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PSI
Principles
for Sustainable
Insurance

The PSI Global Resilience Project

Building disaster-resilient communities and economies

Part one of a research series by the
UNEP FI Principles for Sustainable Insurance Initiative

The PSI Global Resilience Project is led by

IAG
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Contents

The UNEP FI Principles for Sustainable Insurance Initiative (PSI Initiative)

Launched at the 2012 UN Conference on Sustainable Development, the UNEP FI Principles for Sustainable Insurance serve as a global framework for the insurance industry to address environmental, social and governance risks and opportunities.

Endorsed by the UN Secretary-General, the Principles have led to the largest collaborative initiative between the UN and the insurance industry—the PSI Initiative. As of June 2014, 70 organisations have adopted the Principles, including insurers representing approximately 15% of world premium volume and USD 8 trillion in assets under management. The Principles are part of the insurance industry criteria of the Dow Jones Sustainability Indices and FTSE4Good.

The vision of the PSI Initiative is of a risk aware world, where the insurance industry is trusted and plays its full role in enabling a healthy, safe, resilient and sustainable society. The purpose of the PSI Initiative is to better understand, prevent and reduce environmental, social and governance risks, and better manage opportunities to provide quality and reliable risk protection.

'The Principles for Sustainable Insurance provide a global roadmap to develop and expand the innovative risk management and insurance solutions that we need to promote renewable energy, clean water, food security, sustainable cities and disaster-resilient communities.'

Ban Ki-moon, UN Secretary-General

The Principles for Sustainable Insurance

Principle 1	We will embed in our decision-making environmental, social and governance issues relevant to our insurance business.
Principle 2	We will work together with our clients and business partners to raise awareness of environmental, social and governance issues, manage risk and develop solutions.
Principle 3	We will work together with governments, regulators and other key stakeholders to promote widespread action across society on environmental, social and governance issues.
Principle 4	We will demonstrate accountability and transparency in regularly disclosing publicly our progress in implementing the Principles.

'The Principles for Sustainable Insurance are a foundation upon which the insurance industry and society as a whole can build a stronger relationship—one that puts sustainability at the heart of risk management in pursuit of a more forward-looking and better managed world.'

Achim Steiner, UNEP Executive Director & UN Under-Secretary-General

Executive summary

The need for building resilience

Natural hazards have the potential to devastate communities and economies around the world. Natural hazards are inevitable, but not natural disasters. When a natural hazard occurs, it is the collective societal resilience that will determine whether that event results in a natural disaster.

This century, more than one million people have lost their lives to natural disasters.[1] Last year alone around 20,000 people were killed or went missing in natural disasters, the majority in storms, floods and other severe weather events.

The impact of natural disasters can reverberate long after the event itself—global economic losses due to natural disasters in 2013 amounted to USD 131 billion, which represents almost 2% of GDP.[2]

The costs of recovery from these natural disasters—borne by governments, NGOs, business and communities—consume scarce public and private resources which could otherwise be used to develop social, economic and natural capital. Much of this can be prevented by building disaster-resilient communities and economies. Reducing disaster risk before an event can have a direct impact on how well, and how quickly, communities recover.

Across many nations, there is a funding imbalance between investing in pre-disaster resilience and paying the costs of post-disaster relief and recovery. Investment in building up-front resilience and hazard preparedness provides a positive return and reduces the need for recovery. It is estimated that every dollar spent in disaster risk reduction returns between two and ten dollars in recovery savings.[3, 4, 5, 6]

Building resilience to natural hazards requires an awareness of risk, a commitment by all stakeholders to make change happen, and a structured approach to funding and implementing effective measures for disaster risk reduction.

How the PSI Initiative is responding to disaster risk

In response to this global sustainability issue, the PSI Initiative embarked on the PSI Global Resilience Project. Led by Insurance Australia Group, this project aims to deepen understanding of disaster risk reduction globally, assess the social, economic and environmental cost of disasters, and use this information to help governments and communities around the world manage risk.

1 International Federation of Red Cross and Red Crescent Societies, World Disaster Report 2013. www.ifrc.org/wdr2013
2 Swiss Re Sigma report: http://media.swissre.com/documents/sigma1_2014_en.pdf
3 World Bank 2014 World Development Report: http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTWDRS/EXTNWDR2013/0,,contentMDK:23459971~pagePK:8261309~piPK:8258028~theSitePK:8258025,00.html
4 International Federation of Red Cross and Red Crescent Societies: https://www.ifrc.org/Global/global-alliance-reduction.pdf
5 Federal Emergency Management Agency: http://www.floods.org/PDF/MMC_Volume1_FindingsConclusionsRecommendations.pdf
6 Deloitte Access Economics: Australia, 'Building our Nation's Resilience to Natural Disasters' 2013

The PSI Global Resilience Project is taking a phased approach to helping build more disaster-resilient communities and economies:

- The first phase evaluates the effectiveness of risk reduction measures (the subject of this report).
- The second phase will develop a global disaster map which can be used to identify the most vulnerable communities, and the risk reduction measures which can offer them the greatest protection.
- The third phase will focus on mentoring at-risk communities, supporting governments and the private sector in investing in pre-disaster resilience and in implementing risk reduction measures.

About this report

This report aims to assess the effectiveness of risk reduction measures and determine what factors drive success and present obstacles.

There is a wealth of data and information available on risk reduction measures and their effectiveness[7]—this report considered over 300 sources including academic papers, government and scientific reports, case studies and media articles.

However, the research found the information to be often inconsistent and difficult to compare, presenting a challenge to drawing meaningful insights on the effectiveness of each risk reduction measure. For data to be useful on a global scale, it must be consistent, standardised and globally accepted.

This report aggregates and synthesises a pool of existing information on risk reduction. It applies consistent criteria, allowing comparison of the findings of a wide range of research, and making the information accessible and usable. This is particularly important for audiences which need sound evidence to drive risk reduction investment, such as businesses and governments.

This report is neither an academic nor a scientific analysis of risk reduction measures. The objective is to suggest a practical approach to reducing disaster risk and highlight the areas of opportunity.

With its collective experience in disaster risk management, the PSI Initiative, and the insurance industry generally, is well placed to engage collaboratively with other stakeholders to promote deeper understanding of risk and drive better outcomes.

Research outcomes

This report focuses on the three most common and costly natural hazards—cyclone, earthquake and flood.[8] It analyses measures which can reduce the risk of social and economic loss from each hazard.

7 The PSI Initiative commends the work of the UN Office for Disaster Risk Reduction in providing a global portal for disaster risk information and connecting the disaster risk reduction community. See http://www.preventionweb.net/english/

8 From 1970 to 2012, the natural hazards that have created the most devastation globally are cyclone, earthquake and flood. These three natural hazards accounted for 67% of deaths, 64% of persons affected, and 80% of economic damage of natural disasters worldwide: Center for Research on the Epidemiology of Disasters, EM-DAT, http://www.emdat.be/disaster-list

In assessing risk reduction measures, the research focuses on three criteria:

- **Net economic benefit** – An assessment of the economic cost saved through risk reduction measures
- **Net social benefit** – An assessment of the number of lives which could be saved through risk reduction, the number of people who would be spared the need for emergency assistance including food, shelter and medicine and downstream impacts including environmental benefits
- **Cost** – An assessment of the relative cost to implement a particular risk reduction measure compared to other measures

The availability and effectiveness of a risk reduction measure is highly dependent upon the local environmental, social and economic conditions, governance systems, and the disaster resilience maturity of the at-risk community. However, some broad conclusions on effectiveness can be drawn across regions:

- **For cyclones** – Natural ecosystems, such as mangroves and sand dunes, provide high net economic and social impact, as with structural measures such as seawalls. These natural coastal protection ecosystems are particularly effective in reducing risk in combination with structural measures, plus they bring downstream benefits
- **For earthquakes** – Targeting the structures with the highest exposure and largest risk of collapse through retrofitting and building codes are seen as the best way to reduce adverse impact
- **For flooding** – Structural measures that protect against high severity exposure (for example, controlled and permanent barriers) will have a large impact, as will a strategic focus on an entire flood basin (for example, upstream erosion management and downstream basin storage). Wetlands are a natural alternative and bring downstream benefits. Land-use planning is an effective measure to promote disaster risk-sensitive development choices

Across all types of hazards, there are three risk reduction measures which can have a significant impact:

- Developing more risk-aware communities through education and communication
- Understanding hazard exposure through risk mapping
- Robust warning systems and emergency evacuation

Impediments to effective disaster risk reduction

This report identifies two issues which have the potential to stand in the way of an effective response to disaster risk reduction:

- **Data quality and assessment tools** – There are significant issues with currently available data, which is inconsistent and difficult to compare. Universal data standards are needed to assess the effectiveness of risk reduction measures and to make the case for pre-disaster resilience investment to governments and other stakeholders
- **Lack of standardised framework for decision-making** – The adoption of standards for decisions on risk reduction efforts is required for a globally consistent and effective response to the threat of natural disasters. A standardised framework does not mean

a one-size-fits-all approach to risk reduction. Rather, it supports tailored and localised measures by providing a robust framework for identifying the most effective areas of focus for risk reduction.

The improvement of data quality, use of consistent data metrics and the adoption of standards within a framework (for example, a cost-benefit analysis) would deliver insights to make the case for risk reduction and support a shift to greater pre-disaster resilience investment.

The need for a portfolio approach

While one risk reduction measure in isolation can be beneficial, this benefit is amplified by adopting several measures which work together as part of a risk reduction portfolio.

For example, mangroves and sand dunes can work together to block storm surge over a greater section of coastline. Also, some risk reduction measures are prerequisites for others—evacuation can only be effective if the community has first been educated on how, when and why to evacuate.

Each risk reduction measure needs to be tailored for the community it is protecting, so different combinations will be effective under different circumstances. However, it is broadly true that several measures work better than one, particularly when they form part of a clear and integrated risk reduction strategy.

Disasters, climate change and development

Climate change is making the world a riskier place to live, particularly for communities vulnerable to natural hazards.

As the risk exposure is evolving and changing, it is important to challenge assumptions based on historical data to make sure they take increased risk into account.

Even the most effective, well-planned risk reduction measures can fail under previously unforeseen stresses. Ongoing vigilance is needed to reevaluate risk exposures and the effectiveness of existing measures.

Natural disasters hold back development; so risk-aware communities and disaster risk reduction investments are critical to making sure that hard-won development gains are protected. It is in this light that disaster resilience becomes a foundation for sustainable development—one that sustains society, the economy, and the environment.

Introduction

Disaster risk management – A continuum of activity

Disaster risk management aims to systematically avoid, lessen or transfer the adverse impacts of hazards and the possibility of disaster.[9] It spans a range of activities and elements, before and after an event:

- **Understanding and assessing disaster risk** – Effectively managing disaster risk must start with an understanding of its causal factors. Hazards, exposure and vulnerability are determinants of disaster risk
- **Disaster risk reduction and prevention** – Mitigating the causal factors of disasters through reduced exposure to hazards, lessened vulnerability of people and property, and increasing resilience. It also involves building the capacity of a community, and its emergency services, to prepare for and cope with an event
- **Disaster response and relief** – Responding in the aftermath of an event to save lives, treat the injured, protect property and meet basic human needs
- **Disaster recovery** – Restoring facilities, livelihoods and living conditions of disaster-affected communities
- **Disaster risk financing** – The shifting of the economic burden of loss to another, through risk sharing or risk transfer mechanisms such as insurance

The role of insurers in disaster risk management

In 2013, global economic losses due to natural disasters amounted to USD 131 billion, which represents almost 2% of GDP. Of these losses, USD 37 billion were insured, down from a 10-year average of approximately USD 55 billion.[1]

The insurance industry plays a critical role in providing financial protection and security to at-risk communities to support, and preserve the gains of, social and economic development.

It is finding new ways to respond to the diverse needs of individuals, government and commercial enterprise.[10] Microinsurance provides protection to low-income communities by insuring their crops, livestock or assets, and extends to accident, health, life and funeral insurance. Catastrophe insurance pools and index-based insurance solutions can facilitate the coverage of natural hazard risk in highly-exposed and vulnerable communities. Insurance-linked securities, such as catastrophe bonds, can bring alternative capital to cover natural hazard risk.

However, the insurance industry's contribution to managing disaster risk extends well beyond the losses it pays out.

9 UN Office for Disaster Risk Reduction
10 http://www.oecd.org/daf/fin/insurance/OECD_APEC_DisasterRiskFinancing.pdf

- Insurers are in the business of understanding, managing and carrying risk. Their expertise looks back—leveraging aggregated data from past events—as well as forward—modelling exposure in an evolving risk landscape. Insurance pricing and other policy terms and conditions can provide clear risk signals and reward risk reduction efforts.
- Insurers live in the communities they serve and experience disasters first hand, as well as their adverse consequences. When disaster strikes, insurers help communities recover from the economic and social impact of events. Insurers mobilise their own resources and those of their supply chain partners to respond to the losses suffered by their customers.
- Insurers help communities reduce disaster risk through research, advocacy, and practical support at the local level.[11]

Disaster risk reduction – A better way

The insurance industry's experience tells us that natural disasters and extreme weather events are becoming more common and more severe. Together with higher exposure through population growth and urbanisation, this is expected to result in a significant increase in losses arising from natural hazards over coming decades.

Risk transfer mechanisms such as insurance will be important in helping communities and economies meet these threats.

However, communities must also better protect themselves, reduce avoidable loss and build resilience to cope with events that arise.

And it's simple economic common sense. It is estimated that every dollar spent in disaster risk reduction returns between two and ten dollars in recovery savings.[3,4,5,6]

More investment in disaster risk reduction will lead to:

- Safer and more resilient communities and economies
- Less public and private funds spent on disaster relief and recovery, enabling better investment
- More access to affordable insurance to help communities manage the uncertainty of adversity and the financial hardship associated with unexpected losses

These are complex challenges and require the goodwill and collective effort of many. With the insurance industry's long-standing expertise in disaster risk management, it can play a key role in building the resilience of communities and economies to natural hazards.

The Post-2015 Framework for Disaster Risk Reduction – A major opportunity

The United Nations 'Hyogo Framework for Action 2005-2015: Building the resilience of nations and communities to disasters' (HFA), is the first global plan to set out what is required from all sectors and actors to reduce disaster losses and bring them into a coordinated common system. The HFA outlines five priorities for action, and offers guiding principles and practical means for achieving disaster resilience.[12]

11 See for example Tokio Marine & Nichido Fire Insurance's commitment to mangrove planting: http://www.tokiomarine-nichido.co.jp/en/news/pdf/131203e.pdf

12 United Nations Office for Disaster Risk Reduction: http://www.unisdr.org/we/coordinate/hfa

As the HFA is expiring in 2015, a new framework is under development and will be produced at the 3rd UN World Conference on Disaster Risk Reduction in Japan in March 2015, then put to the UN General Assembly for endorsement.

Within the consultation process for this new framework, there is much focus on the key roles of different stakeholders in disaster risk reduction, including the insurance industry and the broader private sector.

In 2013, the UN issued a stark warning to the world's business community that economic losses linked to disasters are 'out of control' and will continue to escalate unless disaster risk management becomes a core part of business investment strategies.[13]

'We have carried out a thorough review of disaster losses at national level and it is clear that direct losses from floods, earthquakes and drought have been underestimated by at least 50%. So far this century, direct losses from disasters are in the range of USD 2.5 trillion. Economic losses from disasters are out of control and can only be reduced in partnership with the private sector which is responsible for 70% to 85% of all investment worldwide in new buildings, industry and small to medium-sized enterprises. The principles of disaster risk reduction must be taught at business schools and become part of the investor's mindset.'

Ban Ki-moon, UN Secretary-General

Other international public policy processes will likely explore the opportunity for the insurance industry and broader private sector to build resilience and drive sustainability, together with governments, regulators and civil society.

These include:

- The UN Sustainable Development Goals, which will succeed the UN Millennium Development Goals and form part of the Post-2015 Development Agenda
- An international climate agreement under the UN Framework Convention on Climate Change to be decided by 2015
- The Global Framework for Climate Services
- The 2016 World Humanitarian Summit

The PSI Global Resilience Project highlights the role of the insurance industry across the spectrum of activities in disaster risk management. The findings of this report can help guide communities and policymakers towards public policies that will mobilise the risk management expertise and resources of the global insurance industry to help meet these challenges.

13 United Nations Office for Disaster Risk Reduction: http://www.unisdr.org/files/33003_2013gar15final.pdf

Data issues and research methodology

Key points

- **Data from over 300 sources was analysed, presenting challenges in terms of consistency and data standardisation**
- **These challenges were addressed by assessing all data under three criteria—the social benefits, economic benefits, and cost of disaster risk reduction**

There is a wealth of data available on disaster risk reduction measures and their effectiveness. This report considered over 300 sources including academic papers, government and scientific reports, case studies and media articles.

The research found the information to be often inconsistent and difficult to compare, presenting a challenge to drawing meaningful insights on the effectiveness of each risk reduction measure. For data to be useful on a global scale, it must be consistent, standardised and globally accepted.

