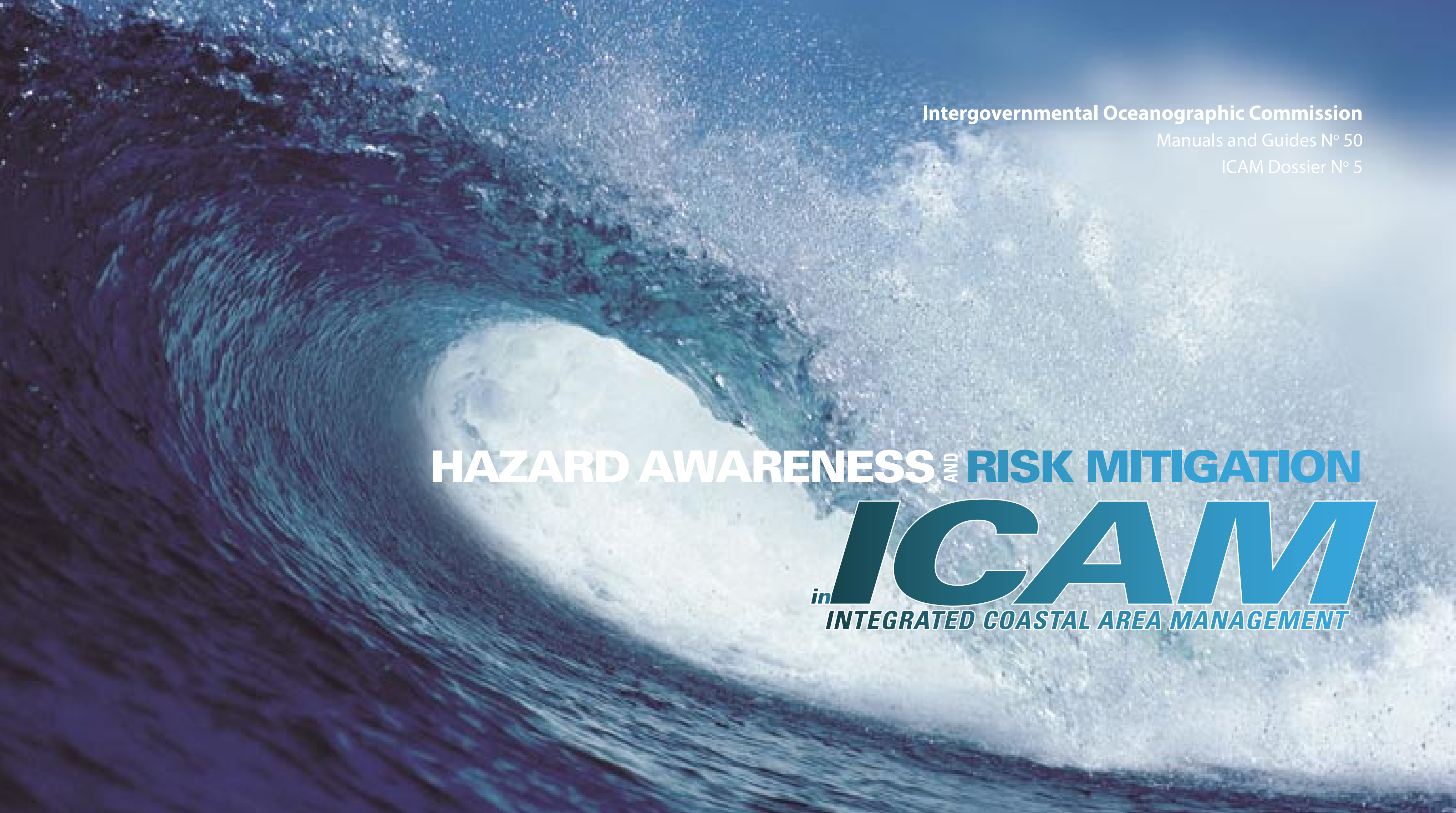

Intergovernmental Oceanographic Commission
Manuals and Guides Nº 50
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HAZARD AWARENESS AND RISK MITIGATION in ICAM
INTEGRATED COASTAL AREA MANAGEMENT

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

ICAM

World Meteorological Organization

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HAZARD AWARENESS AND RISK MITIGATION in ICAM

INTEGRATED COASTAL AREA MANAGEMENT

Intergovernmental Oceanographic Commission
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These guidelines have been compiled by an international group of experts working under the auspices of the IOC. The group included specialists in the fields of sea-level related hazards, marine meteorology, vulnerability and risk in respect of natural hazards, early warning and preparedness, risk mitigation, and coastal zone management.

