Disaster* curriculum that includes nearly 200 lesson plans and other materials that meet national educational standards for children from K-8 on disaster safety and emergency preparedness.⁷⁶ In Japan, the Japanese Educational Ministry have also been recognized for their K-12 disaster mitigation and prevention curriculum, which has been credited with contributing to survival during the 2011 Great Japanese Earthquake and Tsunami.⁷⁵

Similarly to the Healthcare and Public Health SSP, the US Education Facilities Sector (EFS) SSP lists seven specific RMAs. First and foremost, EFS sees all-hazards comprehensive emergency management plans as the most important RMA to improve education infrastructures' protection and resilience. The other education-specific RMAs include:

- Administering the Readiness and Emergency Management for Schools (REMS) and Emergency Management for Higher Education (EMHE) discretionary grant programs;
- Sponsoring REMS and EMHE grantee trainings;
- Collaborating, coordinating, and communicating with partners to identify and tailor emergency management tools to school and higher education settings; and
- Developing and making available emergency management-related materials (e.g., tools, publications, resources, and guidance) on current issues and initiatives.⁷⁷

In 2003, FEMA published *Building a Disaster-Resistant University* (FEMA 443) which provides high level guidance on developing a hazard mitigation plan for higher education institutions. The plan discusses six broad categories of mitigation actions including:

1. Prevention – Actions such as planning and zoning, open space preservation, soil erosion and sediment control;
2. Property Protection – Actions such as relocation, installing storm shutters and flood barriers, flood insurance, and structural retrofits;
3. Public Education and Awareness – Actions such as outreach projects, hazard information centers, and technical assistance;
4. Natural Resource Protection – Actions such as erosion and sediment control, stream corridor protection, and wetlands preservation;
5. Emergency Services – Actions such as hazard threat recognition, hazard warning, emergency response, and protection of critical facilities. and
6. Structural Projects – Actions such as installing revetments, high flow diversions, spillways, retaining walls, and storm sewers.⁷⁸

FEMA also runs the Emergency Management Institute (EMI) in Emmitsburg, Maryland which developed the Emergency Management Higher Education Program in 1994 with the aim of promoting college-based emergency management education for emergency managers. In addition to hosting numerous institutional and educational resources on their website, an extensive list of academic programs in emergency management, homeland security and other related fields of study can be found on their site.⁷⁹

A similar Canadian example that lists available programs can be found on the [Ontario Ministry of Community Safety and Correctional Services](#) website which hosts a list of emergency management course that are offered across the province including York University's undergraduate emergency management certificate and bachelor and master's degrees in disaster and emergency management.

8 DRIVERS, CHALLENGES, & NEXT STEPS IN DISASTER RISK REDUCTION

While it is nearly impossible to prevent all disasters, be they natural or man-made, it is possible to greatly mitigate the social, economic and environmental impacts of disasters through risk analyses,

disaster risk reduction (DRR) and preparedness. This document reviewed the main mitigation strategies that are discussed in the current literature. Whether intentionally or not, the majority of the literature presents strategies that fall under one of the Hyogo Framework for Action's (HFA) five key priorities including: ensuring DRR is a national and local priority, performing risk assessments and enhancing early warning systems, educating communities to build resilience, reducing underlying risk factors and strengthening preparedness for effective response on all levels of society.⁸

Some drivers of success in disaster risk reduction include:

1. A multi-hazard approach to DRR that links a full range of hazards to all aspects of risk management;
2. Recognizing gender as a decisive factor in the implementation of risk reduction and mitigation strategies. In particular, recognizing that women play a key role in educating children about disaster preparedness as well as responding to and taking care of those directly affected by disasters;
3. A focus on continued capacity development;
4. Addressing the needs of those who are the most vulnerable to disasters due to socio-economic factors; and
5. A focus on community engagement.⁴⁵

Although these are recognized success factors, many of the participating nations in the HFA recognize that these factors need to be more fully integrated into the strategies, frameworks and mitigation efforts.⁴⁵

Another set of best practices for successful risk reduction and disaster mitigation were identified by the IPCC:

- Risks should be recognized as dynamic and assessments should be well integrated into development policies, strategies, and actions, and management, along with climate change adaptation strategies. Policies and plans should target vulnerable areas and groups.
- DRR legislation should be supported by regulations that are enforced across sectors and societal levels.
- Risk management should be coordinated across sectors and led by organizations at the highest political levels
- Risk should be quantified and factored into national budgets through a range of measures (e.g. relief expenditure, reserve funds, risk financing).
- Decisions should be science based (tools and methodologies) and include observed changes in weather, climate, vulnerability and exposure as well as historic disaster losses.
- Early warning systems should be effectively developed and managed in partnership with the community and result in effective response.
- Mitigation strategies should include concrete infrastructure-based solutions as well as soft solutions such as capacity building and ecosystem-based responses.⁴

Despite these known success factors, numerous challenges and gaps remain. From a broad perspective, although mitigation strategies are fairly well recognized and agreed upon in the literature, and some key success factors are known, translating frameworks, national strategies and even legislation and policies into effective DRR is still a challenge. In particular, integrating climate change adaptation strategies, a key overarching disaster mitigation mechanism, has proven difficult to achieve in national policies. Many nations also lack the organization (e.g. assigning roles and responsibilities for managing mitigation strategies, getting risk assessment information to reach sector decision makers) or resources (i.e. the ability to invest in fulfilling DRR goals ranging from for early warning systems to school education programs) to affect more progress on the HFA or other DRR activities.⁴⁵

Socio-economic and security issues have also been noted as challenges in the field of DRR. When disasters hit those that are most socially and economically vulnerable, issues such as restoring livelihoods, health and infrastructure take precedence over disaster mitigation activities.⁷⁸ The need for basic survival following a disaster is a similar issue in war-torn or post-war societies where time, energy, resources and logistics are all impediments to DRR.⁴⁵ Unfortunately thought, post-disaster recovery is actually an ideal time to integrate disaster mitigation through such programs as the Build Back Better^j program.

Other broad challenges and gaps noted by the IPCC include:

- Efforts at the international level do not necessarily translate into substantive results at the local level;
- Risks assessments are not always effective in estimating the likelihood or magnitude of extreme events and their impacts and are often simply lacking at local levels in many places;
- Climate change will require reallocation of efforts in DRR;
- Rapid urbanization and the growth of megacities, which have led to informal settlements and inadequate land management, particularly in developing nations;
- Inequalities in societies influence local coping and adaptive capacities; and
- The dynamic, uncertain and complex nature of risk and vulnerability need to be taken into account in order to develop successful risk management policies.⁴

On a national level, the following HFA implementation gaps have been noted:

- Struggles exist with implementing risk reduction efficiently and integrating response mechanisms in practice;
- Lack of coordination within and between national and state policies;
- Lack of ownership for cross-sector coordination and local implementation; and
- Lack of policy guidance or directives at local levels where DRR gaps already exist.¹²

Additional national challenges can be found in the [UNISDR Implementation of the Hyogo Framework for Action - Summary of reports 2007-2013](#).

^j The Build Back Better concept is based on the notion of rebuilding post-disaster in a way that reduces risk and increases resilience in the face of future disasters. <http://practicalaction.org/principles-building-back-better>

From a more local perspective, challenges and gaps in disaster mitigation arise from:

- Individual and organizational defence mechanisms: A lack of belief in the chance or severity of significant disasters;^{12,65}
- Institutional design: Organizations are largely structured with authority shifting upward but this is often ineffective during critical events which require local, rapid and flexible decision making authority;
- Cost of preparation: Mitigation and contingency planning are expensive (time and money) and do not have immediate visible outcomes;
- Politics: Investing in resilience, with a focus on self-reliance and improvisation, is a hard sell for the top-down structures of much of politics;⁶⁵
- Situational awareness: It is frequently difficult to gain the necessary data, information or insights to make strategic decisions during disasters that can continue to mitigate impacts;²⁶
- Coordination: A lack of government coordination at all levels (city, state, federal) in responding to disasters means that immediate response is often dependent on individuals and community based organizations;²⁹ and
- Lessons Learned: While lessons learned are valuable, they do not always lead to implementations of change or may not be sufficient for subsequent disasters (e.g. this was the case with some lessons from Hurricane Katrina that, although followed, did not sufficiently prepare New York City for Hurricane Sandy).^{18,26,29}

