TSUNAMI RISK ASSESSMENT AND MITIGATION FOR THE INDIAN OCEAN

KNOWING YOUR TSUNAMI RISK – AND WHAT TO DO ABOUT IT

July 2015
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An international group of experts in the fields of tsunami sources, propagation and inundation; hazard, vulnerability and risk assessment; also specialists in national and community preparedness and early warning; in community resilience; and in the strategic mitigation of tsunami hazard have contributed to their preparation. A Task Team established to lead the revision of the Guidelines met at the offices of the Disaster Management Centre in Colombo, Sri Lanka in February 2013 to develop the contents of the revised guidelines, to assess and plan for acquisition of information, and to develop Terms of Reference for consultants to undertake the revision. Their production has been guided by a Task Team of Working Group 1 led by Sam Hettiarachchi (University of Moratuwa, Sri Lanka, Chair of WG1) and Tony Elliott (Head of ICG/IOTWS Secretariat).

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Russell Arthurton edited and coordinated the preparation of the Guidelines.
Foreword

The Intergovernmental Oceanographic Commission (IOC) of UNESCO was given a mandate by its Member States to facilitate the expansion of global coverage of tsunami warning systems following the disastrous Indian Ocean tsunami in December 2004. This development built on the experience of the Pacific Tsunami Warning System (PTWS), operational since 1965. Additional warning and mitigation systems, co-ordinated by IOC, covering the Indian Ocean (IOTWS), the North-East Atlantic, Mediterranean and Connected Seas (NEAMTWs) and the Caribbean (CARIBE-EWS) region are now operational.

The imperative for these warning systems stemmed from the need to reduce the tsunami risk to coastal communities. However, the systems are intended to become integral components of comprehensive Multi-Hazard Early Warning Systems, covering, for example, storm surge and extreme wind-forced wave events. Each will link with appropriate existing hazard warning systems and established specialized centres. These include systems coordinated by IOC and the World Meteorological Organization (WMO), through the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). The implementation of these Multi-Hazard Early Warning Systems embraces the detection, forecasting and warning of hazard events, as well as communication and dissemination, and mitigation – an ‘end-to-end’ system.

A key component of each system is the improvement of preparedness through public awareness, education and risk assessment. Tsunami Service Providers have the important role of planning and implementing regional programmes, and providing tsunami information services to National Tsunami Warning Centres, ensuring full coordination between National Tsunami Warning Centres in the region and taking maximum advantage of this high-level cooperation. The onward communication of hazard events and the issuance of warnings by National Tsunami Warning Centres to local authorities and communities at risk are the responsibilities of individual countries.

In 2012, IOC UNESCO secured funding from the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) Multi-Donor Trust Fund for Tsunami, Disaster and Climate Preparedness in Indian Ocean and South East Asia Countries for a project entitled: “Enhancing Tsunami Risk Assessment and Management, Strengthening Policy Support and Developing Guidelines for Tsunami Exercises in Indian Ocean Countries.” One activity of the project was to revise and update Guidelines on “Tsunami Risk Assessment and Mitigation for the Indian Ocean” published in 2009 as IOC Manuals and Guides No. 52.

The purpose of the revised Guidelines is to further facilitate the implementation of tsunami risk assessment and reduction by IOC Member States. They have been produced as an initiative of Working Group 1 (WG1) of the Intergovernmental Coordination Group (ICG) for the Indian Ocean Tsunami Warning and Mitigation System (IOTWS). They have been compiled within the context of the ‘Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters’ and the follow-up agenda of the ‘Sendai Framework for Disaster Risk Reduction 2015-2030’. They describe a process aimed at fully integrating disaster risk reduction into relief and development policies and practices.

The Guidelines have been prepared by an expert group within WG1. They are intended to be user-oriented and, although focused on the Indian Ocean region, they are relevant to tsunami risk assessment and reduction at the global scale. Their compilation includes information from guidelines produced in 2009 as part of the IOC-ICAM (Integrated Coastal Area Management) programme to promote hazard awareness and risk mitigation in coastal management (IOC Manuals and Guides No. 50). They have been developed in accordance with Resolution XXIV-14, ‘Tsunamis and Other Ocean Hazards Warning and Mitigation Systems (TOWS)’, in the 24th Session of the IOC Assembly (June 2007). This resolution recognized that ‘the development and implementation of multi-hazard strategies and interoperable systems, including for tsunamis, can only be achieved through close consultation, coordination and cooperation among all stakeholders with tsunami and related ocean hazard mandates’.

Vladimir Ryabinin
Executive Secretary of IOC
Assistant Director-General of UNESCO
Executive Summary

THE DISASTER RISK REDUCTION CONTEXT OF THE GUIDELINES

The Guidelines are intended to inform and assist coastal managers and policy makers at local to national levels both in their assessment of the tsunami risk to which their communities may be subject, and in the ways in which that risk can be managed and reduced as part of their broader strategies for disaster risk reduction and emergency management. They highlight the uncertainties that affect many aspects of the assessment process, both in terms of the scale and frequency of tsunami inundation events and the social and environmental changes that might exacerbate the consequences of those events.

Much of the guidance, whether for risk assessment or risk reduction procedures, is devoted to the enhancement of technical capacities in terms of skills and knowledge at local government or community levels. However, it is the development of functional capacities at all levels of government, whether for policy-making or for implementation, that will enable a country’s technical capacities to lead to positive outcomes in risk management. The existence of an appropriate legal framework and functional capacity at the enabling (policy making) and organizational (executive) levels of government are likely to be prerequisites for success by individual practitioners at the local or community level. Thus, part of this guidance is addressed to those with responsibilities for policy making and executive management in respect of the promotion of the population’s safety and wellbeing.

The procedure described forms a sequence of assessment steps and management responses to be promoted by national policy makers and applied by managers at the local or community level as part of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS) (Fig. 1). The Guidelines accord with existing international agreements and initiatives in Disaster Risk Reduction (DRR), and are presented within the framework of Integrated Coastal Area Management (ICAM), in which the interests of all coastal stakeholders, the functioning of supporting ecosystems and the potential impacts of climate change are taken into account.

The Guidelines cover three main areas of activity.

• Chapters B–E together deal with assessing the tsunami risk. They describe the process of assessing the risk that the tsunami hazard poses to the coastal population, its supporting systems and its assets. Each of these chapters includes a table of the information sources that may be useful in making these assessments.

• Chapters F–H describe the approaches that will help to reduce the tsunami risk by strategic management and by improving the community’s preparedness in the event of a tsunami emergency.

• Chapter I considers the ways in which the reduction of tsunami risk can be promoted at the institutional level, within your country’s legal frameworks and policies for managing natural hazards, and in the context of current international initiatives and frameworks for DRR and ICAM.

The linkages between the various elements of the risk assessment and risk reduction procedures (Chapters B–H) are shown in Fig. 1. Chapter J provides an overview of the rationale and key steps to be followed in applying the sequence of procedures. Descriptions of the procedures are supplemented by case studies (Chapter K) and by details of relevant new tools and methods whose application may be considered by users of the Guidelines (Chapter L). The Appendices (M) include details of the alerting and monitoring procedures within IOTWS, describing the role of the Tsunami Service Providers; also an example of guidance in risk assessment and management at national and local levels carried out as part of IOTWS for the Sultanate of Oman.

ASSESSING THE LIKELIHOOD OF A TSUNAMI IMPACT ON YOUR COAST AND THE RISK TO YOUR COMMUNITY

Unlike storm surges and extreme wind-driven waves, which are climate-related and can be confidently forecast days ahead, most tsunamis are generated by movements on faults in the earth’s crust whose timings and magnitudes are unpredictable. Depending on the location of the tsunami’s origin, there may be little time for people at risk to evacuate to places of safety. Thus, to plan for such events, there is an imperative to understand the magnitude and spatial distribution of disaster risk, and to understand the uncertainties attached to the forecasting of loss and damage.

Chapter B describes the process of appraising possible tsunami sources and forecasting the likelihood and scale
of a tsunami inundation on your coast. The outputs from these procedures, facilitated by computer modelling, are inundation and local hazard maps covering credible tsunami scenarios from which the parameters of physical forcing at any point on the inundation zone may be estimated.

The next stage in the risk assessment process is to assess your community's vulnerability in respect of a tsunami inundation (the hazard) and to estimate the potential loss of life and damage to the built and natural environments in the event of specified tsunami scenarios (Chapter C). By integrating information on the physical nature of the inundation with knowledge of the susceptibility of people and assets to the damaging effects of such conditions, the fate of people and assets exposed to the inundation can be assessed, the information stored geospatially as an exposure map and database.

Besides the community’s intrinsic vulnerability, there are intangible characteristics and circumstances of the community that add to its susceptibility. These relate mainly to factors of governance and institutional capacity, which, taken together, impact on the community’s state of preparedness in terms of: awareness of the tsunami threat and how to respond it; capacity in terms of existing skills and resources to anticipate and manage a tsunami emergency, including participation in an early warning system; and the resilience to cope with, and recover from such an impact, including the community’s arrangements for risk transfer (Chapter D).

Chapter E deals with evaluation of the risk to the coastal community. This is a function of the community’s vulnerability in terms of its potential human and economic losses and material damage for a given scenario, its preparedness, and the probability of that scenario occurring within a defined period. The resulting risk assessment should provide policy makers and managers with a sound rationale for their responses aimed at risk reduction.

MANAGING AND REDUCING THE RISK OF DISASTER FROM A TSUNAMI IMPACT

The factors that contribute to tsunami risk, and thus the risk itself, are dynamic. An assessment carried out today may be misleading or even inappropriate in, say, twenty to fifty years’ time. Despite these uncertainties, you may be able to reduce the risk over the longer term (decades, say) by reducing your community’s vulnerability through strategic management. In the short term (a few years, say), you may be able to significantly reduce the risk by improving your preparedness to anticipate, cope with and recover from a tsunami inundation event.

The strategic management and preparedness responses that can lead to risk reduction are described in Chapters F–H. These actions are designed to address the issues identified in the assessment process, after consideration by the community of the acceptable levels of risk. They should be implemented in an ICAM context, taking account of other natural hazards to which a coastal community is, or might be, exposed, as well as other relevant issues of social, economic and environmental management.

The wave height of a tsunami on its impact on your coast and the frequency of occurrence of tsunami events are beyond your control. However, strategic management approaches may help in reducing the risk to the community of inundation from a tsunami landfall. A protective (structural) approach involves the construction or maintenance of natural or engineered physical barriers that restrict or prevent inundation; or, e.g., the introduction of building codes with the aim of making buildings less susceptible to the forces of inundation. An accommodating (non-structural) approach accepts the inevitability of inundation, but reduces risk by, e.g., reducing the exposure of community assets through land-use planning and regulation; or by the adoption of risk transfer – spreading the risk of loss and damage by insurance or re-insurance schemes.

In this guidance, preparedness is dealt with separately from vulnerability. However, it is fair to reason that any actions taken to improve preparedness, e.g., participation in an effective early warning system, or enhancing capacities at all levels of governance and management, will lead to a reduction in the community’s vulnerability. Consequently, the community’s risk due to tsunamis – notably the risk of loss of life and loss of social and economic wellbeing – may be significantly reduced by improving its preparedness. This includes its tsunami awareness and its capacity to be ready and cope with a tsunami event; having plans and procedures in place for the evacuation of a threatened community; and maintaining its ability to respond effectively to a possibly devastating event by carrying out drills and exercises.

The process of tsunami risk assessment and mitigation described in the Guidelines forms the framework of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS). The system includes as its core an ‘end-to-end’ system of real-time event detection and alerting by Tsunami Service Providers that is designed to provide your country’s National Tsunami Warning Centre (NTWC) with advisory information and data on tsunami threats.

TSUNAMI RISK ASSESSMENT AND RISK REDUCTION IN THE CONTEXT OF INTERNATIONAL INITIATIVES

Chapters A and I review the international initiatives relevant to assessing and managing the risk to coastal communities of inundation from a tsunami landfall. Improving the functional capacity of institutions that can enable and organize responses leading to DRR is a recurrent theme. UNISDR’s ‘Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters’ describes a process aimed at fully integrating DRR into relief and development policies and practices. Building on the outcomes of the Hyogo Framework, the Sendai Framework sets the agenda to 2030, focusing on
cross-cutting issues including understanding disaster risk, strengthening governance for managing risk, investing in resilience, enhancing effective response and improving recovery and reconstruction. Another UNISDR initiative, ‘Resilient Cities’, encourages local (city) governments to commit to implementing DRR activities.

The 2004 Indian Ocean tsunami disaster caused huge loss of life and devastation and prompted several governments to establish new institutions with legal mandates and budgets to plan and implement DRR. Even so, the lack of appropriate institutional structures and mechanisms to address risk in an integrated manner continues to impact development at national and sub-national levels. The governance process of ‘mainstreaming’ helps ensure that development is protected from the impacts of disasters, and that development does not exacerbate risk. To protect people and assets from natural hazards, DRR needs to be integrated or ‘mainstreamed’ into broader socio-economic development planning strategies as part of the development planning processes at national and sub-national levels. A risk-profiling and consequently a capacity-needs assessment should form the basis for institutional and governance alignment to address the risks in a systematic manner.

Establishing national disaster loss and damage information systems may be a key step in improving our understanding of the risks and building risk knowledge. Information about risks provides sound basis for decision making on every aspect of development. Communicating standardized risk information in a format that is easy to understand by various groups can lead to action, empowers policy makers and individuals.

A different type of management framework is that seen in the ICAM process, upon which the Guidelines are partly modelled. In line with that process, it is important to design strategic tsunami risk reduction responses that take account of other sea-level related hazards – notably storm surges and, over the longer term, sea-level rise related to global climate change, as well as the impact of those responses on other ICAM management efforts. There is a prime need to achieve a sustained coordination of effort among the many stakeholders, whether in risk assessment, or in the planning and implementation of risk reduction measures. The successful application of these processes, whether in planning or in emergency response, or in post-impact recovery, will depend on the effective operational coordination and cooperation of the many parties involved.
The definitions of terms used in these Guidelines accord with those of the 2009 UNISDR Terminology on Disaster Risk Reduction.

**Capacity:** The combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals.

**Coping capacity:** The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.

**Disaster:** A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

**Disaster risk:** The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.

**Disaster risk reduction:** The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events.

**Early warning system:** The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

**Exposure:** People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

**Hazard:** A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

**Mitigation:** The lessening or limitation of the adverse impacts of hazards and related disasters.

**Preparedness:** The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.

**Resilience:** The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

**Risk:** The combination of the probability of an event and its negative consequences.

**Risk assessment:** A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.

**Risk management:** The systematic approach and practice of managing uncertainty to minimize potential harm and loss.

**Risk transfer:** The process of formally or informally shifting the financial consequences of particular risks from one party to another whereby a household, community, enterprise or state authority will obtain resources from the other party after a disaster occurs, in exchange for ongoing or compensatory social or financial benefits provided to that other party.

**Structural and non-structural measures:** Structural measures: Any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard-resistance and resilience in structures or systems; Non-structural measures: Any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education.

**Vulnerability:** The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. (UNISDR comment: In common use the word is often used more broadly to include the element’s exposure.)

Source: UNISDR, 2009. Available at: http://www.UNISDR.org/we/inform/terminology
### Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>CARIBE-EWS</td>
<td>Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions</td>
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<td>CBDRM</td>
<td>Community-based Disaster Risk Management</td>
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<td>CFZ</td>
<td>Coastal Forecast Zone</td>
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<td>DLR</td>
<td>German Aerospace Center</td>
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<td>DMO</td>
<td>see NDMO</td>
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<td>DMR</td>
<td>Disaster Risk Management</td>
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<td>DRR</td>
<td>Disaster Risk Reduction</td>
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<td>EOC</td>
<td>Emergency Operations Centre</td>
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<td>GAR</td>
<td>Global Assessment Report on Disaster Risk Reduction</td>
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<td>GFZ</td>
<td>Geo-Forschungs-Zentrum (German Research Centre for Geosciences), Potsdam</td>
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<td>GIS</td>
<td>Geographical Information System</td>
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<td>GITEWS</td>
<td>German-Indonesian Tsunami Early Warning System</td>
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<tr>
<td>GIZ-IS</td>
<td>Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH – International Services</td>
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<tr>
<td>GNS Science</td>
<td>Institute of Geological and Nuclear Sciences Limited, New Zealand</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>HFA</td>
<td>Hyogo Framework for Action</td>
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<td>ICAM</td>
<td>Integrated Coastal Area Management</td>
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<td>ICG</td>
<td>Intergovernmental Coordinating Group</td>
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<tr>
<td>InaTEWS</td>
<td>Indonesian Tsunami Warning System</td>
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<td>INGO</td>
<td>International Non-governmental Organization</td>
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<td>IOC</td>
<td>Intergovernmental Oceanographic Commission</td>
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<td>IOTWS¹</td>
<td>Indian Ocean Tsunami Warning and Mitigation System</td>
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<td>ITIC</td>
<td>International Tsunami Information Centre</td>
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<tr>
<td>JCOMM</td>
<td>Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology</td>
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<td>JMA</td>
<td>Japanese Meteorological Agency</td>
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<td>JTIC</td>
<td>Jakarta Tsunami Information Centre</td>
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<td>LIPI</td>
<td>Indonesian Institute of Sciences (Lembaga Ilmu Pengetahuan Indonesia)</td>
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<td>MSL</td>
<td>Mean Sea Level</td>
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<td>NDMO</td>
<td>National Disaster Management Office</td>
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<td>NEAMTWS</td>
<td>North-east Atlantic, Mediterranean and Connected Seas Tsunami Early Warning and Mitigation System</td>
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<td>NEXIS</td>
<td>National Exposure Information System, Australia</td>
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<td>NGO</td>
<td>Non-Governmental Organization</td>
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<td>NEXIS</td>
<td>National Exposure Information System, Australia</td>
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<td>NTWC</td>
<td>National Tsunami Warning Centre</td>
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<td>PSHA</td>
<td>Probabilistic Seismic Hazard Analysis</td>
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<td>PTHA</td>
<td>Probabilistic Tsunami Hazard Analysis</td>
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<td>PTWS</td>
<td>Pacific Tsunami Warning System</td>
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<td>SOP</td>
<td>Standard Operating Procedure</td>
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<td>STHA</td>
<td>Scenario-based Tsunami Hazard Analysis</td>
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<td>TNC</td>
<td>Tsunami National Contact</td>
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<td>TOWS</td>
<td>Tsunami and Other Marine Hazards Warning System</td>
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<td>TSP</td>
<td>Tsunami Service Provider</td>
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<td>TWFP</td>
<td>Tsunami Warning Focal Point</td>
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<td>UNDP</td>
<td>United Nations Development Programme</td>
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<td>UNEP</td>
<td>United Nations Environment Programme</td>
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<td>UNESCAP</td>
<td>United Nations Economic and Social Commission for Asia and the Pacific</td>
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<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
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<tr>
<td>UNISDR</td>
<td>United Nations International Strategy for Disaster Relief</td>
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<tr>
<td>UN-OOSA</td>
<td>United Nations Office for Outer Space Affairs</td>
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<tr>
<td>UNU-EHS</td>
<td>United Nations University Institute for Environment and Human Security</td>
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<tr>
<td>WG1</td>
<td>Working Group 1 of the ICG/IOTWS</td>
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<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
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¹The IOC Assembly at its 28th Session in Paris, France, June 2015 (IOC-XXVIII, Dec.8.2i) decided to change the IOTWS acronym to IOTWMS to fully reflect the actual name of the System and the importance of Mitigation in the work of the ICG.
A Introduction

This chapter introduces the scope of the Guidelines in the context of the current international initiatives which aim to achieve disaster risk reduction (DRR) through the efforts and support of all levels of society, but with a particular focus on the roles of national and local government.

A.1 THE DISASTER RISK REDUCTION CONTEXT

Coastal areas are increasingly favoured for development and recreation. Because of this, coastal communities are becoming increasingly exposed to natural hazards that result from marine forcing. One such hazard is the catastrophic inundation of coastal land and its communities caused by a tsunami landfall. Where tsunamis are known to have occurred or are expected to occur there is a growing risk of disasters for those communities.

Whereas coastal flooding hazard events such as storm surges and extreme wind-driven waves tend to occur often enough for communities to be aware of their dangers, tsunami impacts are comparatively rare. However, geological and historical records show that they have occurred, some documenting major devastation and loss of life. In much of the region, extremely damaging tsunami events have occurred within recent living memory.

Unlike storm surges and extreme wind-driven waves which are climate-related and can be confidently forecast days ahead, most tsunamis are generated by movements on faults in the earth’s crust whose timings and magnitudes are unpredictable. Depending on the location of the tsunami’s origin, there may be little time for people at risk of inundation to evacuate to places of safety. Thus, to plan for such events, there is an imperative to understand the magnitude and spatial distribution of disaster risk, and, in particular, to be aware of the uncertainties attached to the forecasting of loss and damage, both in its scale and the frequency of its occurrence.

The environmental and demographic factors that contribute to tsunami risk, and thus the risk itself, are dynamic. An assessment carried out today may be misleading or even inappropriate in, say, twenty to fifty years’ time. There may be real uncertainties about the rates and scales of these contributing factors, adding to the challenge of effective management for risk reduction.

Much of the guidance, whether for risk assessment or risk reduction procedures, is devoted to the enhancement of technical capacities in terms of skills and knowledge at local government or community levels. However, it is the development of functional capacities at all levels of government, whether for policy-making or for implementation, that will enable a country’s technical capacities to lead to positive outcomes in risk management. The existence of an appropriate legal framework and functional capacity at the enabling (policy making) and organizational (executive) levels of government are likely to be prerequisites for success by individual practitioners at the local or community level. Thus, part of this guidance is addressed to those with responsibilities for policy making and executive management in respect of the promotion of the population’s safety and wellbeing.

The Guidelines describe the ways in which countries and communities can assess their tsunami risk and manage it as part of their broader strategy for natural disaster risk reduction and emergency management. The procedures form a sequence of assessment steps and management responses to be promoted by national policy makers and applied by managers at the local or community level as part of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS; Fig. 1). The Guidelines accord with existing international agreements and initiatives in disaster risk reduction, and are presented within the framework of Integrated Coastal Area Management (ICAM), in which the interests of all coastal stakeholders, the functioning of supporting ecosystems and the potential impacts of climate change are taken into account.

Fig. 1 The main topics addressed by the Guidelines and the linkages between them. Links in the risk assessment process are shown in orange, links from risk assessment to risk reduction in blue; feedbacks are shown in grey.
A.2 INTERNATIONAL AGREEMENTS AND INITIATIVES

Over the last 10 years, early warning systems and risk assessment have been widely recognised as vital components in our efforts to tackle disaster risk. They have featured prominently in many of the global initiatives intended to engage stakeholders and offer priorities for action. This part of the document describes in outline some of these agreements and initiatives. A more comprehensive description of each is available in the suggested additional reading at the end of this chapter.

A.2.1 HYOGO FRAMEWORK FOR ACTION 2005-2015 (HFA)

See also synopsis in Section I.1.1.

The Guidelines have been compiled within the context of the ‘Hyogo Framework for Action (HFA) 2005–2015: Building the Resilience of Nations and Communities to Disasters’ (UNISDR, 2005) and the follow-up agenda of the ‘Sendai Framework of Disaster Risk Reduction 2015–2030’ (United Nations, 2015), building on the experience of the HFA. They describe a process aimed at fully integrating disaster risk reduction into relief and development policies and practices, offering solutions for local governments and actors to manage and reduce urban risk. Local governments are the closest level of government to citizens and their communities. They play the first role in responding to crises and emergencies and they deliver to their citizens the essential services for health, education, transport and water services which need to be made resilient to disasters. The HFA has provided the basis for other initiatives as well as the Sendai Framework; these are described below, including the Global Assessment Report on Disaster Risk Reduction (GAR), the Global Risk Identification Portal (GRIP), and the UN campaign on Making Cities Resilient.

In 2005 the United Nations convened the Second World Conference on Disaster Reduction in Kobe, Hyogo, Japan. During this conference the HFA was negotiated and adopted by 168 countries. This international agreement shifted the paradigm for disaster risk management from post-disaster response to a more comprehensive approach that would also include prevention and preparedness measures.

The HFA outlined five priorities for action, and offered guiding principles and practical means for achieving disaster resilience. Its goal was to substantially reduce disaster losses by 2015 by building the resilience of nations and communities to disasters. This meant reducing loss of lives and social, economic, and environmental assets when hazards struck. It was intended to secure the commitment and involvement of all actors concerned, including governments, regional and international organizations, civil society including volunteers, the private sector and the scientific community. The identified priority areas for action were to:

• Strengthen disaster preparedness for effective response at all levels.
• Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.
• Identify, assess and monitor disaster risks and enhance early warning.
• Use knowledge, innovation and education to build a culture of safety and resilience at all levels.
• Reduce the underlying risk factors.
• Strengthen disaster preparedness for effective response at all levels.

Priority action 2 – to identify, assess and monitor disaster risks and enhance early warning – recognised that the starting point for reducing disaster risk and promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face. It also emphasized a need to understand the ways in which hazards and vulnerabilities are changing in the short and long term, and to promote action taken on the basis of that knowledge (Box 1).

Although primarily focused on strategic level guidance, HFA did identify specific actions around early warning. These included a need to develop early warning systems that are people-centred and take into account the demographic of the target community. It also stressed the need to periodically review and maintain information systems as part of early warning systems, and to establish institutional capacities to ensure that early warning systems are well integrated into governmental policy and decision-making processes.

Since the adoption of the HFA, countries in all regions have been reporting steady progress in strengthening their institutional, legislative and policy frameworks. Many have suggested that this has contributed to decreasing mortality risk, especially from floods and tropical storms. Progress has also been made in risk assessment, education, research and public awareness, and many countries have been increasing their investments in risk reduction, as well as developing risk-transfer mechanisms. Such reports suggest that the HFA has been an important instrument in raising institutional awareness and understanding, while also instilling political will.

Despite this positive evaluation, biennial reports of countries on the HFA implementation indicate that exposure of people and assets in all countries have been increasing faster than vulnerability has been decreasing. This has resulted in new risk and increasing disasters losses, with significant socio-economic impact in the short, medium and long terms, especially at the local and community level.
INTRODUCTION

Following these evaluations, a post-2015 framework for disaster risk reduction was conceived to update and reorder the strategic goals and priorities, giving appropriate visibility to all levels and placing greater emphasis on stakeholders and their role in advancing the priorities.

A.2.2 POST-2015 FRAMEWORK FOR DISASTER RISK REDUCTION


The Sendai Framework is a stand-alone document that builds substantively on, and supersedes, the HFA in order to offer a single reference document to policymakers and practitioners. It also attempts to strike a balance between, on the one hand, the need for precise and detailed guidance on a variety of critical issues of a cross-cutting nature that are relevant to all States and other stakeholders; and, on the other hand, the need to produce a concise, focused and practical outcome document.

The starting point for developing the Sendai Framework was that, overall, the HFA has provided critical guidance to reduce disaster risk. Its implementation has, however, highlighted gaps in addressing the underlying risk factors and in the formulation of goals and priorities for action.

Building on the HFA, the Sendai Framework aims to achieve the following outcome over the next 20 years: The substantial reduction of disaster losses, in lives, and in the social, economic and environmental assets of persons, communities and countries.

Taking into account the experience gained through the implementation of the HFA, and in pursuit of the expected outcomes and goals, the Sendai Framework recognises a need for focused action across sectors by States at local, national, regional and global levels.

Source: UNISDR, 2014.

BOX 1 PROGRESS AGAINST HFA PRIORITY ACTION 2

Progress against Priority Action 2 - to identify, assess and monitor disaster risks and enhance early warning

- Many countries reported progress in carrying out risk assessments. Although few countries have multi-hazard risk assessments, the development and implementation of risk assessments for specific hazards is progressing well.
- Several challenges for promoting more widespread risk assessment were reported. The most pressing is the need for setting a national standard or framework for risk assessment.
- The lack of an existing standard is related to poor coordination and the implementation of multiple risk assessments by numerous organizations (often sectoral ministries and institutes). National governments need to play a stronger role in guiding data sharing and standardising future risk assessments.
- Many countries explained the challenges in developing integrated information management systems to monitor, archive and disseminate data on key hazards and vulnerabilities. Almost all countries identified the challenge in collecting and sharing data between ministries, agencies and organizations. Consequently, there is a lack of coordination, and information is scattered across these various entities.
- Financial constraints and limited human capacity are pressing challenges for early warning systems, and there is a dependency on donors for financing.
- Along with resource and capacity issues, many countries cited a lack of multi-hazard early warning systems as a major constraint. In several cases EWS for certain risks are not present, while in others, diverse early warning systems are poorly coordinated.
- Some governments reported difficulties in delivering early warnings to every single individual, which resulted in the creation of the phrase ‘outreach to the last mile.’ Challenges are often due to distance and physical or topographical accessibility, social and institutional factors.
- Many countries emphasized the role media and telecommunications providers can play in delivering early warning related services. Because these sectors are usually private, formal procedures are required. In some countries, awareness of the media and telecom sector on disaster risk, and how they can play a role, are nonexistent; therefore, governments must support capacity building in these sectors. Media and telecommunications should be seen as critical infrastructures and made resilient to disasters.

Source: UNISDR, 2014.
Early warning systems and risk assessment also continue to feature prominently among the Sendai Framework priority areas for action:

- Understanding disaster risk: Policies and practices for disaster risk management should be based on an understanding of risk in all its dimensions of vulnerability, capacity and exposure of persons and assets and hazards characteristics. This requires an all-states and all-stakeholders effort on a number of areas for action, such as collection, analysis and dissemination of information and data, advancement of research, and the development and sharing of open-source risk models, as well as continuous monitoring and exchange of practices and learning.

- Strengthening disaster risk governance to manage disaster risk: Governance conditions the effective and efficient management of disaster risk at all levels. Clear vision, plan, guidance and coordination across sectors and participation of all stakeholders, as appropriate, are required. Strengthening the governance of disaster risk management is therefore necessary.

- Investing in disaster risk reduction for economic, social, cultural and environmental resilience: Investing in risk prevention and reduction through structural and non-structural measures is essential to enhance the economic, social, cultural resilience of persons, communities, countries and their assets as well as the environment. Such measures are cost-effective and instrumental to save lives and prevent and reduce losses. A continued integrated focus on key development areas, such as health, education, agriculture, water, ecosystem management, housing, cultural heritage, public awareness, financial and risk transfer mechanisms, is required.

- Enhancing disaster preparedness for effective response, and to ‘Build Back Better’ in recovery, rehabilitation and reconstruction: The steady growth of disaster risk, including the increase of people and assets exposure, combined with the learning from past disasters, indicate the need to further strengthen preparedness for response at all levels. Disasters have demonstrated that the recovery and reconstruction phase needs to be planned ahead of the disaster and is critical to building back better and making nations and communities more resilient to disasters.

A.2.3 THE MAKING CITIES RESILIENT: ‘MY CITY IS GETTING READY!’ CAMPAIGN

See also ‘Concept of resilient cities as a DRR framework’ (Section L.6).

The Guidelines are in accord with the subsequent UNISDR initiative, Resilient Cities, which builds on the priorities of the HFA. Resilient Cities has a ten-point checklist for making cities resilient that local governments sign up to. By doing so, local governments commit to implementing disaster risk reduction activities along these Ten Essentials (H.5, Box 34). The initiative emphasises that national governments, local government associations, international, regional and civil society organizations, donors, the private sector, academia and professional associations as well as every citizen need to be engaged in reducing their risk to disasters. All these stakeholders must play their part in contributing to building disaster resilient cities.

In a bid to strengthen our readiness to reduce disaster impacts, on 30 May 2010 in Bonn, Germany, UNISDR launched a campaign to raise awareness and boost commitment for sustainable development practices that will increase a city’s well-being and safety. With an initial two-year campaign, ‘Making Cities Resilient: My City is Getting Ready’, urged leaders and local governments to commit to a checklist of Ten Essentials that would make their cities more resilient.

UNISDR was identified as the overall coordinator of the campaign, but with the support of partners including the United Nations Human Settlements Programme (UN-Habitat), United Cities and Local Governments, (UCLG), ICLEI-Local Governments for Sustainability (ICLEI), CityNet, the European Commission Community Humanitarian Office (ECHO), the World Bank Global Facility for Disaster Reduction and Recovery (GFDRR), academic institutions and civil society groups. However, local, regional and international partners as well as participating cities and local governments were seen as the main drivers of the initiative. At the time, the stated aim of the campaign – to enlist over 1,000 local government leaders worldwide to invest more in disaster risk reduction – seemed remote. However, by April 2012, nearly two years after the launch, 1019 cities had signed up to the campaign.

In 2012, UNISDR published a report that provided a snapshot of resilience-building activities at the local level and identified trends in the perceptions and approaches of local governments toward disaster risk reduction. It examined factors that enable urban disaster risk reduction activities.

With the support and recommendation of many partners and participants, and a Mayors Statement made during the 2011 Global Platform for Disaster Risk Reduction, it was decided that the ‘Making Cities Resilient’ campaign would carry on beyond 2015. The required investment in
disaster risk reduction will take time, even for those cities that have committed to the campaign, and in doing so to improving urban planning, infrastructure and building safety; reinforcing drainage systems to reduce flood, storm and health threats; installing early warning systems; conducting public preparedness drills; and taking measures to adapt to the increasing impacts of climate change. Focal areas of the campaign have been:

- Know More and Commit: sign up more local governments and national government support for resilient cities.
- Emphasis on partnerships and UNISDR capacity as a platform and knowledge management hub.

Based on the success and stock-taking by partners and participating cities in the first phase, the campaign has shifted its focus to more implementation support, city-to-city learning and cooperation, local action planning and monitoring of progress in cities. In addition, the campaign continues to advocate widespread commitment by local governments to build resilience to disasters and increased support by national governments to cities for the purpose of strengthening local capacities.

A.2.4 GLOBAL RISK IDENTIFICATION PROGRAMME

Officially launched in 2007, the Global Risk Identification Programme (GRIP) was adopted by the UN International Strategy for Disaster Reduction system to support worldwide activities to identify and monitor disaster risks (Box 2).

GRIP is a multi-stakeholder initiative that directly aligns with the HFA’s Priority Area 2: risk identification, assessment and monitoring. Although hosted by UNDP, GRIP’s structure, is inherently multi-stakeholder, as it is a set of harmonized activities contributing to commonly-agreed-upon objectives. Dozens of organizations have been involved in its preparation, design and implementation. GRIP’s programme design reflects the information and support needs identified by the risk identification community. As one of the key thematic platforms for the implementation of the HFA by the UNISDR system, the programme was officially launched in 2007 at the 1st session of the Global Platform for Disaster Risk Reduction and has been adopted by the UNISDR system to support worldwide activities to identify and monitor disaster risk.

To achieve its objectives, GRIP mainly focuses its work on the following goals:

- Improve Coordination at global, regional and national levels to avoid duplication of efforts, optimize resources and increase effectiveness in disaster risk reduction.
- Promote Quality by developing minimum standards for risk information and establishing the necessary Quality Control mechanisms.
- Provide Integrated Support by compiling and coordinating capacity development resources that support risk assessment implementation at all levels.

A.2.5 THE GLOBAL ASSESSMENT REPORT ON DISASTER RISK REDUCTION (GAR)

A further initiative by UNISDR is the “Global Assessment Report on Disaster Risk Reduction” (GAR). This is a biennial global assessment of disaster risk reduction and a comprehensive review and analysis of the natural hazards that are affecting humanity. The GAR contributes to achieving the HFA through monitoring risk patterns and trends and progress in disaster risk reduction, while providing strategic policy guidance to countries and the international community. The GAR aims to focus international attention on the issue of disaster risk and encourage political and economic support for disaster risk reduction.

The first Global Assessment Report, ‘Disaster Risk Reduction, Risk and Poverty in a Changing Climate’ (GAR09), as well as the second, ‘Revealing Risk – Redefining Development’ (GAR11), focused primarily on public policy and the role of national and local governments in disaster risk reduction. The key message of GAR09 was that addressing the underlying risk drivers is critical not only to the achievement of the HFA, but also the Millennium Development Goals (MDGs) and climate change adaptation.

GAR11 built on that evidence to provide guidance to governments on how to effectively manage their disaster risk. GAR09 highlighted how intensive disaster risk is disproportionately concentrated in lower-income countries with weak governance. Within countries, it showed how underlying drivers – e.g., poor urban governance, vulnerable rural livelihoods and declining ecosystems – concentrate extensive disaster risk in low-income communities and households and drive further the depth and breadth of poverty, undermining development. It also found that, although progress was being made to strengthen capacities
for disaster preparedness and response, governments were challenged to tackle underlying risk drivers.

GAR11 provided further evidence on why disaster risk was increasing and why existing efforts in its reduction were failing to address underlying risk drivers. The report provided an updated analysis of global disaster risk and loss trends and a second biennial review of progress against the HFA. It then identified political and economic imperatives for increased public investment in disaster risk reduction. A cost-effective strategy for layering disaster risk management was proposed—which layers of risks to reduce; which to insure; and which to retain.

GAR11 described the mechanisms through which governments can deliver responsible and consistent policies for risk reduction, integrate disaster risk management into existing development instruments, and build and strengthen risk governance capacities.

Building on the findings of GAR09 and GAR11, the third GAR explored why increasing disaster risks represent a growing problem for the economic and business community at different scales. The report examined how paradoxically business investments that aimed to strengthen competitiveness and productivity may have inadvertently contributed to increasing risk. It also recognized that in most economies, public investment represents only 15–30 per cent of gross fixed capital formation. The way in which the other 70–85 per cent of investment is made, therefore, has far-reaching consequences on disaster risk accumulation and on the underlying risk drivers. Despite their importance, GAR13 noted that business investment practices were neither highlighted in the HFA nor have interactions between business investment and disaster risk and the factors that mediate those interactions been seriously examined.

GAR13 explored how businesses, by investing in disaster risk management, can reduce costs and interruptions represented by disaster losses and impacts; how performance and reputation can also be enhanced by minimising uncertainty and unpredictability; why effectively managing disaster risks should be the hallmark of a competitive, sustainable and resilient business; and why a broader approach to business value creation that also addresses underlying drivers of risk is required.

Scheduled for publication in 2015, the overall objective of GAR 2015 is to determine whether the HFA has been fit for purpose. It is expected that GAR 2015 will provide a global assessment of disaster risk reduction and a comprehensive review and analysis of natural hazards affecting humanity.

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**BOX 2 GRIP’S DATA AND INFORMATIONAL PORTAL**

**GRIP’S DATA & INFORMATIONAL PORTAL**

is a place to share or find data and information on disasters and risks at all levels.

**COUNTRIES AND RISK INFORMATION**

The countries and risk Information portal is a way to access risk-related information by country, as well as by region, such as country’s disaster risk profiles, hazard risk maps and datasets, documents and publications, databases and information systems, projects and programmes.

**THE WORLD’S DISASTER DATABASE CATALOGUE**

The Disaster portal aims at providing valuable disaster loss information by facilitating centralized access to disaster loss databases worldwide. The disaster portal builds on DisDAT, which is the result of the collaboration between the Centre for research in Epidemiology of Disasters (CRED) and the Global Risk Identification Programme (GRIP), with the financial support of United States Agency for International Development (USAID).

**EARLY WARNING SYSTEM CATALOGUE**

This portal provides easy access to an inventory of early warning systems worldwide to support humanitarian and development actors in disaster risk reduction. The portal integrates information on existing early warning systems around the world to cover all natural hazards and all levels (global, regional, national and local). Among other applications, information in the portal can be used to identify gaps and needs in this specific field.

**GLOBAL DATASETS CATALOGUE**

The portal features a collection of different thematic datasets produced by various organizations and institutions around the world. The datasets cover demographics, geophysical and economic information, as well as development indicators on regional and global levels.

Source: http://www.gripweb.org/gripweb/
### A.3 LESSONS LEARNED FROM RECENT TSUNAMIS

This section is based on the reports of three major tsunamis – Indian Ocean 2004, Chile 2010 and Japan 2011 – case studies for which are included in Chapter K.

The large, destructive tsunamis which have occurred during the last two decades, impacting countries around the Pacific and Indian Oceans, have exposed the weaknesses in our competence and understanding to cope with these catastrophic events.

Some of these weaknesses are of a technical nature, for example, those concerning the techniques employed in characterizing the earthquakes which might lead to the generation of a tsunami. Others relate to the procedures of early warning for communities at risk of potentially damaging tsunamis and the response to tsunami warnings issued by national authorities. A third area of weakness has been recognized in the extent to which people at all levels in communities have awareness of their vulnerability with regard to tsunamis and knowledge of what they should do in the event of a tsunami emergency. Lastly, lessons have been learned concerning physical vulnerability – our understanding of the vulnerability of buildings and protective infrastructure in the event of tsunami inundation.

A prime need identified as a consequence of the Indian Ocean 2004 tragedy was for the establishment of a global tsunami warning system, with procedures for tsunami hazard and risk assessment, warning guidance and preparedness. In response, the international community, under the auspices of the Intergovernmental Oceanographic Commission, now operates tsunami early warning systems in the Indian Ocean and in the North-East Atlantic, Mediterranean and Connected Seas, in addition to the previously established system covering the Pacific and a coastal hazard warning system in course of development for the Caribbean and adjacent regions.

Inadequacies in procedures and seismic networks used to characterize earthquakes and the magnitudes of potential consequent tsunamis were identified from the Chile 2010 and Japan 2011 events. In the case of Japan, it was important to ensure that networks included seismometers far from the epicentre, which could not be saturated, so that these could be used to estimate magnitudes even in the case of extremely large events. Also, a trade-off between the time allocated to provide the first warning and the more precise estimation of earthquake parameters needed to be considered. For the Indian Ocean event, a need for faster seismological techniques was specified. Weaknesses in communications were exposed in the Chile 2010 event – there was a need to ensure redundancy in communications, especially for Civil Protection agencies, and procedures needed to be strengthened to guard against the misunderstanding of warning messages. Also in the case of Chile, the liabilities of tsunami warning centres in their routine operations needed to be properly addressed, particularly when there were not enough data to make precise forecasts, or when there were delays in the provision of information. There was a need for warning centres to improve their Standard Operating Procedures (SOPs), to make them adaptable to events of various magnitudes or intensities.

‘The need for awareness’ is a topic that features strongly in the messages from all three of these recent events. People should not underestimate their vulnerability in case of very large events, and awareness of those at risk is essential to minimize loss of life. Tsunami awareness is vital – the public needs to be educated about what actions to take to save lives during a tsunami emergency, including evacuation without a warning. The exceptional scale of the Japan tsunami was leading to a re-examination of policies and procedures including those for tsunami hazard assessment where such events may be extremely rare.

With regard to physical vulnerability, in Japan, the post-event damage assessment of sea walls and breakwaters has led to a re-evaluation of such structures leading to improvements in the elaboration of fragility curves for infrastructure. In Chile, compliance with the existing strict building codes may encourage house owners to reduce their physical vulnerability. From the Japan experience, the location of critical infrastructure, including shelters, hospitals, schools, power plants, emergency operation centres and airports needs to be revised in the context of very large tsunamis. Mid- to high-rise reinforced concrete buildings with robust shear walls and strong foundations have been shown to survive both the earthquake and the tsunami and can be used for vertical evacuation.

### SUGGESTED ADDITIONAL READING AND INFORMATION SOURCES


UNISDR. (n.d.) Making Cities Resilient: My City is Getting Ready http://www.UNISDR.org/campaign/resilientcities/
Assessing the tsunami hazard

Tsunamis constitute a hazard to coastal communities when and where they catastrophically inundate their coastal land. The forecasting of such inundation is difficult. Compared with the incidence of flooding from extreme waves or storm surges, tsunami inundation is, in most parts of the region, a rare, or even very rare, event and there may be much uncertainty about its scale and timing. However, the incidence of tsunami-driven disasters in the Indian Ocean and other regions over the last few decades gives good reasons why tsunamis should be included within maritime countries’ coastal management policies that aim to prevent or reduce their disaster risk (A.3). A main aim of the guidance in this chapter is to assist coastal and emergency managers in making rational judgements on the likely scale and frequency of damaging events to which their communities may be subjected.

The assessment of the tsunami hazard forms an integral part of the risk assessment objectives of the IOTWS. International expertise has been involved in the development of coastal hazard maps, with some products, including the regional scale Indian Ocean Tsunami Hazard Map (Table 1), being made available to participating countries. Local hazard maps or inundation maps, because of their much larger scale and local relevance, may be produced by national institutions, assisted as appropriate by international modelling experts. The process of compiling inundation and local hazard maps provides an opportunity for coastal scientists and emergency managers to work together, so that the parameters of inundation are well understood and particular danger zones or hazard ‘hot spots’ recognised.

A prime aim of these guidelines is to assist coastal and emergency managers in making rational judgements on the likely scale and frequency of damaging tsunami events.

WHAT IS A TSUNAMI?

A tsunami is a series of travelling waves of extremely long length and period, generated by a sudden displacement of the sea bed; the commonest causes are submarine earthquakes. In the deep ocean, tsunamis may be unnoticeable due to their small wave height. Their speed, however, may be in excess of 900 km/hr and, as they enter shallow coastal waters, they slow down, their wavelengths shorten and their wave heights increase (Fig. 4 and Fig. 5). On their landfall, the waves may be several metres high. Tsunami events become disasters when they harm people and damage property beyond the ability of the community to cope. When a tsunami wave inundates a low-lying coastal area, it creates strong landward currents which exert potentially destructive forces on anything in their pathway. Anything moveable may become entrained. Following the peak of an inundation, draining waters form strong seaward currents charged with debris of all sorts that may be carried out to sea. The arrival of a tsunami at the coast may be presaged by a drawdown of sea level, causing an unusual recession of the shoreline and exposure of the seabed.

KEY TASKS IN THE HAZARD ASSESSMENT PROCEDURE

- Define the geographical limits of your coastal management area.
- Examine the historical and geological records of tsunami events.
- Access information on tsunami origins and propagation patterns.
- Acquire and compile data on nearshore bathymetry and coastal topography.
- Determine the likely impact of credible tsunamis on your coast.
- Determine the likely physical nature of possible tsunami inundation.
- Determine the probabilities for credible tsunami scenarios.
- Construct inundation and local hazard maps.
- Convey results to risk and emergency managers.
This section reviews the various sources of tsunamis which have affected, and are likely to affect, the Indian Ocean region. The sources are described under two broad headings – subduction zone earthquake sources and non-subduction zone sources.

B.1.1 SUBDUCTION ZONE EARTHQUAKE SOURCES

See also Case Study at K.6

The important sources of earthquake-generated tsunamis in the Indian Ocean are along the northern margin of the Arabian Sea – adjoining the Makran coasts of Iran and Pakistan – and from the northern tip of the Bay of Bengal, through the western margin of the Andaman Sea, and skirting the southern coasts of Sumatra, Java, and the islands of Lesser Sunda. These oceanic tracts are subduction zones, characterized by large earthquakes and, along the Indonesian coasts, by active volcanism as well (Fig. 2).

The subduction zones have developed as consequences of differential movements between the Indian, Eurasian, Burma, Australian and Sunda plates (Fig. 2). The process of plate movement may be continuous but its manifestation at the surface tends to be spasmodic, with increasing stresses released periodically by displacements along fractures called faults. Friction between the subducting Indian-Australian plates and their overriding plates impedes continuous motion and invokes elastic loading. When the elastic stress exceeds the frictional yield, a plate may fracture catastrophically, perhaps by several metres, along a segment of the subduction zone. It is these sudden releases of energy that we observe as earthquakes.

Fig. 2. Major plates and subduction zones that are potential sources of Indian Ocean tsunamis. Major accumulations of seabed sediments shown in pale blue to orange. Source: modified from Burbidge et al., 2009. The Sunda Arc is referred to as the Bengal-Sumatra-Sunda subduction zone in this account.
Catastrophic vertical displacement of the sea bed causes a commensurate collapse of the overlying water mass, initiating a tsunami.

The plate boundary in a subduction zone is marked at the ocean floor by a trench. When an earthquake occurs, faulting at depth may extend upwards to displace the seabed. Catastrophic vertical displacement of the sea bed causes a commensurate collapse of the overlying water mass initiating a tsunami. The scale of the disturbance depends primarily upon the length and the slip (amount of vertical motion) of the earthquake rupture. If earthquakes are small or if the rupture does not extend to the sea bed, no tsunami will be generated. Depending on the lateral extent of the fault displacement, the tsunami’s source may be compact or, in the case of the 2004 Indian Ocean tsunami, elongated over a thousand or so kilometres. The Bengal-Sumatra-Sunda subduction zone is one of the most active plate boundaries in the world. Many of its tectonic characteristics change significantly along its length. The Indian-Australian and Sunda plates meet 5 km beneath the sea surface along the Sumatra Trench. Here the Indian-Australian plate is subducting, and is being overridden by the Sunda plate. Spasmodic movements between these plates on a fault termed a megathrust give rise to powerful earthquakes. Studies show that large megathrust earthquakes have not been distributed evenly along its length. Historical records spanning some 250 years show that some sections have been active, while others have remained relatively quiet. However, all sections of the subduction zone are considered capable of generating large megathrust earthquakes and thus have the potential to generate significant tsunamis.

The Makran subduction zone of Iran and Pakistan is seismically less active than its eastern counterpart but has also produced great earthquakes and tsunamis. The last major tsunami in the Arabian Sea was in 1945, caused by a great earthquake in the eastern part of the zone. The Makran subduction zone is marked by unusually thick sedimentary cover, which itself may be source of tsunamis caused by sediment slumping. Well-defined terraces of raised seabed that feature on the Makran coast indicate a continuing potential for large earthquakes in this zone (Box 3).