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FOREWORD

Following the disastrous December 2004 tsunami that affected coastal states around the Indian Ocean, 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. This expansion builds on the experience of the Pacific Tsunami Warning System (PTWS) that has been operational since 1965. Three additional warning and mitigation systems are in the course of development, co-ordinated by IOC. These respectively cover the Indian Ocean region (IOTWS), the North-eastern Atlantic, Mediterranean and Connected Seas region (NEAMTWS) and the Caribbean (CARIBE-EWS).

While the main impetus for these developments has come from the perceived need to protect communities from tsunamis, these warning systems are intended to be an integral component of a comprehensive multi-hazard and multi-purpose warning system. Each will cover storm surge and its atmospheric forcing (e.g., tropical cyclones), and extreme wind-forced wave events as well as tsunamis, linking with existing hazard warning systems and established specialized centres as appropriate and feasible. 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 plans of these multi-hazards warning systems embrace the detection, and forecasting and warning of hazard events, as well as their communication and dissemination. Regional Centres have an important role in planning and implementing regional programmes, and in providing guidance on forecasting and warning services to National Centres, ensuring full coordination between National Centres in the region and taking maximum advantage of this high-level cooperation. The onward communication of hazard event and the issuance of warnings from National Centres to local authorities are the responsibilities of individual countries.

The implementation plan for Working Group 4 (WG4 – Advisory, Mitigation and Public Awareness) of the Intergovernmental Coordination Group for NEAMTWS specifically included an action to prepare guidelines, as requested by IOC Member States, which aim to mainstream the awareness and mitigation of sea-level-related hazards and risks in Integrated Coastal Area Management (ICAM).

These guidelines have been compiled within the context of the "Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters" (UN/ISDR, 2005). They describe a process in the ICAM framework aimed at fully integrating disaster risk reduction into relief and development policies and practices. Their development has been closely allied to that of companion guidelines produced as a contribution to the IOTWS, primarily for tsunami risk assessment and management in the Indian Ocean region, but with global relevance (IOC Manuals and Guides No.52).

The Guidelines are intended to be user-oriented and global in scope. They have been developed in accord 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'.

Working within the ICAM and Tsunami programmes of IOC, the Guidelines have been prepared by an expert group under IOC's auspices and with the support and cooperation of other intergovernmental bodies including the WMO. It is with pleasure that I record WMO's endorsement of the Guidelines.

Patricio Bernal
Assistant Director-General of UNESCO
Executive Secretary of IOC
Intergovernmental Oceanographic Commission

EXECUTIVE SUMMARY

THE ICAM CONTEXT

These guidelines aim to assist policy makers and managers in the reduction of the risks to coastal communities, their infrastructure and service-providing ecosystems from tsunamis, storm surges and other coastal hazards within the phased framework of Integrated Coastal Area Management (ICAM).
As a context for the procedures presented in the Guidelines, Section 2 sets out the full framework of the ICAM process. This shows how the assessment of coastal hazards and the mitigation of the risks in respect of those hazards can be embedded within the four phases of ICAM, each with its respective procedural steps. Each step is described – including its purpose, its key considerations, the management challenges that it poses and its anticipated outputs.