To address this, the research used a relative analysis of measures, looking at net economic and net social impact (including downstream impact) as well as cost. This section describes the limitations presented in the data and the research methodology used to deal with these issues.

Data issues and research methodology

Data standardisation

- **Inconsistent study goals** – While all sources examined focused on projects aimed at reducing risk, each study had unique goals, and a different area of focus. For example, some studies were specifically focused on reducing economic loss, while others focused on reducing human and social losses. Even when different studies had the same objectives and focus, the data was often defined and measured differently
- **Inconsistent study assumptions** – The underlying assumptions that measure outcomes vary greatly between studies. For example, economic loss can be limited to insured losses in some cases, but can include uninsured losses in other cases. Some studies include deaths as only those directly caused by the event, while others include both direct and indirect deaths

Data validation

- **Sources disagree on the economic and social impact that natural hazards have caused** – For example, EM-DAT reported the death toll from the 2010 earthquake in Haiti to be 222,570 people. By contrast, the Haitian government reported the death toll at 316,000 people[14] and the US Agency for International Development, which conducted a house-to-house study, reported the death toll to be 65,575 [15]

14 O'Connor, Maura, Columbia Journalism Review, 2012, http://www.cjr.org/behind_the_news/one_year_later_haitian_earthqu.php?page=all
15 Schwartz, Timothy, USAID, 2011, www.sentinel.ht/documents/BARR_Report_PauP_Final.docx

- **Expected benefits for risk reduction measures vary greatly between sources** – This is not surprising given the lack of consensus on data points between different sources for events that have already occurred

Research bias

- **Published research on disaster risk reduction measures focuses almost exclusively on success stories** – The lack of data on failures eliminates the possibility of learning from them and creates an overall research bias [16]

Research methodology

Disaster risk encompasses a range of hazards:

- **Natural hazards** – Including storms and cyclones, drought and extreme temperatures, earthquakes and volcanic activity, fires and floods
- **Biological hazards** – Including epidemics, animal and insect infestation
- **Technological hazards** – Including industrial pollution, factory explosions and transport accidents.

This report focuses on the three most common and costly natural hazards—flood, cyclone and earthquake[8] and examined three types of risk reduction measures:

- **Behavioural** – Measures which rely on human behaviour (for example, evacuation)
- **Structural** – Measures which rely on built infrastructure (for example, levees)
- **Ecosystems** – Masures which make use of or improve environmental features and natural ecosystems (for example, mangroves, sand dunes) to reduce the impact of a hazard

This report considers risk reduction measures which address specific hazards. It does not address the need for broader societal resilience to adaptively cope with the impact of disasters when measures fail.

Focusing on the primary needs to save lives and protect property, all data was analysed under three criteria:

Net economic benefit

- **Loss prevention (cost savings)** – What are the expected cost savings by implementing this specific risk reduction measure compared to the other measures?

Net social benefit

- **Loss prevention (lives saved)** – How many lives will be saved by implementing this risk reduction measure compared to the other measures?
- **Reduction in lives adversely affected** – How many fewer people will be adversely affected as a result of implementing this risk reduction measure? 'Affected', in this case, means people requiring immediate assistance during a period of emergency—people requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance

16 According to Roy Lewis III of the National Association of Environmental Professionals in the United States, 'Unsuccessful (or only partially successful) projects are rarely documented.'

Relative cost

- How much does it cost to implement this risk reduction measure compared to the other measures?

Downstream impacts were also considered. For example, does the risk reduction measure positively or negatively impact the local economy, environment or surrounding communities? Will it create prolonged displacement and unsafe or undesirable conditions in which to live?

The PSI Initiative acknowledges the work of the Partnership for Environment and Disaster Risk Reduction[17] and its member partners to consider the effectiveness of ecosystem-based approaches to managing climate and disaster risk and the integration of biophysical and environmental factors into this analysis.[18] This is important to truly understand what is at stake and to have a more holistic view of approaches that can be taken. This is why ecosystem-based approaches were included in the types of risk reduction measures researched, along with behavioural and structural approaches. However, a detailed consideration of every type of risk reduction measure is beyond the scope of this report.

About the charts in this document

At the beginning of each section, the risk reduction measures discussed are analysed according to their costs as well as their social and economic benefit (Figure 1). Downstream impacts—positive or negative consequences which may result from the implementation of these measures—are also considered.

Given the data challenges set out above, qualitative assessments of social and economic benefit and cost were made based on the available material.

Figure 1 **Template used for disaster risk reduction measure comparison**

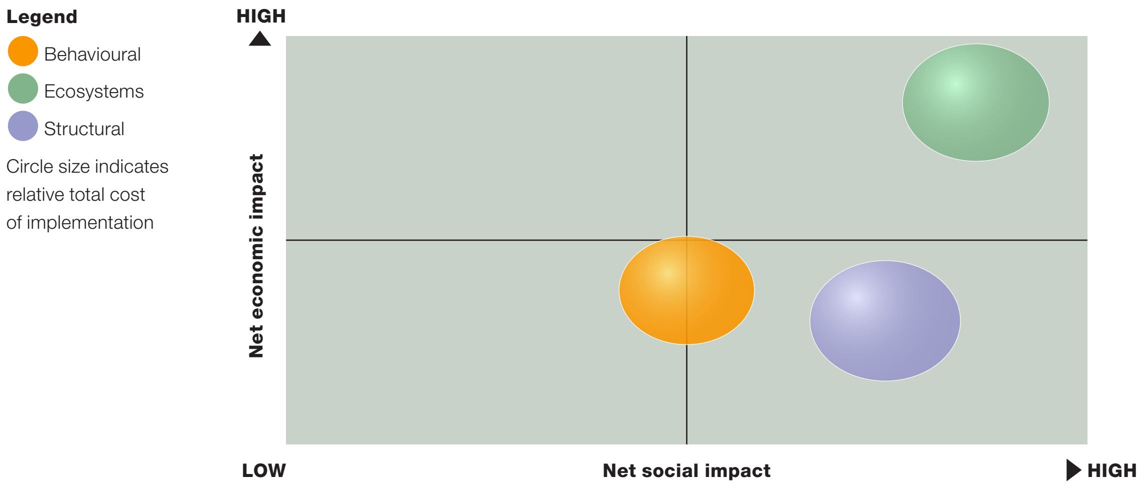
Risk reduction measure	Net economic benefit		Net social benefit		Downstream impact
	Loss prevention (cost savings)	Relative cost	Loss prevention (lives saved)	Reduction in lives adversely affected	
Measure 1	High impact	High cost	High impact	High impact	• Wild animal habitat • Reduced property values
Measure 2	Moderate impact	Low cost	Moderate impact	Moderate impact	• Empowered citizens
Measure 3	Low impact	Moderate cost	Low impact	Low impact	• Abandoned property

Also, risk reduction measures were analysed on the relative total cost of implementation compared to other measures for the hazard. This analysis considers risk reduction measures according to their type—behavioural, structural or ecosystems. The size of the circles in this analysis (Figure 2) indicates the cost effectiveness of each risk reduction measure compared to others for the same hazard.

17 Partnership for Environment and Disaster Risk Reduction: http://pedrr.org/

18 N. Doswald, R. Munroe, D. Roe, A. Giuliani, I. Castelli, J. Stephens, I. Möller, T. Spencer, B. Vira & H. Reid , Climate and Development (2014): Effectiveness of ecosystem-based approaches for adaptation: review of the evidence-base, Climate and Development, DOI: 10.1080/17565529.2013.867247

Figure 2 Template used for comparison of cost effectiveness of risk reduction measures



Risk reduction measures – Overview

Key points

- **Assessing the effectiveness of risk reduction measures needs to take into account economic benefit, social benefit and cost**
- **Risk reduction can only be effective in an enabling environment, with engaged stakeholders, a data-driven approach, appropriate planning, and the implementation of a range of measures**

Key initiatives – Benefits and costs

Risk reduction measures outlined in this report were assessed according to economic benefit, social benefit and cost, with each criteria ranked low, moderate or high.

The research focused on the three most frequent, and most destructive, natural hazard risks—cyclone, earthquake and flood. Also, measures were identified which can have a positive impact on all risks.

This table summarises the PSI Initiative's findings in relation to risk reduction measures discussed in this section.

Figure 3 **Multi-hazard risk reduction measures – Cyclone, earthquake and flood**

Initiative	Economic benefit	Social benefit		Cost
		Lives saved	Reduction in lives adversely affected	
Education and communication	High	Moderate/High	High	Low
Risk mapping	Moderate	High	High	Moderate
Emergency evacuation	Low	High	High	Low

Figure 4 **Cyclone risk reduction measures**

Initiative	Economic benefit	Social benefit		Cost
		Lives saved	Reduction in lives adversely affected	
Mangroves	Moderate/High	Moderate	Moderate	Moderate
Coastal sand dunes	High	Moderate	Moderate	Moderate/High
Cyclone shelters	Low	High	Moderate	Moderate
Early warning system	Moderate/High	High	Moderate	Low
Improved building codes	Moderate/High	Moderate	High	Low
Prediction	Moderate	Moderate	Moderate	Low/Moderate
Seawalls	High	High	High	High

Figure 5 **Earthquake risk reduction measures**

Initiative	Economic benefit	Social benefit		Cost
		Lives saved	Reduction in lives adversely affected	
Relocation	High	High	Low	High
Earthquake prediction	Low	Low	Low	High
Tsunami warning systems	Moderate	High	Low	High
Soil assessment	Moderate	Moderate	Moderate	High
Building codes	Moderate/High	High	Moderate	Low
Retrofitting	Moderate/High	High	Moderate	High

Figure 6 **Flood risk reduction measures**

Initiative	Economic benefit	Social benefit		Cost
		Lives saved	Reduction in lives adversely affected	
Permanent barrier – Block	Moderate/High	Moderate	High	Moderate/High
Controlled barrier – Block, divert	High	High	High	High
Temporary barrier – Block	Low/Moderate	Low	Moderate	Moderate
Wetlands – Block	Moderate/High	Moderate	High	Moderate
River modification – Block	Low/Moderate	Moderate	Moderate	High
Conveyance – Divert	High	High	Moderate/High	Moderate/High
Basin storage – Divert	Moderate/High	Moderate	Moderate	Moderate
Relocation – Reduce	High	Moderate	Moderate	Moderate/High
Warning system – Reduce	Low	High	Low	Low
Land-use planning – Reduce	Moderate/High	High	High	Low

Enabling environment

The research reveals important themes and common good practices necessary for an enabling environment that builds disaster resilience.

1 **Active engagement** – All stakeholders across a range of disciplines and perspectives need to be engaged collaboratively in resilience-building efforts

2 **Proper planning** – Stakeholders need a detailed understanding of the disaster risk exposure and the environment in which the risk reduction measure is implemented. This understanding is only possible with accurate and consistent data

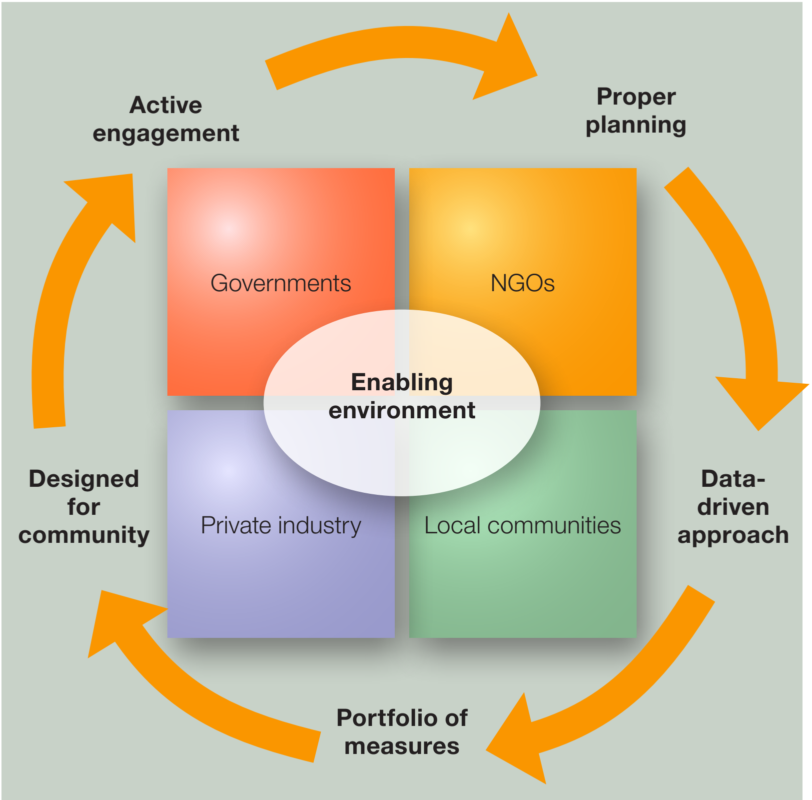
3 **Data-driven approach** – To identify and justify resilience investments, potential funders require hard data on the future benefits of implementation

4 **Portfolio of measures** – In most cases, a single risk reduction measure does not deliver the maximum or sufficient benefit. It is the use of a portfolio of complementary measures that is most effective to drive risk reduction. For cyclones, mangroves and coastal sand dunes can block storm surge, while effective building codes and enforcement will protect buildings from strong winds. Risk education together with effective early warning systems will enable communities to best prepare for flooding. A tailored portfolio approach to risk

reduction will likely be most successful in reducing vulnerability to natural hazards. It also allows communities to adapt their risk defenses as their situations develop

5 **Designed for community –** The engagement of at-risk communities at all levels helps ensure the effectiveness of any measure. Cooperation among all stakeholders is needed to understand disaster risk, how these risks are best met, and potential barriers to effective implementation. While knowledge sharing across regions is important, simply replicating a risk reduction measure without taking into account the unique circumstances of the local geography, environment, demography and culture will limit effectiveness

Figure 7 **Important themes and common good practices that build disaster resilience**



Multi-hazard risk reduction measures – Cyclone, earthquake and flood

Key points

- **Risk mapping, education, and effective evacuation procedures have the capacity to reduce economic and social impacts across all disaster types**
- **Effective risk mapping enables the identification of at-risk communities, and the initiatives most likely to benefit them**
- **Education creates risk-aware stakeholders and communities equipped to act on risk mapping to reduce their level of risk**
- **Emergency evacuation procedures have obvious benefits in removing people from dangerous situations, and can help communities recover more quickly**

Risk mapping, education and evacuation preparedness are measures that are broadly applicable to the hazards of cyclone, earthquake and flood. Like many risk reduction measures, they can be interdependent.

Risk mapping

Risk mapping is the identification of high-risk areas susceptible to a hazard.

Risk mapping relies on a probability analysis of many variables such as frequency, severity or magnitude. The inherent uncertainty in probability analysis makes mapping for natural hazards helpful but still very susceptible to outliers, particularly for earthquake.[19, 20]

For risk mapping to be most effective, up-to-date data on population density and built assets is needed.

Net social benefit

The net social benefit for this measure is moderate to high.

In isolation, the net social impact of risk mapping is limited. However, it is critical to informing development and planning regulation and building code standards. When a community maps out its risk exposure to natural hazards, it can better identify and plan for the types of structures that can be built in certain areas and design building codes to reduce exposure.

Net economic benefit

The net economic benefit for this measure is moderate.

19 Lomnitz, Cinna, 1989, http://www.bssaonline.org/content/79/5/1662.full.pdf
20 Seth Stein, 2012, 'Why earthquake hazard maps often fail and what to do about it', http://www.earth.northwestern.edu/people/seth/Texts/mapfailure.pdf

Cost

The cost for this measure is moderate.

The cost of risk mapping varies across regions, and also depends on data availability, reliability and accessibility, and mapping resolution.

Hazard risk mapping

Recommended practices

- **Foundational input to risk reduction investments**

Obstacles

- **Lack of available, reliable and accessible data**
- **Vast collection of hazard information sources**
- **Translation inaccuracy**

Education and communication

Sharing knowledge among stakeholder groups including governments, NGOs, scientists, communities, individuals, and business owners is critical to effective disaster risk reduction. Education promotes a united and therefore more effective approach, improves safety, generates risk awareness, and supports resilience-building efforts.

An organised and systematic method for coordinating communication among a variety of stakeholders is a key success factor for effective risk reduction.[21]

The need for consistency in communication has been emphasised by the UN General Assembly in a 'call to action' for disaster risk reduction education to be integrated into humanitarian action plans. At least 4% of humanitarian budget allocations should go towards education initiatives.[22]

Effective education needs to be appropriately tailored to each audience, and must focus on three critical issues:

- Potential losses
- The chances that the losses will take place in a certain amount of time
- How to cut the losses[23]

But while education is a precondition for effective risk reduction, it does not automatically lead to appropriate action.[24]

21 As stated by the US National Disaster Education Coalition 'The coalition recognizes that it is important for all agencies to deliver consistent disaster safety messages. When the public receives consistent information, they will prepare and respond appropriately when disaster threatens.' The National Disaster Education Coalition. http://www.disastereducation.org/about.html

22 Greubel Lauren, Xanthe Ackerman and Rebecca Winthrop. The Brookings Institution. 'Prioritizing Education in the Face of Natural Disasters.' October 2012. http://www.brookings.edu/blogs/up-front/posts/2012/10/31-natural-disasters-winthrop

23 Martin, II, James R., Federal Emergency Management Agency National Preparedness Directorate. 'Session No. 13-Earthquake Hazard and Emergency Management-Risk Communication Strategies and Public Outreach.'