**BOX 3 THE MAKRAN SUBDUCTION ZONE AND ITS TSUNAMI HAZARD**

The Makran subduction zone, located off the Indian Ocean coasts of Iran and Pakistan, is an important tsunami-generating zone for the region. On the 27 November, 1945, it was the site of a major earthquake with a moment magnitude of 8.1. This earthquake produced a tsunami with a run-up (Fig. 6 and Fig. 7) of 5–12 m above sea level and killed about 4000 people. Archival research has revealed at least five tsunami events in the Makran coastal region from a variety of different source types, including earthquakes, volcanoes and landslides.

The Makran tsunami hazard was investigated using semi-probabilistic and full probabilistic methods. The semi-probabilistic method infers the hazard from the maximum tsunami wave height (Fig. 5) caused by the largest expected earthquake in the region, as determined from a probabilistic seismic hazard assessment (PSHA). The results from a PSHA for this region show that the largest expected earthquake has a moment magnitude of about 8.3 and a return period of about 1000 years. Numerical modelling indicates that the tsunami produced by the largest expected earthquake for the region could reach a maximum run-up height of 9.6 m along the Makran coast.

To determine the likelihood of a tsunami affecting the Makran coast, a probabilistic tsunami hazard assessment (PTHA) was conducted (B.4.4). A PTHA combines the probability of an offshore earthquake occurrence with numerical modelling of a tsunami in order to determine the probability of a tsunami wave exceeding a given maximum water elevation at a coastal site. Based on the results of a PTHA for the Makran subduction zone, the probability of tsunami wave heights exceeding 5 m along the Makran coasts during the next 50 years is 17.5 per cent. For a moderate tsunami, with a wave height in the range 1–2 m, this probability is as high as 45 per cent.

Recent studies have shown that the large run-up of up to 12 m observed following the 27 November, 1945, Makran tsunami cannot be reproduced using only the seismic source of this tsunami. Therefore, an additional source, possibly a submarine landslide, contributed to the seismic source which further intensified the tsunami run-up. The hazard from submarine landslide-tsunamis in the Makran region was further emphasized following the 24 September, 2013, Pakistan inland earthquake. While this earthquake occurred ~300 km inland, it generated a small tsunami in the Makran region. Analysis of seismic and tsunami data showed that a submarine landslide was responsible for the observed tsunami. These observations have demonstrated that seismically-triggered submarine landslides pose a real tsunami hazard for the Makran region.

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Sources: Heidarzadeh et al., 2008a,b and 2009; Heidarzadeh and Satake, 2014 and 2015
Neither of these subduction zones is fully understood and it is difficult to accurately predict the location and magnitude of future earthquakes. Thus it is similarly difficult to evaluate the levels of tsunami hazard that they pose and to make informed decisions on likely tsunami scenarios. The record and likelihood of earthquake occurrence in these zones and the implications for tsunami generation are discussed in B.1.2

**B.1.2 NON-EARTHQUAKE SOURCES**

Globally, subduction zone earthquakes are by far the commonest source of tsunamis. Three quarters of the world’s tsunamis are caused by earthquakes causing displacement of the seabed. Of the 18 known historical Indian Ocean-wide tsunami events, only one was not caused by an earthquake. Other possible sources of tsunamis are volcanic eruptions, submarine landslides and asteroid impacts.

**VOLCANIC ERUPTIONS**

The 1883 eruption of Krakatau is the only known major volcanic eruption that has triggered a tsunami which has affected the Indian Ocean. This eruption caused a local tsunami which devastated the Sunda Strait coasts of Java and Sumatra (37 m and 22 m maximum run-up respectively; Fig. 6 and Fig. 7), killing more than 35,000 people. This tsunami also reached appreciable run-up heights at regional distances, for example, 1–2 m along the coast of Western Australia. The tsunami-generating potential of other volcanoes in the region, such as Barren Island in the Andaman Sea, is uncertain.

**SUBMARINE LANDSLIDES**

Submarine landslides have the potential to produce large, local tsunamis (Box 3 and Box 4). Contributing factors are steep seafloor slopes and rapid sedimentation. The Indian Ocean includes the two largest seafloor accumulations of sedimentary material in the world – the Indus and Bengal fans – fed respectively by the Indus and Ganges rivers, with sediments derived from the Himalaya mountain range (Fig. 2). These fans adjoin the Makran and Bengal-Sumatra-Sunda subduction zones, earthquake activity in which could provide a trigger for submarine landslides. Some submarine landslides might be triggered by seismic waves emitted during an earthquake. These considerations suggest that the threat of submarine slides as a source of tsunamis in the Indian Ocean may be underestimated. However, although the general location of these events may be predicted, forecasting their timing is fraught with uncertainty.

**BOX 4 A PROBABLE SUBMARINE LANDSLIDE TRIGGER FOR A TSUNAMI**

On 17 July, 1998, a magnitude 7.0 earthquake generated a 10–15 m high wave along a relatively small section of the coast of Papua New Guinea. By 7 August, 2182 people had been reported dead with 500 still missing. It is unusual for an earthquake of this size to generate such a large wave. Research after the event suggests that the wave was generated by a submarine landslide triggered by the earthquake.

*Source: ITIC.*

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**Fig. 3 Modelled propagation of a hypothetical Makran-sourced tsunami.** The maximum tsunami wave amplitude map (also known as the energy map) matching a Makran Mag. 9 earthquake scenario, with superimposed tsunami travel time contours (also known as isocrones) away from the earthquake rupture. The amplitude is estimated for waters deeper than 20m. The water height at the beach will be higher than the nearby deep-water wave amplitude shown on the map. Source: TSP Australia.
Propagation of a tsunami is the process by which it travels across the ocean from its source. The pattern of propagation depends on source parameters such as the lateral and vertical extents of seabed displacement (Fig. 3). Also it is usually strongly influenced by factors such as ocean depth and the presence of shoals, islands and headlands that may be intercepted.

**Assessing the tsunami hazard**

Propagation of a tsunami is the process by which it travels across the ocean from its source. The pattern of propagation depends on source parameters such as the lateral and vertical extents of seabed displacement (Fig. 3). Also it is usually strongly influenced by factors such as ocean depth and the presence of shoals, islands and headlands that may be intercepted.

Care should be taken in the use of terms relating to the dimensions of tsunamis (Fig. 4 and Fig. 6). In common parlance, the 'height' of a tsunami on its impact at the coast is taken as the water level above datum at the shoreline – this is either the mean sea level or mean low water at the time of tsunami attack (Fig. 6). However, in its strict definition 'wave height' is the vertical distance between a wave crest and its preceding trough. Adding to possible confusion is the use of the terms ‘amplitude’ and ‘height of the maximum forecast wave’ in the context of tsunami modelling, alert messaging and coastal forecasting (H.3.4) – the amplitude being half the wave height, positive or negative; or the vertical distance from still water level to the wave crest (positive) or wave trough (negative).

Once a tsunami has been generated, its energy is distributed throughout the water column, regardless of ocean depth. A tsunami comprises a series of very long waves. Its dominant wavelength (Fig. 5) depends on the generating mechanism and the dimensions of the source. The larger and more extensive the earthquake, the greater will be its initial wavelength and period. Conversely, if the tsunami is caused by a local landslide, both its initial wavelength and period will be shorter. The period of constituent waves in a tsunami event may range from 5 to 90 minutes. As they propagate, the wave crests (Fig. 5) can range from just a few kilometres, to more than 100 km apart.

The wave height of a tsunami in the deep ocean may range from just a few centimetres to more than one metre, depending on its generating source. In the deep ocean, tsunami waves can travel at high speeds, covering thousands of kilometres and losing little energy in the process; the deeper the water, the greater the rate of propagation. In the deepest waters, the speed of propagation may be more than 900 km/hour (Fig. 4).

Where the tsunami enters shallow coastal waters, wave heights may become many times greater than those in the open ocean.

As it reaches coastal waters, a propagating tsunami may be diffracted around obstacles such as headlands and islands resulting in marked changes relative to the undisturbed wave field regime. Similarly the wave may be refracted by variations in water depth. In some cases a tsunami may be reflected from a coastline in a way similar to that of wind-forced waves being reflected off a seawall (Box 5 and Box 6). Significantly, the wave height is greatly increased where the tsunami enters shallow coastal waters in the process of shoaling, resulting in wave heights many times greater at the coast than in the open ocean (Fig. 4 and Fig. 5).

**Box 5 Multiple Waves, Wave Refraction and the Effect of Tides**

The tsunami wave that hit the Seychelles islands on 26 December 2004 had travelled approximately 5000 km from its source, offshore Sumatra, in less than seven hours. At 1 p.m. waves 2.5–4 m high hit the east coast of Praslin, La Digue and Mahé islands. The effects were felt all along the east coast of Mahé, propagating over a 30-minute period. Refracted waves hit the west coast of Praslin and Mahé 30 minutes to 1 hour after the respective east coasts were hit. Another wave occurred at 5 p.m., followed by two smaller waves, at 10 p.m. and at 5 a.m. on the following day (27 December).

The second wave had more or less the same effect as the first because, although smaller, it occurred at high tide. The two smaller waves caused damage only on the west coast of Praslin. The surges caused by the waves flooded the low-lying areas of Mahé, Praslin and La Digue and caused widespread damage to beaches, coastal vegetation, roads, bridges, other infrastructure and houses. The flooding continued for about 6 hours. Two people lost their lives.

David Obura and Ameer Abdulla
The island state of Sri Lanka was severely affected by the 2004 Indian Ocean tsunami. Its eastern coast, directly exposed to the source, was heavily inundated by shoaling tsunamis. The south-eastern and south-western coasts were also affected and, at many locations, inundation levels of 5–10 m were recorded. The combined action of nearshore shoaling processes and local geomorphological features contributed to these high values.

On approaching land, the wave first interacted with the continental shelf, during which process the initial transformation took place. Part of the energy was reflected and the balance transmitted. Sri Lanka has a narrow continental shelf. The mean distance between the coast and the 200-m depth contour is about 20 km reducing to around 5 km at the southern end of the island. The narrow shelf led to wave transformation from deep to shallow water over a short distance without significant energy dissipation. On reaching shallower water, the wave heights increased. This increase was accompanied by the processes of refraction, diffraction and reflection around bays and headlands. Cities located adjacent to bays and headlands (e.g., Hamabanthota and Galle) witnessed very high waves. Wide variations in inundation heights were observed over short distances along the coastline.

On the western coast, not directly exposed to the tsunami source, the highest waves recorded corresponded to those reflected from the Maldivian atolls to the west, illustrating the influence of such natural submarine features. Analysis of tidal gauge readings and measurements from equipment located off the coast of Colombo confirmed that the highest wave arrived about 3.5 hours after the first wave. Sea-bed currents at this location increased from 20 cm/s to 70 cm/s.

Inundation on the southern coast would have been greater but for the low tidal conditions on tsunami impact (albeit a microtidal shore).

The wave height predictions for coastline provided by the TSP are based on the simplifying assumption of the presence of uniform sea bed slope from 30 m to 1 m and a single representative value for every 100-km length of coastline (coastal forecasting cell). This single representative value is based on the results of a number of coastal forecasting points within the 100-km cell. However, in reality the assumption of uniform slope is not valid for most occasions and in the case of bays and headlands there may be an enhancement of the tsunami wave height due to wave energy concentration or a reduction in wave height due to energy dissipations by reefs and wave energy dissipating characteristics of the sea bed. Comparison of wave height prediction from TSPs and inundation modelling for risk assessment for the City of Galle indicates that wave height may be amplified by a factor of the order of 2.5 within bay areas. Similarly the presence of reef and rock outcrops at the sea bed can reduce the wave height by a factor of the order of 0.3.

Sam Hettiarachchi

**Fig. 4 Tsunami shoaling: the effect of water depth on wave length and velocity.** Source: Tsunami Glossary, UNESCO, 2006.
One of the first indicators of an impending tsunami impact on a country’s shores may be the temporary withdrawal of the sea from the nearshore zone, with wide expanses of seabed becoming unusually exposed. This shoreline recession is a feature well known to some coastal communities and knowledge of it has been the key to their survival (C.1).

**Assessing the tsunami hazard**

The transformation of a wave profile as waves propagate inshore and/or with decreasing water depth is the process of shoaling. This is illustrated in **Fig. 5**.

**B.2.1 USING TSUNAMI PROPAGATION MODELS**

Once the size and shape of the initial wave is calculated from a source model, this wave is the one used as input into a tsunami propagation model. The propagation model incrementally solves a series of mathematical equations to take the initial wave and ‘bring’ it to the coast. In order to model the tsunami accurately, the spatial resolution of the model must be much smaller than the smallest wavelength of the tsunami. The spatial resolution of the model controls the spatial resolution of the input data, such as the bathymetry. So, if the wavelength of a tsunami generated by an earthquake is, for example, 100 km, then the grid resolution to accurately model this wave should be much smaller than this. Grids for deep-water propagation models are typically 1–2 km in spacing when modelling earthquake-induced tsunamis which are dominated by wavelengths of 100 km or more in deep water.

Countries may be able to obtain global bathymetry datasets from global data sources (such as ETOPO2 or GEBCO, Table 1). Many countries’ Geological Surveys and/or Navies may have better datasets for their respective country’s waters than exist in the global datasets. Ideally, for areas closer to the coast, such data would be used instead of that from the global datasets.

Shallow water tsunami propagation models typically need a higher resolution grid than is needed for deep water models. Therefore one of the main limitations which influence the offshore depth chosen for a regional hazard study is the availability of high resolution, accurate bathymetric data close to the coast. Very often, regional hazard maps are made outside reefs and other areas of complex shallow inshore bathymetry. For continental regions, the edge of the continental shelf (typically from about 50 m to 100 m in depth) can be chosen.

**B.3 UNDERSTANDING TSUNAMI INUNDATION**

Observations of the impacts of the 2004 tsunami event have contributed greatly to our understanding of tsunami inundation. They have shown how variable it can be, even along a few kilometres of coastline. The form of the nearshore bathymetry is one of the key determinants. The influence of coastal bathymetry on tsunami wave height and velocity, and on the forces exerted, during the shoaling process has received considerable attention from researchers. The on-shore coastal geomorphology is also a key factor influencing the extent of inundation and run-up (Fig. 6 and Fig. 7). Other modifiers of inundation are coastal vegetation – especially mangrove – and the built environment, including any existing engineered defences. The impact of a tsunami can also be exacerbated by materials that become entrained in the course of inundation and also, importantly, during its subsequent drainage. The inundation and its drainage can result in significant erosion, e.g., by scouring around buildings foundations, and sedimentation, for example, causing degradation of coral reefs.

**Observations of tsunami impacts show how variable the inundation of coastal lowland can be, even along a few kilometres of coastline.**

**Fig. 7** shows terminology associated with tsunami inundation. Source: IOC Technical Series 91.
B.3.1 USING TSUNAMI INUNDATION MODELS

The modelling of tsunami inundation and run-up has received considerable attention, and many models are now available (L.1). Key inputs to these models include the open ocean (deep water) wave height (Fig. 5), and digital nearshore bathymetric and coastal elevation data (Fig. 8). Tidal data may also be important (Box 3 and Box 5).

The severity of a tsunami impact is critically dependent on complex bathymetric and topographic effects near the area of interest. Estimating the physical impact of a tsunami on a shore therefore requires modelling of the non-linear process by which waves are reflected and otherwise shaped by local bathymetry and topography. These complex effects generally require elevation data of a resolution much higher than is used by the propagation models, which typically use data resolutions in the order of kilometres or less (sufficient to model long-wavelength tsunamis in open water). The data resolution used by inundation models, by contrast, is typically in the order of metres.

Running an inundation model capable of resolving local bathymetric effects and run-up using detailed elevation data requires more computational resources than the typical propagation model. Except for the case local (near-field) tsunamis, where the tsunami is generated immediately offshore the shore site of interest, it is impractical to use an inundation model for complete end-to-end (source to run-up) modelling of a tsunami event. Instead, a hybrid approach is typically used. In this, the output from a propagation model is used as input to an inundation model at the seaward boundary of its study area. The output of the propagation model thus serves as a boundary condition for the inundation model. In this way, we restrict the computationally intensive part of the modelling to the

**Fig. 8 Bathymetry and topography (training exercise)** Values expressed respectively as contours in metres of uniform depth (isobaths) and height above mean sea level. Source: UNESCO-IOC and UNDP, 2009.

(a) Modelled maximum inundation map at Mean Sea Level: the figure shows the maximum water depth caused by the tsunami.

(b) Modelled maximum inundation map at Highest Astronomical Tide: the figure shows the maximum water depth caused by the tsunami.

(c) Modelled maximum flow velocity map at Highest Astronomical Tide, the flows resulting from the inundation.

geographical area where a detailed understanding of the inundation process is required (Box 7).

Furthermore, to avoid unnecessary computations, some inundation models (e.g., ANUGA, see L.1) work with an unstructured triangular mesh rather than the rectangular grids typically used by propagation models. The advantage of an unstructured mesh is that different regions can have different resolutions, allowing computational resources to be directed where they are most needed. For example, one might use very high resolution near a community or in an estuary, whereas a coarser resolution might be enough for deeper water, where the bathymetric effects are less pronounced.

To implement a scenario, the inundation modeller requires suitable initial conditions (such as a tidal height), boundary conditions (such as data from the adjoining propagation model), forcing terms if appropriate and, importantly, bathymetric and topographic data for the study area. The calculated run-up height and resulting inundation is determined by these inputs, as well as by the cell resolution. In addition, the pattern of flow velocities attained during inundation and drainage can be determined.

The data should ideally capture all complex features of the underlying bathymetry and topography, and cell resolution should be commensurate with the underlying data. Any limitations in the resolution and accuracy of the data, including the cell resolution, will introduce errors to the inundation maps as well as to the range of model approximations. National scale datasets are often held by national geological and oceanographic survey departments, and local scale datasets by State and Local Governments. Local data sets are usually required for an inundation model, due to the higher resolutions required. In many cases there are limitations on use between different agencies according to the licence agreements.

The outputs of tsunami inundation modelling are relevant in evacuation and land-use planning. Guidance on integrating such modelling into land use and evacuation planning is given in sections L.3 and L.4.

B.3.2 VALIDATION OF TSUNAMI MODELS

The recent proliferation of tsunami modelling codes highlights the need for verifying that models accurately solve the appropriate hydrodynamic equations, and to ensure that they can accurately reproduce the observed phenomena. There are a number of analytical and laboratory benchmarks against which tsunami models can be verified.

Models and their input data can be validated by comparing results from modelling a historic event for which observational data exist. Typical data used to validate the source and propagation models are deep ocean pressure gauge data (e.g., from the DART network) or coastal tide-gauge data. If the propagation model is coupled to an inundation model, then the observed tsunami run-up and inundation distance observations from historic events can also be used for validation. If the difference between the observed and modelled results is too large, then either the model, or (more typically) the input data, needs to be improved. This could include obtaining better/higher resolution bathymetry and topography, a better model of the source and/or using a more sophisticated numerical model. The exact requirements to reduce such misfits between observation and the model vary from one validation run to another.

B.4 ASSESSING THE LIKELIHOOD OF A TSUNAMI IMPACT

In evaluating the risk of loss and damage to a community from tsunamis, there is a prime need to know about the frequency of occurrence and scale of the likely scenarios that might impact your coast. Even if you have reasonable confidence in predicting the location of a tsunami impact, its scale and timing may both be highly uncertain. For example, the impacting wave height of the Japan 2011 tsunami (K.3) far exceeded the maximum height forecast from consideration of much regional information.

Regarding the impacts of tsunamis on exposed communities, the greater the wave height, the greater the related loss and damage. Conversely, the greater the wave height, the less likely is its occurrence. For example, historical and geological evidence might suggest that a tsunami with a wave height of at least 3 m occurs approximately once in 50 years (a return period of 50 years), whereas one with a wave height of 5 m, although potentially much more damaging, occurs only in one thousand years (a return period of 1000 years). The estimate of the return period for a specified tsunami wave height and the estimates of potential loss and damage (measures of vulnerability) corresponding to that wave height provide the basis for risk evaluation (Chapter E).

There are three sources of information that can be used to estimate the likelihood or probability of a tsunami impacting your coast:

- historical evidence of past tsunamis;
- geological evidence of past tsunamis, and
- tectonic models for earthquake occurrence.

While these sources of information are complementary, they are also incomplete, and any tsunami hazard assessment should clearly express this uncertainty.
B.4.1 HISTORICAL EVIDENCE OF PAST TSUNAMIS

The historical record of past tsunamis – the written or oral accounts of past tsunami impacts – generally provides a high level of certainty for the estimation of probability for return periods much shorter than the historical record. Historical knowledge of past hazard impact events to have affected a designated coastal area or region may be anecdotal, from the local community; and it may be derived from national archives or international tsunami databases (see Table 2). However, major, ocean-wide tsunamis occur infrequently – there may be one every few hundred years or longer – and it is rare to find historical records that extend over the many return periods needed to estimate the probability of such events. Even where the historical record extends for millennia, the completeness of records more than a few hundred years old is open to question. Despite recent research efforts, little is known about maximum earthquake magnitudes and rupture modes, or the recurrence times of tsunamiigenic events in the Indian Ocean region.

While historical evidence of past tsunamis is invaluable in establishing the likelihoods of past tsunami events, it is invariably incomplete. Thus, we are seldom able to confidently characterize the largest, most dangerous events that, typically, have long return periods. So, in addition to historical evidence, a tsunami hazard assessment should consider other sources of information, such as those described below.

B.4.2 GEOLOGICAL EVIDENCE OF TSUNAMIS

Geological evidence can extend the knowledge of historical tsunami events further into the past. The information gleaned from such sources can provide a reliable indication of the return periods for tsunamis, enabling confidence in forecasting future events and thus in assessing the risk to coastal communities from tsunamis.

Researchers have pieced together evidence from a variety of sources, ranging from the recognition of tsunami-formed sand deposits (extending back over thousands of years and providing some of the most tangible evidence of tsunami risk), through historical documentation to anecdotal material, in order to compile a record of tsunami events around the world. The record of tsunami deposits provides crucial evidence for estimating tsunami return periods, adding to, or extending, the instrumental and written records. For example, current research in Thailand and on Sumatra in Indonesia has identified evidence for as many as three ancestors to the 2004 tsunami within the past few thousand years (Box 8). Efforts have also been made to interpret the magnitudes of tsunamis from the characters of these ancient tsunami deposits.

Despite the success of these efforts, geological studies of past earthquakes and tsunamis in the Indian Ocean region are not at an advanced stage. Only for the Sumatra section of the Sunda subduction zone, have such studies enabled the building of a catalogue of the past occurrence of large earthquakes that could be regarded as complete for the past 700 years. Similar studies of other sections of the Indian Ocean subduction zones are only just beginning, and it may take many years before a similar level of information is available for them. Moreover, geological studies can provide only a minimum constraint to tsunami occurrence, because a lack of geological evidence does not prove non-occurrence (for example, tsunami-formed deposits may not have been preserved).

B.4.3 TECTONIC MODELS OF EARTHQUAKE OCCURRENCE

An alternative approach to estimating tsunami event probabilities that does not rely exclusively on the physical evidence of past events uses mathematical models based on the physics of earthquake occurrence. This approach combines the observed movements of the tectonic plates that cause earthquakes in subduction zones with a mathematical description of earthquake frequency and magnitude. This permits the estimation of the likelihood that earthquakes of a given magnitude will occur on a particular subduction zone. An example of the results of this work is shown in Fig. 9.

This approach has the advantage of including earthquake source zones which may be of concern, but for which there is no actual evidence of tsunami occurrence. This lack of evidence could be due to the incompleteness of the historical record or to the difficulty in obtaining geological evidence for prehistoric earthquakes. The approach can also take into account other indications of the potential for earthquake occurrence, such as geodetic monitoring that may indicate a build-up of stress towards an impending earthquake (or the lack thereof).

A major disadvantage of this approach is that the curves describing earthquake occurrence on individual subduction zones are poorly constrained by the available data. Perhaps more importantly, the use of this technique might mask this lack of information, giving the appearance of a very complete, though false, knowledge of earthquake occurrence. On the final assessment, a range of possible maximum magnitudes and earthquake recurrence relationships should be used in order to demonstrate the effect of the uncertainty in these parameters. Another disadvantage is that the technique ignores sources of tsunamis other than megathrust earthquakes; these include volcanoes, landslides, and asteroids as described above, as well as non-megathrust earthquakes.
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B.4.4 EXPRESSING THE POTENTIAL FOR TSUNAMI IMPACT

In order to implement effective tsunami mitigation measures, emergency managers and planners in coastal communities need information about how large and how likely tsunamis affecting their communities might be. There are two approaches that are widely used for expressing the potential for tsunami impact – Scenario-based Tsunami Hazard Analysis (STHA) and Probabilistic Tsunami Hazard Analysis (PTHA) – both described below. Although the two approaches may appear at first glance to be mutually incompatible, they are actually complimentary and probably most effective when used in combination. A scenario-based approach focuses on a maximum credible event and historical experience. In the case of tsunamis, this approach is normally used for developing inundation maps and evacuation plans. A probabilistic approach considers a broad range of potential events and their likelihoods.

The reliability or credibility of each approach depends on an accurate characterization of the tsunami sources, an accurate representation of tsunami propagation (for example, accurate bathymetric data) and on the uncertainties in this characterization. Any hazard analysis should therefore attempt to make the best possible use of data concerning past events.

Scenario-based (deterministic) tsunami hazard analysis focuses on a maximum credible event and historical experience. Probabilistic analysis considers a broad range of potential events and their likelihoods.

SCENARIO-BASED TSUNAMI HAZARD ANALYSIS (STHA)

STHA, sometimes called deterministic tsunami hazard analysis, attempts to describe the effects that a particular tsunami scenario, or suite of tsunami scenarios, will have on a coast of interest. These scenarios are chosen to include the worst credible and/or the most likely tsunami events, according to some presumed geological framework. STHA is a straightforward and useful way to understand the potential effects of a tsunami, especially if the worst credible event is well established. Such a scenario analysis can have likelihood information associated with it, based on estimated return times of the scenarios used. However, that is not a requirement for carrying out an STHA. Finally, STHA may, or may not, include inundation modelling (B.3.1). Normally the term “hazard analysis” is used only for a broad-scale assessment of a country’s coasts. It would not usually involve inundation modelling at the local scale. STHA is limited in that it essentially addresses only one which asteroids of different sizes impact the earth can be used to estimate how often these would result in tsunami impact. However, the lack of observational data to constrain such events means there is considerable uncertainty in the generation and propagation of tsunamis excited by such impacts.

BOX 8 RECORDING THE EVIDENCE OF PAST TSUNAMI EVENTS

Sedimentary evidence for recurrent Indian Ocean tsunamis at Phra Thong Island, Thailand. A pit excavation adjacent to the shore exposes layers of sand (light brown), deposited by a series of palaeotsunamis, interlayered with soils (dark brown), accumulated during the intervals between the palaeotsunami events.

Kruawun Jankaew

Fig. 9 Hazard curves describing the return periods as a function of exceedance magnitude. These curves give the return period for an earthquake exceeding a certain magnitude at a given subduction zone. They are derived from the fit of a curve for global subduction zone earthquake occurrence (lower red curve) to an earthquake catalogue (black curve), along with information on the length and convergence rate of the tectonic plates at each subduction zone. The observed return periods for large earthquakes at the Nankai (SW Japan) and South Chile subduction zones are also shown by star-shaped symbols. Source: Thomas and Burbidge, 2009.

It should be noted that a conceptually similar approach can be used to estimate tsunami impacts due to asteroids/meteorites. Statistical descriptions of the frequency at which asteroids of different sizes impact the earth can be used to estimate how often these would result in tsunami impact. However, the lack of observational data to constrain such events means there is considerable uncertainty in the generation and propagation of tsunamis excited by such impacts.
question – “What is the potential impact of a particular suite of scenarios (and sometimes only one scenario) on a particular coast?” It is of limited usefulness for broader policy and planning decisions, because it contains little or no information about the likelihood of a tsunami event. It is less suitable for a situation in which the coast of interest may be affected by a number of very different scenarios of varying likelihood; or if the relative hazard due to many scenarios needs to be evaluated over a broad geographical region; or where there is an interest (e.g., for building codes, C.5.2) in tsunami effects expected at various return periods. Also, STHA typically requires high-resolution bathymetric and topographic data for the coast of interest.

STHA (deterministic) analysis, based on particular source scenarios, may best serve the needs of emergency managers in evacuation planning; also the needs of coastal engineers and planners in the development of effective tsunami counter-measures.

STHA or deterministic analysis neither involves, nor implies, information on the probability of a specified scenario. Thus, a deterministic analysis cannot, by itself, provide an assessment of risk. Despite this limitation, detailed, deterministic modelling, based on particular source scenarios, may best serve the needs of emergency managers in evacuation planning; also the needs of coastal engineers and planners in their design and development of effective tsunami counter-measures and in land-use planning.

PROBABILISTIC TSUNAMI HAZARD ANALYSIS (PTHA)

PTHA is at an early stage of development. Its approach has been derived from, and is closely allied to, Probabilistic Seismic Hazard Analysis (PSHA). In contrast to STHA, PTHA attempts to consider a large class of tsunami scenarios, essentially all those which might cause a significant impact, and is often based on more than one geological framework. PTHA, which forms the basis of the Indian Ocean Tsunami Hazard Map, is focused less on what the effects of a particular tsunami scenario will be and more on the question of the likelihood that a tsunami of a given height at sites of interest will be exceeded. PTHA produces a very information-rich result, which can be used to express hazard in many different ways – for example, maps of tsunami exceedance height for various return periods, or de-aggregated hazard maps showing the relative contributions of different sources to the hazard at a particular site (see Table 1). These products can be used to answer a variety of questions about the tsunami hazard of interest to emergency managers and coastal planners.

A crucial limitation of PTHA, at least in its implementations currently available, is its inability to model the detailed effects of tsunami inundation. This is because of the large amount of computation required and, sometimes, because the lack of accurate bathymetric and topographic data for the shore of interest. This restricts PTHA’s ability to address site-specific mitigation measures, such as the identification of safe areas and evacuation routes. Also, because this approach requires a much more complete characterization of potential tsunami sources than STHA, its results are more sensitive to uncertainties in the specification of those tsunami sources. Applications of PTHA should take care to adequately express this. PTHA methodologies have been the subject of recent review with a view to improving tsunami hazard assessment guidance in the United States of America.

B.4.5 CONSIDERING JOINT PROBABILITY OF INDEPENDENT EXTREME EVENTS

The probability of a tsunami impact coinciding with one or more other independent inundation forces – high Spring tide events, extreme wind-forced waves, storm surges or the discharge of land-water floods – may be considered. Of these forces, the state of the tidal cycle is likely to be the most significant in considering the probability of increased levels of coastal inundation from tsunamis (Box 5).
Assessing the tsunami hazard

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic event probability assessment</td>
<td>Hazard curves (see Fig. 9) These describe the relationship between the return period and the maximum tsunami amplitude for a particular model output point. The tsunami amplitude (Fig. 5) given on the y-axis is predicted to be exceeded with the average return period given by the x-axis.</td>
</tr>
<tr>
<td>Tsunami hazard assessment</td>
<td>Maximum amplitude maps The maximum tsunami amplitude that will be exceeded at a given return period for every model output point in a region. A different map for the region can be drawn for each return period.</td>
</tr>
<tr>
<td>Bathymetric data, coastal topographic data</td>
<td>Probability of exceedance maps For a given amplitude, these maps show the annual probability of that amplitude being exceeded at each model output point in a region. A different map can be drawn for each amplitude for that region.</td>
</tr>
<tr>
<td>Inundation maps</td>
<td>De-aggregated hazard maps These indicate the relative contribution of different source zones to the hazard at a single location. A different map will be obtained for every choice of model output point (and for different return periods), and so there are a great many possible de-aggregated hazard maps that may be drawn for any given region.</td>
</tr>
<tr>
<td>Tsunami models</td>
<td>Regional weighted de-aggregated hazard maps These give an indication of the source of the hazard to a country or region as a whole, and are not specific to a particular offshore location. Regional weighted de-aggregated hazard maps provide a convenient summary of the source of hazard over a region. However, if one is interested in the hazard at a particular location, near a large town, for example, then one should consult a de-aggregated hazard map for a model output point near that particular location.</td>
</tr>
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Table 1 Products that may be generated from the database of the Indian Ocean Tsunami Hazard Map. Source: Geoscience Australia.

<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>VARIABLES (AND STANDARDS)</th>
<th>SOURCES</th>
<th>GLOBAL DATASETS AND PROGRAMMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic event probability assessment</td>
<td>Frequency; magnitude; location</td>
<td>National seismological institutes</td>
<td>NOAA/WDC Historical Tsunami Database (<a href="http://www.ngdc.noaa.gov/hazard/tsu_db.shtml">http://www.ngdc.noaa.gov/hazard/tsu_db.shtml</a>) Novosibirsk Tsunami Laboratory Historical Tsunami Database for the World Ocean (<a href="http://tsun.ssc.ru/On_line_Cat.htm">http://tsun.ssc.ru/On_line_Cat.htm</a>)</td>
</tr>
<tr>
<td>Tsunami hazard assessment</td>
<td>Open ocean wave height</td>
<td>Satellite altimetry</td>
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<tr>
<td></td>
<td>shoreline wave height, inundation limit, run-up</td>
<td>Local records; anecdotal accounts</td>
<td>Indian Ocean Tsunami Hazard Map</td>
</tr>
<tr>
<td>Bathymetric data, coastal topographic data</td>
<td>Bathymetry; onshore topography; existing defences</td>
<td>Hydrographic charts; LIDAR survey; digital terrain modelling</td>
<td>General Bathymetric Chart of the Oceans (GEBCO) (<a href="http://www.gebco.net/">http://www.gebco.net/</a>) ETOPO2 (<a href="http://www.bodc.ac.uk/projects/gebco/index.html">http://www.bodc.ac.uk/projects/gebco/index.html</a> <a href="http://srtm.csi.cgiar.org">http://srtm.csi.cgiar.org</a>)</td>
</tr>
<tr>
<td>Inundation maps</td>
<td>Satellite imagery; modelling; surveying; local records; anecdotal accounts</td>
<td>COAST-MAP-IO Project, Improving Emergency Response to Ocean-based Extreme Events through Coastal Mapping Capacity Building in the Indian Ocean (<a href="http://www.ioc-cd.org/">http://www.ioc-cd.org/</a>) GITEWS project (<a href="http://www.gitews.org">http://www.gitews.org</a>) Hazard mapping methodology: Indian Ocean Tsunami Information Centre (<a href="http://www.iotic.org">www.iotic.org</a>)</td>
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Table 2 Information sources for tsunami hazard assessment
This part of the chapter describes the procedure for the refinement of hazard mapping to show the potential inundation limits and variations in the parameters of physical forcing within the inundation zone for specified tsunami scenarios impacting your coast.

An inundation map carries information on the spatial and temporal parameters of physical forcing by sea water following a tsunami’s landfall.

The output, usually based on computer modelling, is an inundation map (Fig. 10). This carries information about the parameters of the inundation over the shoreline and coastal lowland not only during the flooding episode but also during the subsequent drainage back to the open sea. These parameters include its landward limit (inundation line or limit) and its run-up height (Fig. 6, Fig. 11); also the depths, velocities and directions of its flow during the inundation event, providing information about the ‘drag’ effect. As such, the map represents the spatial and temporal variations of physical conditions in the inundation zone. The parameters define the extent and nature of the physical forcing to which any parts of the community and its assets located within the inundation zone would be exposed, though they take no account of the destructive impact of solid debris entrained by the inundating water.

Fig. 10  Inundation mapping (training exercise) The bold red line marks the maximum horizontal inland penetration of a tsunami from the shoreline. The fine dotted red line defines the area subject to high flow velocities. A hypothetical example of a 3 m (offshore wave-height) tsunami is shown. Bathymetry and topography expressed respectively as contours in metres of uniform depth (isobaths) and height above mean sea level. Source: UNESCO-IOC and UNDP, 2009.
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Understanding tsunami hazard and possible local impacts is a prerequisite for local authorities and other stakeholders in tsunami preparedness in order to anticipate future tsunami events. Different initiatives concerning tsunami hazard mapping are currently under way in Indonesia. For many Indonesian coastal communities in tsunami-prone regions, however, still very little information is available and it is uncertain whether such communities will receive the attention they need.

A current initiative in Indonesia, in three pilot districts in Java – Bantul, Kebumen and Cilacap, is to initiate the design of a participatory, simple, and low-tech but sufficient and adequate tsunami hazard mapping methodology that can be applied at district level in order to understand tsunami hazard and become prepared for future disasters – especially in those regions where there is a persistent lack of understanding about tsunami hazard and limited attention from existing hazard mapping initiatives.

The initiative has resulted in a preliminary tsunami hazard map for each of the three participating districts; it has increased knowledge and awareness among the participants about the potential tsunami threat as well as overall tsunami characteristics, and has developed vital capacities for tsunami preparedness. The methodology may be downloaded at: http://www.jtic.org.

A more comprehensive approach is being applied for the hazard mapping of the coastal areas of West Sumatra, South Java and Bali. The hazard maps are generated based on a multi-scenario approach. This deterministic approach uses a large number of realistic scenarios and combines the inundation results to integrated hazard maps. The analysis of probabilities of earthquake occurrences derived from historical data and geophysical research is included in the derivation of hazard probability maps. The maps are provided at 1:100,000 (map scale) for the respective coastal areas, and in greater detail – e.g., 1:25,000 (map scale) – for the pilot regions of Padang, Cilacap and Bali.

The results in the hazard maps are displayed as continuous values or as derived hazard zones. The definition of the hazard zones can be linked to the different levels of warnings provided by the InaTEWS Early Warning System. The hazard zones are related to the levels of warning (tsunami warning or major tsunami), which are linked to the expected wave heights at the coast. An example is shown in Fig. 12.

Harald Spahn (GIZ IS), Kai Zosseder and Günter Strunz (DLR). Source: GITEWS project. Courtesy: GIZ-IS, DLR

BOX 9 HAZARD MAPPING IN INDONESIA – APPROACHES WITHIN THE GITEWS PROJECT

Fig. 11 Inundation mapping, coast of Oman. Colour-coded values for Tsunami Run-Up (outer fringe) and Inundation Length (inner fringe) at the national scale. Source: IH Cantabria (see appendix M.3).
Using GIS technology and Smartphone applications, the inundation map can be constructed to show layers of information relating to two or more possible tsunami scenarios. The inundation map may also be used to provide indications of how hazard parameters might be affected by tidal variations (Box 7) or by sea-level variations caused, e.g., by possible climate-driven surge conditions.

An inundation map displays information from a deterministic analysis (STHA) for specified tsunami scenarios. It may be configured as a local hazard map by the attachment of probability levels expressed, e.g., as return periods, to the scenario-based map outputs (Box 9; Fig. 12). It may be elaborated to a hazard danger map by the depiction of danger zones or hot-spots, derived from the parameters of inundation, information on proximity to the shore or a channel, and the likely frequency of inundation. Such maps can be used effectively as a tool for reducing the direct impact of the hazard, by land-use and emergency planning and site monitoring (L.3 and L.4).

![Fig. 12 Tsunami hazard map for city of Denpasar, Bali, Indonesia. Source: GITEWS Project. Courtesy DLR.](image)

**B.6 OUTPUTS FROM THE TSUNAMI HAZARD ASSESSMENT**

**INFORMATION OUTPUTS BASED ON THE BACKGROUND AND PROCEDURES DESCRIBED IN THIS CHAPTER INCLUDE:**

- a listing of all known tsunamigenic events to have impacted your region;
- analysis of pre-calculated tsunami propagation patterns for tsunamis from likely earthquake sources to determine the potential for impacts on your coast;
- a map showing your coasts that are most prone to potential tsunami impact;
- inundation and hazard maps for specified tsunami scenarios showing expected inundation limits, run-up, flow depths at maximum inundation, inundation- and drainage-flow indicators; and
- estimated return periods for the specified tsunami scenarios.
SUGGESTED ADDITIONAL READING AND INFORMATION SOURCES


C Assessing your vulnerability

This chapter describes how to assess your levels of vulnerability to specified tsunami hazard scenarios, and use that information to estimate the potential for loss of life and damage to the built and natural environments in the event of inundation from those scenarios. The procedures form an integral part of the risk assessment objectives within IOTWS.

The next stage in the risk assessment process is to assess your community’s vulnerability and estimate the potential loss of life and damage as a consequence of a tsunami inundation.

The term ‘community’ (as used here) includes its social and economic aspects, its infrastructure, life-lines, and supporting environmental systems. A community’s vulnerability in respect of a specified tsunami scenario is determined by its characteristics and conditions that make it susceptible to the damaging effects of that scenario. Vulnerability may be determined for any or all of a range of social, physical, economic, and environmental dimensions (C.5), or for specific conditions such as the age or infirmity of community dwellers or the robustness of building construction, or for sectors of community activity, e.g., health or education. By its UNISDR definition (as used in these guidelines), [a community’s] vulnerability is independent of [its] exposure to the hazard; however, you should be aware that, in common use, the word is often used more broadly to include exposure (UNISDR, 2009; see Box 10).

The results of a vulnerability assessment may be complex. In some guidance documents you may find that consideration of preparedness at community and national levels – tsunami awareness, capacity of resources and skills, and resilience to recover from a tsunami impact – has been included within the assessment of vulnerability (UNESCO, 2009). In these guidelines the assessment of preparedness is described separately, in Chapter D.

KEY TASKS IN THE VULNERABILITY ASSESSMENT PROCEDURES

- Define the geographical scale and limits of the assessment.
- Define the temporal scale of the assessment.
- Create a census and asset (inventory) database for people and their supporting systems within and adjoining the perceived inundation zone.
- Create an exposure database of people and their supporting systems and assets for specified tsunami scenarios.
- Classify people’s vulnerability (age, gender).
- Classify asset vulnerability.
- Produce vulnerability maps.
- Estimate potential loss of life and damage for specified tsunami scenarios.
- Convey vulnerability results and loss and damage estimates to risk and emergency managers.

The vulnerability assessment can be simplified by a process of aggregation (C.9), providing classes of overall vulnerability (e.g., high, medium, low) and estimates of the potential losses and damage (numerical and monetary) that will be used in the evaluation of risk (Chapter E).

C.1 UNDERSTANDING VULNERABILITY – AND HOW TO ASSESS IT

Following the 2004 Indian Ocean tsunami, post-impact damage and loss surveys were carried out in nearly all the affected Indian Ocean states. In a similar way, damage and loss surveys were conducted more recently for tsunamis in Samoa (2009), Indonesia (2010), and Japan (2011). These surveys revealed high levels of social, physical, economic and, in many cases, environmental vulnerability. Many of these assessments could relate damage and loss to known tsunami heights. Such post-impact empirical observation has the potential for producing reliable vulnerability assessments. These guidelines, however, are concerned with achieving a realistic vulnerability assessment before a tsunami event, so that action can be taken to reduce the levels of vulnerability in anticipation of such an event.

There is yet no global consensus on how vulnerability to natural hazards should be assessed. Because of its multifaceted nature, it is difficult to measure and its measurements carry uncertainties. Recognising these uncertainties, this part of the Guidelines sets out options for assessment approaches that focus on measurable indicators that are relevant to achieving the overarching objective of risk reduction.
Vulnerability analysis must be adapted to the specific objectives determined by the policy maker and relevant to the emergency manager. The choice of approach may depend on the scale of the assessment required. For the assessment of the whole national coastline or relatively large coastal areas, a broad-scale resolution may be appropriate. At more local levels there are options to apply an increasing resolution to the assessment process. Managers need to consider the time period that the assessment is intended to span. Factors that contribute to vulnerability are dynamic. They are likely to change over time because of, for example, changing (usually increasing) coastal population, economic developments, social structures, and environmental states.

For an assessment of a community’s vulnerability in respect of inundation from a specified tsunami scenario, key factors from the hazard analysis to be taken into account are:

- the likely inundation limit (Fig. 10);
- the physical parameters of inundation (flow depths (Fig. 7), flow velocities and directions, entrained debris, etc.).

For example, to what extent would people or buildings at any given location within the inundation zone be susceptible to the modelled flow depths and velocities implicit in the local hazard mapping? What would be the expected outcomes in terms of human lives and monetary loss or damage? On the basis of these findings, what level of vulnerability would you assign to the people and buildings? For a more complete picture, particularly for human casualties, these estimates should be integrated with information from the assessment of preparedness, which includes the important topics of your community’s tsunami awareness, capacity and readiness to respond, and post-impact resilience (Chapter D).

**C.2 CREATING AN ASSET MAP AND AN EXPOSURE DATABASE**

The scale and physical nature of the inundation from a specified hazard scenario determine the extent to which a community is exposed to its impact. Using the outputs from the inundation and local hazard mapping (B.5), those conducting the vulnerability assessment and emergency managers will need to create a database of community assets, which can then be used to create an asset map.

The asset map is a geospatial inventory of the community both within and adjoining the inundation zone. It shows the distribution and values of physical, economic and environmental assets, e.g., different types of buildings, community centres, utilities, transport infrastructure and beaches. It also provides a base for representing people and their day-night and seasonal changes, e.g., linking buildings with occupants or beaches with holidaymakers. The asset map and its database carry information on the intrinsic susceptibility of the various assets (e.g., elderly people, the robustness of buildings), and, for assets, their monetary value in the case of loss and damage.

An asset map provides a geospatial inventory of the community and its assets within and adjoining the presumed inundation zone.

An overlay of the asset map on the inundation map produces an exposure map which shows the distribution of people of defined groups, infrastructure, life-lines and community assets in relation to the various hazard parameters of physical forcing by sea water (inundation limit, run-up, flow depth, inundation and drainage flow velocities, etc.) within the inundation zone for the specified hazard scenario. In this way the impacts of inundation on exposed people and community assets (with their intrinsic vulnerabilities) can be considered. Information derived from this map may be conveniently stored in an exposure database (Fig. 13).

![Fig. 13 Exposure map and database (training exercise). A database of the distribution of people and their supporting assets that may be exposed to a tsunami hazard. Figure shows a training GIS display of the distribution of buildings (by type) and people (by day and by night) exposed to a hypothetical 3 m (offshore wave-height) tsunami inundation in a fictitious coastal city. Bold red line = inundation limit; pecked red line = limits of high flow velocity zone. Source: UNESCO-IOC and UNDP, 2009.](image-url)
Key data of interest include:

- census data (population distribution, income, and statistics such as age, occupation, disability, education);
- building classifications, construction materials and techniques, ground level elevations;
- critical infrastructure (roads, water, power, sewerage, emergency facilities including evacuation shelters, hospitals, etc.);
- economic location data (business sectors, industrial production, exports, imports, etc.); and
- environmental services.

In order to conduct vulnerability assessments on a national scale, exposure databases need to be developed, beginning at the local level then integrated at district or national levels, so that uniformity in the assessment process can be assured.

An exposure map and database provides information on the extent to which the community and its assets would be directly impacted by the physical forces of inundation – the hazard.

C.3 CHOOSING AN ASSESSMENT APPROACH – THE OPTIONS

For a vulnerability assessment it is up to the policy maker or emergency manager to decide on the approach to be used and the level of detail required. They will need to specify their priorities for assessment – those being of particular relevance or importance to the community. The approach may be constrained by data availability or may be determined by the defined scale – whether for local, district or national overview purposes.

Dimensional vulnerability assessments may assist policy makers in the identification of critical areas or weak spots in respect of, for example, human and buildings security, industrial and utilities infrastructure and ecosystem fragility. Another approach is the assessment of vulnerability by considering sectors of development. From a policy-relevant point of view, this latter approach, cross-cutting dimensional boundaries, takes into consideration the fact that agencies in charge of these sectors are responsible for vulnerability reduction within their respective sectors.

A FIRST-ORDER ANALYSIS

The most basic approach is to assume that all community assets that are exposed to a tsunami are vulnerable. Geospatially referenced positions (including topographic levels) of people and their community assets such as buildings and infrastructure would be juxtaposed with specified levels of tsunami exposure, an operation achieved by use of GIS technology. This is the least reliable of the assessment approaches described here (L.3). However, it may be appropriate for an initial assessment of relatively large coastal areas. Typically, this is the approach used to define evacuation routes (H.2.2).

A SECOND-ORDER ANALYSIS – DIMENSIONS OF VULNERABILITY

The complexity of communities and their support systems has led experts to recognise dimensions of vulnerability – social, physical, economic and environmental. Each dimension is characterized through a variety of parameters (C.5). In making such an analysis, it should be recognized that the boundaries between dimensions are generally not clear-cut. Thus, losses in, say, the physical dimension (notably, buildings) may have clear implications for losses in social and economic dimensions.

REFINING THE ANALYSIS

Assessment of each dimension of vulnerability may take into account the outcome of a more refined analysis. The degree of potential damage or loss of community assets may differ considerably within the defined coastal area. This may be because of different levels of exposure (associated with a specified tsunami scenario). For example, physical damage related to inundation tends to be greatest in parts of the area closest to the shore where exposure is highest. Social vulnerability in the case of tsunamis may be greatest amongst infants and small children, the old and disabled – such people having high susceptibility to harm in the event of an impact. Such considerations offer refinement to the ‘dimensions of vulnerability’ approach and may be appropriate in detailed assessments of relatively small areas.

THE SECTOR APPROACH

As an alternative to the ‘dimensions of vulnerability’ approach and in recognition of the (often) fuzzy boundaries between dimensions, an approach based on the notions of sectors of development may be considered (C.6, Table 5). From a risk management point of view, particularly when assigning responsibilities with respect to the mitigation of existing vulnerabilities, this approach may have an appeal. Logic dictates that responsibility for the reduction of vulnerability within each sector of development (e.g., health, transport or education) rests with the agency in charge of that sector, irrespective of the dimensions involved.
C.4 USING THE ‘FIRST ORDER ANALYSIS’ APPROACH

The ‘First Order Analysis’ approach is useful to heighten awareness of the types of assets which would be exposed to tsunami inundation. However, it is not meant to characterize the degree of vulnerability of such assets. In this approach assets may be divided into categories (schools, health centres, houses, hotels, public infrastructure, etc.), geo-referenced through ground-surveys or using global navigation satellite systems and superimposed on the tsunami hazard map using a GIS. If no local hazard map is available, at least an inundation map related to the most probable tsunami scenario could be used.