IDENTIFYING AND QUANTIFYING THE HAZARDS

The physical features of the sea-level related coastal hazards that form the subject of these guidelines are described in the context of ICAM (Section 3). These descriptions, including information on hazard sources and magnitudes, are followed by procedures for assessing the likelihood or probability of a specified hazard scenario occurring (Section 4). The procedures take into account the hazard events' locations, their frequencies and magnitudes, and the pathways that may modify their magnitude and thus their physical impact. The assessment should delineate the boundaries of potential hazard impacts, for example, inundation of coastal lowlands, and inform authorities on the likelihood of such hazard impacts occurring within a timescale relevant to the ICAM Management Plan.
The recommended key tasks are to:

- define the geographical limits of the coastal management area;
- examine the historical record of coastal hazard impact events;
- access information on hazard origins and propagation patterns;
- acquire and compile data on nearshore bathymetry and coastal topography;
- determine the spatial parameters of hazard impact – the exposure;
- determine probabilities for specified hazard scenarios;
- display exposure and probability results as hazard maps; and
- convey the results of hazard assessment to risk and emergency managers.

The expected principal outputs from these procedures are:

- hazard maps for specified, credible hazard scenarios showing exposure parameters of coastal land affected (inundation limits, run-up, erosion, water depths at maximum inundation, inundation and drainage flow velocities.

MEASURING VULNERABILITY

The assessment of the vulnerability of the hazard receptors – the coastal community and its supporting systems – is a key part of the Guidelines' approach (Section 5). Assessment of the various dimensions of a community's vulnerability – the people, their physical assets (buildings), economies and supporting environment – assists policy makers in the identification of critical areas or weak spots in respect of human security, industrial and utilities infrastructure and ecosystem integrity. This task may be accompanied by an assessment of deficiencies in preparedness, an indicator of institutional robustness. Changes over time in the levels of vulnerability must be considered, particularly those caused by land-use, e.g., coastal urbanization and environmental changes.

The recommended key tasks are to:

- define the geographical scale and limits of the assessment, considering the geographically determined hazard exposure limits (Section 4);
- define the temporal scale of the assessment – this may be a rolling scale;
- gather geospatially referenced data on human and social, physical and economic, and environmental parameters (an asset database) using, e.g., GIS technology; gather data on deficiencies in preparedness;
- translate these data into levels of vulnerability with regard to the exposure to each hazard; assess as separate vulnerability dimensions or as aggregated vulnerability, taking all dimensions into account.
- assess institutional deficiencies in preparedness, particularly in respect of early warning and impact response;
- produce vulnerability map(s) and reports for the designated coastal management area; and
- communicate the vulnerability (including preparedness) assessments to all involved in the ICAM process.

The expected principal outputs from these procedures are:

- an asset database for the coastal area being assessed, vulnerability maps and reports (including deficiencies in preparedness) produced for the designated coastal areas, whether at the regional or the local scale, covering each of the different dimensions of vulnerability for each of the recognized hazards. The maps should cover future scenarios as well as existing conditions, taking into account the likely effects of mitigation and emergency preparedness responses. A preliminary appraisal of the state of preparedness including early warning practices, evacuation plans, Search and Rescue Operations and risk transfer schemes.

ASSESSING THE RISK

The integration of the hazard probability and vulnerability (including preparedness) assessments produces assessments of the risks to the various community dimensions (human and social, physical (buildings) and economic and environmental) in respect of the identified hazards (Section 6). These assessments take into account deficiencies in preparedness at the institutional level.

The recommended key tasks are to:

- define the geographical scale and limits of the assessment, using determined geographical hazard limits (Section 4);
- define the temporal scale of the assessment;
- integrate geospatially referenced hazard exposure information and probabilities with assessed vulnerability zonation using, e.g., GIS technology;
- translate integrated hazard and vulnerability output into levels of risk for each vulnerability dimension in respect of each hazard; assess risk for separate vulnerability dimensions or aggregated, taking all dimensions and deficiencies in institutional preparedness into account;
- produce risk map(s) for the designated coastal management area in respect of selected hazard scenarios;
- analyse and evaluate uncertainties;
- assess future risk(s) taking preparedness and mitigation measures into account (sections 7 and 8); and
- communicate the results of the risk assessment to policy- and decision makers.

The expected principal outputs from these procedures are:

- risk maps and reports produced for the designated coastal areas, whether at the regional or the local scale, covering each of the different dimensions of vulnerability for each of the recognized hazards, taking deficiencies in preparedness into account;
- the maps should cover future scenarios as well as existing conditions, taking into account the likely feedbacks from enhancing emergency preparedness (Section 7) and strategic mitigation (Section 8); and
- effective communication of the risk assessment outputs to all levels involved in the ICAM process. The assessments are vital inputs to the policy-making process within ICAM, determining the nature and level of response (Management Plans) with the aim of reducing risk.