24 Pacific Earthquake Engineering Research Center. 'Framing Earthquake Retrofitting Decisions: The Case of Hillside Homes in Los Angeles.' March 2000. http://peer.berkeley.edu/publications/peer_reports/reports_2000/0003.pdf

Risk awareness of itself may not be sufficient to motivate people to take action, which can be impacted by levels of individual empowerment or anxiety, lived experience of hazards, and the attitudes of peer networks. Sustained preparedness for high impact but rare events is also problematic.[25 26]

Case study Education in Japan, Chile and Haiti

The INSEAD Humanitarian Research Group conducted a study on the link between economic development and humanitarian response in earthquake and tsunami events that occurred in Japan, Chile and Haiti between 2010 and 2011. The following statistics demonstrate the link between loss and existing levels of disaster mitigation, preparedness, governance and socio-economic conditions in place at the time of each disaster.

The 2011 Japan 9.0-magniude earthquake killed 13,858 people (or 0.01% of population).

- One of the most advanced earthquake early-warning systems with a network exceeding 1,000 seismographs
- Embedded public education models and disaster education in school curriculums
- Community level social education
- No major casualties as a result of the earthquake itself, but the tsunami was the major cause of deaths

The 2010 Chile 8.8-magnitude earthquake killed 562 people (or less than 0.01% of population).

- Seismic building codes and strict enforcement of laws on construction
- Community risk awareness based on past earthquakes

The 2010 Haiti 7.0-magnitude earthquake killed 230,000 people (or 2.4% of population).

- Policymakers did not mandate risk mitigation
- Poor quality buildings
- No culture of risk awareness

INSEAD concluded that behaviour of individuals can be influenced by education and training. People in Japan knew the procedures and safest places to go to when the earthquake struck. Education and training helped build disaster resilience and the ability to respond adequately. Similarly, Chile's coastal town population was able to use the lessons from the past when they felt the earthquake. However, people in Haiti were unprepared for how to deal with a major earthquake.

Overall, they concluded that education of society and communities is an important element in risk reduction. It helps avoid human losses and mitigate underlying risk factors. Therefore, local capacity building through education and training can build disaster-responsive local communities.

Source: INSEAD, 'Why the Japan disaster is so different from the other disasters,' by Jurgita Balaisyte, and Luk N. Van Wassenhove, May 10, 2011.

25 Paton et al., 'When good intentions turn bad: promoting natural hazard preparedness' The Australian Journal of Emergency Management, Vol. 20 No 1. February 2005

26 Becker et al., 'A model of household preparedness for earthquakes: how individuals make meaning of earthquake information and how this influences preparedness' Nat Hazards DOI 10.1007/s11069-012-0238-x

Net social benefit

The net social benefit of education is moderate to high.

Fewer lives are lost or affected when individuals understand fundamental hazard safety and respond appropriately. Education enables communities to act in an organised and structured way that facilitates emergency responses.[27]

Net economic benefit

The net economic benefit of education is high.

Educated communities, individuals and business owners who know what to expect before, during and following a natural hazard can prepare in advance and recover more quickly from property loss.[28]

Cost

The cost of education is low relative to other measures.[29]

Costs include the collaborative effort of civic organisations, scientists, educational institutions, government and NGOs to get the right information to the target audience.

Education

Recommended practices

- **Ensuring that there is communication to communities, and between governments and stakeholders**

Obstacles

- **Differing literacy levels of individuals across regions**
- **Ensuring that communication is culturally-sensitive and appropriate**

Emergency evacuation

When meteorological prediction systems identify the probable path and intensity of a severe natural hazard, emergency evacuation requires an immediate and urgent response from communities to move out of harm's way. It also requires effectively addressing the concerns of the community and communicating the severity of the event, as those asked to evacuate may be concerned about the threat from looters and reluctant to abandon their property.

Net social benefit

If planned and executed well, the net social economic benefit is high.

The number of lives saved depends on population density and compliance with evacuation orders.

27 Denver UASI, State of Colorado and Federal Stakeholders cooperating through the Wide Area Recovery and Resiliency Program. 'Denver UASI All-Hazards Regional Recovery Framework.' October 2012. http://www.fema.gov/media-library-data/20130726-1910-25045-8957/51_rrkp_urban_area_recovery_attachment_1_denver_framework___cbr_annexes.pdf

28 Gordon, Peter, et al. 'Earthquake Disaster Mitigation For Urban Transportation Systems: An Integrated Methodology That Builds On The Kobe And Northridge Experiences.' http://www-bcf.usc.edu/~pgordon/pdf/earthquake.pdf

29 The California Seismic Safety Association. 'California Earthquake Loss Reduction Plan.' 2001. http://www.seismic.ca.gov/pub/CSSC_1997-02_CELRP.pdf

The warnings must be strongly worded and indicate if the evacuation is mandatory or simply recommended. According to a study conducted by the University of South Carolina, just 50% of survey respondents said they would go if evacuation was recommended instead of mandatory.[30] Also, evacuation depends on proper education on the best evacuation route, what essential items to bring, and the best way to protect belongings left behind so they are not damaged by the hazard.

Net economic benefit

The net economic benefit for this measure is low.

Evacuations do not preserve physical assets that are left unprotected and exposed to the event. However, with preparedness education, communities can 'harden' their homes and property well before an event strikes. While this can impact livelihoods, the trade-off is a high social benefit as demonstrated above.

Cost

The cost of evacuation depends on the number of people requiring relocation and the planning and infrastructure needed to support evacuation.[31] The cost also depends on travel distance to safety, the evacuation time period, and the physical welfare and demographics of the evacuees.[32]

Evacuation

Recommended practices

- **Evacuation plans and routes must be well communicated**
- **Appropriate funding and supplies to sustain displaced residents for an extended period of time**

Obstacles

- **Refusal of residents to leave homes**
- **Finding a safe location which can house large amounts of people for extended periods of time**

30 Gannon, Megan, Live Science, 2012, http://www.livescience.com/22697-coastal-residents-hurricane-evacuations.html
31 Smith, Kevin, East Carolina University, 1999, http://www.cs.rice.edu/~devika/evac/papers/kevinsmith.pdf
32 John R. Maiolo of East Carolina University found the cost per household for evacuation is USD 112. Maiolo, John, 2000, Heading for Higher Ground: Factors Affecting Real and Hypothetical Hurricane Evacuation Behavior, http://www.cs.rice.edu/~devika/evac/papers/Heading%20for%20higher%20ground.pdf

Cyclone risk reduction measures

Key points

- **Natural ecosystems, such as mangroves and sand dunes, can be used to reduce risk and provide high net economic and social benefits, as with structural measures such as sea walls. These natural coastal protection ecosystems reduce the wave height and energy of storm surges and are particularly effective in combination with structural measures**
- **Warning systems and evacuations are also effective and are relatively low-cost**

A cyclone—also known as a hurricane or typhoon—is a large, rotating storm system that brings strong winds, torrential rain, and high coastal storm surges upon landfall.

Cyclones caused 762,832 deaths between 1970 and 2012.[8] Deaths in Bangladesh accounted for more than half of that figure. The United States has experienced more economic loss (USD 513 billion) than all other countries combined between 1970 and 2012.[8] Much of this economic loss is due to a large exposure to infrastructure loss, particularly along the east coast.

Figure 8 (below) shows the exposure of many coastal communities to the devastating impact of cyclones.

Figure 8 **Cyclone exposure by population**

Source: Global Risk Data Platform. Created and hosted by UNEP/GRID-Geneva. Supported by UNISDR. Updated in 2013. http://preview.grid.unep.ch/index.php?preview=about&lang=eng

Ecosystem-based risk reduction measures such as mangroves and sand dunes have proven to be cost effective and, in combination with structural and behavioural measures such as warning systems and evacuation, can be highly effective in protecting lives, property and livelihoods.

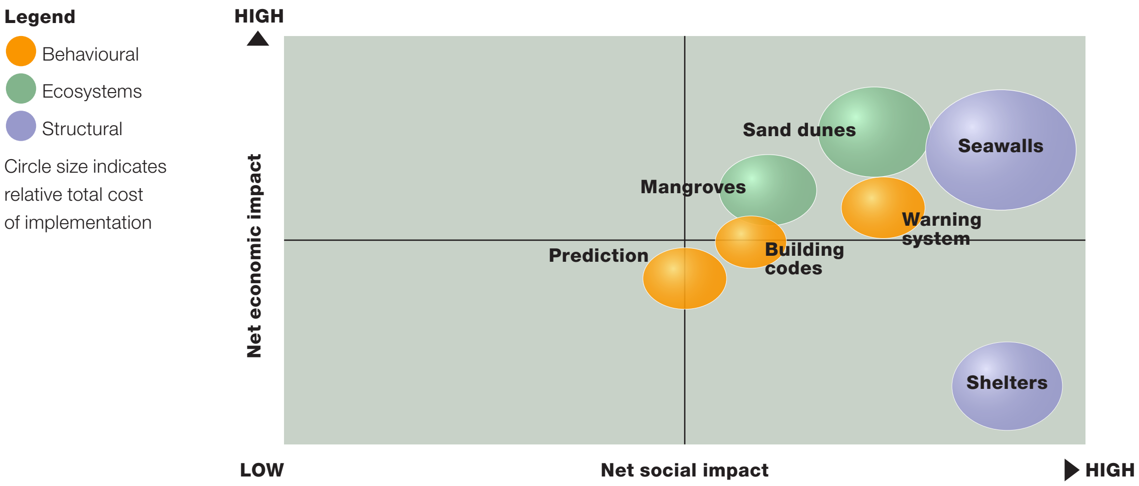
The following table assesses the relative economic and social costs and benefits and downstream impacts of each specific cyclone risk reduction measure. Risk reduction measures also common to earthquake and flood are addressed in the 'multi-hazard' section of this paper.

Figure 9 (below) provides an assessment of each measure's economic and social impact along with its downstream impact.

Figure 9 **Cyclone risk reduction measure comparison criteria**

Initiative	Economic benefit	Social benefit		Cost	Downstream impact
		Lives saved	Reduction in lives adversely affected		
Mangroves	Moderate/ High	Moderate	Moderate	Moderate	• Wildlife habitat • Biodiversity conservation • Opportunities for aquaculture
Coastal sand dunes	High	Moderate	Moderate	Moderate/ High	• Wildlife animal habitat
Cyclone shelters	Low	High	Moderate	Moderate	• Community infrastructure
Early warning system	Moderate/ High	High	Moderate	Low	
Improved building codes	Moderate/ High	Moderate	High	Low	
Prediction	Moderate	Moderate	Moderate	Low/Moderate	
Seawalls	High	High	High	High	• Unsightly • Impact on sediment movement may transfer hazard elsewhere • Potential destruction of ecosystems

Figure 10 **Cyclone risk reduction measure comparison analysis**



Below is an analysis of each risk reduction measure together with available evidence of costs and benefit.

Mangroves

Mangroves grow in tropical and sub-tropical climates and are found in over 120 countries. Mangrove forests are ecosystems that lie at the confluence of freshwater rivers and salty seas.[33] They require frequent partial submersion by coastal tides for survival.

Mangroves occur naturally around the world, protecting coastal communities from the impact of storm surges from cyclones. Mangroves can reduce storm surge water levels by slowing the flow of water, reducing surface waves and absorbing wave energy.[34]

However, it is estimated that more than 50,000 square kilometres or more than 25% of the estimated original mangrove cover of more than 200,000 square kilometres has been lost as a result of human intervention. The greatest drivers of mangrove forest loss are direct conversion to aquaculture, agriculture, and urban land uses. Coastal zones are often densely populated and pressure for land is intense. Where mangroves remain, they have often been degraded through overharvesting.[35] Given their degradation, spending is focused on conservation and restoration.

Other coastal and marine ecosystems—such as coastal marshes and coral reefs—are also suggested to provide natural protection from cyclone storm surge.[36, 37] As with mangroves, conservation and restoration may provide cost-effective reduction of cyclone risk.

Net social benefit

The social benefit for this measure is moderate. As illustrated by the case study below, communities protected by mangroves have a better chance of minimising loss of life than communities with no mangrove protection.

As with other ecosystem-based measures, mangroves can support biodiversity conservation and carbon capture.

Net economic benefit

The economic benefit for this measure is moderate to high.

Studies estimate that mangroves generate between USD 2000 to USD 9000 per hectare per year. [38]

33 Stecker, Tiffany, Scientific American, 2012, http://www.scientificamerican.com/article/restoring-mangroves-may-prove-cheap-way-to-cool-climate/

34 McIvor, A.L., Spencer, T., Möller, I. and Spalding. M. (2012) Storm surge reduction by mangroves. Natural Coastal Protection Series: Report 2. Cambridge Coastal Research Unit Working Paper 41. Published by The Nature Conservancy and Wetlands International. 35 pages. ISSN 2050-7941. URL: http://www.naturalcoastalprotection.org/documents/storm-surge-reduction-by-mangroves

35 'Mangroves report reveals threats and opportunities to global economy and the planet', United Nations Environment Programme: http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=630&ArticleID=6645

36 Shepard CC, Crain CM, Beck MW (2011) The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. http://www.plosone.org/article/fetchObject.action?uri=info:doi/10.1371/journal.pone.0027374&representation=PDF

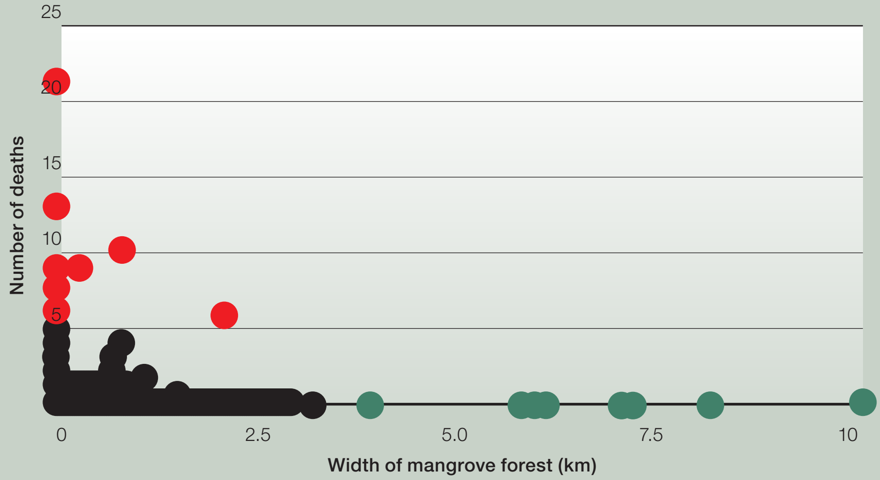
37 Ferrario, F. et al. The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nat. Commun. 5:3794 doi: 10.1038/ncomms4794 (2014). http://www.nature.com/ncomms/2014/140513/ncomms4794/pdf/ncomms4794.pdf

38 'Mangroves report reveals threats and opportunities to global economy and the planet', United Nations Environment Programme: http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=630&ArticleID=6645

Case study Mangrove forests in Orissa, India

The University of Delhi conducted a study on the social benefit of mangroves based on a super cyclone that hit India in 1999. This cyclone killed nearly 10,000 people with 70% drowning in the storm surge. Average mangrove forest width fell from 5.1 kilometres in 1944 to 1.2 kilometres in 1999. However, those villages that were protected by a wider mangrove forest experienced fewer deaths than those that were unprotected or had little mangrove protection. See Figure 11 below.

Figure 11 **Deaths per village during 29 October 1999 cyclone plotted against width of mangroves between each village and the coast**



Source: Das and Vincent (2009)

Overall, this study found that there would have been 1.72 additional deaths per village in the 154 villages within 10 kilometres of the coast. This study accounted for the fact that 150,000 people were evacuated prior to the cyclone's arrival. The social benefit, which saved the lives of 256 people, is complemented by the economic benefit that mangroves provide to their communities.

The Wildlife Institute of India conducted a study on the economic benefit of the mangrove ecosystem with a focus on three Indian villages impacted in 1999 by Cyclone 05B. One had no mangrove protection, another one had a thick mangrove forest between it and the coast, and the third had a mangrove forest and an embankment. According to the study, 'in the mangrove-protected village, variables had either the lowest values for adverse factors (such as damage to houses), or the highest values for positive factors (such as crop yield).'[39]

The Centre for Environment and Development Economics also notes that mangroves provide downstream benefits beyond that of coastal protection. Their moisture-rich environment serves as a nursery for aquatic life and supports coastal and marine fisheries. This benefit to the fisheries in the area is roughly USD 100,000 per year for 1,200 hectares[40] (USD 83 per hectare per year) of mangrove forest. While the benefits are high, both for individual families and economies, mangrove reforestation comes at a cost.