Very recent or up-to-date satellite imagery can be used to pinpoint the location of these assets. Such a process facilitates the visualization of all these assets and their location in respect of inundation (Fig. 14). In this approach all elements belonging to the same category are considered as having the same level of vulnerability, implying that they will be affected in the same way by a tsunami but without further notions concerning potential impacts or losses.

The approach can be used as the first step in the prioritization of those communities or regions where more robust or precise vulnerability assessments should be undertaken (L.3). The approach can be used to assess which assets of a particular category are exposed to a tsunami and which are not. It is particularly appropriate if different ministries in charge of sectors of development need to become aware of exposed infrastructure.

Data gathered from satellite imagery combined with that from ground surveys, including population census, can be used to estimate the numbers of people exposed to inundation.

Methodologies developed by experts from the space and the Earth observation communities can be applied to classify urban and rural land-uses, allowing for the estimation of the number of exposed elements. The combination of data gathered from satellite imagery and in-situ data from ground surveys, including population census, can then be used to estimate the number of people exposed to tsunamis during day and night, for example.

In addition, if information on the vulnerability of different types of buildings is known, the classification of buildings using Earth observation methodologies (object-based classification methodologies) can be combined with this information to estimate potential damage to all buildings within an inundation zone (Box 10).

BOX 10 REMOTE SENSING CONTRIBUTIONS IN TSUNAMI RISK ASSESSMENT.

Hazard assessment and monitoring

The near-real time provision of detailed information on tsunami inundation extent and its spatio-temporal evolution is essential to support crisis management activities. A multi-scale flood monitoring system (Martinis et al., 2013) is used to accomplish continuous inundation monitoring at a high revisit interval by using daily available medium resolution (250-500m) satellite data of the MODIS sensor on NASA’s Terra Satellite. Based on MODIS information, Synthetic Aperture Radar (SAR) sensors like TerraSAR-X can be triggered on demand to derive more detailed information on the flood situation for defined areas of interest at local to regional scales with an improved spatial resolution (~1-14m).

Fig. a: Flooded coastal areas near Sendai, Japan, after the tsunami on March 11, 2011, based on TerraSAR-X radar images acquired on March 12, 2011 (Source: DLR 2011).
Exposure assessment

In case of a tsunami, people or objects within the maximum inundation area are directly exposed to the tsunami hazard. Earth observation data have the capability to provide up-to-date and area-wide data capturing the small scale and complex urban landscape (Fig. b). Object-based classification methodologies for the extraction of land cover information like buildings (Taubenböck et al., 2013) and the derivation of population information based on very high resolution satellite data can be used for exposure assessment at detailed scale. The Global Urban Footprint (Esch et al., 2012) provides a global binary settlement mask that outlines urban and non-urban areas at a spatial resolution of ~12m. This product can be used to assess building and population exposure on broad-scale level.

Vulnerability assessment

An exclusive assessment of the structural vulnerability of the building inventory with building-by-building analysis by structural engineers is decreasingly able to cope with the high spatio-temporal dynamics of urban environments. Using a supervised learning framework (Geiß et al., 2014), remote sensing can greatly support the vulnerability assessment of buildings when combined with in situ information. The result shown (Fig. c) refers to building vulnerability assessment for Earthquakes. Examples for tsunami can be found in Mück et al. (2013). Gained results provide crucial information concerning tsunami risk analysis, mitigation and evacuation planning.

Damage assessment and recovery monitoring

In the past, acquiring tsunami damage information was limited to only field surveys and/or using aerial photographs. By taking advantage of satellite remote sensing, the spatial distribution of structural damage by a tsunami can be identified (Fig. d). The advantage of using high-resolution optical satellite images for damage interpretation is the capability of understanding structural damage visually. These images also enable us to comprehend the spatial extent of damage at the regional scale, where post-tsunami surveys hardly penetrate because of limited survey time and resources (Suppasri, A., 2012). The Center for Satellite-based Crisis Information (ZKI) provides a 24/7 service for the rapid provision, processing and analysis of satellite imagery during natural disasters like tsunamis. For the 2004 and 2011 tsunamis in Indonesia and Japan, various disaster extent and damage maps were produced in order to support rapid crisis management and post-tsunami recovery actions. (http://www.zki.dlr.de)
Fig. 14  Satellite image of the City of Galle, Sri Lanka, shortly before the 2004 tsunami indicating the location of critical infrastructure exposed to tsunami. Source: Satellite image by GeoEye through European Space Imaging. Copyright: European Space Imaging, ESI, GMBH.
Vulnerability assessment involves the identification of indicators or proxies which may qualitatively or quantitatively capture the following factors:

- social – issues such as gender and age distribution; levels of literacy, education, social equity, peace and security; access to human rights, traditional values, beliefs and organizational systems;
- physical – susceptibilities of the built environment, including infrastructure;
- economic – issues of poverty, level of debt and access to credits;
- environmental – natural resource depletion and degradation.

In practice, the boundaries between these dimensions are far from clear cut. For example, there are obvious overlaps between the social and economic dimensions in respect of gender and poverty. These dimensions are described in more detail below and information sources are listed in Table 4.

C.5.1 SOCIAL DIMENSION

Assessment of social vulnerability aims to determine the predisposition of people within the coastal community to be affected by inundation from a tsunami.

Social (or human) vulnerability is a pre-existing condition that strongly determines a community’s predisposition to be affected by a tsunami. It can be linked to its ability to prepare for, cope with, and recover from, a disruptive event. Disasters and similar shocks make social vulnerability visible, since unequal patterns of suffering and recovery become apparent. The assessment of social vulnerability aims to determine the predisposition of people and their livelihoods, societies, and organizations within the coastal community to be affected by a tsunami. This predisposition may be rooted in social structures and cultural values as well as people’s access to resources and opportunities. Levels of social vulnerability may also be related to social castes or ethnic differences, and tend to be highest among women, children and the elderly and marginalized groups such as the poor (Box 11).

Other parameters which may contribute to the social dimension of vulnerability, particularly in urban areas, are:

- population growth and migration patterns, notably in coastal megacities;
- fragmentation among different social groups and sectors in urban areas.

In rural coastal communities, people dependent for their livelihoods on inshore artisanal fishers, such as those on the Indian Ocean coasts of Somalia, Kenya and Tanzania (see Box 27 and Box 28), would be particularly vulnerable to a significant tsunami impact on their shores.

While it is imperative to measure the current state of vulnerability of a community, it is equally important to assess the root causes related to those social, political,

Box 11 GENDER AND AGE-RELATED DIFFERENTIALS IN SOCIAL MOBILITY

The 2004 Indian Ocean tsunami manifested gender and age-related differential aspects with respect to the social dimension of vulnerability. Children in the youngest age group (0–10 years old) and adults over 40 years old could be considered as highly vulnerable when looking at the mortality rates in the coastal cities Galle and Batticaloa in Sri Lanka. Similar results have been presented for women based on mortality rates by gender. Findings in the Ampara District of Sri Lanka confirmed the notion that children in the youngest age group are highly vulnerable, as well as people over fifty. Researchers have concluded that women are far more vulnerable than men in these same geographical areas. A mortality survey in Tamil Nadu in India similarly highlighted the differential vulnerability of children, elderly and women.

In the case of children, higher mortality can be explained by physiological differences. Their small mass means they can be readily carried away by a tsunami as they lack the strength to grasp fixed objects such as trees. For women, higher mortality may be attributed to psychological and social characteristics. Like children, women may have less strength than men. In addition, learned skills tend to differ between men and women, particularly swimming and climbing trees, activities usually taught to boys but not to girls. Finally, some authors argue that the traditional division of labour means that women spend substantial amounts of time inside houses which could collapse on tsunami impact due to structural vulnerability. In the case of Sri Lanka and India, a social aspect which could contribute to higher mortality for women is the traditional wearing of saris, which could hamper running and swimming, and become tangled with heavy objects, leading to death by drowning.

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BOX 12  SUB-NATIONAL VULNERABILITY ASSESSMENT IN INDONESIA – THE GITEWS PROJECT

The vulnerability assessment within the GITEWS project focuses particularly on vulnerability factors of people exposed to tsunamis in terms of loss of life, injury and loss of livelihood. The assessment framework outlines two potential paths for reducing disaster risk and vulnerability through preventive measures before a disaster manifests, and through disaster response and management in the aftermath of a disaster. As a result, the project aims at providing sound information to support:

- crisis management capacities (e.g., emergency assistance) during an early warning scenario and
- developing disaster risk reduction strategies, such as measures for adaptation and mitigation.

Accordingly, the GITEWS vulnerability assessment aims at providing indicators and assessment tools for the continuous improvement of intervention tools, such as early warning and evacuation planning, disaster response and rehabilitation. The vulnerability assessment hence addresses the following components:

- the susceptibility and degree of exposure of vulnerable elements (population, critical facilities, built environment and regions affected), and
- the ability to respond (cope) and recover from the disastrous impact of a tsunami.

The vulnerability assessment results allow monitoring and quantification of the spatial vulnerabilities within the timeline of disaster occurrence. That means that, at each location, people’s vulnerabilities to tsunami warning (e.g., people’s ability to receive and understand a warning, ability to take an evacuation decision), to respond immediately (ability to evacuate and to reach a safe area), and to restore their livelihoods are quantified.

At sub-national scale, the assessment of vulnerability to tsunamis, linked to the question of effective people-centred early warning, encompassed different indicators that help to estimate the ability of people to respond to a tsunami. Areas where people face unusual difficulties to cope with a tsunami are disclosed and can be reduced when promoting respective adaptation and mitigation strategies. At the community level, vulnerability assessment products are being developed, taking into consideration specific local planning needs in the context of disaster management (e.g., for evacuation and contingency planning, e.g., Fig. 37). The vulnerability assessment results address specific end-users, such as early warning centres and disaster management agencies.

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in institutional, economic, environmental, and cultural factors which have led to the current state of vulnerability of such a community. The assessment of root causes is useful when promoting a broader perspective within the context of risk management.

C.5.2 PHYSICAL DIMENSION

The following account deals with physical vulnerability (also referred to as ‘structural’ or ‘infrastructure’ vulnerability) relating to tsunami impacts. It should be recognised that, in the case of near-field events, earthquake damage and loss may affect a community before a tsunami impacts. In such cases, damage and losses due to the tsunami impact will be compounded.

Physical (or structural) damage to buildings as a consequence of a tsunami impact is characterised by features such as:

- complete sliding of superstructures off their foundations;
- failure of structural members, including columns or load-bearing walls, due to impact loads from hydrodynamic forcing or the momentum of floating debris;
- collapse of infill wall panels due to strong lateral loads; and
- undermining of foundations due to scour, leading to full or partial collapse.

The assessment of physical vulnerability focuses on the combination of construction materials, building techniques, and the overall architectural design, which could be then related to damages which are typically observed. For example, the use of reinforced concrete framing to confine masonry, and of cement blocks or burnt-clay bricks in the construction of houses, reduces the vulnerability of such houses when compared with less robust structural systems or materials. Multi-storey construction is also known to perform well, as are houses with force-reducing hydrodynamic shape.

Assessment of physical vulnerability focuses on the performance of buildings’ construction parameters in response to the physical forcing of a tsunami inundation.

A starting point for this assessment is the compilation of a buildings exposure database which identifies the critical parameters relating to physical vulnerability. An example is the NEXIS database for residential buildings in Australia (Box 13).

Buildings exposed to tsunamis are subject to buoyant, hydrostatic and hydrodynamic forces. Damage may result
The National Exposure Information System (NEXIS) is a geospatially referenced database generated for all Australian residential buildings and contains information about building type, construction type, people, replacement value and contents value at buildings level. It is built from a number of fundamental datasets, such as Census, Mesh blocks, Cadastre, ABS Housing Survey and the Geo-coded National Address Framework. NEXIS-Residential is used to estimate the number of residential buildings affected by a tsunami event. Business or commercial buildings and infrastructure are not considered in this project as this NEXIS component is not yet mature and the vulnerability models are developed only for residential buildings. The input datasets are of various qualities and resolutions; therefore NEXIS derives buildings-level information based on generic rules and assumptions which produce errors and uncertainties. Any estimates of damage based on these data therefore are compared on a relative scale, rather than in absolute figures. A similar database has been created for commercial and business buildings, and one for industrial buildings is under development. These databases are periodically updated.

Krishna Nadimpalli

from a combination of these forces. The level of damage sustained is dependent on the magnitude of these forces as well as on the capacity of the structure to withstand them. The former is a function of the flow depth and velocity of the flow during inundation, while the latter is determined by the building’s physical vulnerability. Both of these factors can exhibit considerable variability across an inundation zone and thus the spatial pattern of damage may be variable. In addition, impact forces produced from debris transported by the tsunami and secondary effects such as fire may compound the damage. On the other hand buildings shielded by vegetation or other buildings will suffer less damage. The assessment of physical vulnerability is particularly important in the identification of buildings considered for vertical evacuation (Fig. 15 and see also H.2.2).

In calculating potential damage resulting from a particular hazard scenario, the maximum inundation depth at the structure of interest is the most important parameter. You may see this referred to as the ‘transfer parameter’. Inundation depth plus flow velocity would provide a better understanding of the forces to which the structure is subject, though most fragility models do not require velocity as a parameter. The type and quality of construction can have a significant effect on the damage sustained and should be taken into account when vulnerability assessments are being undertaken.

Fig. 15 Buildings vulnerability map. This example identifies buildings potentially suited for vertical evacuation in part of the city of Padang, Sumatra, Indonesia. The analysis is based on structural surveys combined with remote sensing techniques. Source: GITEWS Project. Courtesy DLR and Andalas University, Padang.
Available fragility functions focus on empirically based (post-impact) approaches that relate observed damage to an inundation parameter, such as the water depth above ground (or in some cases ground floor level) at the structure of interest. (Fragility functions are a method of linking hazard and physical vulnerability to damage or loss states, information that is key to risk evaluation). Observed damage is typically described qualitatively using a classification comprising four or five different damage states, some of which have been derived to be consistent with those developed for seismic damage assessment. In previous decades much of the research into damage functions has been largely exploratory, but now there is a growing literature from which consensus can be reached regarding the parameters that need to be incorporated in these functions. Although only a very approximate guideline, asset loss corresponding to the damage states in Fig. 16 can be considered as 100, 80, and 40 per cent for the damage states ‘complete’, ‘partial (usable)’ (referring to major structural damage) and ‘partial (unusable)’ respectively (referring to ‘non-structural’ minor physical damage). Damage due to exposure to water (even without any other physical damage) can result in asset loss of up to 30 per cent higher values being chosen when finishes, fixings, and partitions are susceptible to moisture. It should be noted that great care and judgement must be exercised if applying these empirical fragility functions beyond the context in which they were derived.

Another method to estimate damage is the use of vulnerability models or overall damage curves, originally developed for storm surge inundation and for river flooding (stage damage curves). The vulnerability models are based on limited data found in the literature as well as observations from historic events like the 2004 Indian Ocean tsunami. They can also be derived from fragility curves together with the damage percentages associated with each damage state; or even arrived at by expert consensus. The models could incorporate the following parameters which are considered to influence building damage:

- inundation (flow) depth at building site; or above ground-floor level; and
- types of building materials and heights of construction (e.g., the number of storeys)

Fig. 17 shows three vulnerability (damage) curves developed through expert consensus, co-ordinated by Geoscience Australia and developed for the UNISDR Global Assessment Report 2015. They show that the vulnerability of reinforced concrete residential buildings reduces with the number of storeys. Note also that, while the fragility functions are typically S-shaped, these curves tend to be concave downwards throughout.

### Table 3  Median inundation depth ranges by construction material and damage state

<table>
<thead>
<tr>
<th>DAMAGE STATE</th>
<th>TIMBER</th>
<th>MASONRY</th>
<th>REINFORCED CONCRETE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>~1.6 m</td>
<td>2.3–2.5 m</td>
<td>5.4–7.3 m</td>
</tr>
<tr>
<td>Major structural</td>
<td>~1.3 m</td>
<td>~1.9 m</td>
<td>~3.5 m</td>
</tr>
<tr>
<td>Minor structural</td>
<td>~1.2 m</td>
<td>1.3 m</td>
<td>1.4–1.9 m</td>
</tr>
<tr>
<td>Non-structural</td>
<td>0.3–0.5 m</td>
<td>0.3–0.5 m</td>
<td>0.3–0.5 m</td>
</tr>
</tbody>
</table>

The median inundation depth values required for various damage states for single-storey buildings constructed in three commonly used materials is shown in Table 3. The median inundation depth is that depth at which 50 per cent of the relevant building stock would have reached the specified damage state. These parameters are based on the growing body of literature on post-tsunami surveys.

![Fig. 16 Physical fragility functions. Showing the probability of being in, or exceeding, a damage state given the tsunami inundation depth. Source: Peiris, 2006.](image)

![Fig. 17 Overall damage curves for reinforced concrete (RC) residential buildings with varying number of storeys. Source: Maqsood et al. (2014); Geoscience Australia (with permission from UNISDR).](image)
Although the development of a satisfactory methodology to assess physical vulnerability is still immature, there are now sufficient data for making reasonable assessments of vulnerability. Furthermore, the PTVA model is also being developed to accommodate a much larger range of parameters than is possible with post-tsunami fragility curves (Box 14).

C.5.3 ECONOMIC DIMENSION

The economic dimension of vulnerability is related to the susceptibilities of the livelihoods, income and economic activity that would be affected by a tsunami scenario. The term ‘economic’ is so broad that it is difficult to make generalizations. The variety of manifestations of formal and informal economies, the interconnectivity between commercial services and economic activity, and the links between local and national levels in terms of supply, demand, and routine transfer of merchandise make it difficult to structure the analysis of this dimension of vulnerability in a simple framework.

Considering the concepts of direct and indirect vulnerability, direct vulnerability focuses on the predisposition of businesses and economic activity to short-term disruption. In contrast, indirect vulnerability addresses their predisposition to long-term, even permanent, disruption (see Box 15 and Box 17).

Considering the reliance of economic activity on the commercialization of merchandise or products of a various kinds, the vulnerability of such merchandise and products is an element to assess within the scope of this dimension. Important aspects to consider would be the susceptibility of damage or destruction of merchandise when inundated (for example, cement powder or paper products). Other elements related to this dimension are related to commercial operations (cash or credit transactions).

Potential economic losses can be broadly classified as tangible or intangible, and sub-categorised into direct and indirect losses. In terms of estimating losses in respect of tsunami inundation, tangible direct losses are defined as losses resulting from the impact of the event such as physical damage to buildings, infrastructure, contents, and vehicles (Box 16). Tangible indirect losses measure the disruption to businesses, transport and utility networks, clean-up costs, and emergency response and relief costs incurred as a consequence of the event.

The extent of the indirect costs is dependent on the availability of alternative sources of supply, markets for the products and the length of the production disturbance. Intangible indirect losses from natural disasters include death and injury, and loss of memorabilia. Intangible direct losses incorporate household disruption (schooling, social life), and health effects. There are no market values for intangible losses but non-market valuation techniques can be implemented to provide proxy values.

Ideally, an assessment of economic vulnerability in respect of a tsunami inundation can be conducted taking information on such losses into consideration. However, in the first instance, tangible losses are likely to be sufficient in providing conservative estimates of economic losses. Intangible losses are more difficult to estimate, given the need for proxy values. In any case, as tangible direct losses follow most directly from the physical impact and are the simplest to obtain; they are also the most readily developed and applied on a regional or national scale.

**Tangible direct economic losses due to tsunami inundation are the simplest to estimate and to apply on a regional or national scale.**

## Box 14: The PTVA Model for Calculating a Building’s Vulnerability

The PTVA (Papathoma Tsunami Vulnerability Assessment) Model is an index method based on a GIS platform that calculates the relative vulnerability of individual buildings to tsunamis. The vulnerability level is described using a numerical score, named Relative Vulnerability Index (RVI). The PTVA Model obtains RVI scores by combining contributions from the following factors:

- Attributes of the building structure, including the building material, number of stories, foundation type, hydrodynamics of the ground floor, building shape and preservation condition;
- Attributes of the building surroundings, including the protection provided to the building by natural or artificial barriers and the additional threat posed by nearby sources of large movable objects, such as car parks or marinas;
- The tsunami water depth expected to impact on the building.

The model has been validated against actual tsunami damage observations. Being relatively easy to apply, the PTVA Model offers the advantage of incorporating many idealised building attributes in the calculation of the total vulnerability of a building, whereas most tsunami fragility curves use the construction material only. As such, the PTVA Model can sensitively determine the differences in vulnerability between different building units. On the other hand, index-based methods such as the PTVA Model are relative, so the final vulnerability scores have no stand-alone meaning and can be used only to compare the expected performances of different buildings.

F. Dall’Osso, D. Dominey-Howes, The School of Geosciences, The University of Sydney
Sources: Dall’Osso et al. (2009a, 2009b, 2010)
Assessing your vulnerability

The economic assessment should establish those criteria and features of economic sectors that determine their vulnerability to tsunamis. This should cover potential direct impacts regarding the location of activities with respect to the inundation zone as well as indirect disruption of economic activities and critical infrastructures through the interruption of, for example, transport lines or distribution networks. Dependencies between different economic sectors and critical infrastructures should be assessed.

Electricity can play a crucial role for business continuity in the context of the tsunami hazard; the potential losses in different sectors in the event of the destruction of a generating site should be taken into account.

Guidance on the categorization of economic vulnerability in terms of loss levels may be found in the ECLAC publication described in Box 16 (see also C.7).

BOX 15 DIRECT AND INDIRECT ECONOMIC VULNERABILITY OF THE FISHING ACTIVITY IN GALLE, SRI LANKA.

The fishing sector in Galle could be characterized via a formal component, which is characterized in terms of formal enterprises that make use of fishing fleets, permanent workers, and formal economic practices, leading to the commercialization of fish at the regional, national, or even international level. In contrast, there is an informal component characterized in terms of local communities of fishermen which make use of small, personal fishing vessels, and who market their products in the local fish markets through the informal economy.

Economic activity, in either case, depends on the use of fishing vessels and equipment. The use of fibreglass as a material to construct boats is typical, particularly in the informal segment. But as witnessed during the 2004 Indian Ocean tsunami, such boats are extremely susceptible to destruction. As such, it could be stated that the sector has a direct vulnerability associated with the physical vulnerability of boats and fishing gear.

In the case of indirect vulnerability, the experience in Galle showed that, although local fishing communities were provided with new fishing boats and equipment, their economic activity took several months to recover. In this case, local eating habits were changed abruptly by gossip concerning fish caught by local fishermen. It took more than three months for local people in Galle to resume the consumption of fish caught by local fishermen. As such, it can be stated that this sector faces both direct and indirect vulnerabilities in respect of economic activity.

Juan Carlos Villagran

BOX 16 DIRECT ECONOMIC VULNERABILITY OF PETROL STATIONS IN GALLE, SRI LANKA

The city of Galle has nine petrol stations serving local and district needs. Four of these were exposed to tsunamis resulting in:

- injury of staff operating the stations;
- destruction of pumps to deliver fuel to vehicles;
- contamination of storage tanks; and
- loss of financial resources as cash and credit vouchers.

The vulnerability of pumps relates to the fact that they are not properly anchored, nor designed to resist a tsunami impact. The vulnerability of the storage tanks relates to the fact that they were not properly designed to avoid the introduction of a tsunami surge once pumps become dislodged, and the fact that fuel inside such tanks may become contaminated. The vulnerability of financial resources was high in the context of credit vouchers typically used; as such, paper vouchers have no resistance in the event of a tsunami surge.

Juan Carlos Villagran
C.5.4 ENVIRONMENTAL DIMENSION

Tsunami inundation may have a devastating effect on coastal ecosystems both on- and offshore. Because of its wide-ranging parameters, this dimension may be one of the most difficult to quantify. The rapid environmental assessment carried out on behalf of UNEP after the 2004 Indian Ocean tsunami drew attention to the scale of environmental vulnerability of the shores that were impacted. The assessment highlighted the problems of contamination of water supplies by saltwater (and in some cases faecal bacteria) both from groundwater and in wells; also the salination of inland waters, wetlands and agricultural land fundamental to people’s livelihoods (Box 18).

Anecdotal evidence and satellite photography before and after the tsunami event seems to corroborate claims that coral reefs, mangrove forests and other coastal vegetation, as well as peat swamps, provided natural protection from the impacts of the tsunami (Box 19; G.1). Vegetated sand dunes appear to have provided an excellent first line of defence. The damage to coastal ecosystems was highly variable, and the damage to coral reefs was due mostly to the impact of debris and sediment flushed from the land.

Assessment of environmental vulnerability includes the appraisal of the predisposition of ecosystems, natural resources and environmental services to be affected (through depletion or degradation) by tsunami inundation. Elements that can influence environmental vulnerability are:

- exposure to toxic and hazardous pollutants;
- inappropriate waste management; and
- physical degradation.

Parameters that need to be taken into account are:

- surface water;
- groundwater;
- soil;
- ecosystems;
- ecosystem services including natural defences;
- landscape / topography;
- dependency of coastal community on environmental resources and services; and
- linkages between environmental resources and land management.

The level of environmental vulnerability depends on the quality and fragility of the environmental resource base, as well as the dependence of the community on this resource base.

For each of these properties, parameters that could be affected by tsunami inundation should be identified. For example, the surface water parameter has to be assessed in terms of potential salinity, contaminants and the presence of debris. The possible impact for each selected property should be assessed, taking into account the environmental coping capacity both with, and without, human intervention. Such analysis will facilitate the prioritization of mitigation and rehabilitation measures. The level of dependency of the coastal community on the resource base, such as surface water, should also be appraised in case of contamination resulting from inundation. Thus the overall level of environmental vulnerability depends on the quality and fragility of the environmental resource base, as well as the dependence of the community on this resource base (see Box 19).

BOX 17 ECONOMIC IMPACTS OF THE 2004 INDIAN OCEAN TSUNAMI IN ACEH PROVINCE, INDONESIA, AND SRI LANKA

In Aceh Province, the immediate economic impact (total damage and loss due to the earthquake and tsunami) was estimated by the World Bank at about USD 4.45 billion. Of that amount, 60 per cent was damage (direct loss) and 40 per cent was loss of income flow to the economy (indirect loss). The sector most affected was agriculture, in particular, fisheries. Half of the fishermen were confirmed dead and 40–60 per cent of coastal aquaculture ponds were seriously damaged. It was also estimated that 60–75 per cent of the small-scale fishing fleet and its associated gear were destroyed.

In Sri Lanka, damage to the national economy was estimated at around USD 1 billion or 4.5 per cent of the GDP, and the cost of reconstruction at USD 1.5–1.6 billion. Tourism and fishing suffered massively in the tsunami-affected areas. More than 80 per cent of the island’s fishing fleet was wiped out. Approximately 30 per cent of the room capacity of tourist hotels was damaged. While the rice crop was not badly affected, it was noted that heavy loss of life would probably lead to a manpower shortage affecting the harvest.

Source: Athukorala and Resosudarmo, 2005.
Assessing your vulnerability

**BOX 18  ECLAC HANDBOOK FOR ESTIMATING THE SOCIO-ECONOMIC AND ENVIRONMENTAL EFFECTS OF DISASTERS**

The Handbook describes a tool that enables one to identify and quantify disaster damages by means of a uniform and consistent methodology that has been tested and proven over three decades. It also provides the means to identify the most affected social, economic and environmental sectors and geographic regions, and therefore those that require priority attention in reconstruction. The degree of detail of damage and loss assessment that can be achieved by applying the Handbook will, however, depend on the availability of quantitative information in the country or region affected. The methodology presented allows for the quantification of the damage caused by any kind of disaster, whether man-made or natural, whether slowly evolving or sudden. The application of the methodology also enables one to estimate whether there is sufficient domestic capacity for dealing with reconstruction tasks, or if international cooperation is required.


**BOX 19  CONTAMINATION AND SALINATION IN SRI LANKA.**

In Sri Lanka, water wells remained contaminated months after the 2004 Indian Ocean tsunami. This forced the Red Cross and the Government to supply potable water to rural communities located on the coast for quite some time. In addition, salination of the soil used for agricultural purposes decreased agricultural yields. While it is not expected that such a condition will be permanent, restoration of affected ground by rain-fed leaching could take years.

*Source: Renaud, 2006*

**BOX 20  CORAL REEF VULNERABILITY AND COMMUNITY DEPENDENCY, SEYCHELLES**

Following the tsunami that hit the Seychelles islands on 26 December 2004, two major patterns in coral reef damage were noted, dependent on the geographical location of each island, the direction of exposure at each site, and the reef substrate. The northern islands clustered around Praslin (including Curieuse, La Digue, Felicite and the rocks of Isle Coco and St Pierre) showed very high levels of damage (approaching 100 per cent) on unconsolidated carbonate reef substrates previously weakened (in 1998) by coral bleaching and mortality. By contrast, sites around Mahé showed much lower levels of impact, generally below 10 per cent, due to the shelter provided by the outer northern islands and dissipation of wave energy as the tsunami travelled over the greater distance of shallow water from the outer edge of the banks to Mahé. Coral reefs are very important to the economy, society and infrastructure of the Seychelles – all the damaged northern sites are prime tourist locations for the country, and the most highly damaged terrestrial locations are adjacent to degraded reef areas. Though impacts from the tsunami were less than from other threats, such as coral bleaching, their effects were compounded and possibly synergistic. The roles of, and impacts on, coral reefs with respect to the tsunami highlight the differential vulnerability between different locations; also the need to implement strong measures for reef and coastal conservation.

*David Obura and Ameer Abdulla*
A recently introduced approach to the assessment of vulnerability is through sectors of development. From a policy-relevant point of view, this approach is based on the notion that agencies or institutions in charge of these sectors are responsible concerning vulnerability reduction within their respective sectors (Table 5). These institutions may be government departments or agencies and may span various political/administrative levels.

Vulnerability assessment within the context of the ‘sector’ approach starts by defining:

- the hazard scenario and geographical levels at which the assessment is being made; then
- the sector to be addressed; then
- the component of vulnerability being assessed.

The assessment then focuses on six components of vulnerability. Elements within each component have been deducted from a systematization of damages and losses during the 2004 tsunami.

- The human condition/gender component relates to the presence of human beings and encompasses issues related to deficiencies in mobility of human beings and gender.
- The physical component relates to the predisposition of infrastructure employed by the sector to be damaged or destroyed by an event associated with a specific hazard.
- The functional component relates to the functions which are normally carried out in the sector and how these are prone to be affected.
- The economic component is related to income or financial issues which are inherent to the sector.
- The administrative component relates to those issues associated with the management of routine operations and how such administrative issues can be affected by an event.
- The environmental component relates to the interrelation between the sector and the environment and the vulnerability associated with this interaction.

<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>VARIABLES (AND STANDARDS)</th>
<th>SOURCES</th>
<th>GLOBAL DATASETS AND PROGRAMMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vulnerability maps and reports</td>
<td>Demographic, gender and educational parameters; access to information and hazard awareness; exposure to tsunami - number of people living in the hazard zone (people per ha.).</td>
<td>Asset maps; local census data; health and welfare services; tourism organizations; exposure and vulnerability surveys.</td>
<td></td>
</tr>
<tr>
<td>Social/human condition/Gender</td>
<td>Building materials; types of construction.</td>
<td>Structural vulnerability surveys; exposure surveys; housing census (information on building materials used for walls and floors).</td>
<td></td>
</tr>
<tr>
<td>Structural/physical</td>
<td>Distribution and value of industry, agriculture and infrastructure; the built environment; public utilities.</td>
<td>Land-use maps; Local and National authorities; utility suppliers; trade and industry organizations including ports, agriculture and fisheries; transport companies; insurance companies; exposure and vulnerability surveys.</td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>Distribution and value of habitats supporting human well-being; water supply; groundwater quality.</td>
<td>Asset maps; agriculture and fisheries organizations; water and sewerage utilities; environmental health authorities; exposure and vulnerability surveys.</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 Information sources for assessment by ‘dimensions of vulnerability’.

C.6 ASSESSING VULNERABILITY BY ‘SECTORS OF DEVELOPMENT’
Assessing your vulnerability

<table>
<thead>
<tr>
<th>SCALES OF ASSESSMENT</th>
<th>DEVELOPMENT SECTORS</th>
<th>COMPONENTS OF VULNERABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>Housing</td>
<td>Human condition / gender</td>
</tr>
<tr>
<td>State or Province</td>
<td>Basic lifelines</td>
<td>Physical</td>
</tr>
<tr>
<td>District or Municipality</td>
<td>Health</td>
<td>Functional</td>
</tr>
<tr>
<td>City or local</td>
<td>Government</td>
<td>Economic</td>
</tr>
<tr>
<td>Single unit or house</td>
<td>Commerce</td>
<td>Environmental</td>
</tr>
<tr>
<td></td>
<td>Finance</td>
<td>Administrative</td>
</tr>
<tr>
<td></td>
<td>Industry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communications</td>
<td></td>
</tr>
</tbody>
</table>

*Table 5 The three dimensions of the ‘sectors of development’ approach to vulnerability assessment. Source: Villagran de Leon, 2006.*

The ‘sector’ approach then identifies options for each of these components and assigns weights to each option regarding their disposition to be affected by a scenario. A simple linear combination of the elements is carried out numerically to obtain a numerical output for the intrinsic vulnerability component. This can be characterized as low, medium or high, using a table of ranges. All numerical values regarding options, as well as weights to combine the elements, have been deduced by employing expert judgment.

### C.7 DETERMINING THE POTENTIAL LOSSES FOR A TSUNAMI IMPACT EVENT

**Potential losses from a tsunami event are determined by summing the potential losses from each location or source of loss into an aggregated value.**

Losses may be expressed in many ways, depending on the accuracy of the available information and the application for which the risk analysis is being conducted. In terms of physical quantities, examples of aggregated losses might include estimates for the:

- length of coastline inundated;
- area exposed;
- number of affected population;
- casualties or deaths;
- number of buildings damaged or destroyed;
- extent of critical infrastructure damage, etc.

In terms of environmental measures, examples would include the:

- area affected by salt water intrusion;
- number of trees damaged;
- extent of coastline affected, etc.

For social and economic consequences, estimates of the duration of inundation or resulting disruption to the community also represent measures of potential loss that can be quantified and ranked for different events and their probabilities. Finally, all of these factors and others expressed here can be cast into an economic model in order to estimate the total economic impact of an event. Economic losses are generally grouped in terms of:

- direct losses (those arising from direct physical damage and cost of reconstruction); and
- indirect losses (those arising from the loss of income or utility of an asset).

Ultimately, the measures of loss and the values placed on community assets and their function must be assessed and validated at the community level. Thus, if environmental factors are highly important to the community, these factors must be weighted so that this importance is reflected in the risk assessment. On the other hand, if the potential for loss of life is the main driver for the study, the focus of the risk assessment and basis for loss estimation will naturally be placed on inundation mapping together with buildings and infrastructure damage. In any case, the measures of loss that are included must be consistent with the mitigation measures that are available or appropriate to the situation.
C.8 POST-EVENT LOSS AND DAMAGE SURVEYS

See also Section L.2

When a community or a city is impacted by a tsunami, its government needs to become aware of the impacts of the tsunami inundation as a way to respond to the event and to elaborate and implement a recovery plan. This is done through a loss and damage assessment. Such an assessment provides precise information on the extent of damage to infrastructure used for many purposes (housing, critical lifelines, health, education, road infrastructure, telecommunications, etc.). The assessment also includes the effects of the tsunami on the community’s population in terms of the number of people injured or killed, as well as the number of people who have been evacuated to shelters and those who otherwise have been directly or indirectly affected.

Loss and damage assessments generate data which is then processed to generate information regarding relevant needs that need to be met as a way of coping with the tsunami. These include the provision of humanitarian assistance to those affected, resources to manage temporary shelters, medical supplies and equipment to restore lifelines and basic services. The assessments also identify the degree of losses in financial terms and to estimate the cost of the reconstruction and recovery process.

In some cases, a rapid assessment of losses is conducted in the days following a tsunami inundation, and a more precise assessment of losses and damages is conducted in the weeks after the event as a way to generate more precise data on which to make decisions regarding reconstruction and recovery efforts.

C.9 OUTPUTS FROM THE VULNERABILITY ASSESSMENT

The outputs of the vulnerability assessment are typically presented in reports and may include a range of vulnerability maps. Vulnerability maps represent the status of the coastal community in respect of a specified level of inundation (linked to a specified tsunami scenario). They are a powerful tool for emergency management.

Maps showing vulnerability levels provide key guidance in the provision of specific advice to coastal managers and planners in linking the output of the vulnerability analysis to the input for vulnerability reduction.

Maps covering a range of tsunami scenarios and depicting a range of vulnerability dimensions at different scales, e.g., national or local, may be envisaged (M.3). The vulnerability levels can be expressed on the maps in broad categories – low, medium or high – or in terms of percentages (for example, percentage of vulnerable buildings). Vulnerability levels provide key guidance in the provision of specific advice to coastal managers and planners in linking the output of the vulnerability analysis to the input for vulnerability reduction. When integrated with the assessed probability of a hazard scenario, and with the results of the preparedness assessment (Chapter D), they provide an indication of the level of risk – the probability of the assessed consequences – for communities in the defined coastal area (Chapter E).
KEY OUTPUTS AND RESULTS ASSOCIATED WITH THE VULNERABILITY ASSESSMENT MAY INCLUDE:

- an asset database (or inventory) and asset map;
- an exposure database and map;
- a preliminary appraisal of vulnerability in respect of exposure due to tsunami inundation carried out (perhaps leading to a preliminary risk appraisal), so that local authorities and disaster reduction and prevention agencies may appreciate the importance of setting up a plan for vulnerability assessment of the designated coastal area;
- in-depth assessments of each dimension of vulnerability and its potential consequences in respect of specified hazard scenario(s);
- vulnerability maps and reports produced, with the involvement of end users, for the designated coastal areas, whether at the regional or the local scale, covering each dimension of vulnerability, and aggregated vulnerability, for specified hazard scenario(s);
- vulnerability maps and reports covering future scenarios, taking into account the likely effects of improved emergency preparedness and mitigation;
- reports relating to ‘sectors of development’ as appropriate;
- estimates of potential loss and damage in the event of inundation by a specified tsunami scenario; and
- communication of the vulnerability assessments with potential losses and damages to all involved in risk assessment and emergency management.

SUGGESTED ADDITIONAL READING AND INFORMATION SOURCES


Assessing your preparedness

Assessing your preparedness

This chapter sets out guidance on the steps for assessing the preparedness of your community to cope with a tsunami event. This includes the levels of its awareness of the nature and consequences of a tsunami impact, its access to early warning, the responses of its emergency services before, during and after an inundation, and the extent to which its risk of damage and loss has been transferred. In particular, the guidance emphasises the need for you to identify weaknesses in your existing systems so that these can be addressed as part of your risk reduction campaign.

In addition to the assessment of your community’s intrinsic vulnerability in respect of the tsunami hazard (Chapter C), it is also important to assess, at national and community levels, your preparedness to anticipate, respond to, and recover from a tsunami emergency. Depending on the location of the tsunami’s source, a key feature of this hazard is that there may be very little time to warn and evacuate people at risk. Although a community’s preparedness may provide little defence against damage to its built and natural environments, the evidence from recent tsunamis to affect the region shows the importance of preparedness in saving lives.

In this guidance, preparedness is dealt with separately from vulnerability. However, it is fair to reason that any actions taken to improve preparedness, e.g., participation in an effective early warning system, or enhancing capacities at all levels of governance and management, will lead to a reduction in the community’s vulnerability.

Preparedness assessment focuses on identifying deficiencies which may be manifest as weaknesses of institutions, organizations and communities to deal effectively with the anticipation of, response to, and recovery from, tsunami events.

Preparedness assessment focuses on identifying deficiencies which may be manifest as weaknesses of institutions, organizations and communities to deal effectively with tsunami events. For example, people may not be aware of the risk they face nor be aware of how to react to a tsunami warning; there may be shortcomings in your Early Warning System, including its standard operating procedures (SOPs, D.2) and corresponding evacuation plans to ensure an efficient and timely response. Your emergency management organization may not have the capacity to respond in all locations exposed; or there may be a lack of emergency operation centres (EOCs, D.3) and contingency plans, leading to the poor coordination of response efforts, and gaps or duplication of effort. Another possible deficiency might be a lack of take up of risk transfer mechanisms (D.4), enabling impacts to be confronted and facilitating recovery.

KEY TASKS IN THE PREPAREDNESS ASSESSMENT PROCEDURES

• Appraise the degree of awareness regarding tsunami risk on behalf of key stakeholders (communities at risk, authorities and those conducting emergency response efforts).
• Identify and appraise weakness in your early warning system and in your responses to a warning.
• Identify and appraise the condition of vertical evacuation shelters and evacuation routes.
• Estimate the time required for the population to reach shelters and safe areas.
• Assess the application of risk transfer mechanisms which would facilitate post-impact recovery.

The presence of good institutionalized capacities, effective organizations and good governance may be seen as reducing your community’s vulnerability. However, from a policy-relevant point of view, the responsibility concerning preparedness should be placed on those agencies in charge of preparedness (national or local emergency committees), while vulnerability should be the responsibility of those who generate it. For the latter reason, in these guidelines the assessment of preparedness is treated separately from that of vulnerability.
The 2004 Indian Ocean tsunami, as well as previous tsunamis elsewhere in the world, indicated that not all people in coastal areas were aware of the possibility of tsunamis impacting them, nor the level of risk associated with the tsunami hazard. In many Indian Ocean countries, the term “tsunami” was largely unknown before the December 2004 event. The transmission of a tsunami early warning may not have been properly understood by coastal communities, resulting in an inappropriate response. Some people did not understand the recession of the sea as a natural tsunami warning sign, and others were surprised and had little knowledge regarding how to reach safe areas quickly or the need to flee as quickly as possible, leaving everything behind. In some cases people were unaware of safe areas for evacuation (D.2). The lack of awareness, together with a lack of evacuation route signage, compounded losses.

A community’s knowledge and awareness of the tsunami risk and its implications are important parts of its being prepared and ready for a tsunami event.

Thus knowledge or awareness of the tsunami risk and its implications for the community is an important part of being prepared and ready for a tsunami event. Awareness assessment provides an indication of the extent to which such knowledge exists, not only at all levels in the community, but by your national government as well. For example:

- Do the national policies for disaster risk reduction specifically encompass the tsunami hazard?
- Is there awareness of the benefits and functioning of the regional tsunami early warning and mitigation system, IOTWS?
- Does the educational curriculum include awareness of the tsunami risk and community response?
- Are local government planners and managers aware of the risk to the community and its assets from tsunami inundation?
- Is your community aware of the scale and likelihood of tsunami inundations that might affect it?

In general, weaknesses in awareness may relate to:

- the risks that your community faces with respect to tsunamis;
- the Early Warning System, including responses to a warning or when the signs of an incoming tsunami manifest themselves, before inundation;
- the response after inundation; and
- risk transfer mechanisms facilitating post-impact recovery.

The assessment regarding the degree of awareness of your community concerning tsunamis and how best to respond should be conducted through a survey that targets:

- people who are directly exposed to tsunamis because they reside, work or play close to the seashore (refer to inundation and hazard maps, B.5);
- local authorities;
- people in charge of responding in case of disasters, including members of the fire brigade, Red Cross and similar first aid volunteer organisations, special groups such as search and rescue teams, and your local emergency or disaster management committee.

An awareness survey should also inquire about people’s understanding of safe areas in event of tsunamis and which evacuation routes to use to reach such safe areas. The survey should also assess whether there is access to awareness material on tsunami risk, tsunami early warning, response and recovery efforts in the community, and whether awareness campaigns are conducted regularly in the community at risk. The outcome of such a survey will provide you with guidance regarding how best to plan and conduct a campaign to raise awareness regarding tsunamis, targeting people in the coastal community and relevant stakeholders (0).

See Section L.5 for a description of Community-based Disaster Risk Management (CBDRM).
When the 2004 Indian Ocean tsunami occurred, there was no early warning system operating in the Indian Ocean. However, since early 2005, there have been efforts to design and implement the Indian Ocean Tsunami Warning and Mitigation System (IOTWS), incorporating Tsunami Service Providers (TSPs) and National Tsunami Warning Centres (NTWCs) (H.3). Efforts are underway to ensure that all coastal communities in the Indian Ocean benefit from this early warning system, and that the system is established within an efficient, people-centred framework.

**Are the early warning procedures robust and effective?**

Having a tsunami warning system in place does not mean that the system is flawless, that it can handle all types of tsunamis on a timely basis, and that all people at risk are aware of how it operates and how they should react in case a warning is issued. The 2010 earthquake in Chile that led to a tsunami revealed weaknesses in Standard Operating Procedures (SOPs) regarding tsunami forecasting based on seismic data and of gaps in communications that led to the cancellation of the tsunami warning while tsunami waves were still impacting the coastline.

A Tsunami Early Warning System needs to be regularly tested to ensure not only its technical operability but also the awareness of people at risk of how it operates and how they should react to a warning.

For example, the 2011 Tohoku earthquake in eastern Japan that triggered a catastrophic tsunami revealed weaknesses in the automatic system used by the Japanese Meteorological Agency (JMA) to process data from seismic stations and sea-level gauges. In the case of this very large earthquake, the initial seismic signals received by the system led to an initial indication of a small tsunami. Subsequently, the saturation of the seismometers in Japan allowed JMA to update tsunami warnings using data from sea-level gauges and buoys via GPS networks, but only after the passage of fifteen minutes (see A.3).

A review of critical issues that have hindered the efficient and timely operation of early warning systems has led to the identification of six critical issues:

- implementation of technically-oriented early warning systems, without considering the notions of vulnerable groups and risk assessment;
- weaknesses in monitoring and forecasting potentially catastrophic events;
- weaknesses in understanding that tsunamis occur as a series of waves – the last wave may reach a coastal area several hours after the first;
- weaknesses in communications between regional service providers in charge of monitoring and forecasting tsunamis and NTWCs and emergency response offices at national and local levels;
- weaknesses in issuing warnings and ensuring that warnings reach vulnerable people; and
- weaknesses in community’s capacity to respond to a warning and potentially catastrophic event.

So long as such weaknesses remain, tsunami early warning systems will not be robust and effective in saving lives.

**Are warnings reaching those at risk who need them?**

Considering that tsunamis can occur at any time, day or night, on weekdays or on weekends or on holidays, tsunami early warning systems must be able to operate on a 24/7 basis and be able to issue warnings at any time when required. Since the late 1990s, efforts began to re-shape early warning systems so as to make them more ‘people-centred’. This implies that systems should target people at particular risk – those exposed to the tsunami hazard and the vulnerable.

Key questions to consider when assessing the effectiveness of early warning systems in issuing warnings include:

- Does your country have a 24/7 facility and staff for receiving tsunami alert messages from regional providers (TSPs; see H.3.1, M.1)?
- Are communities at risk able to receive warnings at any time of day or night?
- Does the early warning system have specific procedures to ensure that warnings reach groups with a higher degree of vulnerability – children, the elderly, women, disabled people?
- Does the early warning system have procedures to ensure that warnings reach those in places where large numbers of people congregate – commercial areas, bus and train stations, public markets, etc.?
- Does the early warning system have procedures to ensure that warnings reach indigenous groups?
- Are warnings issued in languages that are easily understood by those at risk?

**Is there enough time for people to reach safe areas located inland?**

The evacuation of people to shelters in high-rise buildings or to safe areas inland is an issue that demands considerable attention from emergency managers. When assessing such evacuation procedures, it is important to...
consider the different types of vulnerable groups and their locations; some of these groups may require more time to evacuate to a safe area. Traffic congestion may impede evacuation (see Box 21 and case study at K.9) even if planned evacuation routes are followed.

**WILL PEOPLE EVACUATE TO SHELTERS AND SAFE AREAS WHEN A TSUNAMI WARNING IS ISSUED?**

While emergency managers would prefer that all people who receive a warning evacuate at once, in reality the decision process concerning whether people evacuate or not depends on several factors including the perception of vulnerability, age, ethnicity, gender, social status, previous knowledge or experience regarding tsunamis, proximity to the coast and the responses of others. The decision whether or not people will evacuate is based on the notion that:

- the warning is real (hence credible);
- they will be severely affected by the event;
- evacuating to a shelter in another place is better than staying where they are, even if they are in their homes.

Hence, it is important for emergency managers to conduct surveys to assess the likelihood that people will evacuate to safe areas or shelters having received a warning; and what beliefs or concerns they may have that inhibit them from taking immediate action (Box 22).

**ARE EVACUATION SHELTERS AND SAFE AREAS REALLY SAFE?**

The 2011 tsunami that devastated coastal areas in Japan affected or destroyed buildings such as community centres and gymnasiums that had been established officially as shelters and safe areas in case of tsunamis. In addition, the tsunami reached areas inland that were not identified in the local tsunami hazard maps as being exposed. As a result, people in some of these shelters were killed or injured, while others recognised the need to evacuate to safe areas beyond those originally foreseen. Emergency managers must assess whether tsunami shelters and safe areas are properly located, considering the most up-to-date information about potential inundation.

**ARE SIMULATIONS AND EXERCISES CONDUCTED REGULARLY?**

Carrying out routine simulations and exercises or drills is geared to identify weaknesses in the tsunami early warning system and to test and validate changes in the Standard Operating Procedures (SOPs) employed by the system; also to contribute to an awareness of those at risk of the system and how it is supposed to function. Infrequent simulations or drills are indicators of a weakness that need to be addressed.