Although there are challenges and gaps, progress continues to be made, in particular, through addressing the HFA priorities.^k As mentioned earlier in this document, consultations for the post-2015 HFA (HFA2) are already underway. These consultations have identified numerous next steps including the need for more specific goals, targets and indicators as well as involvement of stakeholders and partnerships to promote ownership and commitment to HFA2.³ Other next steps include:

- A closer look at the root causes and drivers of risk and development planning models;
- Changes to public and private investment that include an incorporation of risk assessment;¹²
- The integration of sustainable development, climate change and mitigation in disaster risk reduction as these elements should no longer be seen in isolation;^{4,46}
- The development of nationally agreed standards for hazard risk assessment;
- The start of a global safe schools and safe health structures campaign;
- The stimulation of collaboration between private and public sectors at the local and national levels;
- Strengthening scientific and technical support for evidence-based decision making.

^k More details on challenges, gaps and progress on implementing the HFA priorities can be found in the UNISDR [Implementation of the Hyogo Framework for Action- Summary of reports 2007-2013](#).

Along with improving the HFA and the next steps that are identified above, a call for additional research into specific factors that may improve DRR has been issued by the IPCC and includes the following topics:

- Measure the extent to which efforts to build disaster risk management capacities at different scales prepare people and organizations for the challenges posed by climate change.
- Determine whether the current trend of decentralizing disaster risk management functions to sub-national and local governments and communities is effective, given the level of information and capacity requirements, changing risks, and associated uncertainties presented by climate change.
- Investigate how the functions, roles, and responsibilities of different actors working within national disaster risk management systems are changing, given the impacts of climate change at the national and sub-national level.
- Explore how approaches such as flexibility, learning-by-doing, and adaptive management in the context of national disaster risk management systems can be applied in different governance contexts.
- Examine how decisions on disaster risk management interventions are made at different scales when there is limited context-specific information.
- Evaluate the costs and benefits of different risk management interventions when the impacts of climate change and other dynamic drivers of risk are factored in.
- Assess the benefits and tradeoffs of creating integrated programs and policies that seek to manage disaster risk, mitigate greenhouse gases (GHG)s, adapt to climate change, and reduce poverty simultaneously.⁴⁶

9 CONCLUSIONS

The goal of this document was to:

- Identify the threats to critical infrastructure (CI) safety and security discussed in the literature and the major North American and international disasters from the past ten years;
- Review the lessons learned from these disasters;
- Summarize the mitigation methods that are being used or developed to reduce threats and risks to CI safety and security; and
- Review the challenges of the proposed mitigation strategies.

The document began with an overview of the most frequently discussed threats to critical infrastructure in the literature (cyber threats, terrorism) as well as a tally of the major national and international disasters that have occurred in the last 10 years. The vast majority of these disasters were weather-related in North America or earthquake-specific elsewhere. Notably, the most frequent high cost disaster in Canada in the past 10 years was flooding yet Canada does not incorporate coastal regions or inland waterways into any of their critical infrastructure sectors. The document then reviewed the lessons learned from major world disasters since 2003. Many of the post-disaster insights can be tied back to the key priorities in the HFA.

This review found an extensive body of work that discussed mitigation of disaster impacts on society as a whole, but less literature that focused specifically on critical infrastructure. The disaster risk mitigation literature showed that most current efforts to mitigate risks and the impacts of disasters follow the Hyogo Framework for Action's five key priorities. Table 4 presents an alignment between the five HFA priorities and some selected examples of mitigation activities that are either being used or have been learned from past disasters.