39 Badola, Hassain, 2005, Foundation for Environmental Conservatism, http://portal.nceas.ucsb.edu/working_group/valuation-of-coastal-habitats/review-of-social-literature-as-of-1-26-07/BadolaHussain%202005.pdf

40 Barbier, Edward, University of Wyoming, 2000, http://www.sciencedirect.com.libproxy.temple.edu/science/article/pii/S0921800900001671

Cost

The cost of measures for this hazard will depend on the extent of the intervention. Afforestation—the establishment of new forest—may be more expensive than conserving and restoring degraded forest. This means that, relative to other measures for this hazard, the cost for this measure ranges from low to high.

Estimates for rebuilding mangrove forests range widely from USD 200 per hectare up to USD 216,000 per hectare, but a properly managed project can range between USD 200 per hectare and USD 700 per hectare.[41] Using the average in this range of USD 450 and applying the USD 83 in savings per hectare per year over its 22-year lifespan[42] equates to a cost-benefit ratio of 305%. If these ecosystems are properly monitored and maintained, self-regeneration will sustain these ecosystems for many years.[43] Cost of maintenance has been quoted at USD 64 per hectare per year.[42]

Mangrove forests

Recommended practices

- **Sufficient land between coast and village**
- **Advance planning for growth to maturity**

Obstacles

- **Governance failure to regulate and protect mangrove ecosystems**
- **Opportunity cost – Shrimp farms and rice fields**

Coastal sand dunes

Coastal sand dunes can be naturally occurring or man-made hills of sand along coastal beaches throughout the world. Dunes block the storm surge caused by cyclones and prevent damage by seawater inundation.

Net social benefit

The social benefit for this measure is moderate to high.

If other risk reduction measures are not available, dunes can greatly reduce the social impact of storm surge caused by a cyclone.

Net economic benefit

The economic benefit for this measure is high.

Dunes, if properly constructed, provide an economic cost-benefit ratio of between 8:1 and 27:1. One beach town in New York saved USD 200 million in disaster recovery costs largely due to the vital and healthy dune system.[44] However, this benefit requires significant investment that can be prohibitive for a local community.

41 Lewis III, Roy R., 'Mangrove Restoration – Costs and Benefits of Successful Ecological Restoration, 2001, http://www.fao.org/forestry/10560-0fe87b898806287615fceb95a76f613cf.pdf
42 Tuan & Tinh, 2013, Cost–benefit analysis of mangrove restoration in Thi Nai Lagoon, Quy Nhon City, Vietnam, http://pubs.iied.org/pdfs/10644IIED.pdf
43 James, Rick, http://www.riparianmanagement.com.au/docs/Mangrove%20paper.pdf
44 Navarro, Mireya, 2012, New York Times – Resisted for Blocking the View, Dunes Prove They Blunt Storms, http://www.nytimes.com/2012/12/04/science/earth/after-hurricane-sandy-dunes-prove-they-blunt-storms.html?_r=0

Cost

The cost for this measure is moderate to high.

Review of studies conducted on the cost and effectiveness of sand dune construction and maintenance has shown that every coastal situation is different. Therefore, costs (for example, beach nourishment) can vary significantly from one coast to another.[45] Dune construction ranges from USD 30,000 per kilometre[46] to USD 1.25 million per kilometre.[44]

Coastal sand dunes

Recommended practices

- **Community agreement**
- **High, wide dunes**
- **Prevent foot traffic**

Obstacles

- **Cost**

Cyclone shelters

Cyclone shelters are multi-purpose buildings such as schools or municipal centres, generally constructed on concrete pillars with iron shutters over windows, designed to withstand tidal waves and winds of up to 220 kilometres per hour.[47] To be effective they must be used in combination with effective community education programmes and early warning systems. Cyclone shelters can play a pivotal role in saving lives, particularly in developing countries with less cyclone-resistant housing and therefore more reliance on communal protection. Shelters vary in capacity and can usually accommodate 500 to 1,000 people.

Net social benefit

The social benefit for this measure is high.

Beyond saving lives, cyclone shelters can be used for community purposes, such as a school or municipal building, which provides additional social benefit for the community and helps reduce cost.

Net economic benefit

The economic benefit for this measure is low.

Cyclone shelters do not reduce the economic impact of cyclone damage for individuals and communities when buildings are not constructed to sufficient building codes.

45 According to Scott L. Douglass of the University of Alabama, 'there are no typical costs for beach nourishment. Each beach design is too unique. Costs vary tremendously because of many factors including the distance between the sand source and the beach, the size of the nourishment, and the construction measure and timing.'

46 FEMA Success Stories, http://www.fema.gov/media-library-data/20130726-1447-20490-2626/Success-Stories-IV_Final.pdf

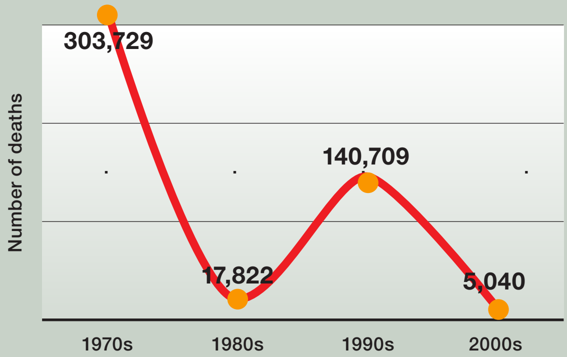
47 IRIN News, 2008, http://www.irinnews.org/report/76490/bangladesh-cyclone-shelters-save-lives-but-more-needed

Case study Cyclone shelters in Bangladesh

Figure 12

Bangladesh – Decrease in deaths is attributed to combination of cyclone shelters and early warning system

(Population: 66.8 million in 1970 / 129.6 million in 2000)



Source: EM-DAT

Bangladesh provides an example of the significant social benefits of shelters. The country has been in the forefront of cyclone shelter development since suffering a devastating cyclone in 1970. Figure 12 shows the reducing death toll since 1970.

In the 1991 cyclone, which was one of the worst to hit Bangladesh in the last 40 years, 138,866 people lost their lives.[2] Twenty-two percent of people that did not reach a shelter perished. However, every person that made it to a shelter survived the storm.

Cost

The cost for this measure is moderate.

Costs to build a cyclone shelter have been estimated between USD 150 and USD 187 per space.[48] These costs are not recovered through a reduction in post-event recovery expenses, but significant numbers of lives can be saved. For shelters to have maximum impact, they need to be implemented in combination with early warning systems and education.

Cyclone shelters

Recommended practices

- **Appropriate building materials and knowledge**
- **Citizen compliance**

Obstacles

- **Gender differences – In some cultures women may not be permitted to leave house without men to seek shelter**
- **Lack of or unclear communication on when to go to shelters**

Early warning system

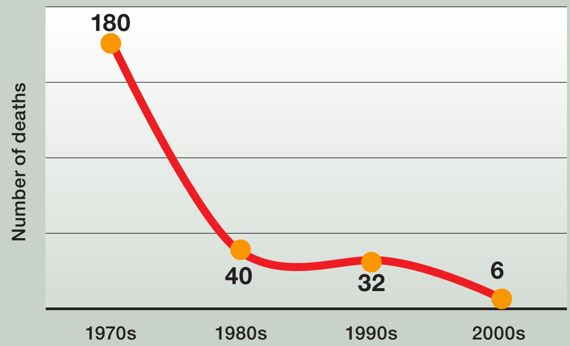
Early warning systems vary by country. In developed countries, local authorities and news services usually communicate the expected timing and strength of an oncoming cyclone. This enables communities to take appropriate action to protect property and stay out of danger. However, in some developing countries, warnings are often relayed through village-to-village messengers. In some cases, villages have satellite phones that can receive alerts from weather authorities, which they relay to surrounding villages.[49]

48 Karim, Nehal, 'Options for Cyclone Protection',2002, http://www.climate.org/PDF/Bangladesh.pdf
49 UNEP Global Environmental Alert Service, 2013, http://www.unep.org/pdf/UNEP_GEAS_NOV_2013.pdf

Case study Early warning system in Hong Kong, Special Administrative Region (SAR), China

Figure 13 **Hong Kong, SAR, China: Decrease in deaths caused by cyclones attributed to early warning systems and building code compliance**

(Population:
3.9 million in 1970 /
6.7 million in 2000)



Source: EM-DAT

An example of positive social benefits can be seen in Hong Kong, where early warning systems have played a big part in the reduction of deaths caused by cyclones. Building code implementation and enforcement has also contributed to this decrease in deaths. Hong Kong's economic prosperity over the years has also contributed to the construction of cyclone-resistant homes.

Net social benefit

The social benefit for this measure is moderate to high.

Early warning systems are highly effective at reducing human impact when used in tandem with cyclone shelters, particularly in developing countries. For early warning systems to be effective, the delivery of information must be well-coordinated and messages easily understood, with enough response time.[50]

Net economic benefit

The net economic benefit for this measure is moderate to high.

With advance warning and time to prepare, communities can protect property and seek shelter. In areas where livestock represent significant economic assets, this warning results in economic benefit as livestock can also be moved to cyclone shelters.

In developed countries, warnings can allow people to board up homes, build sandbag barriers around property, and ensure readiness of equipment to prevent inundation (for example, sump pumps and generators).

Cost

The cost for this measure is low.

Early warning systems do not require extensive engineering efforts to be effective which keeps the cost down. However, to be most effective, early warning systems should be coordinated across national borders and organisations, and supported by relevant scientific research. All countries can benefit from modest but well-allocated spending on such systems and from sharing data among themselves.[51]

50 50 Weyman, James, ESCAP Typhoon Committee, 2013, http://typhooncommittee.org/SSOP/SSOP%20final%20docs/2-SSOP%203rd%20PR-Philippines%20Pilot%20Workshop%20Report.pdf

51 United Nations, World Bank, 'Natural Hazards, Unnatural Disasters', 2010

Early warning system

Recommended practices

- **Cross-border communication**
- **Standardised language**
- **Clarity and timeliness of messages**

Obstacles

- **Lack of cross-government communication and coordination**
- **Lack of community comprehension and compliance with warning and evacuation**

Prediction

Prediction is not a risk reduction measure in itself. However it is a critical prerequisite for other risk reduction measures. Short-term prediction is crucial to effective evacuation and timely access to cyclone shelters, while longer-range prediction of increases in cyclone risk can help communities prepare using a range of measures.

As prediction has such an important role in underpinning disaster risk reduction, its costs and benefits are assessed alongside risk reduction measures.

The accurate prediction of cyclones relies heavily on sophisticated meteorological systems owned by governments and private sector companies. These systems are expensive to develop.

Net social benefit

The social benefit for this measure is moderate.

Accurate predictive models support other risk reduction measures such as early warning systems to protect lives and reduce storm-related injuries.

Net economic benefit

The net economic benefit for this measure is moderate.

In isolation, prediction cannot eliminate or reduce the economic impact of cyclones on coastal regions. However, it can be used together with ecosystem, structural and behavioural measures to reduce the economic impact of cyclones. Prediction can support the effectiveness of early warning systems, which allow people to protect their homes more effectively.

Cost

The cost for this measure is low to moderate.

Generally, responsibility for accurate meteorological forecasting sits with government rather than the private sector.

Prediction

Recommended practices

- **Availability and appropriate use of technology**
- **Communication network**

Obstacles

- **Lack of sophisticated technology or systems**
- **Inaccuracy**

Building codes

When Hurricane Andrew hit Florida in the United States in 1992, it caused USD 16 billion in insurance claims and affected 250,000 people.[8] Adequate building codes could have greatly reduced damage. Recognising this, the state of Florida rewrote their building codes to build resilience for the future.[52] There are several essential components to using building codes as a risk reduction measure, including research and planning, implementation, and enforcement. To be most effective, building codes need to be designed and documented properly and must also be enforced. Impediments to enforcement, such as corruption, can significantly limit the effectiveness of this measure.

Net social benefit

The social benefit for this measure is moderate.

The role of building codes in enhancing resilient buildings and infrastructure will have a major impact on a community's ability to withstand, and recover from, a major cyclone event.

Net economic benefit

The net economic benefit for this measure is moderate to high.

A study performed in Florida that compared the damage caused by Hurricane Charley in 2004 for buildings built before and after 1996, when stricter building codes were implemented demonstrates this point. This study found that, on average, the damage per square foot was reduced by 42%, from USD 24 pre-1996 to USD 14 after 1996.[53]

An Australian study found that of the buildings built after 1985, when building codes were updated, 80% encountered negligible or non-structural damage during Cyclone Larry in 2006, compared with only 60% for pre-1985 construction.[54]

Similarly, according to a Deloitte study conducted in 2013, the application of a more resilient building code in South-East Queensland, Australia could reduce the physical damage of cyclones by around 55% to 66%.[55]

Cost

The cost for this measure is low to moderate.

52 According to Carolyn Dehring of the University of Georgia, 'building codes may impose both technological and enforcement costs yet may provide benefits such as reduced expected mortality and property damage.'

53 Institute for Business and Homes Safety, 2007, The Benefits of Modern Wind Resistant Buildings on Hurricane Claim Frequency and Severity, http://www.coalition4safety.org/resources/IBHS_HurricaneCharleySummaryReport.pdf

54 Australian Journal of Emergency Management http://www.em.gov.au/Documents/13821%20WEMA%20Henderson.PDF

55 Deloitte Access Economics: Australia, 'Building our Nation's Resilience to Natural Disasters' 2013

Buildings constructed to higher standards are likely to require more expensive, higher-resistance materials with higher installation costs.[54] In addition, the enforcement of the codes by individual assessment or certification leads to high compliance costs.

Building codes

Recommended practices

- **Consultation with licensed contractors**
- **Build into law**
- **Enforcement and ethical oversight**

Obstacles

- **Corruption**
- **Cost of compliance**

Seawalls

Seawalls are effective at blocking cyclone storm surge from reaching inland communities. However, the cost to build them may be prohibitively high.

Net social benefit

The social benefits associated with seawalls are high in terms of saving lives and protecting communities. However, they can also be visually unattractive and lead to environmental degradation that results from the loss of beaches and wetlands.[56]

Net economic benefit

The net economic benefit of seawalls is high for the economic assets they protect. However their aesthetic drawbacks and impact on the surrounding environment may affect property values and tourism.

Cost

The cost for this measure is high. These structures are costly to build and maintain, imposing an ongoing economic burden on communities. According to a study in 2010 in the United States, the cost of erecting a single mile of new seawall was estimated to exceed USD 35 million, with annual maintenance costs ranging between 5% to 10% per year.

Figure 14 **Estimated costs of building defences against rising sea levels[56,57]**

	Cost per linear foot (2000)	Cost per linear foot (2009)	Cost per mile(2009)
New levee	USD 1,500	USD 1,922	USD 10,545,520
Raise levee	USD 530	USD 679	USD 3,584,750
New seawall	USD 5,300	USD 6,789	USD 35,847,504

56 Koch, James, 2010, http://www.jrap-journal.org/pastvolumes/2010/v40/koch40_1_pdf.pdf

57 Herberger, M., H. Cooley, P. Herrera, P. Gleick and E. Moore. 2009. The Impacts of Sea-Level Rise on the California Coast. Sacramento: California Climate Change Center

Seawalls

Recommended practices

- **Careful cost-benefit analysis based on specific community requirements**

Obstacles

- **Cost**
- **Adverse impact on local environment and amenity**

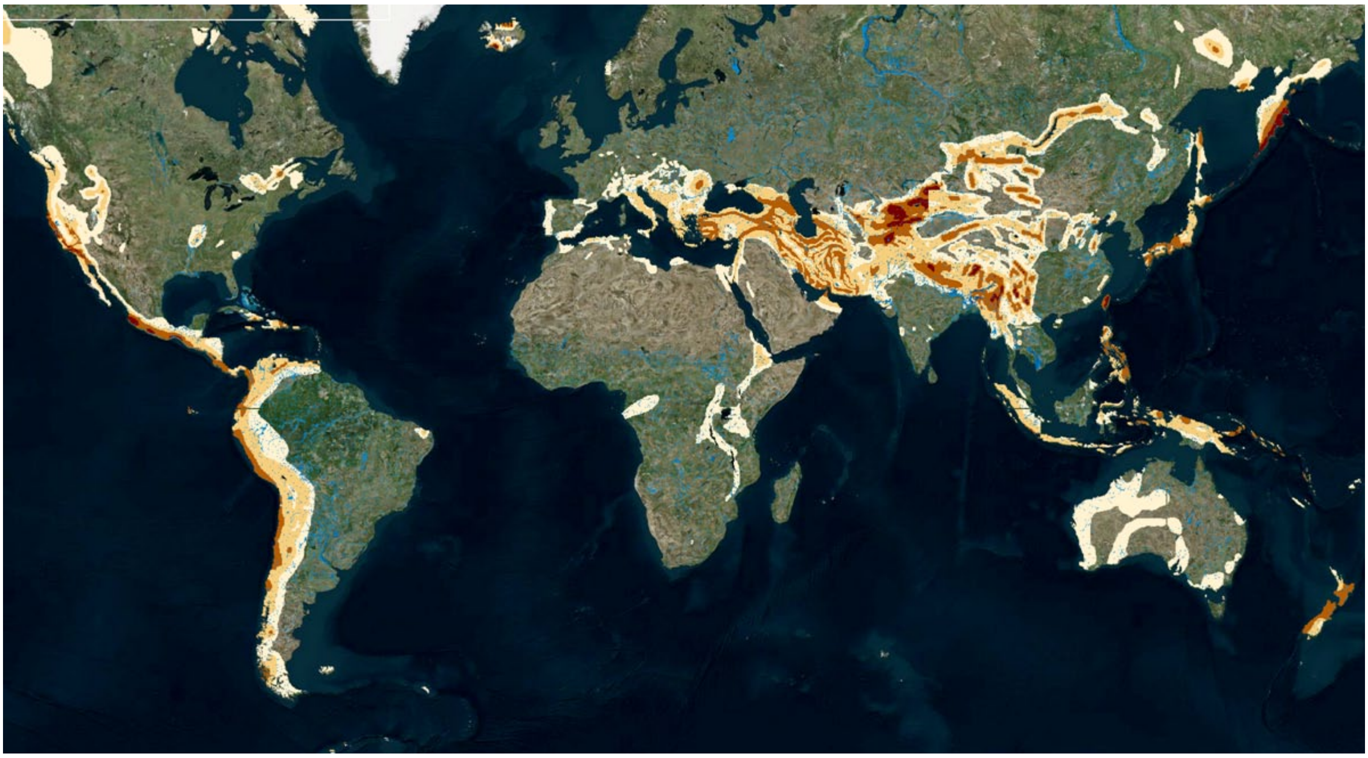
Earthquake risk reduction measures

Key points

- **Earthquakes are responsible for the greatest economic and social damage across all natural hazards**
- **Targeting the structures with the highest exposure and largest risk of collapse through retrofitting and building codes are the most effective means to reduce adverse impact**

Earthquakes have caused 1.3 million deaths between 1970 and 2012, or 37% of deaths caused by natural disasters for that time period.[8] There is little or no warning when earthquakes occur, and this is partly responsible for the high death toll. Earthquakes have also caused more economic loss than any other hazard during the time period. Figure 15 shows the regions affected by earthquakes.