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**BOX 21 EVACUATION FOR 11 APRIL, 2012, SUMATRA OUTER-RISE EARTHQUAKE**

The outer-rise earthquake on 11 April, 2012, triggered activation of the tsunami warning system in Indonesia. The earthquake had an unexpected source, outside the Sumatra-Sunda subduction zone. Nevertheless a warning was issued to the public by the National Tsunami Warning Centre within five to 12 minutes, according to the Centre’s Standard Operating Procedures. The national media also broadcast the warning. The reaction of communities varied.

In Aceh, which was affected by the 2004 tsunami, communities fled in panic away from the sea, mostly using vehicles resulting in a severe traffic jam. In Padang, West Sumatra, a lot of communities without the direct experience of a tsunami refused to evacuate, though they did admit to receiving warning messages by the media, the community radio network or by siren. Provincial government in West Sumatra decided not to activate their siren, because of uncertainty as to whether a tsunami would be generated and since their popular education made no mention of an outer-rise scenario for triggering evacuation orders.

This particular event vividly demonstrated how communities and local government can make different and unpredictable choices in responding to real events, compared to drills and exercises.

*Irina Rafliana from Yulianto and Rafliana, 2012.*
BOX 22 TAKING ACCOUNT OF SOCIAL BEHAVIOUR IN EVACUATION AND RECOVERY PLANNING

Understanding social behaviour after a tsunami warning has been issued in densely populated coastal cities at risk of inundation should be a key element in planning and maintaining community preparedness and readiness to evacuate to places of safety. Experience from surveys in Indonesian coastal cities has shown that, although each is different, some of the provisions made by local government to reduce risk tended to be underused – there were low levels of participation in tsunami drills and an indifference to evacuation signage; there was a low acceptance of the use of vertical evacuation shelters, some vertical shelters were avoided because they were thought to be too close to the beach. There was generally too great a reliance on the use of cars for horizontal evacuation leading to congestion at junctions and on main routes leading to safe areas, critical in cases of near-field tsunamis. There was a need for greater attention to be afforded to vulnerable groups, particularly for near-field tsunamis where warning times might be near, or less than, the times needed for evacuation to shelters of safe areas. Overall there was a need for technical guidelines for the evacuation process that took account of social behaviour in such stressful situations. Social behaviour was also a factor in planning decisions for resettlement of tsunami devastated areas; settlement by incomers with little experience of the tsunami hazard was simply recreating the risk of disaster.

Harkunti Rahayu

D.3 HOW EFFECTIVE ARE YOUR RESPONSE OPERATIONS?

A key area for assessment in preparedness relates to the capacities of disaster management organizations, NGOs, the private sector, volunteer groups including the fire brigade, the Red Cross or similar, and specific search and rescue teams to respond in case of an event. Is your community served by an emergency management organisation that has been trained to cope with tsunami events, with evacuation plans and standard operating procedures in place? Would the response to a tsunami event be timely and efficient? Such a response involves a coordinated approach that considers the type of event and the peculiarities of its occurrence. Weaknesses may be apparent in structures such as those of Emergency Operations Centres (EOCs) which are set up to facilitate the coordination of response efforts; in contingency plans and in specific units involved in response operations in the field.

Short lead times from the issuance of tsunami warnings demand rapid, orderly and coordinated responses from the community’s emergency services as well as from the community at large.

EMERGENCY OPERATIONS CENTRES

Emergency Operations Centres are facilities set up in one location that facilitate the execution of three key tasks: multi-agency coordination, decision-making, and management of information. An EOC is physically arranged to facilitate coordination and information-sharing among all those involved in its operations. The EOCs normally carry out their operations using EOC SOPs and generate the information that is later disseminated to the media and to the public via bulletins or through press conferences. A lack of inter-institutional coordination can lead to the duplication of effort, or to gaps or voids in response, and to costly delays in decision making. The use of EOCs in conjunction with contingency plans helps emergency managers to minimise such inefficiencies.

Key issues to consider in the assessment are whether the EOC:

- has 24/7 staff on duty for receiving tsunami alert messages from National Tsunami Warning Centre;
- includes the participation of all relevant stakeholders (government agencies, NGOs, private sector, civil society);
- is perceived as having the proper structure to facilitate the decision-making process regarding how best to respond in case of a disaster triggered by a tsunami or other hazard;
- includes a proper division of labour for tasks conducted inside the EOC;
- is capable of managing information properly and in a timely manner, in particular in the context of damage and needs assessments;
- is capable of communicating needs to higher level authorities when local capacities have been surpassed;
- has the staff and resources that it requires to carry out its tasks in a timely and effective way;
- is able to communicate effectively with those on the ground conducting a variety of operations (search and rescue, management of shelters, medical operations, security, etc.); and with a variety of organisations that can contribute to response efforts.

Simulations of disasters can assist you in identifying several of these weaknesses, and all stakeholders to agree on how to resolve them.

CONTINGENCY PLANS

Contingency plans are used to analyze the impact of potential hazard events so that adequate and appropriate
arrangements are made in advance to respond in a timely, effective and a way appropriate to the needs of the affected community. In this context, contingency plans should anticipate, pre-empt and solve problems that could arise during a disaster. The contingency plan allows all relevant stakeholders to be meaningfully involved, and to identify who is responsible for what when a disaster occurs.

Possible weaknesses in a contingency plan include, but are not limited to:

- inadequate description of the objectives to be achieved through its implementation;
- inadequate use of the information on hazard, vulnerability and preparedness of the community at risk that it is supposed to address;
- inadequate understanding of who is vulnerable and why;
- inadequate incorporation of gender, culture and other context-specific issues;
- lack of, or improper, incorporation of all relevant stakeholders;
- inadequate incorporation of the existing chain of command or command structures;
- inadequate sequence of tasks to be conducted, leading to unnecessary delays in the execution of response operations;
- improper match of resources to tasks that need to be carried out as part of the response operations;
- inadequate or complex mechanisms to request external assistance and to facilitate the provision of humanitarian assistance;
- inadequate planning regarding the use of special facilities which could be employed to receive and distribute humanitarian aid (airports, ports, train stations, etc.);
- too much rigidity when a degree of flexibility is required to address unforeseen circumstances or unexpected events;
- improper or inadequate management of data and information;
- inadequate incorporation of tasks related to communication and dissemination of information to the media and the public.

Contingency plans should be tested through simulations to identify their weaknesses so as to improve them. In addition, simulations should be conducted regularly so as to maintain the contingency plan ‘fresh’ in the minds of those stakeholders involved in its implementation.

SEARCH AND RESCUE OPERATIONS
Improper knowledge concerning how a tsunami manifests itself in terms of a series of waves over a period of a few hours, as opposed to just one wave, may lead to the start of search and rescue operations that may put more people at risk – in particular those conducting such search and rescue efforts, and those who may think that it is safe to return to coastal areas. So, it is important to identify if the procedures employed are inadequate when deciding when to start such search and rescue operations.

Similarly it is important to recognise that such operations require the allocation of specific, well trained staff and resources. So, it is important to identify the levels of skills of staff conducting these tasks and the type of training they have received; also which key resources are missing that may inhibit the execution of search and rescue operations in a timely and safe way, so as to ensure the safety and well-being both of those being rescued and those conducting these operations.

DAMAGE AND LOSS ASSESSMENT
Inaccurate data regarding damage and loss can lead to inaccurate estimations of the needs to respond to the impacts of the disaster in a timely and effective way. Therefore, emergency response agencies have spent considerable amounts of time and effort to systematise the execution of damage and loss assessment after a disaster.

Key weaknesses in this segment of the response efforts include, but are not limited to:

- a lack of awareness concerning the need to conduct systematised damage and loss assessments after a disaster;
- a lack of awareness regarding how data on damage and loss are relevant during the response and recovery efforts;
- an absence of this task from the contingency plan, and as a source of data for the activities to be coordinated in the EOC;
- delays in carrying out such damage and loss assessment or delays in reporting on the outcomes of such an assessment;
- inadequate procedures within the EOC to process data on damage and loss as a way to generate information on needs.

The relevance of the data gathered through the damage and loss assessment cannot be overestimated. It serves as the basis on which to identify needs, and it is used to decide how to distribute humanitarian assistance where it is needed.

MANAGEMENT OF TEMPORARY SHELTERS
Temporary shelters are needed to provide housing and subsistence to those whose homes have been destroyed or severely damaged.
Possible weaknesses in the provision of shelters include, but are not limited to:

- shelters located in areas exposed to hazards;
- inadequate size and services within the shelters (insufficient number of toilets, inadequate consideration of the elderly, women and children; insufficient access to potable water, food, energy, etc.);
- difficult access to the shelter, inhibiting the provision of resources to those in the shelters (food, blankets, potable water, etc.);
- unsafe conditions within the shelters;
- limited resources to meet the needs of those in the shelters (too little food or potable water, too few blankets, too little space, etc).

**MEDICAL TREATMENT OF THOSE INJURED**

Large disasters usually demand extraordinary efforts to be provided by the medical community, typically under stress due to the large number of persons either injured or killed. For those who are injured, the difference between life and death relies on being able to reach medical facilities and be treated in time to bring injuries under control. Ironically, those hospitals destroyed by disasters are the ones that would be the most needed to provide urgent medical treatment.

Key weaknesses in the provision of medical treatment to those injured include:

- the location of the medical facility in an area exposed to a hazard, rendering it either useless or inhibiting its capacity to provide medical services;
- the limited number of health centres or hospitals in relation to the number of people at risk;
- the lack of sufficiently trained staff (doctors, nurses, technicians) to cope with the demand in case of a disaster;
- the lack of emergency power plants to continue operations when access to electricity is interrupted;
- the susceptibility of the communications between medical facilities to request assistance, medicines or services as needed;
- the lack of resources to treat patients and the incapacity to mobilize additional resources on a timely basis.

The procedure recommended to identify such weaknesses is through a survey in the premises of these medical facilities.

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**D.4 TO WHAT EXTENT IS YOUR RISK TRANSFERRED?**

In developed countries, the use of insurance allows people to transfer their risks in time. Through the payment of premiums, people can manage the impacts of floods or other disasters in a less traumatic fashion. In developing countries, the use of insurance is still only an option for those who can afford it. To this end, it is important to find ways in which to design and operate insurance schemes which may allow you to cope with such events and to recover in a timely fashion.

In some developing countries, governments are establishing national catastrophe funds as a way to access financial resources very quickly to speed up response and recovery efforts. Further information on Risk Transfer is given in Section H.4.

**D.5 HOW RESILIENT IS YOUR COMMUNITY?**

Another component of preparedness concerns the resilience of the community. Resilience assessment provides a measure of the extent to which the community is able to accommodate and readily recover from a tsunami impact and its damaging consequences. This topic has been comprehensively covered by the guide "How Resilient is Your Coastal Community?" for evaluating coastal community resilience to tsunamis and other hazards (U.S. IOTWS, 2007). The assessment of resilience includes questions such as:

- Does the community have the organisation and coordination to understand and reduce tsunami risk, based on the participation of citizen groups and civil society?
- Are there incentives for communities to invest in reducing the tsunami risk they face?
- Does your community maintain an asset inventory and exposure database, prepare tsunami risk assessments and use these as a basis for development planning and decision-making?
- Does the community maintain critical infrastructure that reduces tsunami risk and does it have contingencies for damage to utilities?
- Does the community have the expertise and
KEY OUTPUTS AND RESULTS ASSOCIATED WITH THIS ASSESSMENT MAY INCLUDE:

- an appraisal regarding the degree of awareness regarding tsunami risk on behalf of key stakeholders (community at risk, authorities and those conducting emergency response efforts);
- a preliminary appraisal of the state of early warning practices, so that local authorities and disaster reduction and prevention agencies may appreciate the importance of setting up a plan to strengthen such early warning aspects in the designated coastal community;
- in-depth assessment of response efforts, including identifying deficiencies, in structures such as the EOC, contingency plans, and with respect to key activities conducted during the response phase;
- an appraisal of coverage in terms of insurance and micro-insurance schemes for risk transfer;
- an appraisal of the functional capacities at national and particularly local government levels that may determine the overall resilience of the community to natural disasters including tsunami inundations.

### Table 6 Variables and information sources for preparedness assessment.

<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>VARIABLES (AND STANDARDS)</th>
<th>SOURCES</th>
<th>GLOBAL DATASETS AND PROGRAMMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparedness in the context of early warning</td>
<td>Tsunami early warning system in place; communication links from national warning to coastal communities in place; warning schemes within coastal communities in place and tested; warning schemes target vulnerable groups previously identified; evacuation routes properly identified with visible signs; vertical evacuation shelters in coastal areas and safe areas far inland established on sound knowledge of tsunami hazard and taking into consideration extreme events; time required for vertical evacuation and for evacuation to safe areas inland properly estimated and standard operating procedures for evacuation adapted accordingly; evacuation procedures to shelters and safe areas are designed considering the notion of different types of vulnerable groups; drills and simulations conducted to test the state of readiness of the community to respond to a warning.</td>
<td>Government agencies; NGOs</td>
<td>IOC Unified Tsunami Website <a href="http://www.ioc-tsunami.org/">http://www.ioc-tsunami.org/</a></td>
</tr>
<tr>
<td>Preparedness to respond during and after the event</td>
<td>Emergency Operation Centres operational; Standard Operating Procedures operational; Search and Rescue teams well trained and well equipped; temporary shelters ready to be used at any time, properly staffed and with sufficient resources to cope with the needs to evacuees; medical teams ready to treat the wounded.</td>
<td>Government agencies; NGOs</td>
<td></td>
</tr>
<tr>
<td>Risk transfer mechanisms (see also H.4)</td>
<td>Insurance and micro-insurance provide adequate coverage; catastrophe bonds in place to ensure quick recovery; transparent and efficient mechanisms in place to access national emergency or catastrophe funds.</td>
<td>Insurance companies; re-insurance companies; Government agencies; NGOs</td>
<td></td>
</tr>
</tbody>
</table>
resources needed to plan and realise the implementation of measures to reduce exposure to, and transfer the risk of, the tsunami hazard?

- Does your community enforce building regulations and land-use planning principles that take account of tsunami impacts?
- Does your community allocate safe land for low-income citizens beyond the tsunami inundation zone?

These questions ask about the actions and activities that could affect the resilience of your community in the event of a possible tsunami impact. Many of the issues have been addressed elsewhere in these guidelines, as part of the risk assessment procedures or management responses. In this sense they are repeating what has already been dealt with. Nevertheless it may be useful to consider your responses to decide what, if any, actions need to be taken and to assist in identifying those people with responsibilities for action (risk assessors, emergency managers, land-use planners, etc.) within your community and local government.

Slightly different questions that you might ask in the assessment of disaster resilience are contained in a checklist given by UNISDR (2010). These seek to check whether your city (or community):

- is one where disasters are minimised because the population lives in homes and neighbourhoods with organized services and infrastructure that adhere to sensible building codes; without informal settlements built on flood plains or steep slopes because no other land is available;
- has an inclusive, competent and accountable local government that is concerned about sustainable urbanization and that commits the necessary resources to develop capacities to manage and organize itself before, during and after a natural hazard event;
- is one where the local authorities and the population understand their risks and develop a shared, local information base on disaster losses, hazards and risks, including who is exposed and who is vulnerable;
- is one where people are empowered to participate, decide and plan their city together with local authorities and value local and indigenous knowledge, capacities and resources;
- has taken steps to anticipate and mitigate the impact of disasters, incorporating monitoring and early warning technologies to protect infrastructure, community assets and individuals, including their homes and possessions, cultural heritage, environmental and economic capital, and is able to minimize physical and social losses arising from extreme weather events, earthquakes or other natural or human-induced hazards;
- is able to respond, implement immediate recovery strategies and quickly restore basic services to resume social, institutional and economic activity after such an event;
- understands that most of the above is also central to building resilience to adverse environmental changes, including climate change, in addition to reducing greenhouse gas emissions.

These parameters apply to all cities whatever their settings, not least to coastal cities subject to marine inundation hazards. You should note the emphasis placed on the roles of local government and local authorities in these resilience criteria.

The topic of improving resilience is considered in Section H.5; and that of ‘Resilient Cities’ is discussed as case studies at K.7 and K.8, and in the Chapter on Tools and Methods at L.6 and L.7.
D.6 OUTPUTS FROM THE PREPAREDNESS ASSESSMENT

The outputs of the assessment of preparedness are typically presented in reports and may include a range of maps. Maps represent the status of the community in respect of early warning coverage, the location of emergency operations centres, shelters, and other critical sites. They are a powerful tool for emergency management. Reports highlight critical issues in the four areas: awareness, early warning, response, and the take-up of risk transfer mechanisms.

A list of variables and information sources which could be used to assess your state of preparedness is given in Table 6.

SUGGESTED ADDITIONAL READING AND INFORMATION SOURCES


Evaluating your tsunami risk

This chapter shows how to use the outcomes of your assessments of the tsunami hazard, your community’s vulnerability to that hazard and your community’s state of preparedness to evaluate your risk of loss and damage. The procedure is the culmination of the risk assessment process that forms an integral part of the IOTWS.

The risk to the coastal community due to a credible tsunami scenario is evaluated as a function of the community’s vulnerability – in terms of potential human and economic losses and material damage – and the probability of that scenario occurring within a defined time period. Like the vulnerability assessment, the risk assessment may focus on specific dimensions (e.g. social or physical) or be aggregated to provide an overall value or class. The resulting risk assessment, either numerically quantified (if feasible) or qualified (e.g., high, medium, low) should provide managers and policy makers with a sound rationale for their responses, designed, as appropriate, to manage and reduce the risk of disaster from a tsunami event.

The community’s risk from a specified tsunami scenario is a function of its vulnerability – in terms of potential human and economic losses and material damage – and the probability of that scenario occurring within a defined period.

The quality of the risk estimates depends on the reliability of the hazard assessment and on the availability and quality of vulnerability and preparedness data. Subject to these requirements, risk estimates may be derived for any chosen scale (e.g., from individual buildings to the coastal built environment at the national scale), for any specified dimension of vulnerability (or aggregated vulnerability), or for any specified development sector. Estimates of risk can (and should) be customised. In this way the assessment can meet the specific requirements of the risk manager, the planner or the emergency manager within the defined geographic area.

A convenient and effective way of representing levels of risk (or estimated risk) is geospatially, by means of risk maps (Fig. 19). These maps show the extents of areas with defined risk categories (e.g., high, medium, low) for the required dimension of vulnerability in respect of a specified tsunami scenario. Risk maps can be derived by the integration using GIS technology of tsunami hazard and vulnerability map layers. Risk maps should be defined in relation to a specific tsunami hazard scenario and its forecast return period. They are perhaps the simplest and most effective tool at the community level for input to a wide range of decision making with a view to risk reduction.

**KEY TASKS IN THE RISK EVALUATION PROCEDURES**

- Confirm the geographical scale and limits of the assessment.
- Confirm the temporal scale of the assessment.
- Combine the tsunami inundation parameters (for specified scenarios with defined probabilities) with assessed levels of vulnerability and preparedness.
- Translate the combined hazard, vulnerability and preparedness outputs into levels of risk, denoting the probability of damage and loss for specified tsunami scenarios.
- Produce risk map(s) and reports for the designated management area.
- Communicate the risk assessment outputs to all levels involved in risk and emergency management.
This part of the guidance combines the outputs of the first three chapters – hazard assessment (Chapter B), vulnerability assessment (Chapter C) and assessment of community preparedness (Chapter D). It explains how you can integrate the information on the tsunami hazard with the information on the consequences of a tsunami impact on your communities (their vulnerability and preparedness) to provide a risk assessment in respect of a specified tsunami hazard scenario. This gives you a measure of the probability of those consequences (Fig. 18).

Risk can be reduced by reducing the vulnerability to the hazard and, in particular, with regard to people, improving preparedness. Its assessment is a logical outcome of the processes involved in the hazard, vulnerability and preparedness assessments. As with those assessments, it assumes a definition of its spatial and temporal scales, and its geographical limits. One may consider the risk from a particular event of interest, or risk may be aggregated across a suite of events or all possible events at all probabilities (or return periods).

The hazard assessment should have defined the exposure parameters for inundation relating to the specified tsunami scenario and the probability of that scenario. The vulnerability component should have defined the losses and damages in respect of the social, physical, economic and environmental dimensions of interest. The preparedness assessment should have characterized those limitations which inhibit the community from responding efficiently and in a timely way before, during and after a specific event to minimize fatalities or losses.

The quality of the risk estimates depends on the reliability of the hazard assessment and on the availability and quality of vulnerability data and preparedness information. Subject to these requirements, risk estimates may be derived for any chosen scale (for example, from individual buildings to the coastal built environment at the national scale), for any specified dimension of vulnerability, and for any specified development sector. Estimates of risk can (and should) be customised. In this way they can meet the specific requirements of the risk manager, the planner or the emergency manager within the defined geographic area.

### Table 7 Information sources for risk evaluation.

<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>VARIABLES (AND STANDARDS)</th>
<th>SOURCES</th>
<th>GLOBAL DATASETS AND PROGRAMMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk maps and reports for each identified hazard scenario in respect of: population; structures; economics; environment; or development sectors.</td>
<td>Assessed probability of specified tsunami scenarios; assessed levels of hazard based on inundation parameters; Assessed vulnerability parameters in respect of specified tsunami scenarios; Assessed preparedness factors.</td>
<td>Outputs from tsunami hazard assessment.</td>
<td>Outputs from vulnerability assessment. Reports for the state of preparedness in, or affecting, the community.</td>
</tr>
</tbody>
</table>
Evaluating your tsunami risk

A convenient and effective way of representing levels of risk (or of estimated risk) is geospatially, by means of risk maps. These maps show the extents of areas with defined risk categories (for example, high, medium, low) for the required dimension of vulnerability in respect of a specified tsunami scenario. Possible criteria for determining risk categories for specified scenarios include the following:

- **No impact (or risk)** = No direct damage from tsunami inundation is likely. May be suitable for staging recovery operations such as evacuation shelters and other emergency services.
- **Low impact (or risk)** = Damage likely to older buildings or non-engineered buildings or structures is likely. Life-threatening particularly to young, elderly and infirm. Some potential for locating or identifying structures suitable for temporary evacuation purposes. Requires emergency response planning including evacuation plan in the event of a tsunami.
- **Medium impact (or risk)** = Significant damage to non-engineered buildings and some damage to engineered structures likely. Highly life-threatening to all. Evacuation necessary to mitigate loss of life.
- **High impact (or risk)** = Buildings and human life are unlikely to survive. Evacuation is the only viable response measure.

Risk maps can be derived using GIS technology by overlaying hazard and vulnerability maps. Risk maps are often defined in relation to a specific hazard scenario and are perhaps the simplest and most effective tool at the community level for input to a wide range of decision making with a view to risk reduction (Fig. 19 and Fig. 20). Like vulnerability maps, they may be drawn at a range of scales, local to national, and may focus on specific dimensions, e.g., social (human) or physical (infrastructure) (see M.3) or show aggregated risk.

An assessment of risk needs to be more than just a snapshot of risk under present conditions. The assessment needs to address how risk might change with time. This might be caused by changing socioeconomic and environmental scenarios, as well as by the outcomes of existing and planned mitigation measures.

Successful mitigation can reduce risk by constraining the hazard (for example, by establishing barriers to inundation) and/or reducing the vulnerability (for example, by introducing building codes). However, environmental

Fig. 19 **Tsunami risk map at a local scale.** This example covers the city of Denpasar, Bali, Indonesia. Source: GITEWS Project. Courtesy DLR.
changes such as sea-level rise will increase the risk, because such changes modify the exposure of coastal areas to the hazard. It is also important to recognise that risk may increase over long periods due to unintended consequences of mitigation over time. The implications of these long-term trends need to be considered within the risk assessment process.

The timescales for risk assessment which country authorities may want to consider will vary from one country to another. Globally, there is a move to longer assessment periods due to the long-term implications of many mitigation measures and the recognition of the dynamic nature of risk. Some countries are explicitly considering a 100-year time scale, or even longer, for risk assessment.

Effective communication of the risk assessment outputs to all levels involved in the coastal management and emergency management processes is of paramount importance. The assessments are vital inputs to policy-making, determining the nature and level of response for mitigating tsunami risk.

The following account provides more detail in the methodology and options for combining the assessment of tsunami hazard with vulnerability to determine risk. In this more formal and quantitative approach, the estimation of risk must include information about the likelihood of a tsunami event occurring, together with information about the impact of that event or the resulting loss. The total risk is determined by combining the likelihoods and impacts or losses of the range of all possible events together.

As described in the guidance on the production of risk maps, impact or loss can be described in terms of a wide range of consequences including physical damage, human casualties or fatalities, economic loss, loss of social and environmental services and infrastructure. All of these represent elements of impact or loss. The losses from a particular event will be a function of the dimensions of vulnerability that are of interest, as discussed in C.5.

DEVELOPING A ‘RISK CURVE’

For some decision-making applications, it is useful to capture information about all possible damaging events that could occur, as well as their consequences, in the formation of a risk curve, where the likelihoods and consequences of damaging events can be ranked in order of their severity (Fig. 21). Risk curves are commonly used in quantitative risk assessment, including insurance and engineering applications. Risk curves can be applied to potential losses at the level of an individual household, facility or property, or at an aggregated level for an entire community. Risk curves also provide the opportunity to compare risks to a community at different levels of probability, differences in risks between communities, or between different hazards to the same community. Risk curves can also be combined for different hazards or communities to provide all-hazard estimates of risk across a range of probabilities (or return periods) such as for national-scale assessments where the allocation of mitigation resources will often compete with a variety of other disaster management priorities.

A risk (or loss exceedance) curve, is expressed as the amount of loss as a function of the probability (or likelihood) of losses of any given amount being exceeded.

The concept of a risk curve is demonstrated in Fig. 21. A risk curve is expressed as the amount of loss as a function of the probability (or likelihood) of losses of any given amount being exceeded. For this reason, risk curves are also referred to as ‘loss exceedance curves’. Formally, the risk curve is actually constructed by ordering all events that are possible, as derived from the hazard assessment, from smallest to largest loss. The probability of exceeding a value of loss is then determined by adding up the probabilities of all events whose losses are estimated to be greater than any given loss value.
As with the hazard assessment, probabilities are often expressed in terms of an annualised value (Box 23). This is the probability of exceeding a given loss value in a period of one year. Using this risk-based or ‘loss-exceedance’ construct, the ‘100-year event’ is more accurately defined as the event whose loss has a probability of 1/100 of being met or exceeded at least once during a one-year period. For very rare events, including most tsunamis, this is roughly equivalent to the event that occurs approximately once in 100 years. However, in reality, tsunamis events do not occur at regular intervals.

Most recorded events tend to occupy the higher probability, lower impact range of the curve; whereas, catastrophic (or high impact) events tend to be low probability (i.e., rarer). The 2004 Indian Ocean tsunami is a clear exception in that, at many locations, for example, Sri Lanka and Sumatra, and certainly for the Indian Ocean region as a whole, it would be classified at the extreme end of this curve. Purely from a tsunami hazard perspective, this event is considered to represent a 500-year return period event for the Indian Ocean region. How the consequences of this event rank on any given risk curve depends on the area or community of interest and the vulnerabilities that are considered. The consequences also depend on the extent to which other hazards are included in the assessment. For instance, for Sri Lanka as a nation, the 2004 Indian Ocean tsunami represents the largest single loss of life from any event in its history; however, for India in the last several decades, there have been many other natural hazard events that have caused much greater loss of life. Thus, from a loss of life perspective, the 2004 Indian Ocean tsunami may represent a rare (e.g., a 500-year return period or greater) loss for some communities or nations, but will rank at very much higher probability for others.

**Box 23 Determining Hazard Probabilities**

In order to demonstrate this concept, consider 5 events with losses X1 to X5 (X5>X4>X3>X2>X1), and hazard probabilities P1 to P5. We can rank the events and the exceedance probabilities as follows:

<table>
<thead>
<tr>
<th>Event #</th>
<th>Loss (X)</th>
<th>Probability</th>
<th>P(Loss ≥X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X1</td>
<td>P1</td>
<td>P(X1)</td>
</tr>
<tr>
<td>2</td>
<td>X2</td>
<td>P2</td>
<td>P(X2)</td>
</tr>
<tr>
<td>3</td>
<td>X3</td>
<td>P3</td>
<td>P(X3)</td>
</tr>
<tr>
<td>4</td>
<td>X4</td>
<td>P4</td>
<td>P(X4)</td>
</tr>
<tr>
<td>5</td>
<td>X5</td>
<td>P5</td>
<td>P(X5)</td>
</tr>
</tbody>
</table>

As you can see from this table, each event has losses greater than or equal to a specific value, X1 to X5, so that the probability of Event 1 loss being met or exceeded is simply the sum of the probabilities of all events, and so on. Similarly, Event 5 has the largest loss, so the probability of this loss being met or exceeded is simply the probability of Event 5 occurring. You can see from this process that large losses will generally be rarer (i.e., small exceedance probabilities) than small losses, and, similarly, the probability of having losses greater than any value will generally decrease as the loss value increases.

### SUGGESTED ADDITIONAL READING


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### E.4 OUTPUTS FROM THE RISK EVALUATION

**KEY OUTPUTS AND RESULTS ASSOCIATED WITH TSUNAMI RISK ASSESSMENT MAY INCLUDE:**

- assessments of risk for each dimension of vulnerability (or sector of development) in respect of a tsunami scenario with a defined probability;
- risk maps covering future scenarios as well as existing conditions produced for the designated coastal areas, whether at the regional or the local scale, covering each of the different dimensions of vulnerability (or each development sector) for the specified tsunami scenario(s); and
- effective communication of the risk assessment outputs to all levels involved in the coastal management process. The assessments are vital inputs to policy-making, determining the nature and level of response for risk reduction within the coastal management plan.
Chapters F–H of the Guidelines deal with management responses to the outcomes of the risk assessment procedures, as described in chapters B–E, in order to reduce the risk of a disaster resulting from a tsunami impact. They explain how the risk of human and asset loss and damage caused by the forces of tsunami inundation that has been identified by the assessment procedures can be reduced, as appropriate, to a level that your community considers to be acceptable.

Some of the responses may be similar to those designed to reduce the risk from natural hazards other than tsunamis – aspects of land-use planning or the use of insurance instruments to spread the risk, for example. Institutional responses, enabling the implementation of policy at the community level may also embrace various hazards. However, most of the responses described here are intended to address the issues of tsunami risk specifically.

Broadly, the responses at community level fall into three categories, each of which is covered by the Priority Actions of the Hyogo Framework of Action (HFA; A.2.1; I.1.1):

- Constraining, or reducing your exposure to, the hazard;
- Reducing your vulnerability in respect of the hazard; and
- Improving your preparedness to anticipate, respond to, and recover from the hazard.

These management-oriented parts of the guidance describe the measures to be considered by emergency managers, coastal engineers and planners in respect of strategic risk reduction and preparedness for the tsunami hazard. While many of the preparedness measures might (indeed, should be) implemented in the immediate timeframe, many of the risk reduction measures are for the longer term (over the coming decade, say) and, generally, are the more expensive options. It is therefore important that implementation plans consider management responses that are sustainable and take account of demographic and environmental changes that might occur within the longer timeframe, albeit there may be uncertainty about these changes.

Much of the guidance, whether for risk assessment or risk reduction procedures, is devoted to the enhancement of technical capacities in terms of skills and knowledge at local government or community levels. However, it is the development of functional capacities at all levels of government, whether for policy-making or for implementation, that will enable a country’s technical capacities to lead to positive outcomes in risk management.

Priority Action 1 of the HFA – to ensure that disaster risk reduction (DRR) is a national and a local priority with a strong institutional basis for implementation – is key to the implementation of these responses. At the community level any of these responses might be constrained or be promoted, depending on the existence of institutional support and the legal framework of Disaster Risk Management within which such responses would be undertaken. While some steps towards risk reduction may be taken by individual and community-led initiatives, the existence of appropriate legal and policy frameworks and functional capacity at the enabling (policy making) and organizational (executive) levels of government is essential for a successful DRR outcome with respect to a tsunami impact. Consideration of the importance of institutional engagement in the DRR process for the promotion of the community’s safety and wellbeing is described in Chapter I.

Successful management of tsunami risk demands high levels of cooperation and coordination between all involved agencies.

To be successful, the management of tsunami risk demands levels of cooperation and coordination between all the involved agencies which are difficult to achieve, even in developed countries. The responses to vulnerability, preparedness and risk assessments may be impeded by a lack of political commitment. However, coastal management frameworks, such as ICAM, may help to lower institutional barriers to the application of successful risk reduction measures. The practical application of vulnerability and risk knowledge in actions aimed at risk reduction may be facilitated by strengthening the involvement and co-ownership of the user community and public in the assessment agenda. This helps to establish the credibility, legitimacy and relevance of the research-based knowledge output among practitioners, and to lower the barriers to the take-up of assessment findings by policy makers.

Public opinion and wide stakeholder involvement are valuable tools that should be included in the decision-making process as the risk management strategy is developed. Public support and ‘buy-in’ is important for the success of the strategy as it is for the wider aspects of coastal management. To engage the public, policy makers should educate them about the risks and benefits and drawbacks of various management options. The public should have the opportunity to provide input on the level of risk that is acceptable or needs to be managed.

Public opinion and wide stakeholder involvement are valuable tools to be employed in process of developing the risk management strategy.

The concept of ‘living with risk’ should be introduced in the context of risk reduction. From a practical point of view, prevention and mitigation cannot eliminate risk and there are limits to the availability of funds for such aims. It is
important that strategic risk management measures be developed within a multi-hazard coastal risk assessment framework as an integral component of an overall coastal area management plan (I.3). The possibilities of other physical coastal hazards including storm surge inundation and coastal erosion affecting the shoreline of interest should also be considered in the formulation of such a plan.

All of the risk-reduction responses may be implemented within the context of ICAM (I.3), taking account of other natural hazards to which your community might be exposed, as well as social, economic and environmental management issues that may affect it. Improving your community's preparedness, including its awareness and capacity for early warning and emergency response, is a key objective of the IOTWS (H.2).
Reducing your tsunami risk by strategic management

This chapter provides guidance in the decision-making processes leading to the selection of strategic management approaches that could reduce your community’s risk of loss and damage by inundation from a tsunami impact.

Strategic risk management practices for reducing tsunami risk include structural protective methods, including the use of engineered barriers and natural coastal physical features; and non-structural initiatives, including regulation and land-use planning. The treatment of strategic risk reduction in these Guidelines should be considered as an outline account. A more detailed review and comprehensive description of the options open to policy makers and coastal managers and engineers is available in the IOC-ICAM hazard guidelines (UNESCO, 2009).

**KEY ACTIONS IN THE STRATEGIC RISK MANAGEMENT PROCEDURE**

- Confirm the temporal and geographical scales and limits of the assessment.
- Review the options for strategic risk reduction.
- Consider a hybrid approach to the response measures.
- Incorporate other coastal management goals in the response.
- Apply decision-analysis tools in the management process.
- Involve the public in the decision-making processes.

The overarching goal of strategic risk management is effective and sustainable risk reduction. This entails choosing options for risk reduction that are appropriate to the scale of the designated coastal management area, balancing social and economic pressures against environmental considerations, including sustainability, over the long-term (decades).

*Strategic management options for tsunami risk reduction balance social and economic pressures against environmental considerations, including sustainability and appropriateness to the scale of the management area.*

Strategic reduction of the tsunami risk may involve structural measures, commonly engineered, designed to protect coastal communities and their supporting systems from tsunami impacts; accommodation measures that aim to reduce risk through changes of individual and community behaviour and practice; and measures that seek to reduce risk by promoting a physical retreat from the tsunami hazard by means of land-use planning and financial instruments. In practice, a coastal authority may adopt a risk management plan that incorporates all three types of measures. Some of the measures may encompass long timeframes, extending perhaps over several decades.

A key part of the risk reduction strategy is a long-term plan for the implementation of the measures, including a monitoring programme to assess the effectiveness of the selected measures in reducing risks in respect of the tsunami hazard.

**THE APPLICATION OF DECISION-ANALYSIS TOOLS**

Decision-analysis tools including benefit-cost analysis and multi-criteria analysis can be helpful in evaluating the benefits and drawbacks of the various options for risk reduction. Benefit-cost analysis involves the comparison of the total cost of one or more strategies with the total benefits it would provide. An effective approach is one in which its benefits to the community outweigh its costs. In order to perform a benefit-cost analysis, all costs and benefits must be translated into a common denominator – typically monetary.

Multi-criteria analysis can be helpful for analysing complex, multi-disciplinary strategies with multiple criteria and objectives. Multi-criteria analysis does not require that all alternatives be placed in monetary terms but can incorporate both quantitative and qualitative data, including value judgements.

While there are many different types of decision-analysis tools to select from, policy makers should be sure that the analysis will provide a reasonable comparison of the short- and long-term costs of protection, accommodation and retreat, and account for the major socio-economic and environmental costs of the alternatives as well.
This part of the guidance deals with the options for reducing risk by coastal protection through structural means. Structural protective approaches include constructing or maintaining natural or engineered physical barriers that restrict the inundation of low-lying coastal land from a tsunami impact.

While the underlying principles of protection against coastal inundation and erosion are similar whatever the type of marine forcing, the design of a barrier capable of withstanding the hydrodynamics of a tsunami flow needs to reflect the perceived level of that tsunami at the shoreline (Fig. 7). Furthermore, the possibility of long-term changes in coastal sedimentation and erosion, caused by changes in nearshore bathymetry resulting from a tsunami impact, should also be considered.

Because shorelines are dynamic, structural mitigation measures at a particular location should not be developed in isolation. It is important to understand the hydraulic behaviour of the wider coastline, including its sediment transport regime, which may determine the stability of the shore. Care should be taken to ensure that structural mitigation works at one location do not lead to instability on an adjacent shore.

Structural protection may be achieved not only by artificial methods employing coastal engineering design such as offshore breakwaters, dykes and revetments, but also by natural methods, harnessing the full potential of coastal ecosystems including coral reefs, sand dunes and vegetation such as mangroves.

The type of structural protection adopted may mitigate physical hazards besides tsunamis (these having different magnitudes and frequencies of occurrence), while sustaining multiple uses of the coastal zone. This might be achieved through adoption of a single measure or, more usually, by a well integrated hybrid solution, comprising several measures and also satisfying environmental concerns. Hybrid methods refer to combinations of artificial methods or a combination of natural and artificial methods. Natural solutions, such as planting mangroves, provide cost effective, environmentally friendly solutions to reducing tsunami risk where there is with a low frequency of occurrence (Fig. 22).

Within the framework of a coastal area management plan, measures which reduce the impact of the tsunami hazard represent a coherent set of interventions. These may be specified in time and space to achieve a certain expected level of protection against existing or anticipated damage from tsunamis as well as other hazards. Such solutions can be proactive, leading to shoreline restoration and stability. A project monitoring and control system can also be incorporated within such a plan.

**G.1 USING NATURAL AND ARTIFICIAL STRUCTURAL PROTECTION**

**BOX 24 COASTAL ECOSYSTEMS PROVIDING NATURAL DEFENCES TO TSUNAMI IMPACT IN SRI LANKA.**

Sri Lanka offers some of the best evidence that intact coastal ecosystems, such as coral reefs and healthy sand dunes, helped buffer aggressive waves. For example, most of Yala and Bundala National Parks were spared because vegetated coastal sand dunes completely stopped the tsunami, which was able to enter only where the dune line was broken by river outlets. Some of the severest damage to Sri Lanka’s coast was where mining and damage of coral reefs had been heavy in the past.

**Source:** UNEP, 2005.

**TYPES OF STRUCTURAL BARRIERS**

Structural barriers which constrain the impact of a tsunami may be classified into three types, depending on their location and protective function. These types are:

- partial barriers located in the nearshore zone to reduce the energy of tsunamis before they reach the shoreline;
- full barriers at the shoreline to protect the coastal land at risk by preventing the inland movement of tsunamis; and
- partial barriers at the shoreline to reduce the impacts of tsunamis on entry to the shoreline.

Full and partial barriers, whether artificial or natural, are physical interventions which may be considered a protection solution for populated coasts. In designing artificial barriers it is necessary to ensure the continuity of sustaining multiple uses of the existing natural environment. From an engineering point of view, the design must be robust, functional and reliable. Due consideration should be given to convenient maintenance and effective operation. Equally it is important to minimize negative impacts on socioeconomic, livelihood and environmental issues. Sensitive landscaping of the environment is a priority.
PARTIAL BARRIERS IN THE NEARSHORE ZONE

Offshore tsunami breakwaters are usually partial barriers which dissipate part of the incoming tsunami’s energy before the tsunami reaches the shore. These could also be designed as full barriers with the inclusion of a tsunami gate for complete closure. It is possible to integrate tsunami breakwaters within a strategic port development project; the principal breakwater of the proposed port would serve also as a tsunami breakwater. Coral reefs serve as natural breakwaters in dissipating tsunami- and other types of wave energy. This function is particularly effective during low-tide conditions, an aspect observed along the fringing reefs of the Kenyan coast during the Indian Ocean tsunami of 2004 (Box 5).

FULL BARRIERS AT THE SHORELINE

High-rise seawalls (dykes) constructed on the shoreline at or above the high water mark are designed to provide a full barrier against the tsunami propagation (Fig. 23; see Case Study at K.3). Where the shoreline is interrupted by river mouths, tsunami gates can be installed within seawalls to allow for normal flows and traffic access. The closure of the gate prevents tsunami propagation. Sand dunes can provide natural full barriers against tsunami inundation. Their effectiveness was proved in many countries during the Indian Ocean tsunami of 2004. When overtopped, sand dunes tend to fail progressively by erosion. Dune-cladding vegetation provides reinforcement to the dunes thus impeding erosion. It is strongly recommended that, where circumstances permit, sand dunes combined with coastal vegetation are adopted as a shoreline barrier.

Fig. 22  **Natural structural protection: mangrove rehabilitation in Peninsular Malaysia.** _Rhizophora apiculata_ five months after planting for the rehabilitation of an eroded site (Category 1), using an innovative planting technique, COMP-MAT, with Geotubes as a frontline wave breaker. Bernam Forest Reserve, Selangor, Malaysia. Source: I. Shamsudin, R. S. Raja Barizan, M. Azian and H. Mohd Nasir; Forest Research Institute Malaysia (FRIM). Picture Copyright © FRIM-JPSM & NRE National Task Force Committee of Planting Mangroves and Other Suitable Species Operation in Shoreline of Malaysia.

Fig. 23  **Seawall: An engineered protective structure built parallel to the shoreline at (or above) the high water mark.** Source: IOC Technical Series 91.
**PARTIAL BARRIERS AT THE SHORELINE**

Medium-rise seawalls (dykes) provide partial barriers against tsunami flow and will prevent propagation up to specific design water levels. The design permits overtopping beyond these levels. The stability of such barriers during overtopping and inland drainage issues need to be given due consideration. Coastal vegetation can be used to dissipate tsunami energy via turbulent flow through the media. The effectiveness of dissipation is dependent on the density of vegetation, its overall porosity and its tortuous characteristics of porous matrix. It is important that the vegetation is itself resilient against tsunami propagation and have a root structure that can resist the high velocity regime at the floor bed. Planting mangrove at appropriate locations can also serve to dissipate extreme wind-wave energy (Fig. 22). The extent to which coastal trees, such as Casurinas, at the shoreline can act as bioshields is controversial.

**G.2 USING ACCOMMODATION MEASURES**

Accommodation measures accept the inevitability of inundation but nevertheless reduce vulnerability and thus risk.

**G.2.1 BUILDING CODES TO REDUCE PHYSICAL VULNERABILITY OF INFRASTRUCTURE**

Coasts tend to be areas of high economic activity. However, it is not feasible to transfer all activities to areas that are completely free from tsunami risk. Therefore there may be a need to accommodate the risk. The development and application of design guidance and construction manuals for tsunami-resistant housing and infrastructure form parts of this accommodation. The introduction or strengthening of building codes for construction on low-lying coastal land aims make buildings less susceptible to the forces of inundation – flow depths and velocities (together referred to as ‘drag’, see M.3), and the impact of entrained debris. It may be expected that properly designed structures will withstand the impacts of tsunami with only limited damage.

*There may be a need to accommodate the risk of tsunami inundation by the application of design and construction guidance for tsunami-resistant housing and infrastructure.*

Although cost may be an impediment to tsunami-proofing structures, national authorities may choose to make tsunami-proof structures with flow-through designs, stronger buildings, and deeper scour-resistant foundations mandatory in areas of high risk. The strengthening of masonry buildings with reinforced concrete framing could well be a cost effective measure (e.g., columns, especially at corners; together with plinth-, roof- or lintel-level band beams). The orientation of buildings with respect to the ocean is another factor for consideration. Particular attention should be directed to the security of structures used for vertical evacuation shelters (H.2.2). The design of structures should be based on detailed design guidelines, which are gradually being developed for tsunami loading. In areas of low risk, the extent to which communities should accommodate the tsunami hazard may be difficult to determine, though the precautionary principle should prevail.

It is recommended to develop and apply design guidelines and codes of practice for tsunami resistant structures. This guidance includes:

- upgrading of standard building codes to incorporate elements concerning the reinforcement of infrastructure during construction;
- incorporation of norms to reduce the physical vulnerability of existing infrastructure through retrofitting using updated building codes;

Two types of document are required:

- Design Guidelines on Good Practice providing advice on concept, location, layout, orientation, structural configuration, geotechnical considerations and other considerations leading to good design practice. Such designs will enhance the robustness of the structures to withstand tsunami attack and other coastal hazard impacts without total collapse or failure. These will be especially useful for buildings that do not receive much engineering input – and the majority of housing on the coast will probably be such ‘non-engineered’ buildings.
- Detailed Design Codes of Practice providing information on hydraulic and structural loads, geotechnical parameters and detailed design information. The design approach should be based on the concept of design against failure and in this context attention must be focused on failure modes.

Overall design guidelines could be improved from the experience gained from post-tsunami impact damage assessments from different parts of the country. Such assessments should be analyzed in the context of the hydraulic regime which would have been generated by the tsunami at that location. Relevant information from other countries that have been affected by tsunamis will also be useful for this exercise. It is important that damage assessment should cover infrastructure that was destroyed; damaged; or survived (least affected). The proposed design guidelines should be applicable to:
rehabilitation of damaged structures;
strengthening of existing structures (retrofitting);
and
design of new structures.

Countries may find widely varying recommendations for tsunami design loads. Some harmonization is desirable.

**INCORPORATION OF CODES TO RETROFIT EXISTING INFRASTRUCTURE**

Ordinances should be enacted to ensure that existing infrastructure is retrofitted so that it meets the requirements of the upgraded building codes. Such ordinances could provide intervals of time for owners to carry out the assessment of the physical vulnerability and the changes that may be required to retrofit the infrastructure; then an additional interval of time to implement the required retrofitting measures so as to ensure that the existing infrastructure will meet the requirements of the upgraded building codes.

**G.2.2 RISK TRANSFER**

A community’s vulnerability in respect of tsunami inundation may be reduced by their adoption of risk transfer – spreading the risk of loss and damage by insurance or re-insurance schemes (H.4). Insurance plays an important role in offering financial protection from the costs of flooding. By spreading the risk across policy-holders, insurance enables householders and businesses at risk to minimize the financial cost of damage. Furthermore, because lenders are unlikely to offer mortgages on properties that cannot obtain buildings cover, insurance plays a critical role in the operation of the property market. However, insurance can provide an effective mechanism for spreading the risk only if the risk is at a manageable level.

Reinsurance provides a mechanism for the provision of financial protection to developments located within potential tsunami inundation zones.

Reinsurance is the insurance that insurers themselves take out to deal with catastrophic events/claims. It provides a mechanism that can help insurers provide financial protection to developments located within the limits of potential inundation, and at risk from an inundation event. However, it is anticipated that reinsurers will become increasingly selective of the portfolios they are prepared to take on. Reinsurers model exposure based on the best- available estimates of risk. These are revised as more information becomes available, for instance following a catastrophic event. Where this reassessment leads to a limitation or withdrawal of reinsurance cover, insurers would need to reflect this in the extent of insurance coverage and the premiums they charge. This underlines the need to take a precautionary approach to large aggregations of new development in potential inundation zones.

This topic is covered in more detail in Section H.4.

**G.3 USING RETREAT APPROACHES**

Approaches that reduce exposure of people and critical community assets by physically retreating from the tsunami hazard include land-use planning and regulation and the relocation of critical assets and vulnerable community groups.

**G.3.1 LAND-USE PLANNING INCLUDING DEVELOPMENT ‘SETBACK’**

Land-use planning can be an effective means of implementing the option of managed retreat in tsunami risk mitigation. Information to inform policy on land-use planning, which countries may apply within a regulatory framework, is contained in the inundation, local hazard, vulnerability and risk maps produced as outputs from the risk assessment process (B.5). Guidance on integrating tsunami inundation modelling into land use planning is given in sections L.3 and L.4.

The introduction of development setback lines may be an option in land-use planning for coastal land which may lie within potential tsunami inundation zones.

An option for consideration in land-use planning is the introduction of development setback lines, in a process referred to as ‘managed setback’ (Fig. 24). Development setbacks to cope with, amongst other issues, the threat of coastal physical hazards (coastal erosion and storm surge inundation as well as tsunamis) have become mandatory in a number of countries. Setback lines are determined by local authorities, in some cases within a national legislative framework, to delimit exclusion zones for development in coastal areas that are perceived to be exposed to inundation or at risk from coastal erosion. Development setbacks are intended to direct new development or redevelopment out of identified hazard areas and to protect natural hazard mitigation features such as beaches and dunes by restricting development seaward of a setback line, established parallel to the shoreline. The type of setback used, including how, and from where, it is established, can vary widely. The application of setbacks is a globally accepted good practice in coastal area management (see ICAM hazard guidelines, UNESCO, 2009).
There may, however, be community opposition to set-back schemes. Coastal communities may be reluctant to forgo what they perceive as assured livelihoods in potentially tsunami-prone areas on account of a threat of impacts which may not recur even over several generations (Box 25).