Table 4: Alignment of HFA Priorities and Mitigation Activities

HFA Priority	Selected examples of mitigation activities
1. Integrating disaster risk reduction in national and local strategies and policies	<ul style="list-style-type: none"> National strategies in Canada, US, UK, Australia and elsewhere around the world National Disaster Management Agency known as BNPB in Indonesia Engaging communities in disaster risk reduction activities
2. Identifying, assessing and monitoring risks and enhancing early warning systems	<ul style="list-style-type: none"> Canada's <i>All Hazards Risk Assessment Methodology Guidelines 2012-2013</i> PWC and UNISDR's joint effort to develop the Disaster Risk Management Framework tool for assessing disaster risks to business Studying events that led to Albertan floods to reduce future risks Early warning systems in Japan helped reduce death toll from 2011 earthquake/tsunami Development of the Grand Scenario tsunami warning system in Indonesia Integrating climate change into disaster risk assessments
3. Using knowledge and education to improve resilience	<ul style="list-style-type: none"> Japan's education system, and their integration of disaster preparedness in schools, recognized around the world for creating a culture of resilience Rehearsal of emergency drills Integrating disaster education at all educational levels in North America Development of US educational framework and competency set for health professionals and emergency responders Facilitating exchange and making use of scientific knowledge
4. Reducing underlying risks	<ul style="list-style-type: none"> Christchurch, NZ, actively learning from past earthquakes and implementing structural changes to improve seismic resilience of infrastructure The Build Back Better approach to rebuilding after disasters in ways that reduce risk Building storm shelters, safe rooms, evacuation centers Make use of redundant protection systems
5. Improving disaster preparedness for effective response	<ul style="list-style-type: none"> Development of disaster plans, emergency preparedness, evacuation plans, business continuity plans, community contingency plans Training communities members in first-aid skills Tailored medical relief efforts Establish mutual assistance agreements with other companies in the area Set up back up resources for major utilities (food, energy)

HFA Priority	Selected examples of mitigation activities
	<ul style="list-style-type: none">Engaging the participation of the community

The document also presented the major mechanisms that are being used on the international level, by Canada and the US.

- International
 - Hyogo Framework for Action (2005-2015)
 - United Nations Office for Disaster Reduction (UNISDR)
 - Global Platform for Disaster Risk Reduction
 - Global Framework for Climate Services
- Canada
 - National Disaster Mitigation Strategy
 - National Platform for Disaster Risk Reduction
 - All Hazards Risk Assessment Methodology Guidelines 2012-2013
 - National Strategy for Critical Infrastructure and the Action Plan for Critical Infrastructure
- United States
 - National Infrastructure Protection Plan
 - Disaster Mitigation Act 2000
 - Federal Emergency Management Agency's Mitigation Assessment Team program

Canada's *National Strategy for Critical Infrastructure and Action Plan for Critical Infrastructure* (NS and AP), in contrast to the US's *National Infrastructure Protection Plan* (NIPP), are notably weak in specific actions that CI sectors can adopt to mitigate risks. For example, while the *Action Plan* does recommend identification of CI interdependencies and an evaluation of mitigation efforts, it does not describe how to do this or what activities these mitigation efforts include. Progress on developing the CI forums that are called for in the NS and AP has been slow in many sectors. Other specific gaps in the two documents include:

- The Federal Government's plan for building relationships, collaborative risk management and information sharing are underdeveloped;
- The NS and AP fail to take into account market competition, incompatible institutional cultures, or legal, logistical and political constraints;
- The general "all-hazards" approach to risk management is inadequate with regard to critical infrastructure as risks vary across sectors, geographies, disaster types, etc. and the NS and AP lacks specific guidance on prioritizing risks, their respective management options, and how to respond in the event of a disaster. This is further exacerbated by the fact that the [All Hazards Risk Assessment Methodology Guidelines 2012-2013](#) specifically indicates that it is not designed for CI;
- The NS and AP focus on "larger infrastructure" leaves planning for small- and medium-sized enterprises (SMEs) under-developed and focused on business continuity guidance and post-

event financial assistance. SMEs are critical to supply chains, particularly in the manufacturing sector;

- The NS and AP's practice of leaving individual CI owners and operators responsible for their own systems and performances reduces standardization and potentially accountability;
- There is a lack of clarity on how discrepancies and disagreements about multiple uses, users and accountabilities will be managed. For instance, drinking water is under the domain of Environment Canada, but is also critical to the energy and transportation sectors. Given the interdependencies between CI, the lack of standardization and accountability can potentially lead to one sector off-loading risks to another;
- The NS and AP lack established systems for the sectors to report progress to outside parties,^l and
- The NS and AP's focus on information exchange as a means of increasing resilience is faced with many technical and cultural challenges. Furthermore, without setting standards, requiring behaviour modification and more transparency, this effort may be fruitless.⁵³

Despite the existence of many national strategies for disaster risk reduction, like the Canadians, very few of national strategies specifically address risk mitigation for critical infrastructure in a concrete way. Some guidance on specific risk mitigation activities for CI can be found in the individual US CI Sector Specific Plans and potentially the Sector Annual Reports.^m Specific information on construction/reconstruction, building codes and improving structural resilience can be found in the numerous FEMA Mitigation Assessment Team (MAT) reports. Similarly, although not typically an explicit focus in the mitigation literature, one can see the interdependencies between various critical infrastructures in the discussion of lessons learned. This is particularly notable in the health and safety sectors which are attempting to respond to disasters but are often hindered by breakdowns in energy, communication and transportation systems. One exception can be found in the literature that emerged from the Christchurch, NZ earthquake that specifically identified interdependency planning and mutual assistance agreements as having been key factors in the city's resilience and response to the disaster.