Figure 15 **Earthquake exposure by frequency**



Source: Global Risk Data Platform. Created and hosted by UNEP/GRID-Geneva. Supported by UNISDR. Earthquakes frequency for MMI categories higher than 9 1973-2007. http://preview.grid.unep.ch/index.php?preview=data&events=earthquakes&evcat=3&lang=eng

Lack of predictability, speed of onset, and the fact that earthquakes often trigger other hazards all contribute to injury and property damage. Earthquakes can cause tsunamis, volcanic eruptions, fire, landslides, liquefaction, aftershocks, and surface faulting (displacement that reaches the earth's surface during slip along a fault.)[58, 59, 60] Long-term predictions are based on historical activity although this is limited for rare high impact and low probability events which may precede modern historical records.

Short-term prediction is highly inaccurate and does not provide adequate warning to allow for event preparedness. Unlike other hazards, earthquake early warning systems provide only 2 to 20 seconds of warning and cannot help with managing the frequency or severity of aftershocks.[61, 62]

There are, however, a number of longer-term measures that are proven to reduce economic and social impact and build resilience to earthquakes. In this report, 'structural' measures include anything that maintains the integrity of a building against the elements and includes building improvements, retrofitting, and soil assessment.

The following table assesses the relative economic and social costs and benefits and downstream impacts of each specific earthquake risk reduction measure. Risk reduction measures also common to cyclone and flood are addressed in the 'multi-hazard' section of this paper.

Figue 16 (below) summarises the relative success of commonly used earthquake risk reduction measures using the methods described in the methodology section.

Figure 16 **Earthquake risk reduction measure comparison criteria**

Initiative	Economic benefit	Social benefit		Cost	Downstream impact
		Lives saved	Reduction in lives adversely affected		
Relocation	High	High	Low	High	• New development • Displacement • Community integration
Earthquake prediction	Low	Low	Low	High	• Risk mapping reliant on long term • Increased knowledge sharing
Tsunami warning systems	Moderate	High	Low	High	• Adherence to evacuation plans
Soil assessment	Moderate	Moderate	Moderate	High	• Reduce structural collapse
Building codes	Moderate/High	High	Moderate	Low	• Business continuity management
Retrofitting	Moderate/High	High	Moderate	High	• Business continuity management

58 USGS Earthquake Glossary http://earthquake.usgs.gov/learn/glossary/?term=surface%20faulting

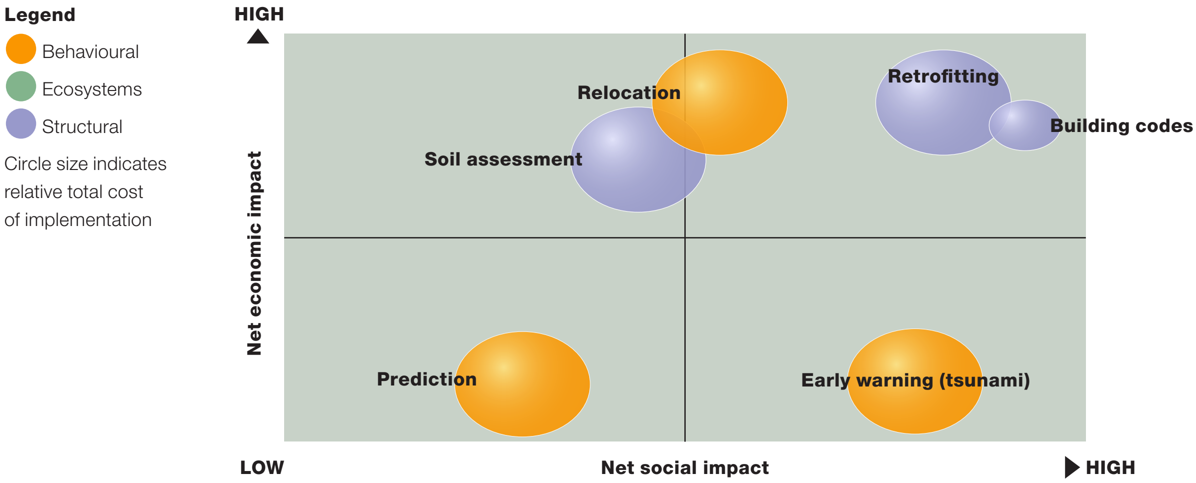
59 California Department of Public Health. 'Know and Understand Natural Disasters.' http://www.bepreparedcalifornia.ca.gov/BeInformed/NaturalDisasters/Pages/KnowandUnderstandNaturalDisasters.aspx

60 World Health Organization. 'Earthquakes – Technical Hazard Sheet – Natural Disaster Profile.' 2014. http://www.who.int/hac/techguidance/ems/earthquakes/en/

61 Seismological Society of America. 'Improving earthquake early warning systems for California and Taiwan.' Science Daily, 30 October 2013. www.sciencedaily.com/releases/2013/10/131030125621.htm

62 University of Berkeley Seismological Lab. 'EEW: Earthquake Early Warning.' 2014. http://seismo.berkeley.edu/research/early_warning.html

Figure 17 **Earthquake risk reduction measure comparison analysis**



Relocation

Relocation involves permanently moving residents from high-risk to low-risk areas. This measure is implemented infrequently in developed areas because of high cost, but can be extremely effective in reducing risk.

Relocation may be mandated when the land after an event becomes unsafe for development, such as in Christchurch, New Zealand.[63] This measure is best implemented with larger populations when the rewards outweigh the social and economic costs of relocation because of the significant number of lives that will be saved in the event of an earthquake, and the costs of rebuilding if a quake were to strike again.

Net social benefit

The net social benefit for this measure is moderate.

Permanent relocation theoretically eliminates displacement following an event. The social cost of relocation can be high and includes intangibles such as cultural impact. However, there can also be significant social benefits including addressing the psychological anxiety of living in an earthquake-prone location.

Net economic benefit

The net economic benefit for this measure is high.

Relocation is expensive, but it reduces significant economic loss. Relocation is less expensive than rebuilding an entire city following a disaster because the recurrent exposure remains.

Cost

The cost for this measure is high.

Both hard costs (for example, infrastructure, housing construction) and soft costs (for example, facilitation, training, social assistance, temporary public services) should be estimated using conservative assumptions, and funded over a period of years, until communities fully adapt to their new location and livelihoods are re-established. Estimates should include adequate provision for costs associated with assisting squatters or those without proof of land ownership

63 http://cera.govt.nz/residential-red-zone

and other land-tenure issues.[64] The accumulation of these costs may mean that relocation is only viable where earthquakes are expected to occur frequently.

Relocation

Recommended practices

- **New location with low-risk exposure to hazards**
- **Location appeal to communities affected**
- **Adequate resources and funding**

Obstacles

- **Compliance – Resistance from residents**
- **Cost**

Earthquake prediction

Earthquake prediction involves an organised network of strategically-placed seismic monitoring stations across the globe that transmits live data 24 hours every day. This network detects early patterns of seismic activity that suggest oncoming earthquakes, and then relays information to local authorities and communities. Though earthquake prediction is not yet advanced enough to be reliable, the research that results from this work informs other ways to reduce risk via hazard mapping and tracking historical activity, and can promote resilience over the long term.

Earthquake prediction can be useful in managing aftershocks which follow more predictable patterns.

Net social benefit

The net social benefit for this measure is low.

The social benefit of earthquake prediction is low since current systems do not provide adequate time for people to take action to protect themselves or their property. Long-term predictability reduces loss and lives affected if clearly identified high-risk areas are not developed or inhabited.

Net economic benefit

The net economic benefit for this measure is low for the same reasons as noted above for net social impact.

Cost

The cost for this measure is high.

The cost of a seismic sensor is relatively inexpensive and easily replaced. However, the communication network required for global monitoring across thousands of stations is expensive.

64 World Bank, Global Facility for Hazard risk Reduction, 'Safer Homes, Strong Communities: A Handbook for Reconstructing after Natural Disasters', 2010

Further, investment in on-going research to develop improved prediction methods is required.[65, 66, 67]

Earthquake prediction

Recommended practices

- **Ongoing research and shared knowledge**
- **Continuous improvement to develop new technologies and methodologies**

Obstacles

- **Inadequate funding**
- **Lagging scientific methods**

Tsunami warning systems

Unlike earthquakes themselves, tsunamis, which are generated by earthquakes, can allow for more warning time. Tsunami early warning systems comprise a network of sensors which detect tide height or pressure changes at sea level. These systems indicate an oncoming tsunami and trigger alarms sent through an international or regional communications infrastructure. Though effective, permanent marine sensors are expensive to install. Temporary stations sit on the ocean floor and collect data until a ship picks them up yearly. Tsunami early warning systems are generally effective although monitoring technology can malfunction (water surface level buoys are susceptible to outages in harsh conditions).

Tsunami warning systems can be effective for 'distant-source' tsunamis but are not as helpful for 'near-source' events when a wave can hit land relatively soon after the source event.

Tsunami warning systems work most effectively when informed by modelling of likely tsunami behaviour and water wave energy.

Net social benefit

The net social benefit for this measure is moderate to high.

The goal of tsunami warning systems is to trigger evacuation plans. When warning systems are used together with evacuation plans, many lives are saved. However, warning systems and evacuation plans do not protect property in the path of a tsunami.

Net economic benefit

The net economic benefit for this measure is low. The network of tsunami sensor stations does not reduce property loss such as homes or businesses.

Cost

The cost for this measure is high.

The cost of tsunami early warning systems varies by region and is impacted by risk reduction

65 Wu, Yih-Min, et al. Seismological Research Letters 84 (6). Seismological Society of America. 'A High-Density Seismic Network for Earthquake Early Warning in Taiwan Based on Low Cost Sensors.' 2013.

66 Braile, Lawrence W. Department of Earth and Atmospheric Science, Purdue University. The Geological Society of America. 'Seismic monitoring.' 2009. http://www.nature.nps.gov/geology/monitoring/files/geomon-10.pdf

67 International Federation of Digital Seismograph Networks. http://www.fdsn.org/about.htm

measures already in place. Warning systems carry a relatively high cost as they require detection devices on the ocean floor, ocean surface, and require qualified individuals to assess the data and perform maintenance on the devices. The Philippine Institute of Volcanology and Seismology was able to develop a cost-effective local early warning system based on a much simpler design using wet and dry sensors attached to a pole to measure rising and falling sea levels.[68]

Tsunami warning systems

Good practices

- **Advisory, watch, warning and information statements issued to alert local authorities and communities as soon as detected**
- **Clear evacuation plans that are well known to the affected community**

Obstacles

- **Compliance – Resistance from residents**
- **Warning system failures and inaccuracy**

Soil assessment

Soil assessments are both an input to hazard identification maps and a risk reduction measure. Assessments measure the liquefaction potential of a site during an earthquake. These tests provide information to identify high-risk areas prone to liquefaction, which is important to understand the extent to which soil can withstand vibration under the weight of buildings and other structures without losing stiffness and strength. There is no global standardised soil assessment measure for liquefaction, and it is difficult to compare results across different sites. It is critical to understand where to test and what values against which to measure results[69] so that buildings and other structures are built on pieces of land that have an increased resilience to shaking ground. After an event, soil assessment may inform land use and rebuilding requirements (for example, stronger building foundations).

Also, the accuracy of soil assessments depends on the experience of the people performing the test.[70] There is a gap between geotechnical and structural engineering design practice that can result in foundation failure. Geological surveyors need to work together with structural engineers to design the most resilient building for the specific site upon which it stands.[71]

While soil assessments are predictive of vulnerability, post-event experiences shows that actual outcomes may vary.

68 Becker, Sven. Spiegel Online. ''Beyond Embarrassing': Tsunami Warning System Millions Over Budget.' September 2012. http://www.spiegel.de/international/world/tsunami-early-warning-system-in-indonesia-to-cost-germany-millions-more-a-855257.html

69 Baker, Jack W. and Michael H. Faber. 'Liquefaction Risk Assessment Using Geostatistics to account for Soil Spatial Variability.' Journal Of Geotechnical And Geoenvironmental Engineering. January 2008. http://www.stanford.edu/~bakerjw/Publications/Baker%20Faber%20(2008)%20spatial%20liquefaction%20risk,%20JGGE.pdf

70 Rogers, J. David. 'Subsurface Exploration Using the Standard Penetration Test and the Cone Penetrometer Test.' Environmental & Engineering Geoscience, Vol. XII, No. 2, May 2006. The Geological Society of America. http://www.geoplanning.it/test/wp-content/uploads/2012/02/Subsurface-Exploration-Using-the-Standard-Penetration-Test-and-the-Cone-Penetrometer-Test.pdf

71 Oliver, Stuart, John Hare and Nick Harwood. 'Soil Structure Interaction Starts With Engineers.' 2013 NZSEE Conference. New Zealand Society for Earthquake Engineering. http://www.nzsee.org.nz/db/2013/Paper_45.pdf

Net social benefit

The net social benefit for this measure is low to moderate.

Soil assessment allows individuals to understand the risk exposure to liquefaction and the opportunity to use mitigation measures to reduce risk.[72]

Net economic benefit

The net economic benefit for this measure is moderate to high.

Overall, economic benefit is high when testing is coupled with building site identification and construction. The extent of damage and recovery costs decreases when buildings are erected on sites with desired soil profiles for the respective area.

Cost

The cost for this measure is moderate.

Individual tests are relatively low cost compared to more sophisticated laboratory measures.[73] However, in high-risk seismic areas where soil is disturbed more frequently, repetitive testing results in larger costs.

While the cost of an assessment may be moderate, to act upon the assessment may be very costly (for example, stronger foundations in existing buildings).

Soil assessment

Recommended practices

- **Set of realistic soil sample profiles**
- **Statistical measures that are more easily interpreted**
- **Multiple tests to identify sites correctly**

Obstacles

- **Difficulty of cross-site assessment comparison**
- **Lack of global standardised assessment methodology**
- **Assessment interpretation varies**

Building codes

Building codes help communities establish common standards for proper construction. They address what types of materials should be used and construction methods. Codes and related updates must be commensurate to the level of risk.

Updating codes too frequently can have adverse effects. For example, in Japan, the average home life span of only 36 years is attributed to frequent building code updates. Four significant updates over the past 40 years have meant it was easier to rebuild from scratch than to update.

72 New York City Government. New York City Natural Hazard Mitigation Plan. 'Earthquakes Hazard Analysis for New York City.' March 2009. http://www.nyc.gov/html/oem/downloads/pdf/hazard_mitigation/section_3h_earthquake_hazard_analysis.pdf

73 Mayne, Paul W. 'Cone Penetration Testing State-Of-Practice.' Transportation Research Board. NCHRP Project 20-05, Topic 37-14. February 2007. http://geosystems.ce.gatech.edu/Faculty/Mayne/papers/NCHRP%20CPT%20Synthesis%20(2007)%20color.pdf

Revision of building codes for sound policy reasons can bring significant funding challenges for communities required to retrofit property to a new standard after an event.[74]

Building codes must be implemented and enforced to be effective. Given the high cost of building code compliance for property investments, corruption has surfaced in some jurisdictions as a barrier to effective enforcement.