**G.3.2 RELOCATION OF SPECIFIC TYPES OF INFRASTRUCTURE OR ASSETS**

Because it is not possible to reduce the vulnerability of children, the elderly, patients in hospitals or women, decision makers should consider the relocation of particular buildings that host such vulnerable groups to locations not exposed to tsunami inundation, or to areas where the exposure is low. In addition, national government agencies or local authorities may wish to assess whether to relocate places where large numbers of people congregate such as markets, bus or train stations, and government buildings which may contain large numbers of employees or visitors. As an alternative, they may wish to consider ways to provide shelter through vertical evacuation to upper floors or terraces in buildings capable or resisting the impact of tsunamis.

In a similar fashion, the vulnerability of some assets may not be reduced due to the intrinsic way in which these assets are made or manufactured (for example, official records or legally-binding documents held in paper format, critical information saved in computers, resources or products typically manufactured and distributed in powder form, perishable items which are not packed in strong, sealed plastic or metal containers, etc.; or products that require controlled temperatures or refrigeration (dairy products, meats, vegetables, etc.). In this case, those who own such assets or who are responsible for such assets may wish to consider whether to store such assets in areas not exposed to tsunami inundation, or in the case of perishable items or commercial products, to consider the use of insurance as a way of recovering their losses in case of a tsunami impact.

**BOX 25  BLANKET NO-BUILD ZONES ARE ‘NEITHER FEASIBLE NOR SUSTAINABLE’**

While it is laudable to try to protect at-risk communities from hazard events, international experience clearly shows the blanket no-build zones are neither feasible nor sustainable. A practical approach is necessary, in which risk assessments are undertaken to identify where to return to original sites is or is not technically and environmentally feasible. These assessments should involve community representatives working with social and technical specialists, and assess the suitability of the original site for rehabilitation, including its vulnerability to various natural hazards, disease and environmental risks, the suitability of land for agriculture, and so forth.


**G.4 OUTPUTS FROM THE STRATEGIC PREVENTION AND MITIGATION PROCEDURES**

The expected principal outputs from these procedures are:

- A portfolio of effective hazard control measures which are consistent with wider coastal management objectives;
- A portfolio of effective vulnerability reduction measures which aim to decrease the susceptibility of the built environment and the reduction in exposure of vulnerable assets whose susceptibility cannot be reduced; and
- A long-term plan for the implementation of the strategy, including a monitoring programme to assess the effectiveness of the selected measures in reducing risks in respect of the tsunami hazard.
SUGGESTED ADDITIONAL READING AND INFORMATION SOURCES

Chock, G., Robertson, I., Kriebel, D., Mathew, F., and Nistor, 2013. Tohoku, Japan, Earthquake and Tsunami of 2011. Performace of Structures under Tsunami Loads. Published by the American Society of Structural Engineers (ASCE).


Improving your preparedness for tsunamis

This chapter describes the steps that can be taken to reduce your tsunami risk by improving your preparedness to anticipate, respond to, and recover from tsunami inundation events in response to the outcome of your preparedness assessment (as described in Chapter D).

Your community may significantly reduce its tsunami risk by improving its preparedness. This includes its awareness of the hazard and corresponding early warning and evacuation procedures, its capacity including trained expertise to anticipate and cope with a tsunami event, and its ability to quickly recover from such an event. The better your community is prepared, the less will be its loss and damage, and, in particular, the greater is likely to be the survival of your exposed population. Programmes targeting the improvement of preparedness are some of the most cost-effective management measures for risk reduction.

Although addressed primarily at coastal planners and emergency managers, the guidance is relevant at all levels of society – national, community and even individual levels. Thus, although this part of the guidance is entitled ‘Improving your preparedness for tsunamis (as managers)’, it is as much about how people at all levels can prepare themselves.

**KEY TASKS IN THE PROCEDURE FOR IMPROVING PREPAREDNESS**

- Raise awareness of the tsunami risk at all levels in the community
- Plan and implement the key operational requirements of an efficient, people-centred early warning system (H.2); including procedures for evacuation to shelters and safe areas.
- Prepare all levels and structures of the community for emergency response.
- Plan for a smooth transition from response to recovery.
- Transfer the risk of loss and damage to the built environment by insurance schemes (H.4) as appropriate.

In order to improve your community’s preparedness for tsunami impacts, thus reducing the risk of a disaster, there may be a need to raise the levels of awareness of the risk related to tsunamis both at community level and at higher levels of governance; also the need to ensure the capacity to participate, both nationally and at the community level, in the IOC-coordinated Indian Ocean Tsunami Warning and Mitigation System (IOTWS), providing the earliest possible warning of an impending tsunami to communities at risk.

The chapter includes information on evacuation planning and procedures, and explains how institutional and community-based actions can contribute to improving preparedness. It covers the emergency management structures that need to be ready for a response to a tsunami event in a timely and efficient fashion. It concludes with a section on risk transfer options. More detailed accounts of the tsunami detection and alerting procedures in the IOTWS and of the mechanism for risk transfer are given at sections H.3 and H.4 respectively.

The better your community is prepared, the less will be its loss and damage and the greater the likely survival of your exposed population in the event of a tsunami inundation.

It is important for your community to be resilient so that, during the recovery process, the elements of disaster risk management should be incorporated. Instead of rebuilding your community with the level of risk that existed before the tsunami inundation, you could rebuild it incorporating strong land-use planning norms and building codes, as well as improved risk transfer (H.4). In this way, the risk would not be rebuilt, but minimized from the outset (but see Fig. 25).

**Fig. 25 The importance of local knowledge.** Everyone knew to run to high ground immediately after an earthquake in the village of Langi, on Simeulue Island off Aceh. The 2004 Indian Ocean tsunami, which reached heights of 10–15 m in the village, began its attack just 8 minutes after the earthquake. Though the waves destroyed all the buildings, all of the population survived. Several months later the villagers had constructed new houses (above) on the foundations of those swept away. Photo: Lori Dengler.
A country’s or community’s imperative for the need for disaster preparedness in respect of tsunamis depends on its perception of its level of tsunami risk. Risk is a measure of the possibility of the consequences of an assessed hazard in terms of potential loss and damage over a defined period. Chapters B–E have described how this level can be assessed.

Some countries may assess their risk as being low and thus have no imperative for improving their preparedness and response. Others might anticipate much shorter return periods of damaging events. These countries may well know from their own experience, or their culturally inherited knowledge, that awareness and preparation for tsunamis may be vital for their wellbeing and survival (Fig. 26, Fig. 27 and Box 26).

In the middle ground, there are those countries for which, although the tsunami risk may not be apparent because of long return periods, there may be historical (including geological) records of large tsunamis impacting their shores (Box 26). If such events occurred today, they would cause major losses and damage to their coastal communities. For these countries, decisions over the appropriate management of tsunami risk are especially problematic. Where the return periods of damaging tsunami events stretch beyond the span of living memory, it may be difficult to sustain credibility and commitment amongst stakeholders.

**BOX 26  THE IMPORTANCE OF ORAL HISTORY.**

The tsunamis on 26 December 2004 and 28 March 2005 killed only seven people on Simeulue Island in Indonesia’s Aceh province. At Langi, on the north end of Simeulue, which is 40 km south of the December earthquake’s epicentre, maximum wave heights exceeded 10 m less than 10 minutes after the shaking ceased. In the more populous south, wave heights averaged 3 m and caused significant structural damage, destroying entire villages. Oral histories recount a massive tsunami that occurred in 1907 and advise running to the hills after ‘significant’ shaking (~1 minute). All the interviewed Simeulue survivors knew of this event and of the necessary action. However, Jantang, on the Aceh mainland, suffered far more casualties. Simeulue’s oral history provided an extraordinarily powerful mitigation tool that saved countless lives where even a high-tech warning system with a 15-minute response time would have been of no help.

Source: McAdoo et al., 2006.
Tsunami survival can depend on education. Education raises awareness of tsunami risks both amongst the community and at higher levels of government and provides guidance on how to live with those risks. Education is especially important in communities where the felt shaking of an earthquake forewarns of a tsunami that may come ashore minutes later. Rooted in local tsunami history and passed down through generations, oral traditions of such natural warnings saved hundreds of lives during the 2004 Indian Ocean and 2007 Solomon Islands tsunamis (Box 26).

Such life-saving use of tsunami history can be furthered through booklets and videos that give a human face to lessons on tsunami survival. One such booklet, available online in English and in Spanish, draws on eyewitness accounts of the 1960 Chilean tsunami in Chile, Hawai‘i, and Japan. Advantage for others can still be gathered from eyewitnesses to even earlier tsunamis as well as from those who survived tsunamis of recent years (Fig. 26 and Fig. 27; Box 27).

A description of the application of Community-based Disaster Risk Management (CBDRM) in enhancing awareness of natural hazards including tsunamis is given in Section L.5.
H.2 ESTABLISHING AN EARLY WARNING SYSTEM

See also H.3

SPECIFIC AIMS OF THE IOTWS INCLUDE:

- ensuring awareness of the tsunami risk and how to respond in case of a tsunami;
- ensuring the operation of an efficient, people-centred early warning system;
- maintaining a Disaster Management Organisation (DMO) ready to respond to a tsunami warning in a timely and efficient fashion, and to cope with recovery operations;
- having evacuation plans in place;
- carrying out exercises and drills to test all the elements related to preparedness.

The objective of a tsunami early warning system, such as that in the Pacific (PTWS) or in the Indian Ocean (IOTWS), is to make people in coastal areas aware of local and distant tsunamis which may or may not affect them. Early warning systems will save lives. An effective, people-centred tsunami early warning system is achieved when all persons in exposed coastal communities are prepared and respond in a timely manner on receiving a tsunami warning or recognizing that a potentially destructive tsunami may be approaching.

An effective warning system is achieved when all persons in exposed coastal communities are prepared and respond promptly to a tsunami warning or their awareness that a potentially destructive tsunami may be approaching.

Achieving this objective, the IOTWS is an end-to-end system which incorporates national and regional warning systems for local, regional, and ocean-wide tsunamis, and promotes preparedness as part of risk reduction against tsunami hazards within a multi-hazard approach. The principal components of a tsunami early warning and mitigation system are listed in Box 28.

During a tsunami event, messages and information from TSPs (Tsunami Service Providers) are available to each Member State through the officially designated national Tsunami Warning Focal Point (TWFP), which is usually associated with the National Tsunami Warning Centre (NTWC) and/or National Disaster Management Office (NDMO). The TWFP is a 24x7 point of contact, who has the responsibility of notifying the national emergency authority of an event and its characteristics. The maintenance of up-to-date contact information for TWFPs and TNCs (Tsunami National Contacts) is a critical element of the operation of the IOTWS, and it is in the interests of each Member State to ensure that its contact information is promptly updated if a change occurs.

Description of the tsunami detection and alerting operations carried out at the regional or international level within IOTWS are given in H.3 of this chapter and are not repeated here. Included in this section is a description of the national aspects of the warning system, from the National Tsunami Warning Centre, through the emergency organizations to those in the community at risk from tsunami inundation.

BOX 28 COMPONENTS OF A TSUNAMI EARLY WARNING SYSTEM

Establishing comprehensive tsunami early warning requires progress in several mutually dependent components (see also Table 1). These include:

- assessment of the tsunami hazard (Chapter B) and identification of a community’s vulnerability (Chapter C);
- provision of a detection, alerting and national warning system that meets international to national to local requirements;
- elaboration and implementation of Standard Operating Procedures (SOPs, H.2.1) to ensure that all decisions can be taken as needed and as quickly as possible and to ensure timely reactions when a warning is issued;
- identification and demarcation of shelters for evacuation or safe areas and evacuation routes to reach them;
- ensuring that vulnerable groups are aware of warnings issued by the tsunami warning centre, also of the evacuation shelters or safe areas to be used and ways to get there;
- executing specific tasks, including evacuation to safe areas, to reduce the impact and loss of life;
- carrying out simulations and exercises to test the SOPs and the different components of the system, and to ensure that all stakeholders and those at risk are aware of how the system operates.

Juan Carlos Villagran
It is the responsibility of your National Tsunami Warning Centre to provide warnings, watches, and advisories to your citizens and agencies.

On their receipt of tsunami alerts from TSPs, NTWCs must in turn provide understandable warning messages to DMOs, local jurisdictions and/or the public to ensure that people at risk evacuate to safe areas. Sustained campaigns of public awareness, education and outreach should be carried out as a key component of the warning system. It is important to note that TSPs do not issue warnings; they provide to NTWCs advisory information and data on tsunami threats. It remains the responsibility of your NTWC, operating within the legal framework of your country, to provide warnings, watches, and advisories to your citizens and agencies (Box 29).

An effective early warning system makes use of information gathered through the risk assessment procedure to identify the most vulnerable groups and their locations. The aim is to ensure that warnings reach them in time for successful evacuation to safe areas. This implies the design of evacuation routes and procedures, taking into consideration the location of such vulnerable groups. Risk assessment information is also used to identify key assets that should be mobilized before a tsunami inundation to ensure its safety, and to minimize the effect of inundation on remaining assets. The use of Smartphone applications to facilitate such identification and convey warnings to people or assets at risk may prove particularly beneficial.

As part of the improvement of a community’s preparedness through early warning, special attention should be given to the critical issues (D.2) that have hindered the operation of existing early warning systems, including weaknesses in communications between service providers, NTWCs and emergency responders, weaknesses in SOPs when decision makers cannot be reached, and weaknesses in the issue and delivery of warnings and the response to those warnings by the community at risk. Another issue is weaknesses in a community’s capacity to respond to a warning and potentially catastrophic event (Box 30 and Box 31).
As a way to improve the effectiveness of early warning systems in being able to issue warnings, the NTWC and emergency managers should address the following issues, which could be handled in the form of a checklist:

- Conduct tests to determine whether communities at risk are able to receive warnings at any time of day or night.
- Conduct tests to determine how long it takes for warnings to reach groups with a higher degree of vulnerability (children, the elderly, women, disabled persons).
- Conduct tests to determine if warnings are reaching people in places where large numbers of people congregate (commercial areas, main bus and train stations, public markets, etc.).

In the case in which your community may contain the presence of one or several indigenous groups, conduct a test to determine if the warning reaches indigenous groups exposed to tsunamis in a language that they can easily understand.

Finally, assess whether the warning messages are easily understood by those groups and those at risk.

Juan Carlos Villagran

In eastern Africa, official information, warning and response networks were non-existent prior to the 2004 Indian Ocean tsunami. Even when an official response was generated in Kenya, the public demonstrated no faith or willingness to act on warnings from officials such as the police. Importantly, information on the tsunami and the generation of an official response were dependent on two technologies, satellite television and mobile telephony. These should be built into future warning systems as key mechanisms and back-ups to official information and warning networks.

David Obura

In Kenya, the first and largest surges (1–1.5 m high) of the 2004 Indian Ocean tsunami occurred around 12.30–2 p.m. in low tidal conditions. If these had been larger tsunamis coinciding with high tide, impacts to lives and infrastructure on the Kenya coast would have been similar to those experienced in Asian countries. While information on both the earthquake and tsunami was available on satellite television and was known to some people, the first responses occurred only when the surges started to impact the coastline. Private sector sources apparently correctly predicted the size and timing of the waves in East Africa, but this information did not go beyond individual recipients and clients of those sources. Privately, many residents and hotels along the coast responded to the obvious surges and news of the earthquake and tsunami by moving people off the waterfront. Through mobile phone calls and text messages, word about the unusual sea conditions spread among friends and, from that, into the coastal science and management community.

Eventually a public response did result from communication channels originating with the Kenya Ports Authority and the National Environment Management Authority, resulting in a Ministerial alert, radio warnings and police action to clear public beaches, all by about 6 p.m. However, the public response was poor even with the evidence of the surges, and many people had to be forced away from the waterfront and beaches by the authorities. The most important thing to note is that though a commendable response was eventually achieved, this happened only after observations within the country. This response was too late. The key lessons to learn are how to maximize information flow between key nodes and response capabilities, and how to link these into a warning system that filters up and down through international, national and local levels.

David Obura
For the case of tsunamis, rapid tsunamigenic potential evaluations of earthquakes are essential to provide the fastest early warning to emergency officials, who must then issue understandable messages that result in immediate public response before the first destructive wave hits. Source: ITIC.

Local (near-field) tsunamis can impact shores within 10 minutes of the earthquake occurrence, so warnings must reach the public well within this time if they are to be even a little effective. Distant (far-field) tsunamis might take many hours to traverse an ocean. In these cases, NTWCs and DMOs may have sufficient time to organize evacuation so that no lives need be lost on inundation. Local preparedness and commitment at all levels of the community are the keys for success. Ultimately, warning systems will be judged on their ability to reach people on the beaches and in low-lying coastal areas and to evacuate them to safe refuges before the first wave hits the coast (Box 31).

Warning systems will be judged on their ability to reach people on beaches and in low-lying areas and to evacuate them to safe refuges before the first tsunami impact.

Achieving success with early warning requires strong and sustained commitment by all stakeholders, including national governments and coastal communities. National governments must collaborate and work together in a regional framework to share data and they must jointly bear the cost for the regional elements of the network (Fig. 29). The need for regional collaboration is a result of the nature of tsunamis: local (near-field) tsunamis can be handled by NTWCs; but, because regional or ocean-wide (far-field) tsunamis travel at nearly 1000 km per hour as they propagate across the ocean, observational earthquake data is required from many countries in a region in order to accurately characterize their tsunamigenic potential.

The most important activity to establish for an effective end-to-end early warning system is stakeholder coordination (Fig. 30). High-level government advocacy and commitment are also needed to make the system sustainable. Successful systems require cooperation at all levels, a commitment of all stakeholders to work together during an actual tsunami warning emergency, and, over the long-term, a sustained effort at high levels to maintain awareness and preparedness. To build organizational support and long-term commitment, a Tsunami Coordination Committee is a mechanism that can bring together stakeholders from government and non-government agencies, science researchers, and the private sector. Such a committee, possibly embedded in an ICAM framework, can enable and advocate for policies, initiate the needed programmes, allocate the necessary resources, and coordinate emergency procedures before, during, and after a disaster.
Fig. 30 Stakeholder coordination is essential. A Tsunami Coordinating Committee engages all stakeholders to develop and participate in comprehensively reducing the risk from tsunamis. Key contributors are the scientists and engineers who assess and evaluate the risk, the tsunami warning centre which is responsible for rapid alerts, and government emergency services which must evacuate people before the tsunami arrives. Source: ITIC.

Fig. 31 Leaflet describing the tsunami early warning system, Sri Lanka. Source: UNU-EHS.
Successful early warning systems require cooperation at all levels, a commitment of all stakeholders to work together during an emergency, and a sustained effort to maintain awareness and preparedness for response over the long-term.

To warn people of an impending tsunami without preparing them for such an event may be ineffective. Preparing them through the provision of a public safety message that is clear, concise, and understandable to every person, with directions on what to do and where to go, is essential (Fig. 31). Tsunami alerts from TSPs are the technical trigger for early warning. But any system will ultimately be judged by its ability to save lives, and simply by whether people move out of harm’s way before a big tsunami hits. For this, seamless communication is essential.

H.2.1 STANDARD OPERATING PROCEDURES

SOPs constitute a set of written instructions describing the steps that are conducted during the routine operation of the early warning system. SOPs should be developed in a collaborative fashion among all stakeholders, and should reflect the agreements among stakeholders and what needs to be done (who, what, where and how). SOPs outline functions, roles, responsibilities and jurisdictions for government, non-government and private sector agencies. Segments of SOPs can be presented in the form of flowcharts describing sequential and parallel tasks, and may include checklists.

SOPs should facilitate the decision-making process by describing in detail the actions that different stakeholders will carry out, and should facilitate the delegation of authority to those who need to make specific decisions or undertake specific actions should the decision-makers or those in command may not be reachable immediately.

SOPs encompass a variety of tasks including data processing, communication channels for different purposes, hazard monitoring, analysis procedures used to forecast the potential extent of specific events, managing uncertainties when access to critical data or information are limited, steps to issue warnings (decision tree, who should be warned first for example); the evacuation to safe areas, security issues, information management concerning events, management of all stakeholders, coordination among stakeholders, and how and when to issue an all clear signal.

Remember to conduct simulations to test the SOPs when new procedures or changes are introduced and to keep all stakeholders aware of their role in the context of the SOPs. This is especially useful in government agencies where changes in staff may take place after electoral processes for example.

Table-top simulations and drills or exercises in coastal communities are used to test and improve SOPs and to test other elements of the warning system, as well as to test the proposed evacuation procedures. The periodic execution of such drills and simulations ensures that all stakeholders and those at risk are aware regarding how the system operates in all its phases.

H.2.2 PREPARING FOR EVACUATION

Attention to evacuation planning is of crucial importance in a community’s quest to improve preparedness and thus to minimize the loss of lives. It is an activity that requires the information on an inundation’s physical parameters and the exposure database, so that planners can predict the feasibility of their proposed evacuation routes in terms of potential flood or debris impass, traffic congestion, and so on.

Evacuation planning is of crucial importance in a community’s quest to improve preparedness and thus to minimize the loss of lives.

Subject to the assessed level of risk in respect of a tsunami event, emergency managers should place a priority on establishing and implementing a policy for the effective, orderly evacuation of the exposed population. The vulnerability maps derived from the inundation maps and the vulnerability assessment provide key information for evacuation planning. Successful evacuation to shelters and safe areas takes into consideration both the existence, as well as the geographical location of vulnerable groups. A consistent approach to evacuation zone identification and mapping supports a common public understanding across communities of tsunami evacuation zones, maps, tsunami evacuation signage, and tsunami response actions.

TSUNAMI EVACUATION ZONES

The key consideration for tsunami planning and information requirements is the number of zones that should be used for evacuation management and the way in which the information might be depicted for the public. The number and type of zones to be used depends on issues such as the geographical location of vulnerable groups, the availability of vertical evacuation structures and their capacity. Use of a single tsunami evacuation zone has the advantage of simplicity for both emergency planning and public understanding. However, because a single evacuation zone must accommodate the very wide range of local risk scenarios, regular ‘over-evacuation’ of the entire zone for common, small scale events can result. Use of more than three or four evacuation zones may better reflect the range of local tsunami risk scenarios. However, such differentiation requires far greater resources and a higher degree of coordination for planning and response, and the complexity of information may create public misunderstanding.
ESTABLISHING EVACUATION ZONE BOUNDARIES

The elevations and methods used to establish these zones are developed at local level, based on local hazard analysis and risk assessments. Evacuation zone boundaries can be drawn based on a variety of hazard models. Ideally, zones need to represent an envelope around all possible inundations from all known tsunami sources, taking into account all of the ways each of those sources may generate a tsunami. The high degree of uncertainty in tsunami source models, and the time-consuming and resource-intensive nature of modelling make this comprehensive approach to tsunami risk assessment unlikely in the short term.

The recommended approach to defining tsunami evacuation zones is to map them now, and progressively refine the accuracy of their boundaries as the science improves over time. It is recommended that authorities proceed with mapping based on current available information and knowledge without waiting for the perceived required knowledge. Zone boundary definition can then be refined as knowledge improves. Often authorities defend their hesitation to define boundaries on the basis that they don’t have sufficient information.

Provisional evacuation zones should be mapped with whatever information is available, then refined as the supporting science improves with time.

Guidance on integrating tsunami inundation modelling (B.3.1) into land-use planning is given in section L.3 and L.4. The first and most basic means to define evacuation zone boundaries is referred to as the ‘bathtub’ model, in which inundation is determined based on a uniform maximum elevation inland from the coast. This approach provides the crudest but simplest model of inundation limits. The second step up would be an ‘approximation by a rule’ which provides for a measure of rule-based wave attenuation inland from the coast. GIS can be used to apply the rule and it delivers a more realistic output than the ‘bathtub’ model. Local knowledge must also be used if available. The third level up would be a computer-derived simulation model that theoretically allows for complexities that a simpler rule cannot, such as varied surface roughness, water turning corners etc. Finally the most complete modelling would be based on an envelope around all inundations from multiple well-tested computer models. It will require a comprehensive scientific understanding of all possible tsunami sources, wave propagation and inundation behaviours across a range of magnitudes.

TSUNAMI EVACUATION MAPS

Maps depicting tsunami evacuation zones, evacuation routes and evacuation times (Fig. 32) as well as tsunami safe areas need to be made available as required by the community. It is recommended that maps are displayed in homes, holiday homes, tourist facilities, workplaces and public buildings in areas subject to tsunami risk. High-use coastal areas should prominently display evacuation maps as part of tsunami information boards. Maps should be prepared and delivered in conjunction with planned tsunami signage placement depicting evacuation zones and routes on the ground.

In addition to the number and appearance of evacuation zones on maps, the basic legend, instruction messages and supporting information on maps should be nationally consistent. To ensure common understanding across communities, maps should use the same or closely similar colours, the same names for evacuation zones, and common symbols.

TSUNAMI EVACUATION SIGNAGE

Signage is an integral part of practical tsunami risk management. Signage depicting evacuation zones and routes raises public awareness of local tsunami risk and provides information to increase the efficiency and effectiveness of an evacuation (Fig. 33 and Fig. 34). Well placed evacuation signs ensure that people are properly guided to safe areas or shelters.

EVACUATION PLANNING

Evacuation planning is a lengthy process which should be embedded in SOPs and be considered an ongoing endeavour which continues to improve in successive iterations. Consideration may be given to embedding such planning in the ICAM process. The time taken for planning activities will be directly related to the:

- geographical size of the management area;
- regional topography;
- regional hazards and vulnerabilities;
- demographics;
- size and density of the population;
- number of agencies involved in the planning process; and
- resources available.

Evacuation in response to tsunamis generally implies voluntary and/or mandatory evacuation, both of which can place a significant burden on the resources of emergency managers in terms of caring for the displaced people. The demands on emergency managers will change as the evacuation progresses through each of its phases (Fig. 35). It is important to recognize that the process of evacuation planning itself is just as important as the final written plan. In addition to developing a working knowledge of the overall plan, this process also facilitates the development of relationships between stakeholders which helps to improve operational capacities. Aspects to be addressed in a tsunami evacuation plan, some of which form part of the SOPs, include:

- conditions under which evacuation may be necessary;
- conditions under which to support people sheltering in place, including vertical evacuation;
Fig. 32 Tsunami warning response map for the city of Denpasar, Bali, Indonesia. The map shows people’s capability to respond to a potential tsunami expressed as the time people need to reach a tsunami safe area (evacuation time). Source: GITEWS Project. Courtesy DLR.

Fig. 33 Safety instructions and signage for tsunami events. 

Fig. 34 Roadside sign describing the tsunami hazard in the city of Padang, Sumatra. Information is given in terms of height above mean sea level. Photo: J.C. Villagran.Project. Courtesy DLR.
• identified ‘at risk’ people/communities who may require evacuation;
• command, control and coordination instructions (including designation of those authorised to order an evacuation);
• warning instructions to be issued to the media, public and businesses;
• procedures for assisting special categories of evacuees for example vulnerable communities;
• specific plans and procedures that address:
  ▪ the circumstances of the emergency;
  ▪ transportation (for example, arrangements for those without vehicles);
  ▪ dealing with community disregard of mandatory evacuation;
  ▪ the evacuation of specific locations; and
  ▪ evacuation routes.
• means of accounting for evacuees;
• welfare support for evacuees; designated reception areas;
• security of evacuated areas;
• procedures for the return of evacuees; and
• maintaining the plan, drills and exercises.

Fig. 35 Phases of the evacuation process. Source: David Coetzee

BOX 32 TSUNAMI EVACUATION PLANNING AND LAST-MILE IMPLEMENTATIONS

Evacuation of people in risk areas is the first priority once a tsunami early warning is received and/or natural warning signs indicate the possibility of a tsunami. As the available time span between a warning and the impact of tsunami waves might be very short, all necessary preparations need to be made in advance to ensure that as many people as possible get a chance to evacuate.

Tsunami evacuation planning – as part of tsunami contingency planning – ensures that evacuation maps and procedures are in place and understood long before a tsunami strikes so that as many people as possible are prepared and get a chance to evacuate quickly in the case of emergency. Therefore a tsunami evacuation plan should be acknowledged as an official government document. This makes it a credible and binding reference for institutions at all levels of government. Deciding which administrative unit is most appropriate for such an official tsunami evacuation plan depends on the local conditions. In Indonesia the provision of local tsunami evacuation plans is the responsibility of district authorities (BPBD), while the planning process itself requires the participation of many stakeholders. District evacuation plans are important references for the further development of tsunami evacuation procedures at institutional, grass root and family level (GIZ, 2010). To strengthen the capacities of local stakeholders, a structured approach to build up local tsunami preparedness was developed for Indonesia (see Figure below) in the frame of the projects GITEWS (German Indonesian Tsunami Early Warning System).
and PROTECTS (Project for Training, Education and Consulting for Tsunami Early Warning System). The rationale for this approach is based on the assumption that the chances to survive a near-field tsunami depend very much on the capacities of the affected people to quickly assess the situation and take the right decisions and actions based on basic but solid knowledge of local tsunami risks and preparedness plans, even in the case of the failure of warning services or in the absence of guidance from local authorities during an emergency (GIZ, 2013). Therefore people in risk areas need to be aware of the local tsunami hazard and risks and understand local warning and evacuation procedures. The capacity development process for the local and household levels is initiated by provincial government and then on district/city level including relevant actors like NGOs, local academia. An essential is to set-up local working groups consisting mainly of local government and representatives from the community and the private sector. In this process local facilitators are trained in evacuation planning and local warning services so that they can support preparedness processes at village level and implement community awareness campaigns at grass root level. Evacuation drills and education play an important role to reach and inform people at risk.

Risk assessment is a logical outcome of the processes involved in the tsunami hazard and vulnerability assessments and aims at identifying the capacities and resources available to address or manage the tsunami threat. The key component determining people’s evacuation capability for rapid onset disasters such as tsunamis is time. Knowledge of the available and required evacuation time is crucial information in the early warning process and disaster management in general.

In the frame of the GITEWS project, a methodology to assess the evacuation time was developed in order to define the best evacuation route from a given point to the next safe area within a specified time. In this concept, accessibility to a safe area is calculated on a cost surface representing a dataset where each location on land is either a passable route or relatively inaccessible, based on parameters like land use, topography, population density and further socio-demographic information. Evacuation speed reduction is calculated based on variations from ideal evacuation preconditions (e.g., empty, flat street). Quantification of these components in a coherent model leads to a fragmentation of the evacuation area into ‘evacuable’ and ‘difficult-to-evacuate areas’ within a certain time. Potential casualty numbers or displaced people can be derived based on available population data. Finally the applied model is used to define evacuation bottlenecks and to recommend/not recommend certain evacuation routes.

Besides the understanding of local tsunami risk and the approximate local evacuation capability, tsunami evacuation planning is comprises the development of a realistic strategy, the identification of roles and responsibilities of local actors, and the dissemination and testing of the plan. Bringing together all relevant actors allows gathering information and perspectives and the creation of a common understanding of the risk and the need for action.

To build local tsunami preparedness in a consistent and coherent way, national guidelines and policies are required to provide the necessary framework for local actors. The National Guideline on Tsunami Warning Services, as developed by BMKG, provides official information regarding the Indonesian Tsunami Early Warning System (InaTEWS), the warning chain from national to local levels, the sequence and content of warning messages – including recommendations on reaction to local authorities – and a clarification on the roles, responsibilities and procedures of all relevant bodies (BMKG, 2012). Other guidelines by the National Disaster Management Agency (BNPB) address topics like risk assessments, local emergency centres and contingency plans.

Comprehensive information for tsunami community preparedness in Indonesia and key elements of tsunami early warning can be found at: http://www.gitews.org/tsunami-kit/index_en.html

References are listed at the end of this chapter.

**Figure:** Multi-level approach to strengthen tsunami preparedness (GIZ IS, 2013) Source: Post et al., 2009.
EVACUATION ROUTES
Evacuation routes have to be designed to permit human and vehicle movement to safe places and evacuation structures. The design should be based on the expected volume of humans and vehicles, speed of evacuation and safety. The design should primarily present the number of routes required, the width and the overall safety of the evacuation process. The design must ensure the safe passage of evacuation and consider the risk of failure of the route itself under disaster conditions. Such an approach will identify weak links which may have to be rectified in advance; also recommend alternative routes in the event of failure of one prescribed. Avoidance of traffic jams and congestion should be a key aim (see case study at K.9).

EVACUATION STRUCTURES
The need for evacuation structures should be identified with respect to the population at risk and time available for evacuation to safe places, if such places have been identified. Evacuation structures are mandatory in the absence of safe places such as high ground or elevated infrastructure which can safely accommodate people at risk. Even if such safe places and facilities are available, it is necessary to be certain that the people at risk can be safely evacuated to such locations. If not, supplementary evacuation structures should be provided (Box 33).

Evacuation structures are mandatory in the absence of accessible high ground or elevated infrastructure which can safely accommodate people at risk.

For this purpose it is necessary to determine the critical time for the tsunami to reach a proposed safe place for a worst-case scenario after the warning is issued; also the maximum time required for evacuation (Fig. 32, Fig. 36 and Fig. 37). In the analysis a safety factor should be included to accommodate any potential delay in the evacuation process. Sometimes the need for evacuation structures may be avoided by having additional routes to the safe zones, thereby accommodating a reduced density of the human evacuation rate on a given route, leading to a higher rate of evacuation.

EVACUATION EDUCATION AND COMMUNICATION
The community must be educated and made fully aware of the risk of the tsunami hazard, the potential for a disaster and the evacuation routes. Evacuation drills must be conducted to ensure training of the community on disciplined evacuation. A mechanism for this entire process, to be monitored on a community-led, sustainable basis, should be established. In effect it is necessary to ensure community ownership of this process. The maintenance of the evacuation route should be given high priority. The community must also develop an effective mechanism for communication during the evacuation process. This will help to ensure that the problems and issues of a panic-stricken population on the move are swiftly resolved, thereby minimizing the level of prevalent chaos.

H.2.3 IMPROVING THE DISASTER RESPONSE CAPACITY OF YOUR COMMUNITY

EMERGENCY OPERATION CENTRES
The EOCs are geared to ensure multi-agency coordination, decision making and information management. These three tasks are necessary to coordinate the execution of response efforts in a timely and effective way once a tsunami has taken place.

Key issues to consider when improving the operation of the EOCs include:

- making sure that the EOC facilitates the participation of all relevant stakeholders (government agencies, NGOs, private sector, civil society);
- working with relevant authorities and local community leaders to ensure that the EOC is

![Fig. 36 Evacuation map for Padang, Sumatra. Map shows the time people need to reach an evacuation building or horizontal shelter area. Evacuation constraints become evident in areas where the estimated evacuation time is very high (dark red colours). The capacities of vertical evacuation buildings are shown in orange colours. Source: GITEWS Project. Courtesy DLR.](image)
Since the 2004 Indian Ocean Tsunami there has been a valuable window of opportunity for us to plan and design, or develop and implement several significant soft and hard measures to improve our preparedness and build our resilience towards future tsunamis as well as other coastal hazards. Examples of soft measures beside establishment of Indonesian Tsunami Early System (Ina TEWS) were the establishment of City/Regency Disaster Management Offices with Emergency Operation Center, Contingency Plan at City/Regency level, endorsement of building codes, a Tsunami Disaster Risk Reduction-based Spatial Plan, and an Indonesian Tsunami Disaster Risk Reduction Master Plan for 2012-2017 at national level; also the development of technical guidelines, standards, risk and evacuation mapping. Hard measures have included retrofitting critical facilities such as government offices and hospitals, road improvements for tsunami evacuation routes, and vertical evacuation shelters (Fig. 38).

Among those hard measure initiatives, tsunami vertical shelters need careful planning and design; existing multi-storey buildings cannot simply be designated as shelters. They require structural testing. In many cases multi-storey buildings do not comply with seismic and tsunami resistant building codes. Many cities/regencies in tsunami prone areas have not yet endorsed such building codes. Learning from such situations, the National Disaster Management Agency of Indonesia (BNPB) in collaboration with the Research Center of Disaster Mitigation at the Institute of Technology in Bandung has developed a series of technical guidelines for Tsunami Vertical Evacuation. These cover the planning and design of tsunami vertical evacuation that can be used to develop new buildings and artificial hills, or to retrofit existing multi-storey buildings. Beside the quality and strength of building design criteria for shelter design, the planning stage should involve the participation of multi stakeholders from the start. The capacity of shelters should meet the need to save “all people at risk.” The design should meet a requirement that the height of the shelter should include a freeboard of 30% of the design inundation height.

Shelters should also consider the needs of disabled people, the elderly and other vulnerable groups of people in designing the access, and should be located away from hazardous sources, such as gas stations, chemical factories or depots and cargo ports. Other documents relevant to vertical evacuation shelters are guidelines for construction, operation and maintenance of the shelters both for buildings and/or artificial hills, e.g., the BNPB Technical Guidelines.

Under good partnership with local communities in operation and maintenance, the shelter will be more effective in saving lives. Such partnership will synthesize a sense of community ownership and trust in the building that may save their lives. For example in Padang City, the KSB tsunami-ready community is a group from a tsunami prone area who dedicated themselves to helping the neighbourhood to be aware of and take care of the shelter.

Harkunti P. Rahayu.

perceived as the proper structure to facilitate the decision-making process regarding how best to respond in case of a disaster triggered by a tsunami or other hazard;

- working with key stakeholders to ensure that the EOC is capable of managing information properly and in a timely manner, in particular in the context of damage and needs assessments;
- working with local authorities to ensure that the EOC is capable of communicating needs to higher level authorities when local capacities and resources have been surpassed;
- working with all stakeholders to ensure that the EOC has the staff and resources that it requires to carry out its tasks in a timely and effective way;
- working with key stakeholders to ensure that the EOC is able to communicate effectively with those in the ground conducting a variety of operations (search and rescue, management of shelters, medical operations, security, etc.); and with a variety of organisations that can contribute to response efforts.

CONTINGENCY PLANS

Considering the relevance of contingency plans in facilitating the conduction of response efforts should a tsunami impact your community, you should consider the conduction of simulations or exercises to test if the contingency plans are designed adequately to meet the needs of your community when and if impacted by a tsunami. Such a simulation should allow you to:

- determine if all stakeholders understand the objectives to be achieved through its implementation;
- assess whether information on hazard and vulnerability of the communities at risk is properly incorporate in the plan;
- assess whether the plan is incorporating issues of gender, culture and other context-specific issues properly;
- determine if all relevant stakeholders are incorporated and involved in some elements of the plan;
- assess whether the plan is properly adapted to the existing chain of command or command structures;
- identify inadequate structure of tasks to be conducted in the proper sequence, leading to unnecessary delays in the conduction of response operations;
- assess whether through the execution of the plan there is a good match between the tasks that need to be conducted as part of the response operations and the resources allocated to such tasks;
- determine if the plan contemplates easy to use mechanisms to request external assistance and to facilitate the provision of humanitarian assistance;
- assess whether the plan is structured with some degree of flexibility to address unforeseen circumstances or unexpected events;
- assess whether data and information are managed in a timely and effective way (acquisition, transmission to the EOC, processing and use to identify needs);
- determine whether the plan incorporates communication and dissemination of information to the media and the public.

SEARCH AND RESCUE OPERATIONS

Search and rescue operations are conducted in a timely and secure way when those conducting such operations have the necessary skills and knowledge to conduct them, as well as the proper equipment. While time is of the essence when conducting such operations, it is imperative that such search and rescue operations start only once the ‘all clear’ signal or message is issued by the tsunami warning system.

Specialised training courses regarding how to conduct such search and rescue operations in case of tsunamis are ideal. However, in some cases the training courses targeting the search and rescue of persons during floods may serve as a solution when no specific courses on tsunamis are available.

In the case of collapsed structures, specialised teams would also benefit from specific training which is conducted in the case of earthquakes.

DAMAGE AND NEEDS ASSESSMENT

A proper conduction of a damage and needs assessments ensures the provision of accurate information to decision makers so that they can then plan how best to allocate humanitarian resources where they are needed.

The conduction of damage and loss assessments is conducted in the field using specific surveys for that end that target specific information that is needed to respond to the disaster. Usually civil protection agencies use specific forms for that end. As a way for you to improve the skills of those conducting this task, it is important that those conducting the task are trained on the use of such surveys and that they all are able to quantify damages and losses in the same way.

The use of novel technologies such as smart phones and tablets may be an interesting option to facilitate the acquisition of data on such damages and losses, and the subsequent transmission to the EOC, where it is processed. The transformation of data on impacts, damages and
losses into needs is conducted in the EOC according to specific procedures. The conduction of simulations may be useful to enhance the skills of those in charge of this task.

**MANAGEMENT OF SHELTERS**

In many cases local volunteers contribute to the operation of the shelter. So, it is important that you also dedicate some attention to the training of such volunteers so that they can conduct the required tasks as needed.

Key issues to consider when improving the operation of the shelters include:

- assessing the location of shelters with respect to the most up-to-date hazard map to ensure that they will not be affected by tsunamis;
- In the case of vertical evacuation shelters, having a structural engineer check the proposed building as a way to ensure that it can stand the impact of a tsunami;
- assessing whether the shelter is properly fitted to the needs of different types of groups (women, children, the elderly, the disabled);
- assessing the easiness with which anyone can access the shelter, including those who are bringing supplies;
- working with relevant stakeholders to assess security issues related to the shelters.

**MEDICAL TREATMENT OF THOSE INJURED**

As expected, the medical treatment of those injured during a tsunami is essential to ensure their recovery. As medical activities in case of disasters like tsunamis may be halted due to lack of resources (staff, medicines, supplies, equipment), it is important that you contact the relevant authorities to make sure that in case there is a lack of resources, that assistance, including international assistance, may be quickly accessed to secure the resources needed to conduct such operations.

**H.3 EARLY WARNING SYSTEMS – MONITORING AND ALERTING IN IOTWS**

*See also H.2 and M.1*

This section describes the real-time monitoring and alerting activities of the IOTWS, carried out by international Tsunami Service Providers (TSPs). It explains how alerts are delivered to the national agencies responsible for issuing warnings to communities at risk.

While disaster prevention or, at least, disaster risk reduction in respect of coastal inundation hazards is a strategic aim in disaster risk management, coastal countries and communities can reduce their vulnerability to tsunami inundation by their participation in the regional real-time tsunami early warning network provided by the Indian Ocean Tsunami Warning and Mitigation System – IOTWS. This participation significantly improves preparedness, potentially saving many lives. An account of the development of the science behind tsunami early warning and its application in the Indian Ocean region is included as a case study in the Guidelines (K.9).

The Intergovernmental Coordination Group for the IOTWS (ICG/IOTWS) is a regional body comprising UNESCO/IOC Member States in the Indian Ocean, with other countries outside the region and other organisations considered Observers. Each Member State is represented by a Tsunami National Contact (TNC) who serves as the intergovernmental contact person for the coordination of international tsunami warning and mitigation activities.

Most countries of the region have established systems and procedures that warn their populations of the likely or possible incidence of natural hazard events. National systems commonly link to regional multi-hazard networks. Extreme climate-driven events, including storm surges, can usually be predicted days ahead, giving National Disaster Management Offices (NDMOs) and emergency managers the time to mobilise effective responses. Geologically driven events – earthquakes, volcanic eruptions, landslides (including submarine landslides) and their possible ensuing tsunamis – may also be predictable spatially; but their timing is usually unpredictable on a scale that is relevant to a NDMO response. Despite this unpredictability, there is usually some opportunity for people at risk to be warned of a potentially damaging or disastrous inundation event and thus reduce, through emergency evacuation, the number of people who might be exposed to the impact of the event.

The opportunity for issuing a warning of an impending tsunami impact is constrained by the time taken by a tsunami to propagate from its source to the coastal point(s) of impact. Depending on the location of the tsunami source relative to the coast, this lead time may range from just a few minutes (near-field events) to several hours (far-field events). In practice, the available opportunity for issuing a warning depends on the effectiveness of event detection and alert messaging. The IOTWS has been developed with the aim of informing coastal communities who may be at risk about impending tsunamis following the detection
of a causative geological (usually seismic) event. It now provides an advanced tsunami forecasting service based on earthquake detection, sea-level measurements and oceanographic modelling, which includes detailed threat information for 571 coastal zones around the Indian Ocean. Most of this section is extracted, with amendments, from a report (Ryan, 2014) commissioned as a contribution to the UNESCAP Project: Enhancing Tsunami Risk Assessment and Management, Strengthening Policy Support and Developing Guidelines for Tsunami Exercises in Indian Ocean Countries. The report provides a description of the real-time monitoring and alerting activities of the IOTWS, carried out by international Tsunami Service Providers (TSPs). A further extract from the report, in particular detailing the responsibilities of TSPs is given as an appendix at M.1.

Other activities required for the effective warning and mitigation of tsunamis including local risk assessment, community preparedness and awareness are addressed elsewhere in these Guidelines. These are generally the responsibility of national and local authorities, though will be most effective when carried out with an awareness of the capabilities and limitations of the TSPs.

Three centres currently act as TSPs. Each covers the whole Area of Service of the Indian Ocean (Fig. 39). They have aligned their coastal forecast zones, accuracy and timeliness targets, and output product formats to ensure that National Tsunami Warning Centres (NTWCs) can readily use the forecasts from any or all of the TSPs. The tsunami models used by the respective TSPs are similar but differ in their detailed configurations. This leads to some differences, generally small, in the forecasts produced by the centres, so it is important that NTWCs understand the basis for the forecasts and the significance of any differences. The area of the Banda and Java Seas is currently served jointly by the IOTWS and the adjoining Pacific Tsunami Warning System. Some segments of coast in Australia, South Africa and northern parts of Indonesia are currently not included in the IOTWS area of service, but will be added as TSPs extend their tsunami model domains.

The TSP products include tsunami arrival and cessation times and maximum wave amplitudes for all threatened coastal forecast zones, and so can be rather complex. Some of the issues involved in interpreting the products are discussed here, including the potential to use modelled tsunami forecasts to improve local risk assessment.

Although the real-time operation of the IOTWS is working well, there are several limitations and areas of potential improvement, most of which are currently being addressed. Limitations and uncertainties that NTWCs should take into consideration are discussed in the Appendix M.1.

Fig. 39 Area of Service of the IOTWS. Source: UNESCO-IoC
H.3.1 IOTWS DETECTION AND ALERTING OPERATIONS

During a tsunami event, messages and information from TSPs are available to each Member State through the officially designated national Tsunami Warning Focal Point (TWFP), which is usually associated with the National Tsunami Warning Centre (NTWC) or National Disaster Management Office (NDMO). The TWFP is a 24x7 point of contact, and has the responsibility of notifying the national emergency authority of an event and its characteristics. The maintenance of up-to-date contact information for TWFPs and TNCs (Tsunami National Contacts) is a critical element of the operation of the IOTWS, and it is in the interests of each Member State to ensure that its contact information is promptly updated if a change occurs.

TSPs do not issue warnings; they provide to NTWCs advisory information and data on tsunami threats. It remains the responsibility of the NTWC, operating within the legal framework of its country, to provide warnings, watches, and advisories to its citizens and agencies.

The IOTWS achieves operational robustness through the existence of multiple TSPs operating as a ‘system-of-systems’. Rather than dividing the area of the Indian Ocean between them, each TSP covers the entire area of service of the IOTWS, providing redundancy in case of failure of any single centre. The system-of-systems approach requires all TSP tsunami information to be interoperable. This means that TSPs use agreed, common formats for information exchange, address common service requirements, follow agreed high-level Standard Operating Procedures (SOPs), and share information on procedures and processes. Some differences do exist between TSPs, in tsunami model formulation, for example, which means that there may be quantitative differences (usually small) in the advice provided to NTWCs.

It is important to note that TSPs do not issue warnings; they provide to NTWCs information and data on tsunami threats. It remains the responsibility of the NTWC, operating within the legal framework of its country, to provide warnings, watches, and advisories to its citizens and agencies. NTWCs will do so after reviewing the information received and considering their independent assessment of the ground situation based on national investigations. NTWCs are encouraged to feed back to TSPs information on the warning status in their country during a tsunami event, so that region-wide summaries of the warning situation can be compiled. Each TSP is also the NTWC for its own country and is therefore responsible for issuing its national warnings.

As they each have responsibility for the whole Indian Ocean, TSPs provide services to all NTWCs. Each NTWC may elect to utilise services from more than one TSP. TSPs issue their products in identical formats, to help NTWCs to compare and assess their information, but, on the basis of a range of tsunami forecasts, each NTWC must establish its own procedure for making decisions on warnings.

Because the authority for issuing tsunami warnings and instructions to the public resides with the NDMO/NTWC and its national partners, TSPs do not make their bulletins publicly available. Instead, secure dissemination methods are used to deliver TSP information direct to NTWCs (see appendix at M.1).

The only publicly accessible information provided by TSPs consists of earthquake characteristics, tsunamigenic potential, sea-level observations and a website showing the real-time tsunami warning status region-wide, based on advice from NTWCs on their local situation.

The implementation of IOTWS alerting operations has been based on a number of operational targets, the most important of which are the minimum earthquake magnitude which triggers TSP activation, the maximum elapsed time from earthquake to issuance of initial bulletins, and the probability of detection of significant earthquakes. Other TSP performance targets, relating to accuracy in earthquake and tsunami data, are described in Ryan (2014).