ENHANCING AWARENESS AND PREPAREDNESS

The guidance in the management of the assessed risks within the framework of ICAM aims to enhance public awareness of the risks and to improve the resilience of coastal communities for coping in emergency situations of the threat or impact of a hazard event (Section 7).

The recommended key tasks are to:
- identify an appropriate early warning framework;
- raise awareness of the risk at all levels in the community;
- establish the key operational requirements of the early warning system; and
- prepare all levels of the community for emergency responses.

The expected principal outputs from these procedures are:
- measures for education and public awareness of risks established;
- an effective, tested, end-to-end early warning system in place;
- special target audiences identified and evacuation planning in place and tested; and
- adequate capacity established to carry out an integrated, inter-institutional emergency response, with functionality of Emergency Operation Centres demonstrated.

MITIGATING THE RISK

The Guidelines describe the options for structural and non-structural responses within the framework of ICAM for the mitigation of the assessed risks by strategic management.
Key tasks and goals for the strategic management of the perceived risks are to:
- define the temporal and geographical scales of the management;
- determine the options for strategic mitigation;
- consider the adoption of a multi-pronged approach to the management response;
- incorporate other ICAM goals in the response;
- apply decision-analysis tools in the management process;
- involve the public in the decision-making processes; and
- identify management responsibilities and sources of adequate funding.

The expected principal outputs from these procedures are:
- a portfolio of hazard mitigation measures which are consistent with ICAM objectives, and collectively can manage coastal hazards; and
- a long-term plan for their implementation, including a monitoring programme to assess the effectiveness of the selected strategy.

Whatever a coastal community's physical or developmental situation, there are ways of reducing risk in respect of these hazards which are sustainable and can be embedded in the culture of that community. Of prime importance is the need to achieve sustained coordination of effort among the many stakeholders, whether in the assessment of risk, the planning and implementation of mitigation measures, or the emergency response. The Guidelines are intended to facilitate the achievement of this objective, by promoting the mainstreaming of hazard awareness and risk mitigation within ICAM. 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.

1 INTRODUCTION

TO WHOM ARE THESE GUIDELINES TARGETED?

These guidelines have been prepared for use by national and local governments whose jurisdiction includes coastal areas. They are also relevant to a wide range of other coastal stakeholders. They aim to facilitate the reduction of the risks to coastal communities, their infrastructure and associated ecosystems due to tsunamis, storm surges and other coastal hazards. The Guidelines are a response to the needs expressed by IOC Member States (MS) to enhance awareness of these hazards; to improve the ability of MS to assess the risks; and to provide MS with recommendations of best practice in the management of the risks within the framework of Integrated Coastal Area Management (ICAM).

WHAT IS ICAM?

ICAM is a multi-phased process that unites government and the community, science and management, and sectoral and public interests in preparing and implementing an integrated plan for the development and protection of coastal ecosystems and resources (figs 1.1, 1.2 and see Section 2). Contributing to the sustainable development of coastal areas, its goals include the protection of public safety, land-use planning, the stewardship of resources, the promotion of economic development and conflict resolution between the various stakeholders. ICAM is functionally the same as ICZM (Integrated Coastal Zone Management) and ICM (Integrated Coastal Management). IOC publications relating to ICAM are listed in Section 2.5.

The general elements of the ICAM process are illustrated in Fig. 1.1. While different models have been developed to illustrate the cyclic, adaptive process of ICAM through a number of steps, it is generally recognized that this process involves three main phases, each with individual steps, the sequence of which may vary, depending on the characteristics of the management area. These phases can be characterized as (1) preliminary identification of issues and conditions, (2) preparation of the management process and plans, and (3) implementation and adaptive management. To these, a fourth phase can be added dealing with consolidation, replication and expansion of an ICAM initiative.

WHAT HAZARDS ARE COVERED BY THESE GUIDELINES?