The effectiveness of building codes in building overall resilience will depend upon their policy setting. Some building codes are directed to saving lives and habitability, but not to the structural integrity of a building or infrastructure, resulting in significant economic loss.

Net social benefit

The net social benefit for this measure is high.

Collapsing buildings cause most earthquake-related deaths.[75]

Building codes and enforcement can reduce deaths. By implementing building codes, developed countries have significantly reduced the number of deaths caused by earthquakes. Developing countries have an opportunity to increase earthquake risk-sensitive property investments—key to this is integrating disaster risk management objectives into development objectives.

Net economic benefit

The net economic benefit for this measure is moderate to high.

While building codes help protect assets, there is still retained risk for events beyond the probable. Catastrophic earthquake events may still result in significant costs to rehabilitate buildings to operational levels.

Cost

The cost for this measure is low.

The cost to develop, update and adhere to building codes for new construction quickly pays for itself because it lowers risk, offsetting future costs. The high cost does not come from developing the codes, but from requiring more expensive materials for building and for retrofitting existing buildings.

Building codes

Recommended practices

- **Align resilience level to expected intensity of highest probability event**
- **Non-structural measures designed to address different disaster scenarios**

Obstacles

- **Lack of adherence to and enforcement of building codes**
- **Incorrect building code interpretation**
- **Lack of structural resilience to forces that exceed design limits**

74 In New Zealand, the Building (Earthquake-prone Buildings) Amendment Bill will require all non-residential and multi-storey residential buildings to be upgraded to new standards or demolished within 20 years.

75 As Jo da Silva, head of Arup International Development, said to the United Nations Office for Project Services, 'Earthquakes don't kill people. Collapsed buildings do.'

Retrofitting

Retrofitting of existing construction enhances building resilience against seismic activity. Cost is the major obstacle to retrofitting. In many developing countries, retrofitting is generally not financially viable for individual households and too expensive for governments.

Masonry buildings are both highly susceptible to risk and more expensive to retrofit than concrete. Since 1989, the US Federal Emergency Management Agency has sponsored 390 grants involving retrofitting. The average cost of these projects was USD 2.8 million.

In terms of funding, targeted retrofitting can be effective, especially when funds are limited and the risk exposure is high. Funds can be selectively targeted to retrofit the highest-risk buildings. Hospitals and historically-significant buildings are often designated for retrofitting.[76, 77]

Case study — Retrofitting practices in Mexico City

The Mexican government identified vulnerable buildings in Mexico City that would not survive even a moderate earthquake. Retrofitting every building in the city would be too expensive and could not be reasonably completed. Therefore, city officials used a targeted approach to identify the most vulnerable 1%, 5% and 10% of buildings by potential death tolls.

The study found that retrofitting the worst 5% of buildings in the city could reduce deaths from a severe earthquake by 50%. A retrofit of the worst 10% of buildings could reduce fatalities from a severe earthquake by 80%.

If a strong earthquake were to strike without appropriate retrofitting, deaths would be very high and the cost of retrofitting would be spread over all of the deaths avoided. However, a less severe earthquake would not cause as many deaths, but the cost of the retrofit would remain the same. Therefore, the cost of retrofit correlates with the anticipated strength of the earthquake. In the example above, the cost per life saved could be between USD 5,000 and USD 50,000.

While the cost may be high, the benefits to both present and future generations are also high. Foreigners would view the city as safer and could lead to increased foreign investments in the economy.

Although not exactly the same magnitude or proximity to Mexico City, there was an earthquake in 2012 similar to the one in 1985. The 2012 earthquake was a 7.4-magnitude event (versus 8.0 for 1985) with an epicentre of 500 kilometres (versus 350 for 1985) from Mexico City. Three deaths were attributed to this event versus at least 10,000 in the 1985 earthquake. It should be acknowledged that various factors played a part in reducing the death toll, but targeted retrofitting and updated building codes were major contributors.

Source: Coburn, Spence, 2006, Earthquake Protection: Second Edition

76 Multidisciplinary Center for Earthquake Engineering Research (MCEER) 'The ABCs of Seismic Building Codes.' https://mceer.buffalo.edu/publications/Tricenter/04-sp02/1-03abcs.pdf

77 'Methods for Seismic Retrofitting of Structures.' Massachusetts Institute of Technology. http://web.mit.edu/istgroup/ist/documents/earthquake/Part5.pdf

Net social benefit

The net social benefit for this measure is moderate to high.

Similar to building codes, retrofitting saves lives by reinforcing existing structures against ground shaking. Also, the preservation of historical buildings and cultural heritage is often a favourable downstream social benefit.

Net economic benefit

The net economic benefit for this measure is high.

In high-risk areas, the economic benefit of retrofitting is particularly high because it helps maintain the integrity of the structure against ground shaking.

Cost

The cost for this measure is high.

Depending on the structure and building materials, retrofitting could cost as much as 40% of the total value of the home. However, it is generally not as expensive as rebuilding after an earthquake event.

A word on ecosystems

Natural ecosystems such as mangroves, coastal sand dunes and wetlands cannot directly reduce earthquake risk. However, they can reduce risk for post-earthquake events such as tsunamis, flooding, seawater inundation, landslides and rock falls.

As for cyclone storm surge, coastal and marine ecosystems such as mangroves and coastal marshes, beach dunes and coral reefs can provide some protection from tsunami waves depending on their height. Conversely, these ecosystems are also disturbed by earthquakes and suffer loss and damage.[78, 79, 80]

In earthquake-prone regions, denser vegetation cover on slopes can minimise the risk of landslide.[81]

78 Marin, Andrés, Stefan Gelcich, and Juan Carlos Castila. 'Ecosystem Services and Abrupt Transformations in a Coastal Wetland Social-Ecological System: Tubul-Raqui after the 2010 Earthquake in Chile.' Ecology and Society. Volume 19, No. 1. 2014. http://dx.doi.org/10.5751/ES-05633-190122

79 Wang, Y.K., B. Fu, and P. Xu. 'Evaluation the impact of earthquake on ecological services.' Procedia Environmental Sciences. Volume 13. Elsevier B.V. 2012. http://www.sciencedirect.com/science/article/pii/S1878029612000904

80 Gupta, Anil K. and Sreeja S. Nair. 'Ecosystem Approach to Hazard risk Reduction.' National Institute of Disaster Management (NIDM). 2012. http://nidm.gov.in/PDF/pubs/Ecosystem%20Approach.pdf

81 Peduzzi, P.: Landslides and vegetation cover in the 2005 North Pakistan earthquake: a GIS and statistical quantitative approach, Nat. Hazards Earth Syst. Sci., 10, 623-640: http://www.nat-hazards-earth-syst-sci.net/10/623/2010/nhess-10-623-2010.pdf

Flood risk reduction measures

Key points

- **Floods have affected more people than all other hazards combined**
- **Structural measures which divert floodwaters are the most effective means for managing flood risk**
- **There needs to be a strategic focus on an entire flood basin**
- **Wetlands are a natural alternative and bring downstream benefits**
- **Land-use planning is an effective measure to promote disaster risk-sensitive development choices**

While floods have claimed fewer lives than cyclones and earthquakes, they have affected more people than all other hazards combined. Moreover, flooding impacts many areas around the world, occurs more frequently than any other hazard, and can occur with little or no warning ('flash floods'). Figure 18 shows the regions affected by floods.

Between 1970 and 2012, 3.1 billion people in Southern and Eastern Asia were affected by flooding.[8] While many survived the floods, the impacts were severe—livelihoods, education and homes were compromised.

Figure 18 **Flood exposure by frequency**

Source: Global Risk Data Platform. Created and hosted by UNEP/GRID-Geneva. Supported by UNISDR.
http://preview.grid.unep.ch/index.php?preview=data&events=floods&evcat=2&lang=eng

Floods affect individuals, communities and businesses. They damage infrastructure and make it difficult to find clean drinking water. Floods contribute to the spread of disease and malnutrition. Only when communities build adequate resilience to the inundation of floodwaters will downstream recovery become manageable.

Communities have largely chosen to live close to water sources, whether for survival or amenity, but this proximity carries with it the risk of flooding. Communities must manage the threat of flood while enjoying the benefits that waterways provide. There are many flood risk reduction measures and more innovative measures are emerging.[82]

The following table assesses the relative economic and social costs and benefits and downstream impacts of each specific flood risk reduction measure. Risk reduction measures also common to cyclone and earthquake are addressed in the 'mutli-hazard' section of this paper.

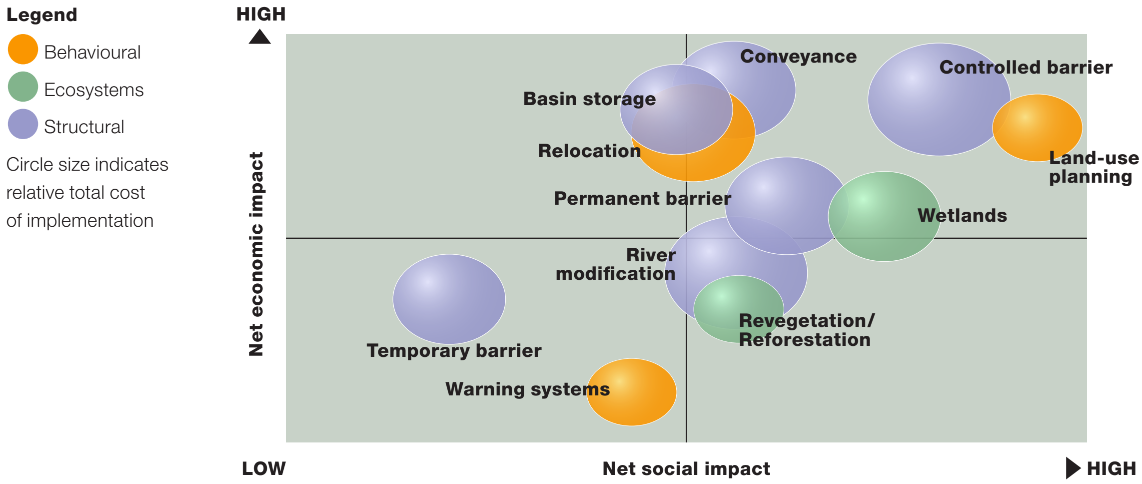
Figure 19 (below) was populated using an assessment of each measure's economic and social impact along with their downstream impact.

Figure 19 **Flood risk reduction measure comparison criteria**

Initiative	Economic benefit	Social benefit		Cost	Downstream impact
		Lives saved	Reduction in lives adversely affected		
Permanent barrier – Block	Moderate/High	Moderate	High	Moderate/High	
Controlled barrier – Block, divert	High	High	High	High	• Potentially negative ecological effects
Temporary barrier – Block	Low/Moderate	Low	Moderate	Moderate	
Wetlands – Block	Moderate/High	Moderate	High	Moderate	• Ecological habitat
Revegetation / Reforestation – Block	Low/Moderate	Moderate	Moderate	Low	• Stronger ecosystems
River modification – Reduce	Low/Moderate	Moderate	Moderate	High	• May increase flooding downstream
Conveyance – Divert	High	High	Moderate/ High	Moderate/ High	• Improved urban drainage • Irrigation
Basin storage – Divert	Moderate/High	Moderate	Moderate	Moderate	• Low-risk use of land
Relocation	High	Moderate	Moderate	Moderate/High	
Warning system	Low	High	Low	Low	• Less benefit for flash floods
Land-use planning	Moderate/High	High	High	Low	

82 Van Wesenbeeck, Bregje K. et al. 'Damming deltas: A practice of the past? Toward nature-based flood defenses.' Estuarine, Coastal and Shelf Science 140 (2014) 1-6

Figure 20 **Flood risk reduction measure comparison analysis**



Strategies for water control

For this paper, the following methodology is used to categorise flood risk reduction strategies:

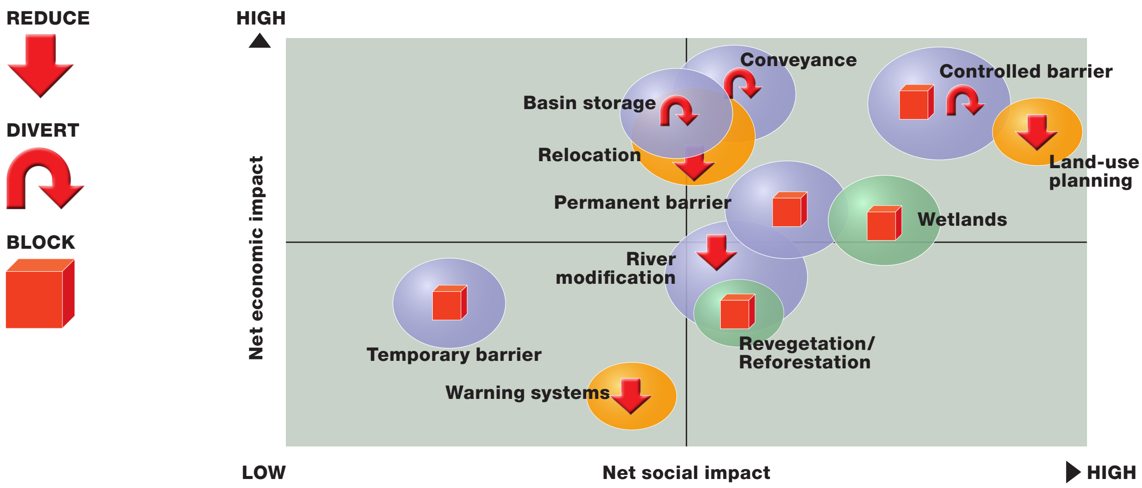
1. **Reduce –** Behavioural measures which attempt to avoid exposure to flood risk
2. **Divert –** Structural measures designed to direct floodwaters to lower-risk areas where the volume can remain for some time and dissipate. These methods often seek to manage water and leverage it for the benefits that flooding can bring. These methods seek to exert a level of control over the water by planning where water will be diverted
3. **Block –** Structural and ecosystem measures that stand up to rushing waters and restrict their advance towards properties. These measures do not reduce overall river basin risk but shifts the flood risk elsewhere

A further emerging category may be adaptive measures that treat the asset, not the water.

Using this categorisation can be helpful in understanding risk reduction strategies and planning. The research makes it clear that a balance of measures across these categories is the most effective approach.

The chart below identifies these categories for each risk reduction measure analysed.

Figure 21 **Flood risk reduction measure comparison analysis including measure type categorisation**



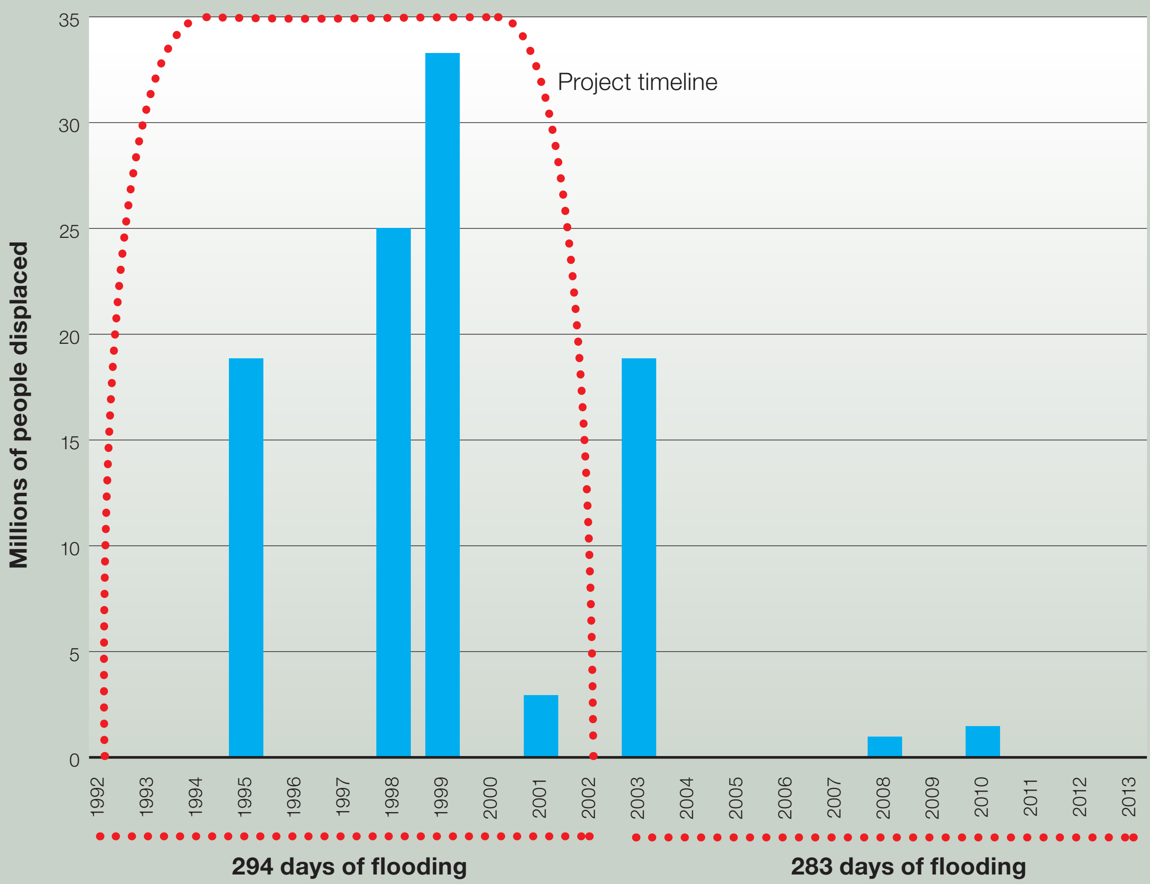
Case study Successful portfolio approach in Dhaka, Bangladesh

Flooding is a major problem in Bangladesh and its capital, Dhaka. Bangladesh is a developing country with 80% of its land mass seated in a flood plain. Given this exposure, the Bangladeshi government implemented a large-scale plan to manage flooding using a portfolio of risk reduction measures. This plan was implemented from 1992 to 2002 and was funded largely by the Asian Development Bank at a cost of USD 160 million, which included land acquisition, project management, consulting services, and materials. The government implemented structural flood protection measures, improved retention and drainage, and invested in warning systems.