In line with widespread international practice, IOTWS alerting operations are activated for earthquakes of magnitude Mw 6.5 or greater in or near the Indian Ocean (see Section B.1). At this magnitude a tsunami might be a significant hazard for the local area (within approximately 100 km), but is unlikely to present danger further afield. The world’s oceans are connected, so it is possible for a severe tsunami in the Pacific or Atlantic oceans to impact Indian Ocean coasts. For this reason, TSPs monitor earthquakes in a region wider than the Indian Ocean. However, only strong earthquakes are able to cause significant tsunami waves at a great distance, so the magnitude threshold of Mw 8.0 is used for earthquakes occurring outside the Indian Ocean.

Consistent with the IOTWS focus on large, long-duration events, the TSPs’ target for issuance of an initial bulletin is 10 minutes elapsed time from the occurrence of an earthquake that meets the magnitude threshold. The initial bulletin may be confined to earthquake information, and is followed by the first bulletin containing tsunami threat information, which must be issued within 20 minutes elapsed time.

Perhaps the most important of the TSP targets is the probability of detection of earthquakes of Mw 6.5 or greater. The target is 100 per cent, which means that the IOTWS operations have been designed to guarantee that all potentially tsunamigenic earthquakes will be detected and alerts issued. This imperative of never missing a tsunamigenic earthquake, combined with the need to issue advisories very quickly, creates the possibility of false alarms, which can be costly and damaging to confidence in the warning system. The TSP product suite minimizes
the potential impact of false alarms through a staged approach, moving towards greater certainty and more detail with time.

H.3.2 THE MESSAGING PRODUCT SEQUENCE

When a potentially tsunamigenic earthquake occurs, the TSPs issue their advisories to NTWCs in the following sequence, adding detail as more information becomes available:

- **Notification Message** - issued within 10 minutes of the earthquake, providing an alert that an TSP Bulletin has been issued, plus the earthquake parameters (magnitude, location, depth; B.1.1).
- **Bulletin Type 1** - Earthquake Bulletin: providing details of the earthquake which has the potential to generate a tsunami. Issued within 10 minutes of the earthquake. The bulletin may also provide advice as to whether the earthquake has the potential to generate a tsunami or not, based only on earthquake magnitude, location and depth, pending more detailed tsunami forecasts based on scenario modelling (B.2.1).
- **Bulletin Type 2** - Tsunami Forecast: issued within 20 minutes of the earthquake, providing an initial forecast of tsunami threat, including arrival times and wave amplitude (half the wave height, Fig. 5). This type of bulletin contains either:
  - Advice that there is no threat to any of the Indian Ocean’s coasts; or:
  - Details of the forecast tsunami threat to coastal zones, based on tsunami modelling.
- **Bulletin Type 3** - Tsunami Forecast and Observations: providing the same information as Bulletin Type 2, with the addition of information on observed sea-level anomalies, confirming the existence of a tsunami.
- **Bulletin Type 4** - Tsunami Service Finalisation: advice on the end of the tsunami threat.

When a tsunami occurs, its damaging waves are not distributed uniformly around the Indian Ocean’s coasts. Some locations will receive destructive waves; others will be affected by only very small sea-level anomalies or none at all. Current limitations on tsunami modelling and prediction have been considered in deciding how precisely the IOTWS can describe the differences in tsunami characteristics along a coast. This resolution or ‘granularity’ of the IOTWS service is based on the division of all coasts around and within the Indian Ocean into 571 zones, termed Coastal Forecast Zones (CFZs). These extend about 100 km along the coast and 50 km seaward from the coast. A recent development has been to refine the zonation to match administrative boundaries as an aid to local warning formulation. The CFZs are used by all TSPs to describe the geographical extent of a tsunami threat. A threat is deemed to exist in any zone if tsunami waves with a positive amplitude (Fig. 5) of 50 cm or more are forecast to occur at the beach (1 m water depth).

The full suite of products which TSPs provide to NTWCs together with guidance on their use and interpretation is included as an appendix at M.1.

H.3.3 MONITORING AND DETECTION NETWORKS

Detection of earthquakes and measurement of tsunamis are central to the effectiveness of the IOTWS, so the seismic and sea-level observing networks used by the TSPs are crucial to their operations. The core of the seismic monitoring network used in the IOTWS is the IRIS Global Seismographic Network (GSN). The TSPs augment this network extensively with other sources, such as the stations of the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO), the GFZ Geofon Extended Virtual Network and stations from other national and regional networks. An overview of the seismic network used by TSPs is shown in Fig. 40.

There are two basic types of sea level gauge: coastal tide gauges and open ocean buoys (tsunameters). Coastal tide gauge stations are operated by a number of countries and organizations, including the Global Sea Level Observing System (GLOSS) of the IOC, that share their data for tsunami warning purposes. In addition, TSPs receive data from several deep-ocean tsunameters located off the major seismic zones of the Indian Ocean. Many of the current set of sea-level stations whose data are available to the TSPs can be seen in Fig. 41.

H.3.4 TSUNAMI FORECASTING METHODOLOGY

All TSPs employ similar tsunami forecasting methodologies, but with differences in the details of their models and processes. The common core of the forecasting approach is to pre-calculate ocean-wide tsunami characteristics in deep water (20-30 metre depth or greater) for a large number of earthquake scenarios, using an oceanographic model based on fluid dynamics and bathymetry data. Model forecast data are stored in the TSP’s library of model forecasts (each set associated with an earthquake scenario). From the model’s grid of forecast tsunami parameters, each TSP extracts for each coastal forecast zone (CFZ) representative values, such as tsunami arrival time and maximum tsunami amplitude. Using the representative values for each CFZ, each TSP extrapolates from the deep water model predictions to 1 metre water depth to determine if the threat threshold (50 cm positive wave amplitude) will be crossed, and the height of the maximum forecast wave (Fig. 5).

When a significant earthquake occurs, each TSP selects from its library the scenario which best matches the real
Fig. 40  Broadband Seismic Stations available to IOTWS TSPs, 2014. Source: UNESCO-IOC.

Fig. 41  Sea-level stations available to IOTWS TSPs, 2014. Source: UNESCO-IOC.
earthquake, and uses the forecast data from that run of the model in its advice to the NTWCs. Sea-level monitoring networks are then used to confirm that a tsunami was generated and to assess the accuracy of the model predictions.

The extrapolation of wave amplitude from deep to shallow water is an approximation based on simplifying assumptions about the slope of the sea floor and the orientation of the coast. All TSP centres use the Green’s Law (see M.1) approximation for this crucial step, and NTWCs should be aware of the inaccuracies which are likely to result. Further information on the modelling methodology and its limitations are given as an appendix at M.1.

**H.3.5 USING LOCAL INUNDATION MODELLING WITH TSP FORECASTS**

The IOTWS forecasting service can be augmented by research into local inundation modelling (B.3.1). Local models can be nested in broad-scale boundary conditions which would be expected in selected earthquake scenarios. The scenarios and databases used to create the TSP forecast libraries can be used as an initial filter to identify the most dangerous earthquake events for selected coastal zones.

As well as allowing better localized risk assessment, local inundation modelling also forms the best basis for planning emergency response and designing NTWC/NDMO procedures. During a real event, when TSP threat forecasts are issued, experience with local modelling would allow the NTWC to refine the broad threat/no threat zone forecasts to focus on particularly vulnerable areas within each affected CFZ.

**H.3.6 EXERCISING OF THE SYSTEM**

An important element of the IOTWS is the regular exercising of the system through region-wide exercises. These ‘IOWave’ exercises, coordinated by the ICG/IOTWS, are generally held every two years. All TSPs are involved and all NTWCs and NDMOs are encouraged to participate. The exercises are designed to simulate a region-wide tsunami threat. Each nation chooses how extensive its simulated response will be, ranging from NTWC-only involvement (receiving and acknowledging TSP bulletins) to full activation of the NDMO including simulated evacuations and emergency response. After each exercise a detailed survey of participants is carried out and a report published, providing guidance for further development of the IOTWS. The communications networks and procedures which are vital to the successful delivery of TSP services are also tested routinely, usually twice each year.

**H.4 RISK TRANSFER**

This section explains how the risk of physical loss and damage from tsunami inundation in a coastal community can be reduced by spreading or transferring the risk through insurance or re-insurance.

Another approach to disaster risk reduction is by transferring the risk through insurance. This approach is appropriate to loss and damage in a community’s built environment and its economic dimension, where the values of potential losses can be estimated with some confidence. Its application is not generally appropriate to the social dimension of risk reduction.

Insurance plays an important role in offering financial protection from the costs of flooding. By spreading risk across policy-holders, insurance enables householders and businesses to minimize the financial costs of damage from inundation. Furthermore, because lenders are unlikely to offer mortgages on properties that cannot obtain buildings cover, insurance plays a critical role in the operation of the property market. However, insurance can provide an effective mechanism for spreading the risk only if the risk is at a manageable level.

Reinsurance is the insurance that insurers themselves take out to deal with catastrophic events/claims. It provides a mechanism that can help insurers provide financial protection to developments located within the limits of potential inundation, and at risk from an inundation event. However, it is anticipated that reinsurers will become increasingly selective of the portfolios they are prepared to take on. Reinsurers model exposure based on the best-available estimates of risk. These are revised as more information becomes available, for instance following a catastrophic event. Where this reassessment leads to a limitation or withdrawal of reinsurance cover, insurers would need to reflect this in the extent of insurance coverage and the premiums they charge. This underlines the need to take a precautionary approach to large aggregations of new development in potential inundation zones.

**H.4.1 AN INSURANCE PERSPECTIVE**

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Two of the most deadly natural catastrophes of the last decade came in the form of tsunamis: the Indian Ocean tsunami of 2004; and the northeast Japanese tsunami of 2011. The Indian Ocean tsunami accounted for a dreadful total of around 250,000 lives; although economic losses were comparatively low as the most affected areas were relatively underdeveloped. Up to 19,000 people lost their lives in the Japan tsunami; but economic losses were estimated at a massive figure of around USD 250 billion. Both events have helped create greater awareness of tsunamis.
Although early warning systems may save lives, they do not save property. Massive economic losses are still possible. However, in comparison to other natural catastrophes, relatively little work has been undertaken on tsunamis. There are a number of reasons for this. Firstly, tsunamis impact near-coastal locations over a large geographical area. The damage caused to the area where a tsunami makes landfall can be exceptionally high. Secondly, tsunamis can have a relatively low frequency and can be challenging to measure. This gives rise to less historical and comparable data than, for example, tropical storms or earthquakes. Thirdly, a tsunami is often the by-product of another event, for example an earthquake, making the modelling process more complex. In addition, many of the countries historically exposed to higher tsunami risk have low insurance penetration.

The re/insurance industry is now getting to grips with what has been a lesser understood peril. The first index products have been created which specifically include tsunami risk (see Case Study, Pacific Catastrophe Risk Assessment and Financing Initiative in Section K.5). This product is supported by a number of development agencies. There have also been increased efforts to understand and model tsunami risk. The focus of these, given its exposure to natural catastrophes, has been Japan (see Case Study, Modelling tsunamis in Section K.4).

**INSURANCE AND NATURAL CATASTROPHES**

When assessing risks, a re/insurer must take into account the fundamental principles – and limitations – of insurability. Disregarding these principles would jeopardise the re/insurer’s solvency and ability to honour its obligations. However, adhering to these principles means that certain exposures are uninsurable. These principles are:

- **Randomness:** Time and location of an insured risk must be unpredictable and occurrence itself must be independent of the will of the insured.
- **Assessibility:** The frequency and severity of claimable events can be estimated and quantified within reasonable confidence limits.
- **Mutuality:** For the insurer and the reinsurer, it must be possible to build a risk pool in which risk is shared and diversified at economically fair terms.
- **Economic viability:** From the reinsurer’s perspective, the price needs to cover the expected cost of acquiring and administering the business as well as the claims cost. In addition, the price must allow for an appropriate return on the capital allocated to the risk, a return which meets shareholder’s return requirements.

Tsunamis, like other natural catastrophes, are insurable risks. However, their relatively infrequent nature and their specific geographical scope meant that they were less understood than other natural catastrophes. Two huge tsunamis, the Indian Ocean tsunami of 2004 and the Japanese tsunami of 2011 have changed perceptions of this risk. Tsunamis are now beginning to be built into the insurance modelling and underwriting processes; and index insurance products for tsunamis are becoming available for the first time.

The insurance sector, and most notably the reinsurance sector, has many decades of experience with natural catastrophes. Indeed, it can be argued that the defining moment of the global reinsurance industry was over 100 years ago in the wake of the San Francisco earthquake of 1906. Despite huge losses caused by the earthquake and subsequent fires, many insurers and their reinsurers helped establish their global reputations by meeting the claims.

Natural catastrophes can be devastating. The resilience of a country or region depends not only on the severity of the catastrophic event but also on available funding for relief, recovery and reconstruction. Economic losses vary substantially by country and disaster event. Economic development, population growth and a higher concentration of assets in exposed areas are increasing the economic cost of natural disasters. A large part of these economic costs are typically un- or underinsured. This financial gap is widening (Fig. 42).

Over the last twenty years a global average of only 20–40 per cent of the economic losses were covered by insurance. This is most notable in emerging and high growth economies, where insurance coverage and penetration is commonly low.

There are many reasons for the gap between the total losses of a disaster and the insured losses. Re/insurers build their expectations of likely losses on historical data; where such data are lacking or inadequate, this is more difficult. There are also structural impediments to sufficient insurance coverage, for example cost of local insurance distribution systems; a lack of a financial risk pooling culture; a lack of financial capacity; or insufficient expertise in covering specific risks. These impediments are particularly common in countries with underdeveloped financial services; and it is many of these countries which are at greatest risk of natural catastrophes.

Traditional insurance models have been based on an ex post claims process. The disaster occurred; individuals and institutions filed claims; and insurers assessed those claims. Such claims and loss adjustment processes are time consuming and expensive, particularly in the chaos that typically follows a major natural catastrophe. This time and costs are barriers that individuals, businesses and sometimes governments, all of which may be facing a sudden loss of income combined with increased immediate financing needs, may struggle to afford.

New approaches to financing disaster risks are, therefore, important to make societies more resilient. Index insurance products have been developed, which can quickly distribute...
funds if the catastrophe meets a measurable point (wind speed in a tropical storm for example). Such products are described as ex ante, as the payment point is clearly defined in advance and triggers an immediate release of funds. These may be put in place by an individual insurer; by a consortium of insurers and institutions; or by a pooled group of investors in the form of a catastrophe bond. Index schemes for developing countries at the sovereign level have been implemented often with support from multilateral development agencies and donors (see Case Study: Pacific Catastrophe Risk Assessment and Financing Initiative, Section K.5).

The inclusion of ex ante financial instruments in its overall disaster management mix helps a country to lower its financial exposure to natural catastrophe risk and reduces the potential burden on the state budget in case of a major event. Financial risk transfer instruments can reduce the volatility of the state budget and lower the need for the government to raise funds after an event. It makes financial planning easier for the responsible government and helps protect specific funding streams.

CONCLUSION

The Indian and Pacific Ocean countries are acting individually and collectively to address tsunami risk. As the market develops, insurers are stepping in to help with risk transfer solutions; but this will not save lives in the critical minutes between a major earthquake and a devastating tsunami. The 2004 Indian Ocean tsunami served as a wake-up call in further developing warning systems. It became all too clear that an event far away can have a devastating impact. Tsunami warning systems play an important role in both raising awareness of the risks associated with tsunamis and implementing solutions that help save lives.

The tsunami model for Japan (Section K.4) is expected to contribute to better evaluation and management of earthquake risks, which would in turn lead to sustainable provision of earthquake protection by re/insurance companies. Tsunami risk assessments should become a standard part of an underwriter’s toolkit for tsunami-exposed markets such as Chile, Peru, Mexico, or Indonesia. The application of the PCRAFI in the Pacific (Section K.5) highlights how the re/insurance industry can make a valuable contribution in providing risk coverage – including tsunami coverage – for some of the poorest countries on the planet.

In providing financing relief, the re/insurance industry is an important partner in improving the resilience of societies. Better understanding of the catastrophes of 2004 and

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Fig. 42 Insured losses vs. uninsured losses in natural and man-made catastrophes, 1970-2013. Source: Swiss Re Economic Research and Consulting.
2011 will help insurance play a larger role providing risk coverage against tsunamis.

A competitive and affordable re/insurance market is important to providing coverage. For premiums to remain affordable, they must be spread amongst a high portion of the population and business owners. Therefore, risk awareness for earthquake and tsunami risks need to be raised. As a result, earthquake and upcoming tsunami insurance are expected to become increasingly economically viable for the re/insurance industry. This will allow the industry to continue playing a key role in risk assessment, risk mitigation and in pre-disaster financing of earthquakes and tsunamis.

Contributions from Swiss Re in Section F.4 and Case Studies I.4 and I.5: Concept and editing: Oliver Schelske; Natural catastrophes, earthquake and tsunami modelling; Andreas Schraft, Balz Grollimund; Japan case: Toru Tamura, Atsuhiro Dodo; Global Partnerships, Pacific islands case: Ivo Menzinger, Eleanor Lee; Editing: Simon Woodward.

H.5 IMPROVING RESILIENCE

Building the disaster resilience of cities is becoming ever more important for coastal cities, where populations continue to swell and pressures on land-use become increasingly acute, leading to more and more vulnerable people living in hazardous conditions. Even without a threat of tsunamis, the risk to communities is exacerbated by increasingly frequent and more extensive inundations of low-lying coastal land as a consequence of sea-level rise through global climate change.

This section describes the key actions that may need to be taken at national and especially at local government or local authority levels – but with broad community engagement – to enhance a community’s ability to understand and cope with the tsunami threat, to respond to a tsunami emergency and recover quickly from a devastating tsunami inundation.

The topic of evaluating coastal community resilience to tsunamis and other hazards is comprehensively covered by a guide produced for Indian Ocean countries under the USAID program following the Indian Ocean 2004 tsunami (U.S. IOTWS. 2007). While the main aim of that document was on the assessment of resilience (D.5), its guidance includes improving and sustaining resilience in coastal communities over the long term. A synopsis of the guide is given at L.7.

Many of the actions that could enhance the resilience of your community in the event of a tsunami impact (e.g., improving community awareness and early warning) have been identified and described elsewhere in these guidelines. Such actions demand technical capacities as part of your risk management responses. However, such actions to improve resilience depend on the existence of functional capacities within government that will enable the creation of appropriate national policies and legislation to be developed, (e.g., for carrying out risk assessments or for land-use planning); also on the effective organization of procedures and the provision of resources for communities to deliver on those mandates. Thus, for some countries, there may be a priority to review legislation and national policies on natural hazard disaster risk management to accommodate possible tsunami impacts, and to ensure that procedures for including the assessment and management of tsunami risk are in place.

The relevance of improving resilience with respect to tsunamis is particularly important for coastal cities. Coastal cities, particularly coastal megacities, are included in a UNISDR initiative entitled ‘Resilient Cities’ (A.2.3). This emphasises that all stakeholders – national governments, local government associations, international, regional and civil society organizations, donors, the private sector, academia and professional associations, as well as every citizen – must play their part in contributing to building disaster resilient cities and to be engaged in reducing their risk to disasters.

A key feature of the ‘Resilient Cities’ initiative is a commitment by local governments to sign up to whereby they report on their progress in the implementation of the Ten Essentials for disaster risk reduction (Box 34).
Improving your preparedness for tsunamis

Essential 1: Institutional and Administrative Framework – Put in place organization and coordination to understand and reduce disaster risk, based on participation of citizen groups and civil society. Build local alliances. Ensure that all departments understand their role to disaster risk reduction and preparedness.

Essential 2: Financing and Resources – Assign a budget for disaster risk reduction and provide incentives for homeowners, low-income families, communities, businesses and public sector to invest in reducing the risks they face.

Essential 3: Multi-hazard Risk Assessment – Know your Risk – Maintain up-to-date data on hazards and vulnerabilities, prepare risk assessments and use these as the basis for urban development plans and decisions. Ensure that this information and the plans for your city’s resilience are readily available to the public and fully discussed with them.

Essential 4: Infrastructure Protection, Upgrading and Resilience – Invest in and maintain critical infrastructure that reduces risk, such as flood drainage, adjusted where needed to cope with climate change.

Essential 5: Protect Vital Facilities: Education and Health – Assess the safety of all schools and health facilities and upgrade these as necessary.

Essential 6: Building Regulations and Land Use Planning – Apply and enforce realistic, risk compliant building regulations and land use planning principles. Identify safe land for low-income citizens and develop upgrading of informal settlements, wherever feasible.

Essential 7: Training, Education and Public Awareness – Ensure education programmes and training on disaster risk reduction are in place in schools and local communities.

Essential 8: Environmental Protection and Strengthening of Ecosystems – Protect ecosystems and natural buffers to mitigate floods, storm surges and other hazards to which your city may be vulnerable. Adapt to climate change by building on good risk reduction practices.

Essential 9: Effective Preparedness, Early Warning and Response – Install early warning systems and emergency management capacities in your city and hold regular public preparedness drills.

Essential 10: Recovery and Rebuilding Communities – After any disaster, ensure that the needs of the survivors are placed at the centre of reconstruction with support for them and their community organizations to design and help implement responses, including rebuilding homes and livelihoods.

Source: UNISDR, 2012

Most of the obligations identified in this list are addressed and embedded in risk assessment and management responses described elsewhere in these guidelines. Implicit in the Essentials 1 and 2 is the importance of the role of national and particularly local government can make both in enabling the understanding of tsunami disaster risk in changing environmental circumstances and in the provision of the resources and capacity needed to anticipate, warn of, evacuate, and recover from a tsunami inundation event.

The topic of ‘Resilient Cities’ is presented as a case study at K.7, and as guidance in the Chapter on Tools and Methods at L.6.
H.6 OUTPUTS FROM IMPROVED PREPAREDNESS AND RESILIENCE MEASURES

EXPECTED PRINCIPAL OUTPUTS FROM THESE MEASURES INCLUDE:

- Communities informed and educated in tsunami risk, aware of natural indicators of a possible tsunami and how to respond to a tsunami warning;
- Early warning system for tsunamis installed at the national level and regularly tested for the receipt of alerts, issuance of warnings to emergency authorities and communities at risk, and effective emergency responses;
- Emergency response structures (EOC, Search and Rescue teams, medical teams, other voluntary teams) functional and tested through simulations and exercises;
- Special target audiences and vulnerable groups identified;
- Evacuation plans in place and tested, including signage, routes and provision of vertical evacuation shelters accessible to vulnerable groups;
- Contingency Plans tested and ready to be used;
- Participation by national or local government in risk transfer schemes as appropriate;
- Functional capacities at local and national government levels to enable community resilience to natural disasters including tsunami inundations.

REFERENCES AND SUGGESTED ADDITIONAL READING AND INFORMATION SOURCES


UNISDR. 2010. My city is getting ready. United Nations
Improving your preparedness for tsunamis


Institutional risk assessment and management within a DRR framework

This chapter reviews the current and recent initiatives whose aims include improving the functional capacity of institutions that can enable and organize the provision of technical responses at local or community levels leading to DRR in respect of inundation from tsunamis and other coastal physical hazards.

I.1 MAINSTREAMING TSUNAMI RISK ASSESSMENT INTO COUNTRIES’ DRR NATIONAL MASTER PLANS

Following the 2004 tsunami disaster, significant changes have taken place in the Asian region with respect to institutional and legal structures for disaster risk reduction. The 2004 tsunami disaster caused huge losses and devastation and it prompted several governments to establish new institutions with legal mandates and budgets to plan and implement disaster risk reduction. Since the disaster and during the last 10 years, the Asian region has witnessed a series of major disasters – in 2008, Kosi floods and Nepal and India; in 2010, Pakistan floods; in 2011, earthquake, tsunami and nuclear disaster in Japan, and Thailand floods; in 2013, Typhoon Haiyan in the Philippines, and numerous small and medium disasters – all of which have negatively impacted development. A combination of the lack of appropriate institutional structures and mechanisms to address risk in an integrated manner and the increased incidence of disasters due to climate change and variability continues to impact development at national and sub-national levels.

The World Development Report (UNDP, World Bank and USAID, 2014) provides five key insights on risk management:

- Taking on risks is necessary to pursue opportunities for development. The risk of inaction may well be the worst option of all.
- To confront risk successfully, it is essential to shift from unplanned and ad hoc responses when crises occur to proactive, systematic and integrated risk management.
- Identifying risks is not enough: the trade-offs and obstacles to risk management must also be identified, prioritized and addressed through private and public action.
- For risks beyond the means of individuals to handle alone, risk management requires shared action and responsibility at different levels of society, from the household to the international community.
- Governments have a critical role in managing systemic risks, providing an enabling environment for shared action and responsibility, and channelling direct support to vulnerable people.

Typically the new institutions, referred to above, are chaired directly by the office of prime minister/president as disasters require a mandate for national disaster risk management agencies to act swiftly, mobilize field operations and convene other departments – and therefore need a strong connection to the political leadership and/or with staff at field level who can act expeditiously. National authorities derive powers from legislation and typically respond to high profile disasters but usually do not address local disasters. The latter mostly affect vulnerable groups in communities and may not be captured by formal disaster reporting structures.

I.1.1 ACHIEVEMENTS OF THE HYOGO FRAMEWORK FOR ACTION (HFA)

See Section A.2.1, where the ‘Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters’ with its five Priority Actions (UNISDR, 2005), is more fully described, along with priorities for the period Post-2015.

According to the HFA progress review (UNISDR, 2014a), 49 per cent of countries reported that there have been substantial achievements in establishing institutional and legal frameworks for disaster risk reduction with recognized limitations in capacities (Priority Action 1). Of course the challenge remains that merely establishing these frameworks has not translated into DRR as these require additional organizations and resources to become operational. Priority Action 2 provides the starting point that knowledge of the hazard and the physical, social, economic and environmental vulnerabilities is essential for reducing disaster risks and for promoting a culture of disaster resilience. According to UNISDR, 45 per cent of countries reported substantial achievement on this priority action with limitations in capacity and resources. Further analysis of the situation in the countries is reported by UNISDR (2014a) as:
‘The most pressing is the need for setting a national standard or framework for risk assessment. The lack of an existing standard is related to poor coordination and the implementation of multiple risk assessments by numerous organizations (often sectoral ministries and institutes). The absence of an overall framework for risk assessment brings the lack of risk assessment in key sectors. Standardized methodologies would help mitigate the burden of risk assessment in certain sectors. Detailed sectoral risk assessment is required to define prioritization against projected investments’.

The outcomes of the implementation of the HFA have formed the basis of the Post-2015 DRR agenda, formulated in ‘The Sendai Framework for Disaster Risk Reduction 2015-2030’ [United Nations, 2015]. The Sendai Framework sets out detailed guidance for practical outcomes on a variety of critical cross-cutting issues, including understanding disaster risk, strengthening governance to manage disaster risk, investing in resilience, enhancing preparedness for response and planning for recovery and reconstruction (A.2.2).

I.1.2 MAINSTREAMING DRR INTO DEVELOPMENT

Mainstreaming is a governance process that helps ensure that development is protected from the impacts of disasters, and that development does not increase existing and future levels of natural hazard risk. To protect people and assets from hazards, DRR needs to be integrated or ‘mainstreamed’ into broader socio-economic development planning strategies as an integral part of the development planning processes at national and sub-national levels.

Risk profiling (exposure and vulnerability mapping) of populations and assets would provide support in determining the types of capacities needed, as well as the budgetary allocations for ex-ante initiatives to reduce disaster risk. A risk-profiling and consequently a capacity-needs assessment should form the basis for institutional and governance alignment to address the risks in a systematic manner.

Based on the extensive experience in countries around the world, UNDP has developed a framework for providing guidance on mainstreaming DRR into development (UNDP 2010 and 2013; Fig. 43):

- Policy development (e.g., integrating DRR into development policies at national and sector levels, such as agriculture or education policies);
- Organizational/institutional development (e.g., identifying DRR focal points across government agencies and strengthening cross-sectoral coordination mechanisms) such as national platforms for disaster risk reduction;
- Improving advocacy and knowledge for DRR (e.g., technical guidelines, training and educational programmes);
- Supporting the implementation of specific DRR measures (e.g., conducting risk assessments and integrating risk reduction into recovery interventions);
- Supporting broad participation in DRR (e.g., community based disaster reduction plans and programmes, as well as increasing the involvement of women in risk reduction plans).

Fig. 43 Disaster Risk Reduction, Governance and Mainstreaming A framework for providing guidance on mainstreaming DRR into development. Source: UNDP, 2010.

I.1.3 ESTABLISHING DISASTER LOSS AND DAMAGE INFORMATION SYSTEMS

With a view to improving the understanding of patterns and trends of disaster risks from small, medium and larger disasters, UNDP has been assisting national governments in establishing national disaster loss and damage database systems. These information systems record disaster events impacting development at local and national levels and allow analysis of impacts at local and national levels and generate a variety of analysis assisted by visual displays to help understand trends and patterns of disaster risks. Analyses from these information systems provide direct inputs to identifying and reducing disaster risks in the countries and to global policy advocacy through the Global Assessment Reports on Disaster Risk Reduction.

IMPROVING UNDERSTANDING OF RISKS AND BUILDING RISK KNOWLEDGE

Information about risks provides sound basis for decision making on every aspect of development. Studies have shown that the information needed for vulnerability and risk assessment lies with several organizations and that it requires strengthening for systematic collection, assessment and sharing of hazard and vulnerability data (UNDP 2009). Detailed risk assessments are required to inform policy decisions and planning by governments, businesses, and citizens. Recognizing, assessing and understanding risk are the first steps toward reducing its negative effects.
I.1.4 PROMOTING INVESTMENTS FOR RESILIENT NATIONS AND COMMUNITIES

The background document on Promoting Investments for Resilient Nations and Communities prepared for the 2014 Asian Ministerial Conference on Disaster Risk Reduction in Bangkok, recommends the following to improve understanding of risks to warrant wider action by all stakeholders engaged in the development processes at various levels (UNDP, World Bank and USAID, 2014):

- Applying risk information for resilient development: Recognizing, assessing and understanding risk are the first steps toward reducing its effects. These risk assessments provide insight on the root causes of risks and provide increasingly useful information for designing more resilient development processes and programmes. For example, a full risk analysis showing the full range of potential losses from these hazards for public and private property is usually needed to make the case for more serious investments to reduce expected losses, both human and economic. Innovations in mapping risk and visualization of hazard and damage scenarios should be fully utilized in communicating the potential scenarios to various groups.

- Investing in risk data and information tools: While it is essential to collect necessary data and information about risks and develop capacities for analyzing and synthesizing data and information to derive insights into the levels and causal factors of risks, the capacity for utilizing analysis is equally important for deriving useful guidance for policy-making and setting up appropriate methods and tools for monitoring the results of policies. In practice, risk assessments can only be as good as the data that informs them. However, in developing countries the underlying data to feed into risk assessments is often lacking. It is important to utilize new technologies in data collection and sharing, combined with participatory and collaborative processes to map hazards, settlements and asset boundaries. Investing in geospatial data and aerial and satellite imagery can fill gaps in risk information.

- Preparing for varied typologies of disaster: Given that hazards can be of various types due to various complex factors, the consequent disaster risk they pose can also vary significantly. Institutional structures need to be able to respond to both extensive (small-scale, more common) and intensive (high magnitude, less common, more headline-grabbing) disaster risks. Following the Great East Japan Earthquake of 2011, Japan realized that single-sector development planning cannot address the complexity of problems posed by natural hazards, let alone mega-disasters, nor can such planning build resilience to threats. The essence of the approach is to design and maintain resilient infrastructure capable of absorbing damage from natural disasters to some extent, even when an event exceeds all feasible and affordable measures. In the wake of the Great East Japan Earthquake, Japan also recognized that additional efforts were required to plan and design measures capable of countering events of low probability but high impact.

- Incorporating risk information in public investment decisions: Communicating risk information in a format that is easy to understand by various groups can lead to action, empowers individuals and policy makers. Risk information lacking a rigorous scientific approach or producing erroneous results can result in poor investment decisions and damage the credibility of those providing it. For example, if communities are engaged in developing hazard maps, it helps to raise awareness and increase understanding of the risks they face and the mitigation options they can undertake. Translating the probability and probable losses of disasters into impacts on lives, livelihoods or the government’s budget can help unpack risk data and translate it to actionable information. UNDP supported disaster loss and damage database information systems in many countries in Asia and around the world also provide insights into disaster and climate risks based on past events and can provide helpful guidance on future potential losses and damages.

- Translating technical information into actions: Policy makers and the public must have access to the right data and information to make good decisions to build resilient societies. For example, decisions include those such as where and how to build safer schools, how to insure farmers against drought, and how to protect coastal cities against future climate impacts need the right risk information to help make decisions. It is equally important that risk data and information is shared in appropriate digital formats with all stakeholders to ensure its conformity to agreed formats and standards, and to improve its usage in future studies and research.
### 1.2 LEGISLATIVE FRAMEWORK

*Instead of pursuing tsunami risk assessment and mitigation procedures as purely technical endeavours, they are more likely to yield positive results for the community at large when they are pursued within the existing institutional and legal structures of a country. This section reviews such legislative frameworks for the conduct of tsunami risk assessment studies and the implementation of their outcomes.*

Huge losses and devastation in the 2004 Indian Ocean tsunami disaster prompted several governments in the region to establish new institutions with legal mandates and budgets to plan and implement disaster risk reduction (DRR). The HFAs First Priority (Sections A2 and I.1.1) was to ensure that ‘DRR is a national and a local priority with a strong institutional basis with good legislative frameworks for implementation’.

The purposes of a country’s law covering the management of the risk of disaster due to tsunami impacts have much in common with those for other natural physical hazards affecting coastal areas. Legal frameworks appropriate to the assessment and management of risk arising from earthquakes or typhoons, or from long-term climate change or demographic pressures, for example, may be broadly similar but with differences reflecting a country’s perceived levels of threat from the various hazards, its governance structures and its capacities. Whatever the hazard, countries face major institutional challenges in achieving DRR. Numerous reports relating to HFA implementation have indicated slow progress in reducing disaster risk at the community level, and a lack of clear information and analysis on the role of legislation (IFRC and UNDP, 2014).

Countries’ Disaster Risk Management (DRM) laws are likely to include a mandate for a specific institution, e.g., an NDMO, to adopt a leading role in DRR. Even with such laws in place, their implementation and enforcement will require the existence of resourced functional capacity and effective governance and engagement at and between national, local and community levels, as well as cross-sectoral cooperation. According to UNISDR (n.d.), such coordinated and coherent action on DRR across different sectors and between central and local governments is not widely developed. However, ‘there is a growing recognition about government’s responsibility for effective DRR policy planning and implementation conducted through a transparent and multi-stakeholder approach’.

The legal framework should cover the responsibilities for the technical procedures for tsunami risk assessment and mitigation responses at the local authority and community levels that are described in these Guidelines. In the context of the tsunami hazard, these include realization of the essential elements of the IOTWS, without which the goal of minimizing loss and damage from tsunami impacts on communities at risk will not be achieved. Tsunami risk assessment including hazard and vulnerability mapping, with a particular focus on vulnerable groups, is a high priority for which there should be a clear legal obligation (Chapters B–E). Other legal requirements should be responses as detailed in Chapter H for enhancing a community’s preparedness, with emphasis on education and public awareness, on early warning, evacuation and emergency planning and, in general, a state of readiness to respond. The institutional mandates for such responses are especially important in the context of the tsunami hazard, for which the lead times for emergency response including evacuation could be less than one hour.

The framework should also encompass the responsibilities for strategic management responses to the outcome of the tsunami risk assessment that lead to DRR, as described in Chapter G. In many instances the mandates for these responsibilities would lie outside the remit of the lead DRR institution, such as a NDMO, involving cross-sectoral coordination and cooperation. Important inclusions would be for legal requirements to reduce the vulnerability of the built environment, whether rural or urban, with attention, for example, to the introduction of more stringent building codes so that buildings withstand the forces of inundation. Cross-sectoral cooperation would also be implicit in the legislation that covers spatial planning, land-use and environmental issues, as well as issues relating to climate change adaptation.

A review of the effectiveness of law and regulation for DRR based on a multi-country study is given by IFRC and UNDP (2014). This review indicates that DRR is a more distinct priority in policies, plans and strategies than in legal frameworks. However, the interaction between law and policy, whilst complex, is often essential for successful implementation. Countries rarely tackle the fundamental reform towards DRR without a specific legal framework, since DRM laws are essential for setting the DRR priorities and mandates of implementing institutions. An overriding question is ‘how can legal frameworks for DRR help to establish an approach that is sustainable within the resources and capacity of each country?’. Because some countries face resource shortfalls for their DRM needs, particularly at the level of local government, it is important to promote greater community participation.
This section reviews the assessment and management of the tsunami hazard in the wider context of physical coastal hazards and promotes the adoption of the ICAM process in achieving risk reduction goals.

The focus of these Guidelines has been the assessment and management of tsunami risk. However, the possibilities of other physical coastal hazards – storm surge inundation, coastal erosion and, over the longer term, sea-level rise related to global climate change – affecting a shoreline that is prone to tsunami impacts should be considered in the formulation risk reduction strategies (UNESCO, 2009).

The ICAM process promotes an integrated plan for the protection and development of coastal resources in a multi-hazard context. Your community’s tsunami risk assessment and reduction procedures can be integrated effectively with other ICAM management efforts. These will take into account the requirements of the many stakeholders, the constraints of coastal marine and terrestrial spatial planning, and your country’s disaster risk reduction strategies and programmes.

Risk reduction plans within ICAM will ideally consider the potential societal and economic benefits of strategic management and improved preparedness; in the short term, to anticipate and cope with tsunami emergencies, and, over the longer term, to reduce a community exposure to the hazard and promote the sustainable use of coastal land. Pressures on coastal land use will continue to grow as a consequence of the present global demographic trend of population increase within the coastal zone. The growth of coastal megacities is a particular concern, with the expansion of urban communities into coastal areas prone to inundation.

### I.3.1 BUILDING AN INTEGRATED APPROACH TO ASSESSMENT AND RISK REDUCTION

Tsunami hazard assessment and its products such as inundation maps are, by definition, specific to the tsunami hazard. However, the modelling skills and surveying resources required may be entirely appropriate for the prediction of inundation limits for specified storm surge levels, as they would be for predicting shorelines for specified levels of sea-level rise over the long term.

The vulnerability assessment in respect of the tsunami hazard may have much in common with vulnerability assessments in respect of the other physical coastal hazards. In particular, the existence of asset maps and an asset database for your community constitutes a shared resource in risk assessment within ICAM. Similarly, the procedures for the assessment and improvement of your preparedness, e.g., to warn, evacuate and recover from an emergency tsunami event, may be similar in many ways to those for your preparedness to cope with another rapid-onset hazard – a storm surge.

The evaluation of the risk of loss and damage in a multi-hazard context must take into account not only the likelihood of inundation by a tsunami within a specified period, but also the likelihood of inundation by a storm surge. As well as this, the evaluation needs to consider rates of coastal erosion and sea-level rise. All of these factors need consideration in choosing approaches for risk reduction in respect of tsunamis, whether for improving preparedness or strategic management including land-use planning for the longer term. For land-use planning in particular, changes in risk levels over time need to be addressed, caused for example by changes in land use, such as coastal urbanization, or changes resulting from proposed risk reduction measures, such as constraining the hazard by structural protection.

Risk reduction by appropriate land use is an important strategic response. Coastal land-use planning is a key component of ICAM and is relevant to all of the sea-level related inundation hazards, both the rapid-onset or catastrophic events caused by tsunamis, storm surges and extreme wind-forced waves, and the long-term, progressive or creeping processes of coastal erosion and sea-level rise. For example, the promotion of residential areas and utility infrastructure away from inundation zones and land prone to coastal erosion is an obvious ideal.

### I.3.2 COOPERATION, COORDINATION AND PUBLIC INVOLVEMENT

The management of natural hazard risks demands cooperation and coordination between all the involved agencies. Strategic coastal hazard management, as with any part of the ICAM, is an iterative procedure. To be effective, it should include a robust monitoring and evaluation component to assess the effectiveness of the chosen strategy and the adopted measures. Policy makers and coastal managers should be prepared to adjust their strategy over time and to be responsive to other pressures and changes – socio-economic, environmental, and political – that may occur.

Within the framework of a tsunami risk management plan, measures which reduce the impact of the hazard represent a coherent set of interventions. These may be specified in time and space to achieve a certain expected level of protection against existing or anticipated loss and damage from tsunamis as well as other hazards. The practical application of risk knowledge in actions for risk reduction may be improved by strengthening
the involvement and co-ownership of the community and public in the science research agenda. This helps to establish the credibility, legitimacy and relevance of the research-based knowledge output among practitioners, and to lower the barriers to the take-up of assessment findings by policy makers. The successful application of the risk assessments may be impeded by a lack of political commitment, but here, also, the ICAM process may help to resolve such institutional barriers to the application of successful risk reduction measures.

Public opinion and wide stakeholder involvement are valuable tools that should be included in the decision-making process as the risk management strategy is developed. Public support and buy-in is important for the success of the strategy as it is for ICAM in general. To engage the public, policy makers should educate them about the risks, benefits and drawbacks of various management options. The public should have the opportunity to provide input on the level of risk that is acceptable or needs to be managed.

Whatever the level of risk, there is likely to be some potential for risk reduction, the overarching objective of process set out in these Guidelines. Programmes of preparedness including public awareness, evacuation exercises and education aimed at improving community resilience may be some of the most cost-effective management responses, particularly in developing countries. However, it may be difficult to sustain credibility and commitment amongst stakeholders where the return periods of damaging tsunami events stretch beyond the span of living memory. Such situations are especially problematic for coastal management. Coastal communities may be reluctant to forgo what they perceive as assured livelihoods in hazard-prone areas on account of a threat of hazard impacts which may not recur even over several generations.

Whatever the coastal communities’ physical or developmental situation, there are sustainable ways of reducing tsunami risk. Of prime importance is the need to achieve a sustained coordination of effort among the many stakeholders, whether in risk assessment, or in the planning and implementation of risk reduction measures. The successful application of these processes, whether in planning or in emergency response, will depend above all on the effective operational coordination and cooperation of the many parties involved.

### I.4 GOOD PRACTICES IN DISASTER RISK REDUCTION

This section outlines the structures of legislative frameworks for the implementation of Disaster Risk Reduction in three countries – Indonesia, Japan and New Zealand.

#### I.4.1 INDONESIA

The key Indonesian legislation relating to Disaster Risk Reduction is the Disaster Management Law of Indonesia (Republic of Indonesia, 2008). In addition to emergency response and disaster relief, the law covers pre- and post-disaster management. Under its ‘General Provisions’, the law is specific in its terminology relating to disaster protection and emergency response. Disasters from tsunami impacts, though not individually specified, are implicitly included. The National Disaster Development Plan and the National Action Plan for Disaster Risk Reduction developed within the law are in accord with the Hyogo Framework of Action (A.2.1).

The law sets out the responsibilities of government at national and regional levels. These stipulate the reduction and integration of disaster risk into the national development programme and regional development policies. The law requires the establishment of a tiered structure of governance comprising a National Disaster Management Agency and Regional Disaster Management agencies whose functions are to provide ‘guidelines and directions on disaster management which include disaster prevention, emergency response, rehabilitation, and reconstruction’. Regional Disaster Management agencies are in turn required to establish Disaster Management Local Agencies tasked with ‘stipulating guidelines and directions in accordance with local government and Disaster Management National Agency policies on disaster management that include disaster prevention, emergency response and rehabilitation’.

In addition to this governance structure, the law spells out the rights and obligations of the community in respect of disaster management. These include the ‘provision of education, training, and skill in disaster management, of written and/or oral information on disaster management policy’; also by ‘participation in the planning, operation, and maintenance of a healthcare aid programme, including psychosocial support’, and ‘in decision-making on disaster management activities, particularly those related to him/her and to his/her community’. The law thus provides for the active involvement of local communities in disaster risk management, not only through their response to disaster emergencies, but also by their assessment and reduction of natural hazard risks. This provision embraces the practice of Community-based Disaster Risk Management (CBDRM, L.5), with communities being empowered to take initiatives in the planning and implementation of risk reduction, including emergency preparedness and procedures, and post-impact recovery.

Within that part of the law dealing with disaster management, activities aiming at DRR, particularly under
non-emergency conditions, include the ‘recognition and monitoring of disaster risk; participatory disaster management planning; promotion of disaster-awareness practices; greater commitment of [the] disaster management team; and application of physical and non-physical efforts, and instructions on disaster management’. The law places obligations on individuals and organizations to abide by its provisions, with punitive measures for those who fail to comply.

I.4.2 JAPAN

The key legislation relating to Disaster Risk Reduction in Japan is the Disaster Countermeasures Basic Act (1961, revised 1997; Government of Japan, n.d.). This act provides for the institutional framework for disaster prevention and management, established through national and local governments and public corporations. It clarifies responsibilities and provides for the formulation of disaster prevention plans and policies for preventive and emergency measures and recovery programmes.

At the national level, the Central Disaster Management Council is required under the Act to prepare a Basic Disaster Management Plan and designated government organizations and public corporations to prepare Disaster Management Operation plans. At the prefectural and municipal levels, disaster councils are required to prepare Local Disaster Management plans. The resulting tiered structure defines the responsibilities for coordinating and applying disaster management policies developed within the Act. In addition to these government and corporate responsibilities, residents within an area under local government have an obligation to contribute to disaster prevention by taking their own measures for disaster preparedness. With regard to warnings, ‘any person having detected an unusual event which may lead to a disaster shall notify’ [an authority] without delay.

Disaster prevention is addressed within the Act by the establishment of Disaster Prevention councils at the Central (national), prefectural and more local levels (villages, towns, cities) whose responsibilities include the formulation and implementation of comprehensive long-term disaster prevention plans for their respective areas of administration. The Act obliges authorities to maintain a state of preparedness for possible disasters, including measures such as plans and drills for evacuation and the stockpiling of materials to be accessed in states of emergency; also in ‘matters related to the issuance and transmission of alarms, recommendations or orders for evacuation’.

The wording of the Basic Act includes no reference to the term ‘Disaster Risk Reduction’ as such. However, the National Report of Japan on Disaster Reduction for the World Conference on Disaster Reduction held at Kobe-Hyogo, Japan, in 2005, (UNISDR, 2005) states that ‘the cornerstone of legislation on disaster risk reduction is the Disaster Countermeasures Basic Act, enacted in 1961, which set out the basis for measures to reduce disaster risk in Japan’. The Act is ‘one element of an integrated system of risk reduction [measures] that includes legislative provisions for a range of specific natural hazards, as well as a high level of regulation in the planning and building sectors, providing a clear indication of how deeply DRR is entrenched in Japan’s overall legal framework’ (IFRC and UNDP, 2014). Under this system, the implementation of DRR in Japan has been mainstreamed into other sectors and devolved to local government (IFRC and UNDP, 2014).

I.4.3 NEW ZEALAND


The RMA is the country’s main piece of legislation setting out procedures for managing its environment, including national direction and responses to national priorities by central government, and the roles and responsibilities of local government. Local authorities have a key role in natural hazard management including the implementation of DRR, the LGA providing the framework within which these authorities operate. The Building Act (2004) includes provision for the management of natural hazards in relation to the construction and modification of buildings.

The CDEMA is legislation that relates directly with DRR, including the management of hazards and risks, emergency response and recovery. Seventeen classes of hazards are specified in the Act, not all of which are ‘natural’. ‘Tsunamis’ and ‘Coastal hazards’ are included. The purpose of the Act (MCDEM, n.d.) is to:

- improve and promote the sustainable management of hazards in a way that contributes to the social, economic, cultural and environmental well-being and safety of the public and the protection of property;
- encourage and enable communities to achieve acceptable levels of risk by identifying risks and applying risk reduction management practices;
- provide for planning and preparation for emergencies and for response and recovery in the event of an emergency;
- require local authorities to coordinate Civil Defence Emergency Management (CDEM) through regional groups across the 4Rs (reduction of long-term risks), readiness, response and recovery) and encourage cooperation and joint action between those groups;
- integrate local and national CDEM planning and activity through the alignment of local planning with a national plan and strategy;
• encourage the coordination of emergency management across the range of agencies and organizations with responsibilities for preventing or managing emergencies.

Under this ensemble of laws, the implementation of DRR in New Zealand has been mainstreamed into other sectors and, notably, devolved to local government (IFRC and UNDP, 2014).

REFERENCES AND SUGGESTED ADDITIONAL READING


Applying the Guidelines

This chapter provides an overview of the rationale and key steps to be followed in the sequence of risk assessment and risk reduction procedures as part of IOTWS within the context of international DRR frameworks and ICAM.

The Guidelines cover three main areas of activity.

- Chapters B–E together deal with ‘assessing your tsunami risk’. They describe the ways of assessing the risk that the tsunami hazard poses for you – your population, your supporting systems and your assets.
- Chapters F–H describe the procedures that will help you to reduce the tsunami risk by strategic management and by improving your community’s preparedness in the event of a tsunami emergency.
- Chapter I considers the ways in which the reduction of tsunami risk can be promoted institutionally, within policies for Disaster Risk Reduction in respect of all natural hazards and in the context of current international frameworks for DRR and Integrated Coastal Area Management (ICAM).

The linkages between the various elements of the assessment and risk reduction procedures are shown in Fig. 1. Descriptions of the procedures are supplemented by case studies (Chapter K) and by details of relevant new tools and methods whose application may be considered by users of the Guidelines (Chapter L).

### J.1 ASSESSING YOUR TSUNAMI RISK

#### J.1.1 ASSESSING THE TSUNAMI HAZARD

**See Chapter B**

It is logical to commence with the hazard assessment, this giving you an indication of the level of danger to which you are exposed, and thus, if appropriate, the imperative to take further action. The information gathering and modelling procedures are tasks for scientific staff and may require links with international expertise, particularly with regard to tsunami sources and propagation. The key steps in the hazard assessment are:

- Define the geographical limits of the coastal management area.
- Examine the historical records of coastal hazard impact events and shoreline change, also the regional and ocean-wide seismic records.
- Access information on hazard origins and propagation patterns, local, regional and far-field.
- For use in modelling, acquire and compile data on nearshore bathymetry and coastal topography.
- By modelling the propagation of credible tsunamis, determine their likely impact on your coast.
- By inundation modelling, determine the likely physical nature of the inundation (extent, flow depths and velocities) caused by such an impact.
- Determine the probabilities for credible tsunami scenarios impacting your coast.
- Display results as inundation and local hazard maps.
- Convey results to risk and emergency managers.