The hazards covered in this guidance (see Section 3) range from tsunamis, with inevitable though unpredictable, possibly catastrophic impacts and warning lead times as short as minutes, to coastal erosion and sea-level rise, whose progressive or cumulative impacts may be apparent only on decadal timescales. Also included are storm surges and their atmospheric forcing (tropical cyclones and extra-tropical storms), and extreme wind-forced waves. Hazards relating to marine water quality – high sea-surface temperatures, harmful algal blooms and oil spills are not included. In these guidelines, the hazards covered are all physical hazards and are referred to generically by the term "coastal hazards".

WHAT ARE THE OVERALL AIMS OF THESE GUIDELINES?

The Guidelines aim to promote ways within the framework of ICAM in which national and local authorities can prepare for, and respond to, these hazards with a planned and coordinated approach among the many agencies and other organizations involved. They aim to assist MS in minimizing the risk to their coastal

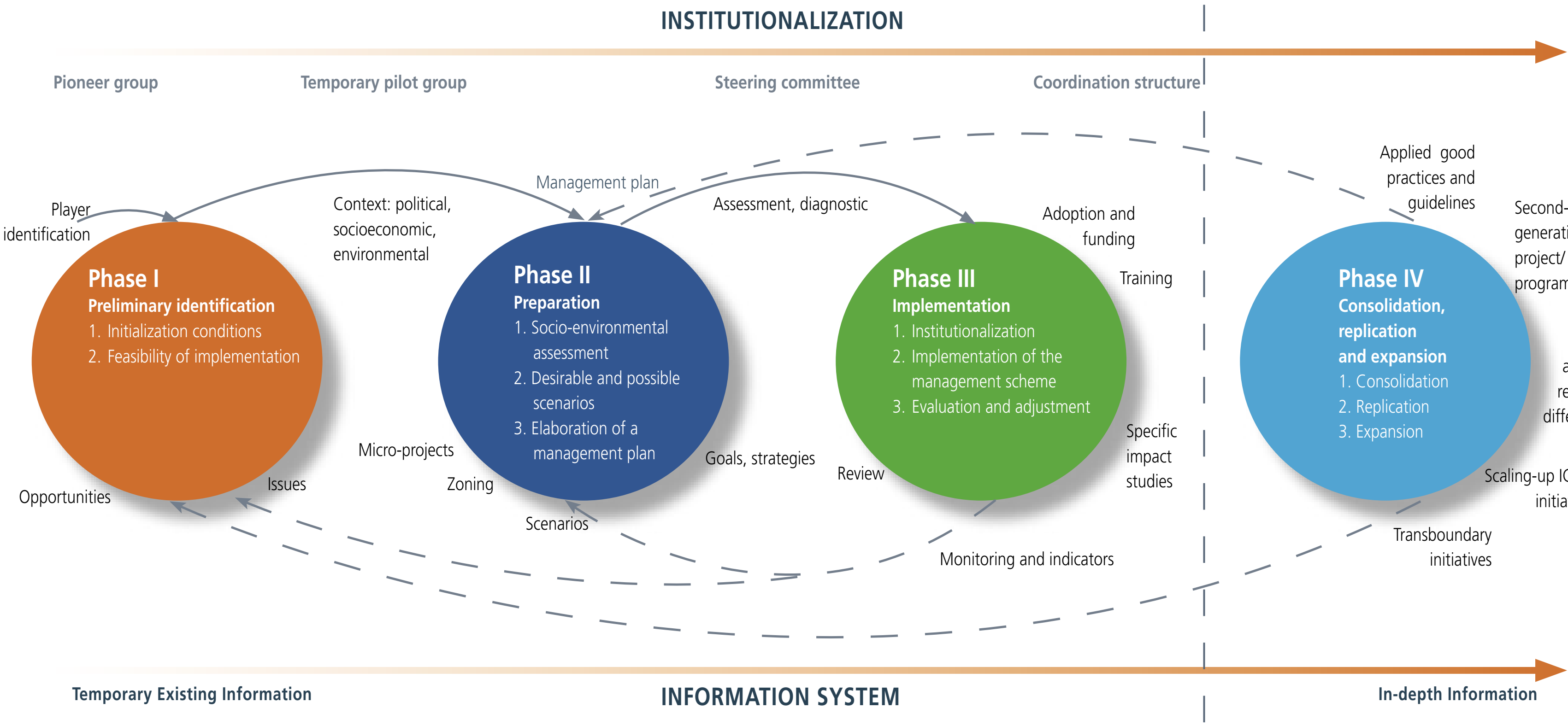

***Fig. 1.1**. The linkages and feedbacks between the general elements of the ICAM process.*

Source: Adapted from Henocque and Denis, UNESCO, 2001.