In the decade after the completion of this flood management strategy, despite a near identical number of days of flooding (compared to the previous decade), a drastically smaller number of people were displaced. Figure 22 (below) shows the number of persons displaced by flooding before and after implementing the flood management plan.

In this case, a combination of structural and non-structural measures were implemented and successfully protected the people of Dhaka from the flooding, and allowed them to continue with their lives without major disruption and cost due to displacement. These measures included barriers, storage, drainage, warning, and social improvement. These measures came at a cost but their implementation has greatly benefited Bangladeshi citizens.

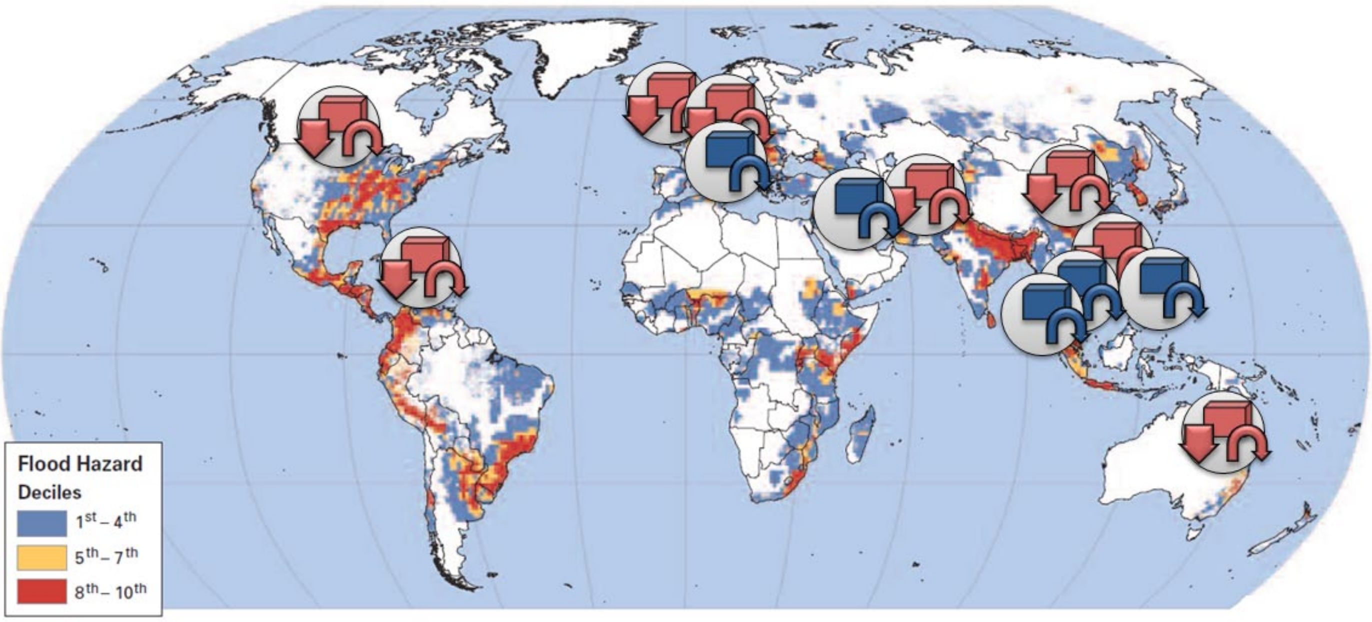
Figure 22 **People displaced by floods in Bangladesh**



Sources: Faisal (1999), Asian Development Bank (2002), Sultana (2012), and Dartmouth Flood Observatory

Almost every study conducted on flood risk reduction recommends a portfolio approach where a mix of reducing, diverting and blocking measures are used across an entire river basin. Figure 23 (below) provides a summary of the type of measure that each study recommended by location.

Figure 23 **Summary of 13 case studies inspected and their recommended types of flood risk reduction measure**



Permanent barrier – Block

Permanent barriers are one of the most frequently used flood control methods. They block water from flowing into high-risk areas. Examples of permanent barriers include dams, levees or dykes, self-closing flood barriers, weirs, floodwalls, seawalls and embankments. These are efficient measures and can provide reliable protection when floodwaters do not exceed designed capacity. However, these barriers may be destroyed or fall apart over time due to natural and human activity.[83] Since they are immobile, they can become less effective over time as they are stressed by rising waters or made redundant through the impact of rising sea levels as a result of climate change.

Stakeholders often rely too heavily on these types of large-scale structural methods.[84] An example of this is the 'levee-effect,' which occurs when people gain a sense of security from what they perceive to be invincible structural protectors. This false sense of security drives them to increase property exposure in the area and subject themselves to loss caused by low-frequency, high-severity floods.[85]

83 World Bank 'Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century' (Jha, Abhas K., Bloch, Robin, and Lamond, Jessica) 2012

84 CSDS-IACC. Comparative Studies on Development Strategies considering Impact of Adaption to Climate Change. 'CECAR series No.12 Climate and Ecosystems Change Adaption Research.' 2012

85 Castellarin, Attilio, et. al 'Identifying robust large-scale flood risk mitigation strategies: A quasi-2D hydraulic model as a tool for the Po river.' Physics and Chemistry of Earth 36 (2011) 299-308

While generally effective, there is a point at which levee heightening is not technically possible or economically feasible. At that point, efforts and funding should be directed towards flood risk reduction measures that have a higher per-dollar impact. In Australia in the 1990s, an Economic Impact Statement determined that the most cost-effective way of reducing local vulnerability to flood was to raise the level of a dam in the Hawkesbury-Nepean Valley by 23 metres.[55]

One type of barrier—embankments—presents potentially negative impacts. Embankments simply move the water farther downstream, which could negatively affect ecosystems and other communities. For example, this is of particular concern in Thailand.[86]

Some structural measures displace floodwaters to a point where downstream towns and villages must relocate. There is also the risk that if the permanent barrier is breached, water will not be able to flow back into the river once floods subside, leading to increased economic damage and social costs.

Net social benefit

The net social benefit for this measure is moderate to high.

Well-planned and implemented permanent barriers can save lives and protect towns from being inundated with floodwater. However, this measure is only effective to the anticipated, designed flood level. Implementing permanent barriers requires little need for a change in behaviour, other than conducting routine maintenance.

Net economic benefit

The net economic benefit for this measure is moderate to high.

Permanent barriers can save towns from being overtaken by floods and causing millions of dollars in damage. In Iran, levees and dams were expected to provide economic benefits ranging from USD 350,000 to USD 6,640,000.[87] These projections represent a reduction in costs that would be incurred in future expected recovery efforts. Beyond avoided recovery costs, the construction of structural barriers creates jobs and demand for construction materials, providing economic and social benefit.

Cost

The cost for this measure is moderate to high.

Structural barriers can be expensive to implement and cost depends on the size of the river and of the barrier. All measures need to be tailored to the circumstances of the communities they protect, particularly in the case of structural barriers. If these barriers are inadequate or unsuitable for their areas, the investment in them may be squandered and the community could suffer large losses. For example, on the Mississippi River in 1993, over USD 55 million of damage was caused by levees that failed.[88]

In Australia, a study for the Gympie Regional Council explored different options for building levees to protect the town from flooding. Costs for construction were estimated between AUD 8 million and AUD 27.6 million per levee. The study recommended the town build a

86 Kuntiyawichai, Kittiwet, et al. 'Comparison of Flood Management Options for the Yang River Basin, Thailand.' Irrigation and Drainage 60 (2011) 526-543

87 Heidari, A. 'Structural master plan for flood mitigation measures.' Natural Hazards and Earth System Sciences 9 (2009) 61-75

88 Heller, Peter, 'Army Engineers Fight to Save Louisiana from Katrina-Like Event', 2011, http://www.bloomberg.com/news/2011-06-09/army-engineers-fight-to-save-louisiana-from-katrina-like-event-.html

levee costing AUD 22.7 million with a useful life of 50 years. This cost only covered a levee that provided 30-year flood protection and did not include the evaluation or flood-mapping costs. Recurring maintenance costs amounted to AUD 40,000 a year.[89] These on-going maintenance costs can add up to a significant portion of a town's annual budget.

Permanent barrier – Block

Recommended practices

- **Flood plain knowledge**
- **Structural maintenance**
- **Proper location**

Obstacles

- **Implementation and maintenance cost**
- **Lack of engineering expertise**
- **Unsightly**
- **Interference with natural flooding**
- **Potential damage to floodplain ecosystems**

Controlled barrier – Block, divert

This risk reduction measure carries the same benefits as permanent barriers but allows for better control of water flow through the structure or to other locations. This allows for water levels behind the structure and in the river to be controlled during times of flood or drought. Examples of controlled barriers include floodgates and sluices.

Net social benefit

The net social benefit for this measure is high.

Controlled barriers allow for management of water levels. This control reduces risk because of the ability to regulate the amount of water flow and maintain consistent water levels via the release of water. This control makes this measure superior to permanent barriers. However, they can have a greater negative effect on ecosystems than permanent barriers because water flow fluctuation disrupts plants and wildlife.

Net economic benefit

The net economic benefit for this measure is high.

The economic benefit of controlled barriers can be even higher than permanent barriers because these structures control water levels and facilitate a dynamic and integrated water management system. This means these systems can handle a larger amount of water than a wall that simply blocks water flow. They also provide a foundation for more developed conveyance storage basins.[90]

89 Aurecon Group, 2013, https://www.gympie.qld.gov.au/documents/40005057/40005560/Gympie-Flood-Mitigations-Options.pdf

90 According to a study by Jean-Luc deKok from the Centre for Integrated Environmental Development, 'controlled retention at the most upstream possible location and largest possible extent generate the most pronounced reduction of average annual damage.' De Kok, Jean-Luc and Malte Grossmann, 'Large-scale assessment of flood risk and the effects of mitigation measures along the Elbe River.' Nat Hazards 52 (2010) 143-166.

Cost

The cost for this measure is high.

The costs for controlled barriers are higher than permanent barriers because controlled barriers require more planning and construction of systems. There are also costs associated with tracking and actively managing the water flow. The high cost is a major deterrent to adopting this risk reduction measure, particularly for many developing countries.

Controlled barrier

Recommended practices

- **Designed and engineered to effectively manage water flow**
- **Location selected for construction of barrier that has the largest positive downstream impact**

Obstacles

- **Implementation and maintenance cost**
- **Lack of engineering expertise**
- **Unsightly**
- **Negative ecological effect**
- **Possibility of human errors in water flow management (for example, floodgates)**

Temporary barrier – Block

Temporary barriers, such as sandbags and clay dykes, are relatively inexpensive and can protect smaller areas and property exposed to flood risk. These measures require advance warning for timely placement and are usually removed shortly thereafter. Temporary barriers can be effectively used to complement other flood management measures.

Net social benefit

The net social benefit for this measure is low to moderate.

Temporary barriers require large quantities of materials (for example, sandbags) and are labour-intensive to install. They have been proven to stop water inundation but do not always provide a watertight seal and only cover a small targeted area. Generally, floodwaters that can be stopped by placing sandbags around homes would not claim lives. However, temporary barriers can have a large social impact by reducing the number of lives affected by flooding by reducing the clean-up cost and the need to replace property.

Temporary barriers can be used for community protection but should not be considered a long-term flood management plan.

Net economic benefit

The net economic benefit for this measure is low to moderate.

Temporary barriers can reduce economic damage caused by floodwaters in small areas, thus reducing recovery costs. These barriers can help block floodwaters and protect house foundations, electrical and plumbing systems, and personal property. However, temporary barriers only protect a small, targeted area, generally at the reaches of the inundation, and therefore can only deliver a moderate benefit.

Cost

The cost for this measure is low.

On a small scale, temporary barriers like sandbags are a relatively inexpensive means of flood management at the household level. The US Federal Emergency Management Agency cites the example of a man in Louisiana who spent USD 800 to protect his home from a coming flood. This amount was less than the deductible of his homeowners insurance and proved to be fully effective at stopping the floodwaters from entering his home.[91]

Other temporary barriers such as clay dykes can provide protection but these are more costly due to engineering required and greater resources needed for implementation. A temporary clay dyke constructed by the US Army Corps of Engineers protected a North Dakota town. The cost of the project was USD 1.7 million and helped protect 220 households that were undamaged by the floodwaters. On average, this equates to a cost of over USD 7,700 per household.[92] This amount is high for an individual but low when compared to large-scale structural measures.

Temporary barrier

Recommended practices

- **Proper setup**
- **Early warning**

Obstacles

- **Requires resident engagement and labour-intensive**
- **Only protects against low-severity floods**

Wetlands – Block

Wetlands are a natural alternative to permanent barriers and provide protection to communities from flooding. Wetlands can absorb floodwaters. One acre of wetlands can store about one million gallons of floodwater. According to the US Environmental Protection Agency, a 65-acre piece of land in Pennsylvania is expected to hold 63 million gallons of water.[93] Wetlands occur naturally, but are often drained to create farmland without an understanding of the protection wetlands can provide in times of flood. Restoring, conserving and constructing wetlands is an effective and sustainable way to prevent flooding for many communities.

Net social benefit

The net social benefit for this measure is moderate to high.

Wetlands provide the same social benefits as permanent barriers and also provide a positive downstream environmental impact. Wetlands can provide nitrogen and phosphorus control which helps increase nutrients downstream. Wetlands also provide recreational benefits and are a source of income and subsistence through fishing and other activity.

91 'Sandbag Levee Saves Homeowner from Flooding - and Grief.' Lessons Learned Information Sharing. FEMA. August 2012. https://www.llis.dhs.gov/content/sandbag-levee-saves-homeowner-flooding-and-grief

92 'North Dakota Community Effort Saves Neighborhood.' Lessons Learned Information Sharing. FEMA. June 2006. https://www.llis.dhs.gov/content/north-dakota-community-effort-saves-neighborhood

93 http://water.epa.gov/type/wetlands/outreach/upload/Flooding.pdf

A study performed by the Wetlands Initiative estimated the net benefit for converting crops into wetlands in a 100-year flood zone in five states along the Mississippi River in the United States. It found a higher number of bird species from 53 to 145 if the plan was implemented. Also, moving human economic activity outside of the 100-year flood zone protected assets. The net social benefit was USD 74 per acre including estimated environmental benefits, but the owner of the land would lose USD 85 per acre in net farming income. This example shows that while converting farmland back into wetland may be socially beneficial, it may not be economically ideal, as it may trade off the economic benefits of farming and impact livelihoods.[94]

Net economic benefit

The net economic benefit for this measure is moderate to high.

Wetlands can provide an overall economic benefit to communities by protecting assets and reducing the frequency of flooding in the same way as barriers. The Mississippi River project led by the Wetlands Initiative claimed to have saved USD 16 billion in flood damage along a five-state watershed.[95]

However, there can be a trade-off if the creation of wetlands restricts the land from being used for farmland or other economic purposes. Partially due to this restriction, one study found that the cost-benefit ratio for wetlands was only 1:1.3 in economic terms.

Cost

As with mangrove forests, the cost of measures for this hazard will depend on the extent of the intervention. Conserving and restoring existing wetlands will be less expensive than establishing new ones.

This means that the cost for this measure ranges from low to high.

The Wetlands Initiative report estimated cost between USD 298 and USD 1,000 per acre to construct wetlands over a 20-year lifespan. This study determined an annual cost of upkeep of USD 40 per year per acre. Land acquisition costs are usually high because of the value of waterfront properties and must be factored into the overall cost of the project. However, these are one-time costs that can be depreciated over the life of the wetland. Overall, wetlands are a low-cost solution relative to other structural flood risk reduction measures, and also provides many positive downstream benefits.