#### J.1.2 ASSESSING YOUR VULNERABILITY

**See Chapter C**

The first step, having agreed the geographical and temporal limits of your assessment, is to create a geospatial census and inventory of people and their assets who could be within, or adjacent to, the possible inundation zone. Combining this data with that from the local hazard map shows the extent to which people and their assets would be exposed to the inundation. The resulting exposure map has two applications: firstly for emergency managers to confirm or develop their evacuation plans; and secondly to continue the vulnerability assessment to enable vulnerability assessors to estimate the extent of loss of life and damage to community assets as the consequence of a specified tsunami scenario.

The assessment of a community’s vulnerability caused by exposure to a tsunami hazard requires the gathering and comparison of geospatial data, preferably using GIS with Smartphone and remote sensing technology, as well as understanding how that vulnerability may change with time. Ideally this action would be carried out jointly...
by scientific and emergency management staff. The key steps in the vulnerability assessment are:

- Define or confirm the geographical scale and limits of the assessment.
- Define the temporal scale of the assessment.
- Create an asset (inventory) database of people and their supporting systems within and adjoining the perceived inundation zone.
- Create an exposure database of people and their supporting systems and assets for specified tsunami hazard scenario(s).
- Classify the levels of vulnerability of people (age, gender).
- Classify levels of vulnerability of the community assets.
- Produce vulnerability maps and reports for the management area.
- Estimate potential loss of life and damage for specified tsunami scenarios.
- Communicate the vulnerability, loss and damage assessments to risk assessors and emergency managers.

J.1.3 ASSESSING YOUR PREPAREDNESS

See Chapter D

The assessment of the preparedness of your community in the event of a tsunami emergency is a task for social scientists, teachers and emergency managers identifying weaknesses in their community systems that would be needed for anticipating, responding to, and recovering from a tsunami inundation. Many issues that may affect the resilience of your community have been addressed elsewhere in these guidelines; however, appraisal of the functional capacities in national and local government may be important in determining your community’s resilience. The weighting that you give to the various aspects of your community’s vulnerability and preparedness, and the way in which those values may be aggregated for the purposes of risk evaluation depends on the particular circumstances of your community and may be determined by expert judgement. Key tasks in this assessment are:

- Appraise the degree of awareness regarding tsunami risk on behalf of key stakeholders (communities at risk, authorities and those conducting emergency response efforts).
- Identify and appraise weakness in early warning systems and in responses to a warning.
- Identify and appraise the condition of vertical evacuation shelters and evacuation routes.
- Estimate the time required for the population to reach shelters and safe areas.
- Assess the application of risk transfer mechanisms which would facilitate post-impact recovery.

J.1.4 EVALUATING YOUR TSUNAMI RISK

See Chapter E

The culmination of the sequence of assessment procedures is the estimation of the risk of a tsunami impact in terms of damage and loss over a defined period. The process of evaluation of the risk of loss and/damage from a tsunami inundation reflects the selection of the categories chosen for assessing vulnerability. This could be, say, the risk of financial loss from the complete destruction of residential buildings, or you might see that the risk level for exposed people in an inundation zone could be significantly raised by low levels of preparedness, such as having no access to an Early Warning System. A checklist for determining levels of risk for consideration by coastal managers follows.

- Confirm the geographical scale and limits of the assessment.
- Confirm the temporal scale of the assessment.
- Combine the tsunami inundation parameters (for specified scenarios with defined probabilities) with assessed vulnerability levels and preparedness judgements. Translate the combined hazard, vulnerability and preparedness outputs into levels of risk, denoting the probability of damage and loss for specified tsunami scenarios.
- Produce risk map(s) and reports for the designated coastal management area.
- Communicate the risk assessment outputs to all levels involved in risk management and reduction.
J.2 REDUCING YOUR TSUNAMI RISK

See Chapter F

The approaches used to reduce the risk of disaster must be carefully targeted, mindful of the costs and benefits of carrying them out and the impacts of the chosen approaches on other aspects of coastal management, such as changes in coastal populations and environmental issues such as the possibility of long-term sea-level rise related to global climate change. The Guidelines are set out to address risk reduction under two main categories – reducing your risk by strategic management; and by improving your community’s preparedness (Fig. 1). Straddling the boundaries of these categories are activities that relate to both – participating in Early Warning Systems; and participating in Risk Transfer schemes. Early Warning Systems, in particular the monitoring and alerting operations in IOTWS are described in H.3 and M.1. The topic of ‘risk transfer’, common to strategic management and preparedness, is described in H.4 and in case studies, K.4 and K.5.

J.2.1 REDUCING YOUR TSUNAMI RISK BY STRATEGIC MANAGEMENT

See Chapter G

The measures to be adopted in strategic risk reduction are responses to the results of the assessment procedures, notably to the information contained in the inundation and local hazard mapping and the asset and exposure databases. With regard to the hazard data, the response should be a portfolio of effective hazard control measures which are consistent with wider coastal management objectives. With regard to the vulnerability assessment information, the response should be a portfolio of measures which aim to decrease the vulnerability of the built environment and a reduction in the exposure of vulnerable assets whose vulnerability cannot be reduced. The responses should have a long-term implementation plan (years to decades), including a monitoring programme to assess the effectiveness of the selected strategy in reducing risks in respect of the tsunami hazard. Key actions in the strategic management process are:

- Define or confirm the temporal and geographical scales of the management area.
- Review the options for strategic management, taking into account wider coastal management objectives.
- Consider a hybrid approach to the response measures.
- Apply decision-analysis tools in the management process.
- Involve the public in the decision-making process.
- Monitor the effectiveness of the implemented plan.

J.2.2 IMPROVING YOUR PREPAREDNESS FOR TSUNAMIS

See Chapter H

The measures to be taken here are mostly about ensuring awareness of the tsunami risk and ensuring a state of readiness of people and structures to be aware of and respond to a tsunami emergency. The key feature of a tsunami emergency is the suddenness of the event, with, in the case of near-field tsunami sources, perhaps only a few minutes to respond. Compared with, say, storm surge inundation, there is very little time to carry out evacuation. Thus people in coastal communities need to know how they may be informed, what to do, and where to go to be safe. Messaging and emergency services must be regularly tested, even though tsunami events may be rare occurrences for many communities. The following are key actions for community and national response in improving preparedness:

- Establish measures for education and public awareness of the tsunami risk.
- Identify special target audiences.
- Establish and test an effective, end-to-end early warning system.
- Establish and test evacuation procedures, updating as necessary.
- Test functionality of emergency response structures (EOC, Search and Rescue teams, medical teams, other voluntary teams) through simulations and exercises.
- Test contingency plans and ensure their readiness to be used.
- Ensure that shelters and medical facilities are operational and would be properly staffed and resourced in the event of a tsunami.
- Plan for a smooth transition from response to recovery.
- Transfer the risk of loss and damage to the built environment by insurance schemes (H.4) as appropriate.
J.3 IMPROVING INSTITUTIONAL ENGAGEMENT

See Chapter 1

A necessary condition for the achievement of each of the preceding goals is for the country to have functional institutional capacity with an appropriate legal framework for disaster risk reduction and policies, and with resources to enable the successful implementation of the tsunami risk assessment and reduction procedures. Key actions include:

- Establish institutional and legal frameworks for disaster risk reduction.
- ‘Mainstream’ DRR, including for tsunami risk, into socio-economic development planning strategies.
- Identify DRR focal points across government agencies and strengthen intra- and cross-sectoral coordination mechanisms.
- Set national standards for the assessment of natural hazard risk, including for tsunamis.
- Enable implementation of tsunami hazard and vulnerability assessments, including an assessment of preparedness.
- Improve knowledge and understanding of disaster risk, including for tsunamis, at all levels of government and the public.
- Support broad public participation in disaster risk reduction plans and programmes, including for tsunamis.
- Incorporate risk information, including for tsunamis, in public investment decisions within a context of Integrated Coastal Area Management (ICAM).
Case Studies K.1–K.3 provide summaries of accounts of strengths and weaknesses in the delivery of early warning for the major tsunami events in the Indian Ocean and Pacific regions since the beginning of 2004. The summaries include lists of the main lessons learned.

K.1 INDIAN OCEAN 2004 TSUNAMI

Source: Reports from various media.

On Sunday 26 December, 2004, at 07:59 a.m. local time a major earthquake with a magnitude estimated at 9.1 occurred off the western coast of northern Sumatra. The subsequent tsunami caused more casualties than any other in recorded history.

THIS EARTHQUAKE AND TSUNAMI MANIFESTED THE FOLLOWING WEAKNESSES

- The primary reason many thousands of lives were lost in the Sumatra tsunami is that there was no tsunami warning system for the Indian Ocean.
- There were difficulties for seismologists to accurately estimate the magnitude of the earthquake.
- In the aftermath of the Sumatra tsunami, there was considerable confusion about what exactly a tsunami warning system is. Many people still seem to believe that warning centres themselves are the warning system.
- Deep-ocean pressure sensors, a critical asset for tsunami warning, were completely missing in the Indian Ocean on 26 December 2004.
- There was no warning centre, inadequate regional seismic networks, no network of remotely reporting sea-level gauges, no designated national authorities for tsunami warnings, no communications methods to reach potential authorities, no tsunami-educated emergency managers or local tsunami experts, no communications to disseminate warnings to coastal regions at risk, and painfully little tsunami awareness.

LESSONS LEARNED

- What the world needs to prevent another tsunami tragedy on this scale is, first and foremost, a global tsunami warning system.
- Faster seismological techniques for more accurate magnitude estimation and source characterization will certainly help the warning system. However, such improvements will be of little benefit to nations or regions where there is still no tsunami warning system.
- Better seismology for such events is something that can help; but with respect to mitigating loss of life from tsunamis, it is of secondary importance to the establishment of a global tsunami warning system.
- A successful warning system is composed of three main components: tsunami hazard and risk assessment, warning guidance, and preparedness. Each component must be functioning; otherwise the system collapses.
- As a part of preparedness, tsunami awareness is vital. The public needs to be educated about what actions to take to save their lives during a tsunami emergency.
K.2 CHILE FEBRUARY 2010 TSUNAMI

Source: Reports from various media.

At 3:34 a.m. on 27 February 2010 the northern coast of Chile was affected by an earthquake whose magnitude was 8.8 on the Richter scale. The earthquake triggered a tsunami which lasted several hours. The Hidrographic and Oceanographic Service of the Naval Forces of Chile (SHOA), in charge of monitoring tsunamis in Chile, generated an initial communication which was sent to the Early Warning Center of the National Emergency Office of the Ministry of Interior (ONEMI). Subsequently, SHOA indicated that the first tsunami waves impacted the coast near Talcahuano within 18 minutes of the earthquake, at 3:52 am; and subsequent very large waves impacted the coastal area at 5:00 am, 5:30 am, and 6:05 am.

THE EARTHQUAKE AND TSUNAMI MANIFESTED THE FOLLOWING STRENGTHS

- Coastal population were aware of tsunamis triggered by earthquakes and evacuated to safe areas even without warnings being issued by ONEMI or SHOA, as indicated by the low number of fatalities (521 people, 56 missing); which was small when compared to other countries experiencing similar or earthquakes of lesser magnitude. Roughly half the number of these fatalities could be attributed to the tsunami. This reduce number of fatalities could be explained either because the country experiences earthquakes very frequently, or because coastal populations are requested to participate in tsunami awareness activities very frequently.
- The adherence to building codes and their enforcement led to reduce damages and losses in those buildings which applied them.
- There was some looting, which was not expected.

LESONS LEARNED

- SOPs should be strengthened to ensure no misunderstanding of messages among institutions; and to minimize the possibility of failures in the interpretation of tsunami warning messages.
- There is a need to strengthen the communication links between SHOA and ONEMI, and to outline specific procedures in those cases where there may be uncertainties.
- There is a need to ensure redundancy in communications, Civil Protection agencies cannot be caught with a weak communications network.
- There is a need to strengthen the monitoring networks (earthquakes and tsunamis through sea-
level gauges) as well as procedures to estimate more accurately the parameters characterizing earthquakes and tsunamis impacting Chile.

- Awareness of those at risk is essential to guarantee minimum loss of lives; and evacuation without a warning should be part of that awareness for people in coastal areas.
- There is an apparent knowledge of safe areas to evacuate to in the case of this tsunami.
- There is a need to improve SOPs, to make them adaptable to events of various magnitudes or intensities.
- Encourage home owners to comply with the strict building codes that are in place in Chile.
- Learn from these lessons learned regarding the value of people well aware of tsunamis and regarding the need to evacuate to safe areas, even if no warnings reach them.
- At least in the case of Chile, the negligence on behalf of the on-duty officer in the Early Warning Center at ONEMI led to civil suits. The on-duty officer was found guilty of negligence to issue warnings which led to fatalities in coastal areas. The court issued the sentence to the on-duty officer. This is a case that needs to be revised by all early warning centres, and SOPs need to be revised, including by legal officers, as a way to be prepared in case of problems that may lead persons to sue government officers in charge of early warning systems.
- In a similar fashion, the liabilities of early warning centres need to be properly addressed in their routine operations, particularly when either not enough data is available to make precise forecasts, or when there are delays to inadequate SOPs.

**REFERENCES**


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**K.3 JAPAN MARCH 2011 TSUNAMI**

*Source: Reports from various media.*

On Friday 11 March, 2011, at 2:46 p.m. local time in Japan, the Great East Japan Earthquake took place near the north-east coast of Honshu. Its magnitude was estimated at 9.0. It resulted from thrust faulting on or near the subduction zone plate boundary between the Pacific and North America plates. The earthquake generated a catastrophic tsunami that affected many coastal communities in Japan, including large cities, ports and the Fukushima nuclear plant.

**THIS TSUNAMI MANIFESTED THE FOLLOWING STRENGTHS**

- Coastal population were aware of tsunamis triggered by earthquakes and evacuated to safe areas even without warnings.
- The adherence to building codes and their enforcement led to reduce damages and losses in those buildings which applied them.
- Vertical evacuation worked in high-risk buildings.
- JMA (Japan Meteorological Agency) provided timely warnings, but there were some problems associated with the warnings.

**THE TSUNAMI MANIFESTED THE FOLLOWING WEAKNESSES**

- The SOPs used by the JMA aim to provide a warning within 3 minutes. This requires the use of the very first signals sent by seismometers. For such very large earthquakes, those very first signals may not really capture the precise magnitude of the earthquake, and hence may lead to an underestimation of the potential severity of a tsunami.
- In some cases, the initial warning sent by JMA, underestimating the precise magnitude of the earthquake and hence, the tsunami, led some people to minimize their reaction. Some people believed it was not necessary to evacuate to shelters or safe areas considering the existence of tsunami sea walls or protection barriers; or they evacuated to nearby shelters which were engulfed by the larger than foreseen tsunami.
LESSONS LEARNED

• There is a need to ensure that seismic networks include seismometers far away of the epicentre, which cannot be saturated, so that these can be used to estimate magnitudes even in the case of extremely large events.

• There is a need to revise the procedures used to estimate the precise magnitude of earthquakes and subsequent magnitudes of potential tsunamis.

A trade-off between the time allocated to provide the first warning and the more precise estimation of earthquake parameters needs to be considered.

• The establishment of tsunami sea-walls and breakwaters can be beneficial, but people should not underestimate their vulnerability in case of very large events.

• The location of critical infrastructure, including shelters, hospitals, schools, power plants, emergency operation centres and airports needs to be revised in the context of very large tsunamis.

• Mid to high-rise reinforced concrete buildings with robust shear walls and strong foundations can survive both the earthquake and the tsunami and can be used for vertical evacuation.

• Awareness of those at risk is essential to guarantee minimum loss of lives; and evacuation without a warning should be part of that awareness for people in coastal areas.

• There is an apparent knowledge of safe areas to evacuate to in the case of tsunamis; even though in this case of this exceptional tsunami, some of these areas were flooded as well.

• This event in Japan is leading to a discussion regarding how best to confront tsunami hazards. While hazard maps were elaborated using up to 400 years of data from historic events, this extremely rare event is forcing Japanese authorities to re-examine their policies and procedures, including those for tsunami hazard assessment. This point is critical for many countries, as in many cases the amount of funds dedicated to preventive measures may not be sufficient to cover extremely rare events such as this one.

• The comprehensive damage assessment of physical infrastructure of many kinds is very useful to understand the physical vulnerability of such infrastructure; in particular the vulnerability of tsunami sea walls and breakwaters. The thorough review of this type of vulnerability has led to improvements in the elaboration of fragility curves.

REFERENCES


K.4  MODELLING TSUNAMIS: CASE STUDY JAPAN

Source: Swiss Re © 2013. All rights reserved.

See also Section H.4.1

Note: Figure references are specific to this section.

Tsunami is one of the relatively few words to have crossed from Japanese into English; and reflects the long history the country has of tsunamis. The magnitude 9.0 earthquake and the tsunami that struck Japan on 11 March 2011 were estimated to have caused around USD 250 billion in economic losses; but insured losses were estimated at around USD 35 billion. The tsunami losses1 had a significant contribution to the economic and human losses. It provoked a major rethinking on risk management and risk coverage on the part of government and insurers alike.2

1 Swiss Re sigma No 2/2012, Natural catastrophes and man-made disasters in 2011: historic losses surface from record earthquakes and floods.
2 The longer version of this paragraph was written by Dr. Toru Tamura and Atsuhiro Dodo, Swiss Re Japan, and published in May 2012 at Swiss Re’s public website, see http://www.swissre.com/clients/newsletters/Japan_tsunami_No_longer_an_unmodelled_risk.html

In order to estimate natural catastrophe risk quantitatively, the re/insurance industry employs probabilistic modelling (B.4.4). A probabilistic catastrophe model normally consists of three major components: a hazard component which generates huge numbers – for instance, 100,000 – of potential catastrophic scenarios; a vulnerability component which assesses the physical damage of these scenarios; and a financial component which translates the physical damage of an event into a financial loss. As a result, based on the probability of occurrence of each event, the model can estimate the probability of a certain financial loss sustained from the natural catastrophe.

TSUNAMI MODELLING: OFFSHORE WAVE HEIGHT

Modellers had to develop a computationally efficient approach to simulate the open water wave propagation of a tsunami. Some scientific studies suggested that on the basis of linearity of tsunami dynamics, arbitrary tsunami propagation can be constructed from pre-computed individual tsunami scenarios. Therefore, tsunami propagation for any magnitude of earthquake can be synthesised by using pre-computed tsunami propagations for a predefined magnitude and epicentre location and scaling the pre-computed propagations by accounting for the actual event magnitude.3 Swiss Re successfully created a probabilistic tsunami event set by coupling original probabilistic earthquake sources with pre-computed tsunami scenarios. Figure 1 shows that a significant tsunami hazard in terms of tsunami wave height exists along the north-eastern coast of Japan once in a 1,000 year period, which would correspond to the latest tsunami event. A tsunami of over 10 m in height can also be expected along the coast facing the Nankai Trough.

TSUNAMI MODELLING: ONSHORE INUNDATION

The insurance industry subsequently needed to model the landfall of a tsunami, assessing how far it would penetrate inland and with what inundation. This was approached by assessing energy conservation between the potential energy of the offshore tsunami at the coast and surface friction.

3 For more information, see NOAA National Oceanic and Atmospheric Administration, Center for Tsunami Research, forecast propagation database at http://nctr.pmel.noaa.gov/propagation-database.html.

APPLYING THE TSUNAMI MODEL

Having ascertained the size of a tsunami wave and the potential distance and inundation it could travel inland, the third stage of the modelling process is overlaid. This focuses on human settlement and economic activity in the afflicted area, providing both an assessment of potential damage and an indication as to where to undertake risk mitigation measures.

By integrating a vulnerability/financial component, the re/insurance industry is able to project insured losses caused by a tsunami. We could validate the model’s capability by comparing simulated and reported losses of several insurance portfolios in the latest tsunami event. The Swiss Re tsunami model for Japan has been in practical use since the beginning of 2012.

Figure 1. Tsunami hazard map: Offshore tsunami height expected to be exceeded once in 1,000 years (red dashes indicate subduction earthquake sources)
The probabilistic tsunami model helps to quantify tsunami risk. Figure 2 shows the expected offshore tsunami height and its frequency for representative locations within the bays of these cities. Tsunamis are not frequent events, but could be large loss drivers in these concentrated cities over a long return period.

Figure 2. Exceedance frequency curves for offshore tsunami height within the bays of Tokyo, Nagoya and Osaka. In the Swiss Re model, small wave heights of less than 1.5 m are truncated on the basis of our assumption of a negligible impact due to tidal/tsunami protections.

Both model and experience have highlighted the exposure of the north-east coast to tsunamis. However, exposure is not limited to this area. Japan’s major conurbations and centres of wealth and human activity are located proximal to the Nankai Trough. The bays of Tokyo, Nagoya and Osaka are all exposed to tsunami risks. A 4.5-metre tsunami – a wave the size of a two-storey house – could hit Tokyo on a return period of around 500–600 years.

The tsunami model can also tell us how much of an annual expected loss has to be added to the annual expected loss of earthquakes. When a tsunami is included, the earthquake risk premium increases noticeably in a typical insurance portfolio on a Japan market-wide basis. It should be noted that the ratio of tsunami contribution is significantly dependent on the geographical distribution, insurance structure and occupancy class of a portfolio. For strongly coastal-exposed accounts, the increase in earthquake risk premium can be substantial. This gap is even more significant for vulnerable coastal communities.

K.5 TSUNAMI RISK TRANSFER: CASE STUDY PACIFIC ISLANDS

Source: Swiss Re Global Partnerships © 2013 Swiss Re. All rights reserved.

See also Section H.4.1

The Pacific Islands countries, with a combined population of almost 10 million people, are highly exposed to natural disasters. The Pacific Disaster Risk Financing and Insurance (DRFI) programme and its Pacific catastrophe risk insurance pilot form an integral part of the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI), an initiative of broader World Bank support to the Pacific region to develop a comprehensive programme of disaster risk management and climate change adaptation. Started in 2007, PCRAFI is a joint initiative between the Secretariat of the Pacific Community Applied Geosciences and Technology Division (SPC-SOPAC), the World Bank and the Asian Development Bank, with financial support from the Government of Japan, the Global Facility for Disaster Reduction and Recovery (GFDRR) and the European Union, in addition to technical support provided by AIR Worldwide, New Zealand GNS Science, and Geoscience Australia.

The risk transfer is the first-of-its-kind in this region, offering index based insurance for earthquakes (including tsunamis) and tropical cyclones. The policies provide immediate liquidity to participating governments in the aftermath of a disaster with an approximate probability of 1 in 15 years. The insurance coverage provided to the five Pacific Island countries is about USD 45m. The payout will be triggered by the intensity of the event.

The pilot relies on state-of-the-art financial risk modelling techniques and is the first ever Pacific scheme to use parametric triggers, linking immediate post-disaster insurance pay outs to specific hazard events (Table 1). This joint effort will allow Pacific Island countries to access earthquake, tsunami, and tropical cyclone catastrophe coverage from reinsurance companies.

MODELLING EARTHQUAKES AND TSUNAMIS

The model used captures the effects of (a) earthquake ground shaking and (b) tsunami waves. The assets at risk include buildings (residential and non-residential), major infrastructure, crops, and population. The modelled losses caused by earthquakes represent estimates of both the cost needed to repair or replace the damaged assets (direct losses) and the emergency losses that local governments may sustain as a result of providing necessary relief and undertaking recovery efforts. Such efforts include debris removal, setting up shelters for those made homeless, or supplying medicine and food. Emergency losses are estimated as a fraction of the direct losses based on empirical data of historical events.

A tsunami is a series of ocean waves generated by a large-scale disturbance such as an earthquake occurring below or near the sea bed. Such large-scale disturbances capable of causing tsunami may also be triggered by landslides above or below water, explosive volcanic eruptions or collapses, and meteorite impact. Tsunami waves so generated often travel long distances across oceans and eventually cause immense loss of life and destruction in vulnerable coastal regions. For example, the tsunami unleashed by the great earthquake that occurred on 26 December, 2004, off Northern Sumatra, caused massive loss of life exceeding 250,000 as well as extensive damage to property in several countries in the Indian Ocean including Indonesia, Sri Lanka, India and Thailand.

Tsunamis in the past have been generated mostly by submarine earthquakes occurring in subduction zones. Subduction is the process where the tectonic plates comprising the Earth's crust (Fig. 1) slide past each other as the plates converge; the heavier oceanic plate is forced beneath the lighter continental plate (Fig. 2).

There are two major active subduction zones with tsunamigenic seismic potential in the Indian Ocean Basin, namely, the Bengal-Sumatra-Sunda subduction zone stretching south from Bangladesh and Myanmar to Java (Segment AE in Fig. 3), and the Makran subduction zone (Segment FG) off the coastline of Pakistan and Iran in the Arabian Sea. The Bengal-Sumatra-Sunda subduction zone may be further divided into four zones for the purpose of assessing the tsunamigenic earthquake hazard: (a) Andaman-Myanmar (Arakan) (Segment AB); (b) Northern Sumatra-Andaman (Segment BC); (c) Southern Sumatra (Segment CD); and (d) Java (Segment DE) (Fig. 3). The above seismic zones present local, regional or distant tsunamigenic sources for different countries in the Indian Ocean.

The subduction zones delineated above are limited to those that could credibly generate a large tsunamigenic earthquake in the Indian Ocean. It must, however, be noted that Indonesia could also be affected by tsunami generated in Banda and Flores Sea to the further east of longitude 120 degrees in Fig. 3.

A large majority of transoceanic tsunami events in the Indian Ocean have been generated in the Bengal-Sumatra-Sunda subduction zone. For instance, a list of past teletsunamis in the Indian Ocean collated by Dominey-Howes (2006) indicates that since 1762 at least 14 teletsunamis have been originated in the Bengal-Sumatra-Sunda subduction zone stretching from Andaman to Southern Sumatra whilst at least one each in the Arakan segment and the Makran subduction zone.

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<th>Ground shaking and tsunami wave</th>
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<td>USGS Centroid Moment Tensor Solution</td>
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</table>

Table 1: Modelling facts
Besides the 2004 tsunamigenic earthquake of moment magnitude 9.3 in the Northern Sumatra-Andaman segment, Okal and Synolakis (2008) identified four other ‘maximum-credible’ seismic scenarios capable of causing destructive tele-tsunami in the Indian Ocean Basin. The fault parameters of these seismic events are given in Table 1 and the respective segments of the seismic zones are identified in Fig. 3. These events mostly represent the worst-case scenarios of seismic rupture for each segment of the subduction zones under consideration. A detailed description of the tsunamigenic seismic potential of these subduction segments is given in Okal and Synolakis (2008).

Scenario 1 has been chosen to represent the worst-case seismic potential of the Arakan subduction segment. Such an event may be categorized as an extremely low probability yet plausible event to occur in a 470-km segment immediately north of the termination of the 2004 mega-rupture. Scenario 2 represents the magnitude 9.3 earthquake of 2004 as the worst-case event for the Northern Sumatra-Andaman segment. Scenario 3 in the Southern Sumatra subduction segment involves a 900-km long rupture also taking into account the partial strain release in its northern segment during the September 2007 Bengkulu earthquake off Southern Sumatra.

Historical accounts since 1550 AD do not indicate an earthquake capable of causing a transoceanic tsunami in the Java subduction zone. However, given the possibility of long seismic cycles, the occurrence of an ocean-wide tsunami generated by a mega-thrust earthquake off the coast of Java cannot be ruled out (Okal and Synolakis, 2008). Accordingly, Scenario 4 envisions the rupture of the entire length of the 500-km Java subduction segment.

Scenario 5 for the Makran subduction zone considers the simultaneous rupture of its eastern and western segments which is an extreme worst-case scenario that cannot be totally eliminated (Okal and Synolakis, 2008).

Prior information relating to the time it takes for the first wave of a tsunami to arrive a given coastline is essential for emergency planning and in early warning. As examples, the computed tsunami travel time contours corresponding to potential tsunamigenic earthquakes identified in Scenarios 1 and 5 (Table 1) are shown in Fig. 4. As the tsunami propagation speed depends only on the water depth, these calculated arrival times should be applicable to a tsunamigenic earthquake of any magnitude in the respective seismic zones. The distribution of the maximum tsunami heights corresponding to the above two scenarios are shown in Fig. 5.

The above assessment is focused on tsunami caused by earthquakes and, in particular, earthquakes occurring in subduction zones. Whilst tsunami can be caused by other sources such as submarine landslides, volcanic collapses and eruptions, and meteorite impacts, earthquakes in subduction zones are by far the most frequent source of large tsunami, and therefore, are the only events considered here.

### Table 1 Maximum-credible seismic scenarios for seismic zones in Indian Ocean region

<table>
<thead>
<tr>
<th>Seismic Scenario</th>
<th>Location of Seismic Zone</th>
<th>Subduction segment in Fig. 3</th>
<th>Moment magnitude of maximum-credible earthquake</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Andaman-Myanmar (Arakan)</td>
<td>AB</td>
<td>9.0</td>
</tr>
<tr>
<td>2</td>
<td>Northern Sumatra-Andaman</td>
<td>BC</td>
<td>9.3</td>
</tr>
<tr>
<td>3</td>
<td>Southern Sumatra</td>
<td>CD</td>
<td>9.3</td>
</tr>
<tr>
<td>4</td>
<td>Java</td>
<td>DE</td>
<td>9.0</td>
</tr>
<tr>
<td>5</td>
<td>Makran</td>
<td>FG</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Sumatra-Andaman segment of the Bengal-Sumatra-Sunda subduction zone. Scenario 3 in the Southern Sumatra subduction segment involves a 900-km long rupture also taking into account the partial strain release in its northern segment during the September 2007 Bengkulu earthquake off Southern Sumatra.

### REFERENCES

Fig. 1 Earth’s tectonic plates (image credit: www.maps.com).

Fig. 2 Movement of plates where one plate is subducting beneath another (image credit: USGS).

Fig. 3 Subduction zones in the Indian Ocean Basin. (modified from Burbidge et al., 2009).

Fig. 4 Contours of tsunami travel time in minutes after earthquake for tsunami generated by: (a) Scenario 1 in Arakan subduction segment, and (b) Scenario 5 in Makran subduction zone; SL – Sri Lanka (after Wijetunge, 2012).

Fig. 5 Distribution of maximum tsunami heights generated by: (a) Scenario 1 in Arakan subduction segment, and (b) Scenario 5 in Makran subduction zone (after Wijetunge, 2012).
**K.7 LOCAL GOVERNMENT’S CONTRIBUTION TOWARDS MAKING BATTICALOA A DISASTER RESILIENT CITY**

Dilanthe Amaratunga and Chamindi Malalgoda, Centre for Disaster Resilience, University of Huddersfield, UK.

See also sections H.5 and L.6 – ‘Concept of resilient cities as a DRR framework’

Batticaloa is a coastal city in the Eastern province of Sri Lanka. Batticaloa remains exposed to significant levels of disaster risks and is distinctive in having suffered from disasters related to a combination of natural and human-induced hazards. The coastal belt of Batticaloa city was one of the most severely affected by the 2004 Indian Ocean Tsunami and the development of the city has been further disrupted by the 30-year long civil war which ended in the year 2009. In addition to tsunamis, Batticaloa city is also vulnerable to, and has suffered from, other natural hazards including floods, cyclones and sea-level rise. Batticaloa city was among the worst affected by the recent flooding and also by the cyclone which hit during 1978.

Batticaloa municipal council area covers some 75 km² and can be considered the most urban area in the Batticaloa district. Findings of a case study conducted on Batticaloa revealed that the municipal council is facing number of challenges in creating Batticaloa a disaster resilient city (Malalgoda et al., 2014). One of the main issues to have emerged is inadequate legislative authority, where disaster management has not been explicitly recognised in the Council Ordinance. In addition, the country’s Disaster Management Act has not delegated adequate legislative powers to local governments. However, in the gazette notification published in 2009 regarding the National Policy for Local Government, a number of sections on disaster risk reduction have been included – the first step towards bringing local governments into Disaster Risk Reduction (DRR) activities. Also, it has been proposed to amend the Disaster Management Act and the municipal Ordinances to incorporate disaster management in council agendas.

Other main issues to have emerged are: lack of adequate tools, techniques and guidelines for DRR; inadequate financial and human resource capabilities; lack of knowledge of disaster risks and vulnerabilities; lack of focus on pre-disaster planning; lack of clear-cut responsibilities and coordination among agencies; incapability of managing the long-term process; dependence on central government; lack of community engagement; poor leadership and organisational culture; and lack of involvement in major development activities, physical planning and regulation of land use.

Batticaloa is a participant city in the UNISDR campaign on ‘making cities resilient – my city is getting ready’, and, since joining the campaign, Batticaloa municipal council has taken several initiatives towards risk reduction in the city. The council has established a Disaster Risk Reduction Unit within the council with the support of an Australian-funded project implemented by UN-Habitat (2013), which could be identified as a key milestone in the process of resilience-building. Establishing a DRR unit is expected to increase the municipal council’s contribution towards resilience-building activities in the city.

The country’s Disaster Management Centre (DMC), with the support of various other government, non-governmental and international organisations, has developed hazard maps showing areas prone to various natural hazards. It is also working on developing vulnerability and risk maps to identify elements that are at high risk to natural hazards. At the city level, workshops, stakeholder meetings and other capacity-building initiatives are being conducted for city officials, aiming at making them more aware of the disaster resilience concepts and practices.

There are a number of NGOs and INGOs who are working closely with the district disaster management office and municipal council providing support in terms of finance, training, capacity building, technical know-how, livelihood development, water supply and sanitation. Also, universities and other technical and research organisations contribute by way of conducting workshops and training programmes for local officials and communities, and provide them with research support.

An institutional and administrative framework is now in place for the implementation of risk reduction which needs to be further strengthened and sustained – good practice contributing towards the goal of making Batticaloa a disaster resilient city.

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REFERENCES

K.9 TSUNAMI WARNING AND MITIGATION FOR THE INDIAN OCEAN REGION


THE PROBLEM
On 26 December 2004, the Indian Ocean was struck by a massive earthquake and tsunami which killed 230,000 people and caused widespread destruction (Doocy et al., 2007). Although we cannot prevent tsunamis, early warning of their approach combined with physical defences and well-practiced evacuation procedures can save many lives. Prior to 2004, tsunamis were not considered a high-risk hazard, certainly not outside the Pacific Ocean. Tsunami science was a niche scientific field, with little translation of knowledge into practice, even though scientists published work on a possible ocean-wide tsunami in the Indian Ocean just months before the 2004 event (Cummins et al., 2004). This combined with rapid population growth of coastal communities in the region set the scene for catastrophic consequences for the Indian Ocean rim in 2004.

THE SCIENCE
The early 1960s saw the development and acceptance of plate tectonic theory, wherein earthquakes and volcanoes were first recognised to be the direct manifestation of the forces that create oceans and build continents (Dewey and Bird, 1970). The first global seismographic network was established in 1961 (University of Michigan, 1964), allowing earthquakes to be monitored worldwide. By the 2000s, great advances had been made in earth observations, computer modelling of hazards and telecommunications. Electronic sensors were developed that could rapidly detect earthquake shaking on land and tsunami waves at sea. For instance, the United States National Oceanic and Atmospheric Administration (NOAA) developed the Deep-Ocean Assessment and Reporting of Tsunamis system, known as DART II, in which a sensor on the ocean floor detects tsunami waves and communicates these to a surface buoy with satellite telecommunications capability (Bernard et al., 2001). Computer models were developed that simulate tsunami impacts on communities (Shuto and Goto, 1978; Titov and Synolakis, 1998); and satellites could now transmit signals to high-speed computers, empowering humans to issue local and pan-oceanic tsunami warnings in minutes (Crawford, 2005; Rudloff et al., 2009).

THE APPLICATION TO POLICY AND PRACTICE
In less than three months following the devastating Indian Ocean tsunami, scientists worked together with policymakers to form an international commitment to develop an Indian Ocean Tsunami Warning & Mitigation System (IOTWS). The IOTWS is now fully operational, comprising a set of Tsunami Service Providers (India, Australia, and Indonesia) issuing tsunami advisories to all National Tsunami Warning Centres of the Indian Ocean rim countries (UNESCO, 2006). The IOTWS also developed the first international guidelines for tsunami hazard and risk assessment (UNESCO, 2009). The most heavily affected nations of Indonesia, Sri Lanka and India developed new disaster management policy frameworks, governance structures and national disaster management plans to address tsunami and other natural disaster risks. For instance, the Indonesian Government developed the Presidential Tsunami Master Plan for Reducing Tsunami Risk (Indonesian National Disaster Management Agency, 2012), which is underpinned by national-scale tsunami hazard mapping to establish tsunami shelters and strengthen warning systems for at risk coastal communities.

DID IT MAKE A DIFFERENCE?
The IOTWS now provides warnings to all Indian Ocean country members, reaching millions of people who had no warnings in 2004. Furthermore, tsunami hazard mapping and evacuation planning has been carried out for hundreds of coastal communities. Gains in tsunami preparedness were demonstrated during the 12 April 2012 magnitude 8.5 earthquake offshore of northern Sumatra, Indonesia. Although no tsunami eventuated, due to the large magnitude and location, a tsunami warning was issued in several countries. In Banda Aceh, where most of the tsunami-related deaths occurred in 2004, over 75% of the population started to evacuate soon after the earthquake (Goto et al., 2012). Despite this, traffic jams slowed the evacuation considerably (Goto et al., 2012), demonstrating that challenges still remain in getting dense populations to safety within very short warning timeframes. Meanwhile, the 2011 Tohoku tsunami severely tested Japan’s highly advanced warning system, seawalls and evacuation plans. Tragically 18,000 people lost their lives (National Police Agency of Japan, 2013), totalling 4% of the population located in the inundation area. In comparison, the 2004 Indian Ocean Tsunami resulted in over 20% fatalities in the inundation area (Doocy et al., 2007). While any fatalities are shocking, it is clear that the application of science and technology can save lives.

REFERENCES

Communities. Dordrecht: Springer Netherlands.


### L.1 TSUNAMI MODELS

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMCOT</td>
<td>Cornell Multigrid Coupled Tsunami model: Cornell University</td>
<td><a href="http://ceeserver.cee.cornell.edu/phil-group/comcot.htm">http://ceeserver.cee.cornell.edu/phil-group/comcot.htm</a></td>
</tr>
<tr>
<td>DELFT3D</td>
<td>Deltares, Netherlands</td>
<td><a href="http://www.wldelft.nl/cons/area/ehy/flood/tsunami.html">http://www.wldelft.nl/cons/area/ehy/flood/tsunami.html</a></td>
</tr>
<tr>
<td>GEOOWAVE</td>
<td>Combination of TOPICS (Tsunami Open And Progressive Initial Conditions System) and FUNWAVE</td>
<td></td>
</tr>
<tr>
<td>MOST</td>
<td>Method of Splitting Tsunami: NOAA, U.S.A. (developed by University of Southern Californial)</td>
<td><a href="http://nctr.pmel.noaa.gov/index.html">http://nctr.pmel.noaa.gov/index.html</a></td>
</tr>
<tr>
<td>TOAST</td>
<td>Tidal Ocean Atmosphere Surge and Tsunami simulation model: IISc, India</td>
<td><a href="http://www.iisc.ernet.in/">http://www.iisc.ernet.in/</a></td>
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<tr>
<td>Tsunami Propagation Model</td>
<td>Joint Research Centre, JRC</td>
<td><a href="http://tsunami.jrc.it/model/">http://tsunami.jrc.it/model/</a></td>
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<td>TSUNAMOS</td>
<td>Tsunami Open Source: NSF (National Science Foundation) funded NEES (Network for Earthquake Engineering Simulation) project, Texas A&amp;M University, Cornell University, University of Hawaii and University of Puerto Rico – Mayaguez</td>
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<td>TUNAMI</td>
<td>Tohoku University, Japan</td>
<td><a href="http://www.tsunami.civil.tohoku.ac.jp">www.tsunami.civil.tohoku.ac.jp</a></td>
</tr>
</tbody>
</table>

*Table 8 A list of tsunami models*

L.2 OVERVIEW OF 2009 UNESCO-IOC SAMOA INTERNATIONAL TSUNAMI SURVEY TEAM (ITST)

Dale Dominey-Howes, School of Geosciences, The University of Sydney, Sydney, Australia.

See also Section C.8 – Post-event loss and damage surveys.

Note: Figure references are specific to this section.

The 29 September, 2009, South Pacific tsunami resulted in deaths and damage to several Pacific Island countries (PICs; Figure 1). International Tsunami Survey Teams (ITSTs) conduct post-event surveys (UNESCO, 1998) and traditionally, these have comprised experts from single disciplines (e.g., numerical modellers, geologists, or engineers) who collect data relevant to their primary fields of expertise. Whilst important, such singular studies only provide a limited understanding of tsunamis. For many reasons, there had never been a coordinated, multidisciplinary, multi-sectoral, ITST survey and there had been no attempts to identify factors contributing to the vulnerability and resilience of communities and their ‘socio-ecological’ systems (Dominey-Howes et al., 2011). This is a pity because without investigating the relationships within the socio-ecological systems, it will be very difficult to develop meaningful tsunami risk management strategies (Dominey-Howes et al., 2011).

The UNESCO-IOC ‘Samoa ITST’ was a global first and comprised numerous experts from various disciplines, the UNESCO Pacific Regional Office, regional organisations like the Secretariat of Pacific Applied Geoscience Commission (SOPAC), the Secretariat of the Pacific Environment Programme (SPREP), the University of the South Pacific (USP), the National University of Samoa (NUS), the Scientific Research Organisation of Samoa (SROS), NGOs and the Government of Samoa (GoS). The Samoa ITST partnered with local stakeholders and the GoS to take account of regional expertise and to ensure that (1) incoming international researchers undertook their work in a culturally sensitive and appropriate way and (2) outputs were relevant to the GoS. The Samoa ITST worked around an agreed ‘Terms of Reference’ (ToR) negotiated with the GoS (see Dominey-Howes et al., 2011 for details).

The Samoa ITST was organised into 5 sub-groups and each included staff from the GoS, all partner organisations and volunteer international researchers and included:

- Sub-group One – Inundation and Run-up
- Sub-group Two – Building Damage
- Sub-group Three - Social Sciences (including video interviewing)
- Sub-group Four – Geology
- Sub-group Five – Ecosystems and Environment (further divided into Group A Terrestrial and Group B Marine)

For details of the Samoa ITST and publications arising, see Dominey-Howes and Thaman (2009) and the Special Issue of Earth Science Reviews (107 (1/2), 2011) dedicated to the event and edited by Goff and Dominey-Howes (2011).

The work of the various post-tsunami surveys, undertaken after the September 2009 event, allows us to learn a series of important lessons. These include:

- The existing approach of sending teams with limited Terms of Reference means that these small teams can gather very detailed information but that this information can only ever provide a very limited statement about the nature and impact of the tsunami. Limited conclusions can be drawn and making generalizations about tsunamis and importantly, implications for disaster risk reduction, should be avoided.

- Given that UNISDR and global environmental change and sustainability sciences fields have all recognized that to undertake effective risk reduction strategies, it is necessary to have a sophisticated understanding of both the biophysical world in which hazard events like tsunamis occur and the social world in which disasters unfold – it is time for the tsunami research and risk management communities to embrace these concepts. Using socio-ecological systems frameworks (Birkmann et al., 2013) provide both powerful theoretical and practical frameworks to explore the hazard, risk and impacts of tsunamis.

- Such efforts – including in post-tsunami survey contexts - should be undertaken in an integrated way with all team members of different discipline fields working together to share their knowledge and expertise. Rather than keeping social scientists, and modellers and geologists separate – putting them together in the same base camp enables cross-fertilisation of knowledge and ideas and an improved understanding of the overall tsunami hazard problem. Fruitful and unexpected ideas and discoveries can emerge when people of different discipline fields who do not normally work together sit and talk and discuss and share.
The use of a ‘socio-ecological systems’ framework by the UNESCO-IOC ITST Samoa demonstrated that a very detailed understanding of the factors influencing both vulnerability and resilience to the tsunami before, during and after the event could be achieved.

REFERENCES


Figure 1 Simulation of the 29th September 2009 South Pacific tsunami by the NOAA Pacific Marine Environmental Lab. The colours relate to the wave amplitude in deep water in cms.

L.3 GUIDANCE ON INTEGRATING TSUNAMI INUNDATION MODELLING INTO LAND-USE PLANNING

Source: Wendy Saunders, GNS Science, Lower Hutt, New Zealand

See also Sections B.3.1, B.5, G.3.1; also a related Case Study presenting guidance on risk-based land-use planning at L.4.

Note: Figure and Box references are specific to this section.

Guidance has been provided in New Zealand to assist land-use planners to use tsunami modelling (B.3.1), which is often prepared for emergency management purposes i.e. evacuation planning (H.2.2). The guidance provides a brief overview of tsunami basics, and then presents a decision tree (see Figure 1) for including tsunami risk into land-use planning (Saunders et al., 2011).

To answer Question 1 regarding whether tsunami should be included in land use planning, first modelling is required of the source mechanism to ascertain the threat. Secondly, a risk assessment is required to determine consequences of an event. Consequences include social, economic, environmental, health and safety, and infrastructure.

Figure 1 Decision tree for including tsunami risk into land-use planning
Question 2 is related to determining if there is a risk. If not, no planning or emergency management actions are required. If there is a risk, the quality of the tsunami inundation modelling data determines if the information can be included in land-use planning (Question 3a). If the data quality is at Level 1 (see Figure 1 and Box 1), it is not considered adequate for emergency management use or for land-use planning purposes, and is not recommended. Level 2 data is recommended as a minimum for inclusion on Land Information Memorandums (LIMs) and for emergency management evacuation planning, warning systems, recovery planning, public awareness and education. If the data quality is at Level 3 or 4, then this information can be included in land-use planning, as well as LIMs and emergency management planning. The outputs from the tsunami modelling (i.e. inundation maps) can be incorporated as an overlay on planning maps, with associated risk-based objectives, policies, and consent restrictions. Pre-event recovery planning for land-use (Becker et al., 2008) should also be undertaken in all instances. Question 3b addresses how uncertainty can be included in planning maps.

**BOX 1. APPLICATIONS IN EVACUATION ZONE BOUNDARY MAPPING FOR LEVELS OF INCREASING DATA QUALITY.**

**Level 1** Cross section at the coast showing how evacuation zone boundaries can be mapped using a projection of wave heights inland, based on a simple ‘bathtub’ model.

**Level 2** Cross-section at the coast showing how evacuation zone boundaries are determined using an attenuation rule, in which elevation decreases from a maximum wave height at the coast and is projected inland according to some slope angle.

**Level 3** Is a computer-derived simulation model that theoretically allows for complexities that a simpler ‘rule’ cannot, such as varied surface roughness from different land uses, and water turning corners and travelling laterally to the coast on its inundation path. Such modelling is expensive and the quality of outputs is dependent on the science behind the hazard model.

**Level 4** Is the most complete modelling, based on an envelope around all inundations from multiple well-tested computer models. Development to this level of sophistication will require a comprehensive scientific understanding of all possible tsunami sources (distant, regional and local), wave propagation and inundation behaviours, across a range of magnitudes.
In 2007, a strategic growth strategy (named ‘Smartgrowth’) was developed to manage growth in the western Bay of Plenty, a coastal region in the North Island of New Zealand. This strategy identified several nodes for future urban growth, including a new suburb called Te Tumu. The strategy identified that Te Tumu could be expected to accommodate approximately 20,000 people and provide a range of commercial, retail and educational activities. However, the location of Te Tumu meant that it was susceptible to a number of local, regional and distant tsunami sources. A subsequent study investigated the levels of inundation resulting from various tsunami scenarios. Based on the modelling undertaken, the greatest level of inundation arrived 50 minutes after fault rupture (Beban et al., 2012a).

Land use planning policy in the region promotes a risk-based approach (Saunders, 2012), where intolerable risk is to be avoided, existing tolerable risk to be reduced, and new development not to be subjected to risk that exceeds acceptable levels. Based on the modelling undertaken, three scenarios gave rise to an intolerable level of risk (being if the annual probability of death exceeded $1 \times 10^{-4}$, or 50 people in an event with a return period of less than 5000 years died, the level of risk was intolerable).

Further investigations were undertaken to see whether the risk could be reduced to an acceptable level for the tsunami scenario that resulted in the greatest extent of inundation, through the use of vertical evacuation refuges (Figure 1). The vertical evacuation refuges (as per FEMA 2008 guidelines) included an existing area of high ground and several apartment buildings. To achieve an acceptable level of risk, 6000 people were required to be evacuated for a night-time event, and 7000 people for a daytime event. Those people who do not evacuate are assumed to remain in their respective buildings, above the inundation depth. The evacuation rates required to achieve an acceptable level of risk for the various land uses were as follows:

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Night-time</th>
<th>Daytime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing (low density)</td>
<td>37%</td>
<td>37%</td>
</tr>
<tr>
<td>Housing (medium density)</td>
<td>27%</td>
<td>27%</td>
</tr>
<tr>
<td>Retirement</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Mixed-use</td>
<td>0%</td>
<td>35%</td>
</tr>
<tr>
<td>Apartment Block</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Rest-home/hospital</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Educational</td>
<td>0%</td>
<td>59%</td>
</tr>
</tbody>
</table>


REFERENCES
To ensure an acceptable level of risk is achieved for the tsunami hazard a combination of land use planning and emergency management measures were recommended to be implemented in a coordinated and collaborative manner (Beban et al., 2012b).