This document also reviewed specific mitigation activities that are being developed in the business, health and education sectors. In terms of business, there is an increasing effort to encourage business to recognize the impact that disasters can have on business and to acknowledge that risk is inherent in investment and should be better accounted for. There is also a growing recognition that incorporating disaster risk assessment in business practices can have a positive return on investment. In the health sector, in addition to specific risk mitigation activities listed in the US Healthcare and Public Health sector's Sector-Specific Plans, efforts are being made to improve facility preparedness as well as medical professionals and emergency responders training and education on disaster response. A recent survey of US medical schools showed that there are continued gaps in integrating core medical competencies for disaster response into curricula. In the education domain, there is increasing recognition that education leads to resilience and that education should start at the earliest levels and continue throughout higher education. Japan's education system, and their early integration of disaster preparedness in schools, has also been recognized as a successful model for building national social resilience.

^lThis may explain why so little information on Canadian CI risk mitigation activities was found in this study.

^mReferences were found to this effect in the sector-specific plans but no sector annual reports were actually found on the web.

One of the key challenges in DRR is implementing the lessons from past experiences or existing research into continued mitigation and preparedness efforts. The major gap in DRR comes from the failure to integrate climate change adaptation strategies into national risk reduction plans, since the majority of disasters are natural and many of them are weather-related. Many other challenges are due to a lack of financial, organizational and human resources as well as a continued need to respond to the immediate impacts of disasters (i.e. the immediate need of basic housing rather than improved disaster-resistant housing) or other societal crises.⁴⁵

One of the limitations of this study is that the search strategy focused on mitigation of risks to critical infrastructure in general and did not include searches on each individual CI sector. This may be one reason why there was limited information on mitigation activities that are occurring in individual sectors. For more in depth studies on the individual sectors, exploratory searches should be performed, however it is equally possible that this type of material is not easily accessible in scientific and technical research databases. Similarly, any additional searches should also attempt to explore and/or focus in on mitigation strategies that address interdependencies between CI sectors. In order to keep up with new national mitigation strategies in general, it is recommended to monitor updates and developments to the HFA2 as well as to monitor the US Sector-specific plans, many of which are in the processes of being updated. Finally, given the link between the types of flooding and changing weather patterns, it is recommended to further explore the links between climate change adaptation/mitigation and CI protection and resilience.

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11 LITERATURE SEARCH STRATEGY

A literature search was conducted in the Scopus database and on the web. The basic search strategy used to retrieve records was based on keywords shown in Table 5 below. Terms or phrases in columns A, B and C were combined using Boolean and proximity operators (AND, OR, NEAR) to cover all aspects of the problem. The search targeted substantive fields such as title, keywords (controlled and uncontrolled vocabularies) and abstracts. The time period was limited to records 2003 to the present. After identifying the major disasters since 2003, a subsequent search was conducted to combine terms or phrases in columns B and D to find information on the specific disasters. Roughly 100 sources, including articles, reports, websites and disaster statistic databases, were reviewed for this report.

Table 5. Search Terms

A: Critical infrastructure	B: Mitigation	C: Risk/threats	D: Specific disasters
<ul style="list-style-type: none"> • Critical infrastructure • Critical assets • Public infrastructure • Key resources 	<ul style="list-style-type: none"> • mitigat* • prevention • preparedness • protect* • resilien* 	<ul style="list-style-type: none"> • risk • threat • crisis 	<ul style="list-style-type: none"> • bam OR kashmir OR yogyakarta OR sichuan OR indonesia OR chile OR haiti OR japan OR new zealand OR italy OR china) AND earthquake* • Cyclone Sidr • Cyclone Nargis • Hurricane Sandy • Hurricane Katrina • Deepwater Horizon • (fire OR flood) AND canada AND disaster