Wetlands

Recommended practices

- **Environmental benefit**
- **Strategic placement to protect greatest concentrations of people and economic assets**
- **Need to serve as a sufficient buffer**

Obstacles

- **Reduced farmland and income generation**
- **Opportunity cost – Where people and assets concentrate the cost of preserving wetlands is higher**

94 Hey, Donald, Wetlands Initiative, http://www.wetlands-initiative.org/images/pdf-docs/pulblications/FLOOD/research/flood_damage_reduction_in_umrb.pdf

95 Environmental Protection Agency. 'Wetlands: Protecting Life and Property from Flooding' May 2006

Revegetation/Reforestation – Block

Mountain forests and other vegetation on hillsides and riverbanks protect against erosion and increase slope stability by binding soil together. They reduce runoff through absorption and transpiration. Catchment forests reduce risk of floods by increasing the absorption of rainfall, and delaying peak floodwater flows, except when soils are fully saturated.[96]

A comparison between Haiti and its neighbour, the Dominican Republic, provides a stark contrast between the devastating impact that heavy rains, poor drainage and denuded hillsides can have.[97]

Net social benefit

The net social benefit for this measure is low to moderate.

As with other ecosystems, it can promote biodiversity conservation and provide wildlife habitat and carbon capture.

Net economic benefit

The net economic benefit for this measure is moderate.

Reforestation and revegetation can provide an overall economic benefit to communities by reducing the severity of flooding by increasing the absorption of flooding rains and reducing silt deposit from erosion.

Cost

The cost for this measure is low, although costs very much depend on location.

Protecting forests and riverbank ecosystems is more cost effective than replacing or replanting them. However, modest cost can result in significant downstream impacts. Cost effectiveness may also be influenced by the commodity value of what is planted.[98]

Revegetation/Reforestation

Recommended practices

- **Consultation with community**
- **Planting vegetation which also has an economic benefit**
- **Identification of incidental community benefits (for example, stronger ecosystems, higher property values)**

Obstacles

- **Reduced farmland and income generation**

96 http://www.coe.int/t/dg4/majorhazards/ressources/pub/Ecosystem-DRR_en.pdf
97 United Nations, World Bank, 'Natural Hazards, Unnatural Disasters', 2010
98 http://waingerlab.cbl.umces.edu/docs/DeltaLandTrustReportFinal.pdf

River modification – Reduce

River modification is designed to reduce the frequency and severity of flooding by increasing river capacity. For the purpose of this paper, river modification includes any structural risk reduction measure that increases the volume of water that can flow down a river, thus reducing the flood plain. This includes methods such as dredging to remove silt and debris from the bottom of the river, lengthening the river, and terracing. River modification is often found to be unsustainable without constant reinvestment, unless the modification returns river flow back to a natural state. As set out above, a better way to increase river capacity may be to protect rivers from erosion through efforts such as planting vegetation. Erosion reduction decreases silt build-up in the river. Reforestation was explicitly recommended as one part of an integrated flood management strategy in Haiti.[99]

The UK Environment Agency suggests 'remeandering' of straightened rivers as a viable flood risk reduction measure. This increases the length of the river and can effectively store more water during flood protecting downstream locations.[100] This can also improve the ecological quality of the river and improve habitats.

Net social benefit

The net social benefit for this measure is moderate to high.

Successful river modification can reduce flooding, save lives and reduce the number of people affected by flooding. However, the unavoidable uncertainty of how the modification will impact the larger natural ecosystem and how effective it will be at reducing flooding in the long term makes the social benefit very difficult to predict, even at an individual project level. Some studies have shown that river modification makes future flooding worse with consequent social impact. The risk of water returning to its natural path will always exist and therefore land use must still be controlled in areas where the water flowed previously.

Net economic benefit

The net economic benefit for this measure is low to moderate.

River modification, when properly planned, implemented and maintained, can reduce the amount of economic damage that flooding can cause.

However, modifications may cause water to move downstream faster, increasing the risk of flooding in other communities. They may also have detrimental downstream ecological effects. River modification provides lower benefits relative to cost when compared to other structural measures such as flood defences and improved urban drainage.[101]

Cost

The cost for this measure is high.

River modification is very expensive and requires on-going maintenance. Annual dredging is usually necessary as floodwater will continue to deposit new silt into the river that must be removed. The US Army Corps of Engineers has spent USD 100 million annually to dredge the Mississippi River.

99 Brandimarte, Luigia, et al. 'Isla Hispaniola: A trans-boundary flood risk mitigation plan' Physics and Chemistry of the Earth 34 (2009) 209-218
100 http://evidence.environment-agency.gov.uk/FCERM/en/SC060065/MeasuresList/M5/M5T2.aspx
101 Ranger, Nicola and Ana Lopez. 'The Role of Climate Change in Urban Flood Risk Management Today.' The World Bank. http://siteresources.worldbank.org/INTEAPREGTOPHAZRISKMGMT/Resources/4077899-1228926673636/5-Nicola_Ranger_Ana_Lopez.pdf

River modification

Recommended practices

- **Removal of silt**
- **Erosion prevention**
- **Continuous monitoring and maintenance**

Obstacles

- **Cost**
- **Lack of knowledge of downstream impact**
- **Continuous silt build-up**

Conveyance – Divert

Conveyance involves building structures that divert the flow of water to lower risk areas[102] and thereby reduce the amount of water that rivers and other watercourses must carry. Conveyance can be accomplished through natural or man-made means. This includes flood channels (for example, green rivers), culverts, increasing infiltration and permeability, drainage systems, and solid and liquid waste management.[82]

Conveyance devices can also be leveraged for daily drainage, which improves urban water management and waste management. Measures that improve the ability of land to absorb water (for example, using alternatives to pavement) will naturally help build resilience to flooding.

Options such as culverts can play an important role in diverting water underneath vital pieces of community infrastructure such as evacuation roads or supply routes, which are essential to developing community resilience. However, directing too much water through drainage systems could put pressure on pipes and culverts and cause them to rupture.[82]

Net social benefit

The net social benefit for this measure is moderate to high.

Conveyance protects people from flooding by reducing the overall flood plain and allowing more water to flow without impacting the community. Conveyance can greatly reduce the impact that the flood has on the community by both diverting water from high-risk areas and increasing water capacity, which allows people to return to their normal lives faster.

Net economic benefit

While difficult to determine, the net economic benefit for this measure is high.

Conveyances are very effective at reducing flooding and protecting property. They can be leveraged as irrigation, which could lead to increased crop yield, resulting in benefits for the local and overall economy.

Cost

The cost for this measure is moderate to high.

102 Piper, Graham. 'Balancing flood risk and development in the flood plain: the Lower Thames Flood Risk Management Strategy' Ecohydrology & Hydrobiology (2014)

Cost for conveyance itself varies greatly based on the specific measure employed and the scale of the project. Flood bypasses in Australia were expected to cost AUD 4.4 million, with recurring costs of AUD 4,428 a year. This was much less expensive than the levee option that was presented. Conveyance does require other structural measures in place, which increases total cost.[89]

Conveyance

Recommended practices

- **Need to be positioned in low-use, non-vital areas to minimise negative impact on livelihoods**
- **Conveyance which helps divert excess water should have adequate carrying capacity (for example, drainage systems should have the right depth to allow good flows of water)**
- **Proper maintenance**

Obstacles

- **Cost**
- **Dependent on other structural measures**
- **Finding low-risk land to divert water to**

Basin storage – Divert

Basin storage diverts water to areas designed to store water during a flood using detention basins and dry wells or as part of everyday water management strategy using retention basins, reservoirs, and rainwater harvesting. Retention basins must be used together and built with other risk reduction measures such as channels and floodgates.

Net social benefit

The net social benefit for this measure is moderate.

Used together with land-use planning, these basins reduce the amount of water that needs to be stored, and can serve a social purpose. An example of this social use is tennis courts and sporting practice fields in Japan. New reservoirs can be used for recreation and tourism or relief in times of drought.[83] It is estimated that basin storage requires 63 times more land than building a channel as a bypass for water and would only reduce water levels by two-thirds in Thailand.[103]

Net economic benefit

The net economic benefit for this measure is moderate to high.

Diverting water into fields could be harmful to crops but protects homes and other structures. One study conducted in Thailand noted that retention storage, in addition to other structural measures, would reduce damage by 22%. In a more recent analysis in Thailand, a bypass was recommended as the best measure, followed by flood storage, and finally dyke structure. Basin storage is most effective when used together with other flood risk reduction measures.

103 Kuntiyawichai, Kittiwet, et al. 'Comparison of Flood Management Options for the Yang River Basin, Thailand.' Irrigation and Drainage 60 (2011) 526-543

Cost

The cost for this measure is low to moderate.

The development of a storage basin on the Wroclaw River in Poland cost USD 51 million but reduced flooding to the point where only a 1000-year flood would cause damage to surrounding towns.[83] Other storage measures offer smaller-scale, low-cost options, such as dry wells that are dug in a low-use area so that water can be stored and absorbed by the well. There are varying scales of basin projects that communities can implement. Generally, the larger the scale and higher the cost of the project, the greater the impact will be. Often, land needs little adaptation to be converted into a detention or retention basin.

Basin storage

Recommended practices

- **Needs to be placed in low-use, non-vital areas to minimise adverse impact to livelihoods**
- **Strategic placement for exposure control**
- **Needs to be extensive enough to serve as a sufficient storage**

Obstacles

- **Takes up land**
- **May require functional conveyance measures to divert flood waters to storage areas**

Relocation – Reduce

Relocation requires individuals to permanently move away from high-risk flood zones. This reduces both economic and social exposure to virtually zero. Though difficult to enforce, this is effective in areas of very high flood frequency as it effectively eliminates the recurrent risk.

Net social benefit

The net social benefit for this measure is moderate.

Weighed against the sense of loss some individuals can feel in being forced to relocate from a place of connection is the positive social benefit others can gain from addressing the psychological anxiety of living in a flood-prone area.

Relocation allows for high-risk areas to be used for public parks or wetlands. Fourteen of 16 flood relocation projects of the US Federal Emergency Management Agency that were analysed for grant effectiveness were found to have positive environmental benefits that included building wetlands at the location.[104]

Net economic benefit

The net economic benefit for this measure is high.

Voluntary buy-back initiatives, where governments and insurers give homeowners the option to sell and relocate, make financial sense for areas where floods are frequent. This can yield particularly high economic benefit when flood insurance is involved and specific buildings can

104 Rose, Adam, et al. 'Benefit-Cost Analysis of FEMA Hazard Mitigation Grants.' November 2007.

be targeted as high-risk with the potential for frequent and severe claims.

Grantham in Queensland, Australia is an example of a successful 'land swap' following the devastating loss of life and property experienced by that community in January 2011.[105] Houses were relocated in some instances to a new location eliminating future exposure to flash flooding.

Cost

The cost for this measure is moderate to high.

Relocation costs include the purchase of high-risk land and its remediation or redevelopment. It also includes moving and transportation costs and may include redevelopment costs at a new location. It requires no on-going maintenance costs and can decrease future losses for both owners and insurers. Focusing on targeted, high-risk properties rather than large, sweeping regions is usually recommended in order to contain costs.

Relocation

Recommended practices

- **New location with low-risk exposure to hazards**

Obstacles

- **Compliance – Resistance from residents**
- **Cost**

Warning system – Reduce

Flood warning systems play a vital part in alerting the public to impending disasters. However, this warning needs to be coupled with appropriate responses from authorities or communities to prepare for an event. For flooding where communities may have several days advance warning, they can erect temporary flood measures, raise or remove assets, or evacuate the area. By contrast, flash floods and failure of structural risk reduction measures allow for very little warning. Flood zones must be properly modelled to ensure all residents are aware of the susceptibility to flooding in the local area of a storm or upstream.

Net social benefit

The net social benefit for this measure is low to moderate.

Appropriate warning can provide residents with time to evacuate an area at imminent risk of flood. They can also construct temporary barriers to protect their property and reduce the impact of a flood on livelihoods.[106]

In 1976, a flood killed 139 people in the Big Thompson Canyon in Colorado in the United States. A flood of a similar force struck the same region in 2013 after a warning system was implemented. However, despite an increased population in the region, only 10 people lost their lives. These systems include hundreds of water level gauges that automatically inform

105 Queensland Flood Commission of Inquiry, 2012, http://www.floodcommission.qld.gov.au/__data/assets/pdf_file/0007/11698/QFCI-Final-Report-March-2012.pdf

106 Linham, Matthew; Nichols, Robert, 2010, Technologies for Climate Change Adaptation – Coastal Erosion and Flooding, http://orbit.dtu.dk/fedora/objects/orbit:86544/datastreams/file_5699563/content

authorities of the water levels in the area, which can then drive evacuation efforts. Without such a warning system, many more people may have lost their lives.

This risk reduction measure is assessed as low to moderate for social impact, particularly as it requires strong communication and effective evacuation efforts.

Net economic benefit

The net economic benefit for this measure is low.

In the Colorado study noted above, the warning system did not prevent damage to real estate and the region suffered USD 2 billion in economic damage.[107] This measure is primarily focused on protecting lives but can give people time to flood-proof homes.

Cost

The cost for this measure is low.

Warning systems are relatively low-cost measures compared to larger engineering efforts designed to block the flow of water. Sensors and other relatively inexpensive technology devices can trigger a warning that will alert citizens to seek shelter.

Warning system

Recommended practices

- **Reach and message clarity**
- **Education**
- **Community compliance**

Obstacles

- **Little warning for flash flooding**

Land-use planning – Reduce

Land-use planning regulates the location of different land uses in areas with the highest flood exposure. It is one of the best ways to reduce overall exposure to flooding, while still allowing access to water sources. Land-use planning includes building designs which elevate living areas or property on higher floors to reduce exposure to floodwater.

Land-use planning is dependent on accurate knowledge of exposure and an understanding of how to ensure optimal protection.[108] This measure requires developing floodplain policies, enforcing building codes and understanding the risks of building near rivers or other watercourses.

Owing to economic constraints, public policy objectives may not always be able to reflect 'best practices' emerging from the insurance industry. For example, property insurer FM Global suggests constructing buildings at two feet above 500-year flood levels.[109] But many governments use what is known as '1% strategy', which requires buildings to be protected

107 Curtis, David, 2013, http://pressreleases.kcstar.com/release/messages/51745/

108 Kuntiyawichai, Kittiwet, et al. 'Comparison of Flood Management Options for the Yang River Basin, Thailand.' Irrigation and Drainage 60 (2011) 526-543

109 http://www.fmglobal.com/fmglobalregistration/Vshared/FMDS0140.pdf

at only the 100-year flood levels—or a 1% chance of flooding each year.[110] These divergent minimum thresholds indicate the level of risk that is acceptable is often a function of the resources, including the economic resources, available for risk reduction.

Net social benefit

The net social benefit for this measure is high.

Effective land-use planning can provide for flood-prone land to be used for parks, playgrounds, and parking lots which bring social benefit and be used for water management. For example, a detention basin used as a tennis court can be flooded with very minimal impact. It has a high net social impact because it reduces community exposure to flooding but means the land can still be used for purposes that increase resilience and social value.

Net economic benefit

The net economic benefit for this measure is moderate to high.

Land-use planning can have significant economic benefit as it identifies flood-prone areas and regulates the type of building and construction materials for these areas. This regulation greatly reduces economic loss—it is a form of risk avoidance, which is usually the best option when dealing with known risk.

Cost

The cost for this measure is low.

Land-use planning requires an in-depth knowledge of the area in question, which can only be obtained by retaining hydrological and engineering expertise in the field. Enforcement of these regulations brings extra cost, mostly administrative in nature. However, these costs are relatively nominal compared to a large-scale engineering effort to control water.

Land-use planning

Recommended practices

- **Enforcement**
- **Urban planning**

Obstacles

- **Lack of enforcement**
- **Valuable land is near rivers – High desirability**

110 http://www.fema.gov/floodplain-management/flood-zones

Conclusion and next steps

Greater investment in disaster risk reduction makes sense—it reduces the human, social, economic and environmental cost of disasters, and enables communities to recover more quickly.

To implement effective risk reduction measures, communities first need to understand the level and nature of the risks they face, and the measures which will most effectively reduce these risks.

While much research has been done on these issues, it has been conducted in isolation, with little standardised, global research on the risks faced by communities around the world, and the best ways to reduce them.

The first step for the PSI Global Resilience Project has been to aggregate and synthesise risk reduction data from around the world, and assess it using consistent, globally-applicable criteria including social and economic benefit compared to cost.

Moving forward

The next phase of the PSI Global Resilience Project will be to create a global disaster map identifying the nature and severity of the threat faced by vulnerable communities worldwide. Using this information, we aim to support communities advocating for and investing in disaster resilience and implementing risk reduction measures.

Developing effective disaster resilience demands a better understanding of the risk landscape and disaster impacts, shared responsibility and new ways to collaborate, and an engaged, adaptive and supported community that is able to act on this common understanding.

Through the PSI Global Resilience Project, the insurance industry is demonstrating its commitment to driving outcomes that build disaster-resilient communities and economies.

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