This example illustrates how, with purposeful consideration of the tsunami inundation modelling, future risks to people and property can be reduced through land use planning.

REFERENCES


WHY USE A COMMUNITY-BASED APPROACH?

In almost all of the major disasters that have occurred in the region, lessons learned from studies of the databases strongly suggest the importance of an approach that focuses on enhancing the community’s ability to reduce disaster risks. These lessons show that:

- The local people in a disaster prone area, due to their exposure and proximity, are potential victims and assume most of the responsibilities in coping with effects of disasters.
- The local people have local knowledge of vulnerabilities and are repositories of any traditional coping mechanisms suited to their own environment.
- The local people respond first at times of crisis and are the last remaining participants as stricken communities strive to rebuild after a disaster.

communities deal in different ways with different types of shocks associated with different risks (whether resulting from natural or man-made events). Communities decide what to do, depending on their perception of the risk, and of the trade-offs and perceived benefits of risk management options and/or indigenous methods. Noting this, a credible tsunami risk assessment within a multi-hazard framework will help communities to become more risk aware and undertake appropriate actions for risk reduction.

WHAT IS THE CBDRM PRACTICE?

The CBDRM practice was introduced systematically in the mid-1990s. The CBDRM approach provides opportunities for the local community to evaluate their own situation, based initially on their own experiences. Under this approach, the local community becomes not only part of planning and decision making, but also a major player in the implementation of those plans and decisions.

Although the community is given greater roles in the decision making and implementation process, CBDRM does not ignore the importance of scientific and objective risk assessment and planning for early warning. The CBDRM approach acknowledges that as many stakeholders as needed should be involved in the process, with the end goal of achieving capacity and resource transfer to the community, which would itself assume the main responsibility for disaster reduction.
**Tools and Methods**

**HOW WOULD A TSUNAMI RISK ASSESSMENT ADD VALUE TO CBDRM?**

Practitioners of CBDRM typically are trained to draw the appropriate participatory methodology from a ‘toolbox’. However, opinions persist that, although these tools had been useful, a common and key weakness was the inadequate use of scientific information in risk assessment. Therefore the opportunity to apply these tsunami risk assessment and mitigation guidelines to the CBDRM practice will be in the following, commonest CBDRM methods and procedures:

- **Participatory Risk Assessment Toolbox** (including transect, seasonal calendar etc.). These methodologies support community-level processes, where communities are engaged in understanding disaster risks, both realized/historical and unrealized/potential. The Guidelines should be able to foster a comprehensive understanding among communities about risk as a configuration of hazards, changing patterns of vulnerability and community coping capacity. Communities would typically know about the realized risks that occurred in their living memory (e.g., the 1907 Simeulue Tsunami), but would be unable to anticipate future tsunami events including their sources.

- **Community meetings, face-to-face interaction, folk songs and traditional cultural presentation, and use of change agents that build awareness and develop public and culturally adaptable information programmes for preparedness.** Studies resulting from tsunami risk assessment must be able to guide community education/awareness activities being undertaken under CBDRM. Besides, community facilitators or change agents must be knowledgeable of the results of risk assessment studies.

- **Community-level preparedness planning processes that engage members of the community.** Results of risk assessment studies must provide an important input to stakeholders who would decide on the elements of community preparedness plan, i.e., contingency plan, evacuation plan, community-based first aid and other life-saving skills enhancement.

- **Processes that promote a culture of safety, particularly for future generations.** The CBDRM tools that may be improved by a tsunami risk assessment include: School-based education programmes; Education for Women; Education for people who have influence over communities, i.e., school teachers, religious leaders, local media, other traditional leaders.

**L.6 CONCEPT OF RESILIENT CITIES AS A DRR FRAMEWORK**

Richard Haigh and Dilanthi Amaratunga, Global Disaster Resilience Centre, University of Huddersfield, UK.

See also D.5, H.5 and the Case Studies at K.7 and K.8.

**WHAT MAKES CITIES VULNERABLE TO DISASTERS?**

Cities and urban areas are becoming increasingly vulnerable to disasters for various reasons. One of the major challenges for cities is the rapid growth of urban population and population density. As a result of rapid urbanisation, the world’s population is increasingly concentrated in large cities with poor housing and lack of basic protective infrastructure (Red Cross, 2010; UNISDR, 2010a). A high population growth is visible in many urban areas which has increased the pressure on land and other essential services such as drainage systems and waste management. Due to the high demand for land in cities, many poor constructions are witnessed in marginal land, floodplains, sloping lands, and reclaimed land unsuitable for human settlements. These improper land-use practices have increased the risk of disasters. The pressure on land has been further aggravated by inadequate supplies of water, electricity, transport and lack of adequate public services (Solway, n.d.). Unplanned development is another major problem for cities. All these have made cities extremely vulnerable to natural hazards. Unplanned development is another major problem for cities. All these have made cities extremely vulnerable to natural hazards. Urbanisation further leads to environmental issues such as soil contamination and siting of water courses, lowering of water tables, loss of mangrove ecosystems and coastal erosion (Pelling, 2003). All these put cities at risk and increase their vulnerability to natural hazards.
Cities are also important because of their strategic and economic role. Concentration of economic assets in cities puts cities at more risk. Even a small disaster can severely affect the economic activities of the city. Thus, the economic cost of a disaster in a city would be substantial. Cities are interconnected and interdependent systems and any disturbance to a city would not be limited to the city but would have an impact on surrounding cities and to the entire nation (Malalgoda et al., 2013).

Weak urban governance has also put cities at high risk (UNISDR, 2010b). Financial and resource capacities of many local governments are very poor and would adversely affect disaster response capacities. Most local governments are not self-sufficient and have to rely on national government in emergencies. On the other hand, the participation of local stakeholders and the community is very low and uncoordinated emergency response services affect the swift response and preparedness (UNISDR, 2012).

Taking the above into consideration, it is important to prioritise investment in cities and to make them more resilient to disasters.

WHAT IS A DISASTER RESILIENT CITY?

The term ‘disaster resilient city’ is now being widely adopted in disaster-related literature and policies (Malalgoda et al., 2013). Godschalk (2003) defined the term as a sustainable network of physical systems (constructed and natural environmental components) and human communities while RecilientCity.org (2010) defined resilient city as ‘a city that has developed the systems and capacities to be able to absorb future shocks and stresses over time so as to still maintain essentially the same functions, structure, systems, and identity, while at the same time working to mitigate the present causes of future shocks and stresses’. Accordingly, when a disaster occurs in a disaster resilient city, the effects to the physical systems and human communities would be minimal. UNISDR (2010a) has identified the following parameters of a disaster resilient city:

- Is one where disasters are minimised because the population lives in homes and neighbourhoods with organized services and infrastructure that adhere to sensible building codes; without informal settlements built on flood plains or steep slopes because no other land is available.
- Has an inclusive, competent and accountable local government that is concerned about sustainable urbanization and that commits the necessary resources to develop capacities to manage and organize itself before, during and after a natural hazard event.
- Is one where the local authorities and the population understand their risks and develop a shared, local information base on disaster losses, hazards and risks, including who is exposed and who is vulnerable.
- Is one where people are empowered to participate, decide and plan their city together with local authorities and value local and indigenous knowledge, capacities and resources.
- Has taken steps to anticipate and mitigate the impact of disasters, incorporating monitoring and early warning technologies to protect infrastructure, community assets and individuals, including their homes and possessions, cultural heritage, environmental and economic capital, and is able to minimize physical and social losses arising from extreme weather events, earthquakes or other natural or human-induced hazards.
- Is able to respond, implement immediate recovery strategies and quickly restore basic services to resume social, institutional and economic activity after such an event.
- Understands that most of the above is also central to building resilience to adverse environmental changes, including climate change, in addition to reducing greenhouse gas emissions.

The above parameters can be used as a framework to assess the level of resilience of a city and has provided opportunities for city leaders to contribute towards making their city resilient to disasters.

STAKEHOLDERS FOR MAKING DISASTER RESILIENT CITIES

Making cities resilient is a complex task which requires the collaborative efforts of various stakeholders. UNISDR (2012) has identified national governments, local government associations, international, regional and civil society organizations, donors, the private sector, academia and professional associations and every citizen as main stakeholders of making a city resilient to disasters and has highlighted the role to be played by them to reduce the risk of disasters. As such, a multi-stakeholder engagement is a key to make a city resilient to disasters and a system need to be properly established to involve all stakeholders to create disaster resilient cities.

All activities related to disaster management are usually centred at national governmental level and hence national government can be identified as the principal stakeholder of disaster management (Moe and Pathranarakul, 2006). In times of disaster and in making cities resilient, the government of the country has to play a major role and should take the lead in each activity. Usually the government assigns the responsibility of each task to different ministries or may form new authorities or committees and assign the responsibility of different tasks to these authorities or committees (Wolensky and Wolensky, 1991). To be successful, proper partnerships and cooperation are essential between local and national...
governments and civil society in order to reduce the costs of risk reduction, ensure local acceptance and build social capital (UNISDR, 2010b). A lack of coordination between different levels of government has been identified as a major problem in many countries. Accordingly, increased coordination and collaboration is needed among all departments and at each level of government to fulfil the functions which are common to most disasters (McClellan, 2005; Aldunce and Leon, 2007; Kusumastuti et al., 2010).

Since many disasters are local events, it is difficult to manage disasters in a centralised system. According to Unlu et al. (2010) the current disaster management system in Turkey is governed by a centralised structure where the responsibility is shared between different ministries and therefore the system is problematic and ineffective. As such, the system has been very weak at local level which has made it difficult to coordinate and manage operations. Similarly, in Sri Lanka, disaster management is governed by a centralised system and as a result several repercussions have been observed at local level (NBRO, 2009).

According to Dogra (2011), a centralised system faces problems such as difficulties in identifying and providing solutions to localised problems. Therefore, when formulating policies by a centralised system, the focus would be concentrated on the major issues of the country ignoring the local needs, preferences and opinions. Therefore the importance of decentralising disaster management has been widely recognised by academics and policy makers in the current context.

THE NEED FOR INSTITUTIONALISING DRR AT THE LOCAL LEVEL

There are strong calls within literature and policy to institutionalise Disaster Risk Reduction (DRR) at local level. The basic idea of decentralisation is that it brings governments closer to the local population and better reflects their needs in public policy making endeavours (Ahmed and Iqbal, 2009). This brings decision making closer to people and provides opportunities to design and deliver services which can effectively address local needs. Accordingly, local governments are expected to play a key role in contributing to making cities resilient, as they are based at local level, where disasters happen (MacManus and Caruson, 2006; Kusumasari et al., 2010; Manyena, 2006; Malalgoda et al., 2013). Though there are strong calls to institutionalise DRR at local level, local governments face a number of challenges in implementing DRR at local level. Some of the major challenges include, inadequate knowledge and capabilities in managing disasters (Kusumasari et al., 2010), financial and human resource scarcity (Pelling, 2003; Stren, 1989), inadequate urban planning and lack of monitoring and supervision of new developments (Voogd, 2004), unstable political systems (Manyena, 2006), lack of political will (Niekerk, 2007), inadequate legislative authority (Bendimerad, 2003), multi-layered governance arrangements and administrative weaknesses (Osei, 2007), relationship issues with the central government (Sabri and Jaber, 2007) and lack of community engagements (Sabri and Jaber, 2007; Pearce, 2003). Thus, it is very important to address these challenges in order to increase local government contribution to make cities resilient to disasters.

It should be noted that very close proximity to the local population may lead to inefficiencies, unprofessionalism, unethical relationships and corruption (Ahmed and Iqbal, 2009). Therefore it is important to have proper control and monitoring mechanisms in order to achieve success. Also, it should be noted that some drawbacks do exist in decentralised systems and these drawbacks should be managed properly in order to be successful in this venture. These shortcomings include confusion with regard to delegation of responsibility for the tasks, overlapping of work, high cost due to excessive staff and elected people, unnecessary competition among regions, and promotion of regional inequalities (Dogra, 2011). Therefore it would be necessary to address these weaknesses in a decentralised system of administration.

Institutions such as UNISDR, the Red Cross and ADPC have also campaigned about the need for local government to undertake the responsibility of managing disasters within their local areas. Due to this emerging need to encourage local governments to implement disaster risk reduction measures, UNISDR has specifically addressed the 2010-2011 world disaster risk reduction campaign to local governments under the theme of ‘Making Cities Resilient – My City is Getting Ready’. While further recognising the importance and long-term nature of the process, the campaign has been extended until 2015.

INTRODUCTION TO UNISDR CAMPAIGN ON MAKING CITIES RESILIENT

The ‘Making Cities Resilient: My City is Getting Ready’ campaign was launched by UNISDR in 2010 to address issues such as local governance and urban risks. The campaign aims at achieving resilient and sustainable urban communities and encourages local governments to act effectively in order to reduce the risk of disasters to cities. After successful implementation of Phase One in 2011, the campaign has now entered its second phase – 2012-2015. In this second phase the main focus areas are:

- Know More and Commit: sign up more local governments and national government support for resilient cities;
- Invest Wiser, Build Safer: Implementation – city-to-city learning and capacity building, handbooks and guidelines;
- Benchmarking and reporting: Local Government Self-Assessment Tool and Resilient Cities Report;
- Emphasis on partnerships and UNISDR capacity as a platform and knowledge management hub.

This campaign has developed ‘ten essentials’ for local governments to make their cities more disaster resilient. They are listed in Box 34 in Section H.5. As part of
the campaign, a Local Government Self-Assessment Tool (LGSAT) has been prepared which provides key questions and measurements against the ‘ten essentials’ (UNISDR, 2012). The campaign requires participating local governments to report progress on the ‘ten essentials’; many have already reported. More details of the campaign may be found at http://www.unisdr.org/campaign/resiliencities/

REFERENCES


NBRO. 2009. Disaster management through local governments, NBRO, Colombo.


Pearce, L. 2003. Disaster management and community planning and public participation: how to achieve sustainable hazard mitigation, Natural Hazards, 28(2-3), 211-228.


A Coastal Community Resilience (CCR) guide was developed by the United States Agency for International Development (USAID) on the basis of lessons learned and experience gained in the Indian Ocean region after the 2004 tsunami, to address coastal hazards and reduce risk to vulnerable communities. The guide addresses many of the key activities identified within HFA priority for action 2 (U.S. IOTWS, 2007).

The CCR guide is intended for use by a broad cross section of government agencies and non-governmental organization practitioners involved in planning and implementing community development, coastal management, and disaster management programmes.

The framework described in the CCR guide was developed in partnership with institutions throughout the Indian Ocean region, and is already beginning to guide development along Asian coasts most in need of building resilience. This guide attempts to broaden the perspective of sector plans so that a more holistic and robust planning framework evolves to truly elevate the potential for community resilience. The results of the CCR assessment process outlined in this guide can fit easily into and enhance development plans for any given coastal area, and can thereby complement traditional planning processes used by local and national governments.

A key theme in this guide is that integration of efforts across sectors and with various organizations is a prerequisite to building community resilience. One of the main lessons in the aftermath of the tsunami of 2004—and seen in other coastal hazards stemming from poorly planned development—is that single-sector development planning cannot solve the complexity of problems posed by natural hazards nor build resilience to them. Resilience requires the spreading of risk and the development of integrated and holistic prevention and management programmes. In this manner, the guide suggests that unexpected changes can be absorbed more easily, so that disaster scenarios can be avoided whenever possible.

SUGGESTED READING

The ICG/IOTWS has identified the capabilities and process required for an operational centre to be recognised as an TSP of the IOTWS. Each TSP must:

- Adopt the common Coastal Forecast Zones (CFZs), harmonised TSP webpage layout, and bulletin formats and content as established by Working Group 2 (WG2).
- Make a presentation to WG2 demonstrating the attainment of capability requirements as agreed by the ICG/IOTWS
- Begin exchanging bulletins with other TSPs
- Participate in Communications Tests and IOWave Exercises
- Have its performance reviewed by WG2 and presented to the ICG/IOTWS
- Begin providing TSP threat information to NTWCs upon agreement of the ICG/IOTWS

(Ref: ICG/IOTWS-IX/12)

All of the TSPs are government agencies, operating 24x7 and possessing seismic and oceanographic expertise, which allows them to monitor and detect earthquakes and tsunamis, and to use computer modelling to forecast tsunami timing and intensity. Each TSP has implemented a sophisticated decision support system to help operational staff to rapidly assess seismic and sea-level data and generate TSP products. Each centre is also the NTWC for its own country and is therefore responsible for issuing national warnings.

The ICG/IOTWS has agreed on a set of key performance indicators (KPIs) and targets which define the level of service which NTWCs can expect from the TSPs. These indicators and targets are summarized in the table below.

### TSUNAMI FORECASTING METHODOLOGY

A general description of this methodology is given in H.3. Further details are given here:

Within the bounds of the common methodology described in H.3, TSPs differ in some technical details of their forecasting process, such as:

- location and spacing of earthquake scenarios on which its library of model forecasts is based;
- assumptions about earthquake rupture geometry and energy transfer to the ocean;
- method of selecting representative values for each CFZ.

The libraries of earthquake scenarios used by TSPs are composed of many model runs based at a large number of likely earthquake locations. At each location it is necessary to carry out several model runs, each at a different earthquake magnitude, so that, when a real earthquake occurs, a scenario which closely matches the observed location and magnitude can be selected. The location/magnitude combinations used by the three centres are as follows:

- Australia – Total = 522 locations x 4 magnitudes
- India – Total = 1462 locations (unit magnitude used to calculate any observed Mw)
- Indonesia – Total = 715 locations x 6 to 8 magnitudes

The tsunami models which the TSPs run to produce their libraries of scenario forecasts are similar in their physics, but differ in their configurations, summarised in the Table 2.

5 InaTEWS scenario library has a high concentration of closely-spaced locations near Indonesia due to the need to provide a detailed national warning service in addition to the TSP role.
Appendices

<table>
<thead>
<tr>
<th>KPI</th>
<th>TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elapsed time from EQ to initial EQ information issuance</td>
<td>10 min</td>
</tr>
<tr>
<td>Probability of detection of IO earthquakes with Mw&gt;=6.5</td>
<td>100%</td>
</tr>
<tr>
<td>Accuracy of EQ hypocenter location</td>
<td>30 kms</td>
</tr>
<tr>
<td>Accuracy of EQ hypocenter depth</td>
<td>25km</td>
</tr>
<tr>
<td>Accuracy of initial earthquake magnitude</td>
<td>0.3</td>
</tr>
<tr>
<td>Elapsed time from EQ to issuance of first bulletin containing tsunami threat info</td>
<td>20 min</td>
</tr>
<tr>
<td>Accuracy of the tsunami forecast amplitude/height</td>
<td>factor of 2</td>
</tr>
<tr>
<td>Probability of detection of tsunami above threat threshold</td>
<td>100%</td>
</tr>
<tr>
<td>Accuracy of time arrival of tsunami (0.02m amplitude)</td>
<td>within 5% of travel time</td>
</tr>
<tr>
<td>Accuracy of time of arrival of 1st significant wave (0.1m)….</td>
<td>within 5% of travel time</td>
</tr>
<tr>
<td>Accuracy of threat threshold exceedance</td>
<td>within 5%</td>
</tr>
<tr>
<td>Percent of IO countries issued a timely product as defined above</td>
<td>100%</td>
</tr>
<tr>
<td>Elapsed time from any product issuance to potential receipt by TWFPs</td>
<td>5 mins</td>
</tr>
<tr>
<td>Percent of time TSP is operating and able to issue products</td>
<td>99.5%</td>
</tr>
<tr>
<td>Percent of regular Comms tests participated in</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 1: TSP Key Performance Indicators and Performance Targets (ICG/IOTWS-IX/12)

<table>
<thead>
<tr>
<th>TSP</th>
<th>AUSTRALIA</th>
<th>INDIA</th>
<th>INDONESIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Name</td>
<td>MOST⁶</td>
<td>TUNAMI N2⁷</td>
<td>TSUNAWI⁸</td>
</tr>
<tr>
<td>Grid length</td>
<td>4 arc minutes</td>
<td>1.5 arc minutes</td>
<td>Adaptive mesh – 50m to 12 km</td>
</tr>
<tr>
<td>Timestep</td>
<td>12 sec</td>
<td>15 sec</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Range</td>
<td>24 hours</td>
<td>25 hours</td>
<td>24 hours</td>
</tr>
<tr>
<td>Domain</td>
<td>Indian + Pacific Oceans</td>
<td>Indian Ocean</td>
<td>Indian Ocean</td>
</tr>
</tbody>
</table>

Table 2: Characteristics of the tsunami models used by the TSPs (⁶ Greenslade et al, 2009, ⁷ Imamura et al, 2006, ⁸ Behrens et al, 2010)

The grid length used in the TSP models is less than the length of most of the CFZs, so model data is usually available for several grid points within a zone. The procedures by which the TSPs select the appropriate forecast values of wave amplitude and arrival times from these grid points varies to some extent among TSPs, but is generally intended to lean towards the safest choices (earliest likely arrival times and maximum likely wave amplitudes).

The process of selecting representative values for a zone is based on a network of 2174 Coastal Forecast Points (CFPs) which has been agreed on by the TSPs and which is independent of their individual model grids. The number of CFPs in a zone varies, but is generally three or four. TSPs determine representative values of maximum tsunami amplitude, and arrival times of the first, maximum and last waves from the values at their model grid points surrounding each CFP. The general form of this selection process is as follows:

- Identify the CFPs in each CFZ
- Identify the model grid points (usually 4) surrounding each CFP
- From the surrounding grid point values for each CFP, identify the maximum forecast value of tsunami amplitude and earliest arrival times.
- From the values associated with each CFP, select for each zone representative values of maximum tsunami amplitude and earliest arrival times.

Because the CFZs lie at the boundary between shallow water and the deep water where the models are applicable, care must be taken in identifying and rejecting grid points which lie in shallow water and so may not have valid forecasts.

Some different strategies can be applied in the selection process. For example, all of the forecast values for a CFZ might reasonably be taken from the grid points surrounding
the CFP which has the largest forecast maximum tsunami amplitude. However, other CFPs within the same zone may be associated with earlier arrival times, so another approach is to choose the earliest arrival times from all CFPs in a CFZ. With this strategy the arrival times and maximum wave amplitudes issued for a CFZ might derive from different points within the CFZ, but the safest forecast is provided. There are some differences in the details of the selection strategies used by the TSPs, but they are continuing to collaborate on refining and standardising this process.

If an earthquake does generate a tsunami, the TSPs are able to utilize the sea-level observation network to compare the wave amplitudes with their model predictions. The models are designed for deep water (greater than 20 to 30 m depth), so tsunameters located well away from coastal shallows provide the most reliable comparisons with the model predictions. In theory it is possible to ‘invert’ the tsunami model, using observed wave amplitudes to calculate the magnitude of the generating earthquake. This method could be used to correct the magnitude determined by seismic measurements, but is not currently used operationally by the TSPs. However, TSPs do currently compare their forecast tsunami amplitudes with tsunameter observations and, if necessary, make appropriate adjustments to the CFZs forecast to be under threat, particularly where the amplitude forecast is close to the threat threshold.

THE TSP PRODUCTS
The full suite of products which TSPs provide to the NTWCs comprises:

- Notification messages - sent to NTWCs when TSP bulletins are issued, via the World Meteorological Organization (WMO) Global Telecommunication System (GTS), e-mail, SMS and fax. The notification messages do not contain detailed tsunami forecasts, since this information is not intended for public dissemination, but provide an immediate ‘heads-up’ to NTWCs.
- Detailed tsunami threat information and bulletins - accessible to NTWCs on each TSP’s password-protected website.
- Graphical products - such as threat assessment maps and wave-height/travel-time maps, also made available to NTWCs on the TSPs’ websites.
- Spatial data files - containing threat assessment and wave forecast data for use in mapping applications, also made available to NTWCs from password-protected web/FTP sites.

Other, more detailed country-specific information or products may be arranged through bilateral agreement between the country requiring the service and an individual TSP.

The Global Telecommunications System (GTS) is operated by the WMO primarily to exchange weather information between National Meteorological and Hydro-meteorological Services (NMHSs). Because the GTS has 24x7 support and a high reliability record, it is a preferred method for receiving the critical first notification of the issuance of TSP products. NMHSs subscribe to products based on each product’s WMO identifier. In countries where the NTWC is not also the NMHS, the agencies should coordinate to ensure rapid delivery of the Notification Messages to the appropriate operational office.

BULLETIN STRUCTURE
All TSPs use the same layout and structure for their bulletins, which consist of some or all of these component sections, depending on the bulletin type:

- Header – Indicates the issuing authority, bulletin number, which is sequential throughout an event, type of bulletin and the date and time in UTC that the bulletin was issued.
- Earthquake Parameters – comprising Magnitude (Mw), Depth (km), Date and Time of earthquake (UTC), Latitude and Longitude of earthquake epicentre, and Location Name of earthquake epicentre.
- Tsunami Evaluation Statement - Based on preliminary earthquake parameters, the first bulletin may contain qualitative information on tsunamigenic potential of the earthquake (local / regional / ocean-wide). If model results indicate a THREAT, the evaluation message indicates that investigation is underway. If any sea-level gauge subsequently confirms the existence of a tsunami that is reported in this section, from the third bulletin onwards.
- Tsunami Threat Information – If model results indicate a THREAT, this section is included from the second bulletin onwards and includes a list of countries where a THREAT is forecast to exist. For each threatened country the coastal zones under THREAT are listed with the expected wave arrival time in UTC for the first wave greater than the 0.5 m threshold, and the expected maximum wave amplitude in metres for that zone.
- Advice - Indicates that the bulletin is issued as an advice only and that the condition of the alert and determination of action based on threat status is up to national or local authorities.
- Updates - A statement indicating when the next bulletin will be issued, or in the case of Type 4 Bulletins indicating that no further bulletins will be issued for the event. Also information about additional information which may be issued by other TSPs.
Contact Information – Details on how to contact the TSP

This structure is illustrated in the sample bulletin below. This example shows the most complex bulletin (Type 3, which includes sea-level tsunami observations and coastal zone forecasts, with the sections separated for illustrative purposes.

TSP-INDIA-20110615-0600-005 (TYPE – III Supplementary 05)

TSUNAMI BULLETIN NUMBER 5
REGIONAL TSUNAMI ADVISORY SERVICE PROVIDER TSP INDIA (ITEWC) issued at: 0632 UTC Wednesday 15 June 2011

... CONFIRMED TSUNAMI THREAT IN THE INDIAN OCEAN ...

1. EARTHQUAKE INFORMATION (Revised)
TSP INDIA issuing earthquake with the following preliminary parameters:
Magnitude: 9.0 M (Great)
Depth: 10 km
Date: 15 Jun 2011
Origin Time: 0600 UTC
Latitude: 7.2 N
Longitude: 92.9 E
Location: Nicobar Islands, India

2. EVALUATION
Sea level observations have confirmed that a TSUNAMI WAS GENERATED.
Maximum wave amplitudes observed so far:
CampbellBay (India) 6.9 93.7 0605Z 15 Jun 2011 12.5m
Nancowry (India) 8.0 93.5 0618Z 15 Jun 2011 2.5m
Kamorta (India) 8.1 93.5 0619Z 15 Jun 2011 14.7m
Sabang (Indonesia) 5.8 95.3 0627Z 15 Jun 2011 8.5m
Based on pre-run model scenarios, the zones listed below are POTENTIALLY UNDER THREAT.
3. TSUNAMI THREAT FOR THE INDIAN OCEAN

The list below shows the forecast arrival time of the first wave estimated to exceed 0.5m amplitude at the beach in each zone, and the amplitude of the maximum beach wave predicted for the zone. Zones where the estimated wave amplitudes are less than 0.5m at the beach are not shown. The list is grouped by country (alphabetic order) and ordered according to the earliest estimated times of arrival at the beach.

Please be aware that actual wave arrival times may differ from those below, and the initial wave may not be the largest. A tsunami is a series of waves and the time between successive waves can be five minutes to one hour.

The threat is deemed to have passed two hours after the forecast time for last exceedance of the 0.5m threat threshold for a zone. As local conditions can cause a wide variation in tsunami wave action, CANCELLATION of national warnings and ALL CLEAR determination must be made by national/state/local authorities.

AUSTRALIA

---

COCOS ISLAND (AU) 0834Z 15 Jun 2011 1.1m
NORTHWEST CAPE TO CARNARVON 1114Z 15 Jun 2011 2.2m

BANGLADESH

---

KHULNA 0846Z 15 Jun 2011 1.8m
COXS BAZAR 0853Z 15 Jun 2011 3.4m

4. ADVICE

This bulletin is being issued as advice. Only national/state/local authorities and disaster management officers have the authority to make decisions regarding the official threat and warning status in their coastal areas and any action to be taken in response.

5. UPDATES

Additional bulletins will be issued by TSP INDIA for this event as more information becomes available. Other TSPs may issue additional information at:
TSP INDONESIA: http://TSPbmkg.go.id
In case of conflicting information from TSPs, the more conservative information should be used for safety.

6. CONTACT INFORMATION

Indian Tsunami Early Warning Centre (ITEWC)
Indian National Centre for Ocean Information Services (INCOIS)
Address: ‘Ocean Valley’, PB No.21,IDA Jeedimetla PO, Hyderabad - 500 055, India.
Tel: 91-40-23895011
Fax: 91-40-23895012
Email: tsunami@incois.gov.in
Website: www.incois.gov.in
DETAILED TSUNAMI FORECAST DATA

So that the text bulletins can be contained to a practical length, the presentation of the detailed tsunami forecast information from the TSPs’ models is limited in these products. The most critical values, arrival time of the first wave over the threat threshold and the expected maximum wave amplitude (which is often after the first wave), are included in the bulletins, but much more information is made available in tables on the TSP web pages.

In addition to a graphical overview of the Indian Ocean showing, by colour-coding, which coastal zones are forecast to be under threat, the TSP web pages also give these details of their model forecasts for each threatened zone:

- Maximum wave amplitude at the coast at water depth 1m (included in text bulletins)
- Time of arrival of first tsunami wave (t1)
- Time of arrival of first tsunami wave amplitude over 50 cm (t2) (included in text bulletins)
- Time of arrival of maximum tsunami wave (t3)
- Time of arrival of last wave amplitude over 50 cm (t4)

(Ref: JATWC, 2011)

An example of an TSP webpage table containing tsunami forecast details is shown in Figure 6.

Other useful graphical products which the TSPs provide on their webpages are tsunami travel time isochrone maps, and diagrams showing the distribution of forecast maximum tsunami amplitude (in deep water), often referred to as energy or directivity maps.

Those NTWCs with Geographic Information System (GIS) capabilities can also download from the TSP websites a DBF file containing spatial data for each event.

Figure 6: TSP tsunami forecast table from web page
LIMITATIONS AND UNCERTAINTIES

The IOTWS has led the world in the implementation of an advanced, modelling-based tsunami forecasting service, but the system is not yet perfect or comprehensive. The limitations discussed below are well recognized by the ICG/IOTWS and the TSPs, and many are currently being worked on. The system will continue to evolve and improve, but in the meantime, NTWCs should take the uncertainties into consideration in the design of their planning and response systems.

5.1 NON-EARTHQUAKE SOURCES

Tsunamis can be generated by mechanisms other than major earthquakes of magnitude 6.5 or greater. Less intense earthquakes, volcanoes and undersea landslides and certain meteorological events can also generate tsunami waves, but the impacts of these events are usually confined to the local area (approximately 100 km radius). The short tsunami travel time over these short distances means that the IOTWS cannot provide an effective alerting service for these mechanisms. Other, less common events, such as meteorite/asteroid impact in the ocean also have the potential to create tsunami waves, but the IOTWS forecasting system has not been designed to respond to such events.

5.2 NEAR-FIELD EARTHQUAKES

As a regional service for the entire Indian Ocean, the IOTWS has not been designed to address the problem of near-field earthquakes in which the tsunami travel time to coastal communities is less than about 15 minutes. The TSP target for issuance of an initial earthquake bulletin to NTWCs is 10 minutes elapsed time from the earthquake, and 20 minutes for issuance of the first bulletin containing tsunami threat information.

TSPs cannot provide alerts or forecasts quickly enough to warn communities which are less than 15-20 minutes tsunami travel time from an earthquake source region. The high density of seismic observations required to identify and respond to earthquakes in less than 5 minutes cannot be utilized by the TSPs over their ocean-wide area of responsibility. Those communities which are less than 15-20 minutes tsunami travel time from potential source zones are also those which will feel a significant earthquake as it occurs. Effective community education which prioritises moving to safety even before official warnings are received is therefore essential. In the Indian Ocean many such locations are also now served by well-developed national warning systems, such as in Indonesia.

5.3 SIMPLIFIED RUPTURE GEOMETRY

Tsunami models generally assume simple sea-floor rupture geometry. The exact size and shape of the movement of the sea-floor during a tsunamigenic earthquake cannot be deduced quickly enough to meet the short timeframes required for tsunami warning, so simplifying assumptions have been made in the TSP oceanographic models. These assumptions can introduce errors into the directionality...
of the forecast maximum waves. Further, the tsunami models assume the maximum possible transfer of energy from sea-floor to the ocean for a particular earthquake magnitude and so may overestimate the magnitude of tsunami waves to some degree.

5.4 NON-REAL-TIME MODEL SCENARIOS

Use of pre-run model scenarios introduces some errors due to the differences between the real-time earthquake characteristics and the pre-run scenario. TSPs are moving towards real-time running of tsunami models, so that observed real-time earthquake location, magnitude and geometry can be used to initialize the tsunami forecasts. However, at present in general real-time earthquake locations are rarely more than about 50 km distant from the closest pre-run scenario in the TSPs’ library of model runs.

5.5 DELAYS IN MAGNITUDE ESTIMATION

Great earthquakes involve ruptures which can extend for many hundreds of kilometres. Such ruptures do not occur instantaneously, but can take several minutes, eg. the 2004 Indian Ocean earthquake took 8 minutes to fully rupture. Because tsunami warning systems are designed to detect and respond very quickly, it is usually the case that the first estimates of magnitude during major tsunamigenic events are made before the rupture is complete and so are lower than the final value. TSPs will issue updated bulletins and model forecasts as soon as magnitude estimates are revised by seismologists. NTWCs should expect and be prepared for an escalation in the number of threatened coastal zones in TSP advices during the first 30 minutes or more of severe events.

5.6 EXTRAPOLATION OF DEEP-WATER MODEL FORECASTS TO THE BEACH

Most deep water propagation models cannot be used in water less than 20 to 30 metres deep, so simple extrapolations using Green’s Law are used to forecast wave amplitude on the beach. Coastal inundation models can be coupled to the broadscale deep-water models to produce detailed coastal wave forecasts, but these require very high-resolution inshore bathymetry and considerable computing power. Generally this is not practical at present for the TSPs.

While shallow water wave amplitude is being forecast by extrapolation from deep-water modelling, the effect of small coastal features such as headlands, bays and sandbars cannot be quantified in TSP products. These features can introduce very large variations in the observed tsunami wave amplitude and run-up within a single coastal forecast zone. There is considerable scope for national agencies to add value to the TSP service by carrying out risk analyses and high-resolution inundation modelling for critical or vulnerable coastal zones.

5.7 COMMUNICATIONS NETWORK LATENCY

Time is of the essence during a tsunami event, and the TSP performance targets reflect this. Although modern communications networks are generally very reliable and prompt, it should be remembered that the time to receipt of notifications from time of issuance by the TSPs is dependent on network performance.

5.8 FALSE ALARMS

The IOTWS has been designed to minimize the impact of false alarms. Many earthquakes of magnitude 6.5 or greater occur without generating a tsunami, but the TSPs cannot wait for confirming sea-level observations before alerting NTWCs of a potential threat. The first bulletins issued therefore act as alerts for national agencies to begin preparations without committing to action. Over years many of these alerts will not move into the confirmed tsunami phase, but NTWCs should take care to ensure that Bulletins Type 1 and 2 (before confirmation) continue to be carefully monitored and assessed.

5.9 COASTAL SEA-LEVEL GAUGE NETWORK DEFICIENCIES

The coastal sea-level gauge network is generally not dense enough to capture a full picture of the distribution of tsunami waves and impact during a major tsunami. TSPs provide tsunami forecasts for coastal zones which are about 100 km long or less, but the spacing between verifying sea-level gauges around the Indian Ocean is much greater. In some events it is possible that the sea-level gauge network will suggest that no tsunami waves over the threat threshold were generated, even though larger waves went unobserved in some zones without gauges.

5.10 SIMPLIFIED INVERSION TECHNIQUES

Deep-ocean tsunameters can provide reliable early observations of tsunami amplitude, but TSP systems cannot currently make full use of this information to calculate refined quantitative tsunami forecast parameters. TSPs currently use tsunameter data to confirm tsunami generation and to make qualitative adjustments to their forecasts. Numerical techniques are available to utilise reliable tsunami measurements to ‘invert’ the tsunami model to refine the initial earthquake assessment and so correct the model’s forecasts. All TSPs are working on implementing this technique.

6 INTERPRETATION OF TSP PRODUCTS

6.1 USING ADVICE FROM MULTIPLE TSPS

During a major tsunami event, the TSPs issue a large number of notification messages, bulletins and graphical products. NTWCs can choose to monitor and assess the products from all three TSPs, but need to ensure that
their procedures protect their operational staff from being overwhelmed or confused by the volume of information. Because of the differences in tsunami models between the TSPs there will be some differences among the centres in the number of coastal zones forecast to be under threat. Figure 8, below, illustrates the high degree of similarity between the coastal zone threat forecasts from two TSPs for a simulated earthquake of Mw 9.0 in the Sunda Strait.

TSPs measure their performance using the key performance indicators described earlier, and NTWCs are able to monitor the indicators from a website maintained by the TSPs. In addition, at the meetings of the ICG/IOTWS (held every two years), the TSPs provide detailed reports on their performance against the KPIs. The reports are available in the meeting documents published on the IOC website.

### 6.2 INTERPRETING FORECAST ARRIVAL TIMES AND MAXIMUM WAVE AMPLITUDES

The detailed forecast information included in the TSP text bulletins and tables is complex and requires some interpretation to be correctly used. The specific forecast values were listed above and are discussed in more detail here:

**Maximum wave amplitude at the coast at water depth 1m** - This forecast wave height is included in the TSP text bulletins and the detailed table of forecast values. The forecast is based on a model forecast of tsunami wave amplitude forecast in deep water within the coastal zone. The deep-water value is extrapolated to a representative value at the beach (1 metre depth) using Green’s Law. The extrapolation does not take into account local bathymetry or the geometry of the coast. A single forecast value represents the whole coastal zone and determines whether the zone is assessed as being under threat or not.

**Time of arrival of first tsunami wave (t1)** – Tsunami travel time forecasts are generally quite accurate, although discrepancies between the source location in the chosen scenario and the actual location of the real earthquake can introduce a small error. The first tsunami wave in this context means the first model forecast of a wave amplitude of 2 cm or more. This time is not the time of arrival of the maximum wave, which will usually be later.

**Time of arrival of first tsunami wave amplitude over 50 cm (t2)** – This forecast arrival time is included in text bulletins with the maximum wave amplitude, but NTWCs should understand that the maximum wave arrival time will be different. The arrival of the first wave over 50 cm amplitude is significant because this is the threshold for determining if a coastal zone is under threat.

**Time of arrival of maximum tsunami wave (t3)** – The highest tsunami wave is usually not the first wave to arrive, so this time will generally be later than t1 or t2. This forecast can be useful after a tsunami has begun to impact a coastal zone in determining if the impact has reached its peak or will continue to intensify.

**Time of arrival of last wave amplitude over 50 cm (t4)** – Finalisation of tsunami warnings requires careful consideration. It is possible that local effects in bays, harbours, estuaries and other features, which are not included in the TSP tsunami models, can cause seiching and currents which could be dangerous for an extended period.
period after the tsunami waves have ceased to arrive at a coastal zone. The TSPs provide the forecast time of arrival of the last wave over the threat threshold, and base the timing of their final (cancellation) bulletin on this forecast. The final bulletin is issued 2 hours after the last t4 in any coastal zone. NTWCs will consider a variety of local factors, including community reaction, as well as the forecast t4, in deciding when to finalise their local warnings.

These four forecast time values are illustrated in Figure 9, below, using a modelled time series from TSP Australia’s scenario library.

![Figure 9: Time series forecast of tsunami amplitude in deep water, from TSP Australia’s scenario library, illustrating t1 (time of first tsunami wave arrival), t2 (time of first wave over threat threshold), t3 (time of maximum wave amplitude) and t4 (time of last tsunami wave over threat threshold) (Coburn and Leggett, 2013).](image)

6.3 MEANING OF THE ENERGY/DIRECTIVITY MAPS

For every earthquake which meets the magnitude/location criteria for TSP assessment, each TSP generates a graphical product which summarises the maximum waves forecast by its tsunami model. This product is also called an energy or directivity map, since it clearly shows the directions in which the largest waves develop away from the earthquake source.

The product is an integrated picture of the largest forecast waves throughout the run-time of the model, which is around 24 hours from the time of the earthquake. It is not a snapshot at a particular instant, but a plot of the distribution of the worst waves over the 24-hour period.

Usually the maps clearly show focusing of the largest waves near the earthquake in the directions perpendicular to the alignment of the fault which has ruptured. Further from the source, the effects of bathymetry (islands and undersea ridges and mountains) are also apparent in local maxima in the forecast wave amplitude. It must be remembered that these maxima are not coincident in time, but can be separated by many hours.

![Figure 10: TSP India Directivity Map for an earthquake of Mw 6.7, south of Java in June 2013.](image)

6.4 USING TSP SPATIAL DATA IN LOCAL GIS

For NTWCs and NDMOs with GIS capabilities the most convenient format in which to receive the TSP products may be the DBF files which are available from the password-protected websites. When combined with local vulnerability or administrative maps in a GIS, the TSP coastal zones and associated forecast amplitudes and arrival times could be used to prioritise and expedite response and evacuation activities. TSP India also provides geo-referenced forecast data in KML format, for use with Google Maps.

The shape file which defines all of the coastal forecast zones is permanently available from the TSP websites. During an event a DBF file which is readable by GIS such as ArcReader is created and made accessible from the websites. The DBF file contains the geo-referenced forecast wave amplitudes and arrival times from the tsunami models.

REFERENCES


### M.2 ESSENTIAL ELEMENTS FOR AN EFFECTIVE TSUNAMI EARLY WARNING SYSTEM

<table>
<thead>
<tr>
<th>Elements</th>
<th>Details</th>
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<tbody>
<tr>
<td>Proper instruments that enable the early detection of potentially harmful earthquakes and tsunamis.</td>
<td>The data obtained by these instruments must be readily available to all nations continuously and in real-time to be effective.</td>
</tr>
<tr>
<td>Proper procedures to analyse the data coming from the networks of instruments as a way to forecast tsunamis more accurately</td>
<td>The National Tsunami Warning Centre (NTWC) must be able to analyse and forecast manifestation of a tsunami, the impact of tsunamis on coasts in advance of the waves’ arrival. The NTWC must also convey the proper information that the tsunami lasts for several hours and should be able to send the ‘all clear’ message once the event is over so that search and rescue operations can begin.</td>
</tr>
<tr>
<td>Warning systems that reliably inform the vulnerable populations immediately and in an understandable and culturally appropriate way.</td>
<td>The local, regional, and/or national disaster management organizations must be able to immediately disseminate information on the threat and to enable evacuation of all vulnerable communities. Clear designation of the national or local authority from which the public will receive emergency information is critical to avoid public confusion, which would compromise public safety. The communications methods must be reliable, robust, and redundant, and work closely with the mass media and telecommunications providers to accomplish this broadcast. The cooperation between the NTWC, the emergency authorities and the mass media is essential to ensure that the media broadcast timely, reliable and accurate information.</td>
</tr>
<tr>
<td>Inter-institutional coordination</td>
<td>Stakeholder coordination as the essential mechanism that facilitates effective actions in warning and emergency response. SOPs tested and validated through table-top simulations and drills or exercises outlining procedures to be followed if warnings are issued. These procedures define coordination mechanisms among institutions and other stakeholders and responsibilities concerning the execution of specific tasks.</td>
</tr>
<tr>
<td>Awareness activities that enable ordinary citizens to recognize a tsunami so that they know what to do.</td>
<td>Citizens should recognize a tsunami’s natural warning signs and respond immediately. This is especially true for the case of a local tsunami, which may hit within minutes and before an official tsunami warning can reach their communities. Recognition and use of indigenous knowledge is important. Citizens should also recognize that a tsunami is a series of waves which can last several hours, and hence the importance of staying in safe areas or shelters until the ‘all is clear’ signal is disseminated by the NTWC.</td>
</tr>
<tr>
<td>Preparedness activities which educate and inform a wide populace, including government responders and those providing lifeline and critical infrastructure services, on the procedures and activities that must be taken to ensure public safety.</td>
<td>Drills and exercises before an actual event, and proactive outreach and awareness activities are essential for reducing tsunami impact. Natural hazards science and disaster preparedness subjects that are part of the required curriculum taught to school children will prepare and carry awareness to the next generations. Gender-related issues in preparedness and family responses in emergencies need to be factored in.</td>
</tr>
<tr>
<td>Planning activities that identify and create the public safety procedures and products and build capacity for organizations to respond faster.</td>
<td>It is necessary to create and widely disseminate tsunami evacuation or flooding maps, and instructions on when to go, where to go, and how to go. Evacuation shelters and evacuation routes need to be clearly identified, and widely known by all segments of the coastal population.</td>
</tr>
<tr>
<td>Strong buildings, safe structures, and prudent land-use policies to save lives and reduce property damage that are implemented as pre-disaster mitigations.</td>
<td>Tall, reinforced concrete buildings may be adequate places to which people can vertically evacuate if there is no time to reach higher ground inland. Long-term planning to avoid placing critical infrastructure and lifeline support facilities in inundation zones will reduce the time needed for services to be restored.</td>
</tr>
<tr>
<td>High-level government advocacy that ensures a sustained commitment to prepare for infrequent, high-fatality natural disasters such as tsunamis.</td>
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</table>

*Table 9 Essential elements for an effective tsunami early warning system. Source: ITIC*
The Environmental Hydraulic Institute, IH Cantabria, from University of Cantabria, has carried out a tsunami hazard, vulnerability and risk assessment for the coast of Oman including a tsunami catalogue of mitigation measures and a handbook of implementation. The assessment was funded by the Ministry of Transport and Communications of the Government of the Sultanate of Oman in support of Oman’s National Marine Hazard Early Warning System (NMHEWS).

The assessment was carried out at two different scales:

- national (along the whole coast of Oman), and
- local (at nine selected study areas: Sohar, Wudam, Sawadi, Muscat, Quriyat, Sur, Masirah, Al Duqm, and Salalah).

The assessment was composed of the following elements:

- Tsunami Hazard Assessment: The hazard level at the exposed areas has been determined by means of a deterministic analysis based on the combination of the set of the worst credible scenarios.
- Vulnerability Assessment: Once the hazard level is known, the exposure and sensitivity evaluation is performed, obtaining the vulnerability of the human and infrastructure dimensions by means of an indicators-indices approach that allows the assignment of classes to the analysis units. Finally, a resilience assessment (e.g., coping and recovery capacity) has been carried out.
- Risk Assessment: Risk results are obtained by combining the hazard level with the vulnerability applying a risk matrix. Two types of results are provided, for each dimension (human and infrastructure) and for the combination of both dimensions. This approach permits understanding the precise cause of the obtained results, thereby providing essential information for risk management.
- Risk management: Based on the Hazard, Vulnerability and Risk Assessment results, risk management can be tackled. A tool to help in the first step of the decision-making processes related to tsunami risk reduction has been developed.

The results of the tsunami Hazard, Vulnerability and Risk Assessment have been disseminated by:

- A Hazard, Vulnerability and Risk Atlas which includes Human, Infrastructure and combined Risk maps, Human and Infrastructure Vulnerability maps and Tsunami Hazard maps at national and local scales for the nine selected study areas.
- A website based on GIS technology which shows the Hazard, Vulnerability and Risk Assessments, complementing the Hazard, Vulnerability and Risk Atlas. The vulnerability and risk maps in the website and in the atlas are the same; however, the hazard maps in the website include not only the envelope map but also the seven scenarios of the worst credible cases that build such an envelope.

The formulation of specific tsunami risk reduction measures for improving preparedness and reducing the exposure and vulnerability has been included in an easy-to-use Mitigation Handbook.

REFERENCES


As a further reference to this work, a video showing the capabilities of the assessment system may be viewed at: https://vimeo.com/99242844
N.1 TRATE PROJECT REPORTS


- This document was commissioned as a contribution to the UNESCAP Project: Enhancing Tsunami Risk Assessment and Management, Strengthening Policy Support and Developing Guidelines for Tsunami Exercises in Indian Ocean Countries.
- Extracts from this report form the basis of Section H.3 in the Guidelines and are reproduced as an appendix at M.1.


- This report focuses on refined Tsunami Wave Forecasting on the coastline taking into account the detailed geometry of the coastline and using detailed inundation modelling. It then compares with values obtained from the Indian Ocean Tsunami Early Warning System (which makes certain simplified assumptions in extrapolating deep water wave heights to the shoreline). This is a strongly technical document.


- This report is a detailed case study on Tsunami Risk Assessment and Management for the Port City of Galle, Sri Lanka. For easy understanding, it is presented in a manner that covers the theory in a generic way, with applications to Galle City made available in text boxes at the end of each chapter. This document is intended for a wider stakeholder base. (See also Box 6)

N.2 OTHER RESEARCH REPORTS


- This document is relevant to all aspects of the assessment and management of tsunami risk in the Guidelines.


- This is a description of the approach to tsunami risk assessment and management in New Zealand, with a focus on its application to land-use planning.