communities, infrastructure and service-providing ecosystems through consultation, coordination and cooperation among all stakeholders with coastal hazard mandates. Their goal is a raised level of awareness of the hazards and their associated risks amongst stakeholders and the "mainstreaming" of these hazards and risks in emergency and strategic planning in order to enhance hazards resiliency and create more hazard-resilient communities. In accordance with "Words into Action: A Guide for Implementing the Hyogo Framework" (UN/ISDR, 2007), they aim to promote among people, their leaders and decision makers an acceptance of the value of managing these hazards to reduce the risks of future losses. The implementation of the Guidelines within MS is expected to lead to an increased resilience to hazard events. In particular, it should promote the institutional capacity for emergency preparedness and response.

WHY IMPROVE COASTAL HAZARD AWARENESS?

Experience over recent years of the impacts of coastal hazards, in developed and developing countries alike, has shown that inadequate preparation for, and response to, emergency situations have contributed to widespread damage and the avoidable loss of lives and livelihoods. In some instances these shortcomings have been due to a lack of warning through poor regional detection and communication systems. But in many cases, they have reflected inadequate awareness, planning and coordination on the part of national and local authorities and agencies. These guidelines present practices that, if implemented by policy makers, address these shortcomings.

WHY PROMOTE HAZARD AWARENESS WITHIN THE ICAM PROCESS?

The ICAM process promotes an integrated plan for the protection and development of coastal resources. The Guidelines assess how hazard awareness and mitigation can be integrated effectively with other ICAM management efforts, e.g., taking into account the requirements and constraints of marine and terrestrial spatial planning in coastal areas. They consider the potential societal and economic benefits of risk management and vulnerability reduction within ICAM, both in the short term for emergency preparedness and response, and, over the longer term, for prevention and sustainable coastal land use and development. The present global demographic trend of population increase within the coastal zone will continue to add to the pressures on coastal land use. The growth of coastal megacities is a particular concern, with the expansion of urban communities into hazard-prone coastal areas.

HOW CAN HAZARD-RELATED RISK ASSESSMENT BE IMPROVED?

The Guidelines seek to facilitate the practical and realistic assessment of risk by Member States in respect of the range of hazards, then present achievable and sustainable strategies for the management of that risk within the ICAM process. They address the procedures for assessing the probabilities of coastal hazard events (Section 4). These procedures take into account the hazard events' locations, their frequencies and magnitudes, and pathways that may modify their magnitude. The assessment of hazard pathways or local physiographic factors, for example, may delineate the boundaries of potential hazard impacts and inform authorities on priorities for mitigation. Alternatively it may indicate whether action is needed at all, thus helping authorities to focus response resources on the most critical coastal areas and their communities.

The assessment of the vulnerability of hazard receptors is a key part of the Guidelines' approach (Section 5). Assessment of the various dimensions of a community's vulnerability – people, economic infrastructure, ecosystems and institutions – assists policy makers in the identification of the most critical areas or weak spots in respect of human security, industrial and utilities infrastructure, ecosystem integrity and the robustness of governance. Changes over time in the levels of vulnerability are addressed, particularly those caused by land use, e.g. coastal urbanization or environmental changes. The integration of hazard and vulnerability assessments lead to risk assessments (Section 6) which inform the policy- and decision-making processes, leading to the management of those risks within an ICAM Management Plan (Section 2.2).

In addition to the recommendations included in these ICAM-related guidelines, readers are referred to companion guidelines produced specifically for tsunami risk assessment and management in the Indian Ocean region, as part of the development of the Indian Ocean Tsunami Warning and Mitigation System (IOC Manuals and Guides No. 52; UNESCO, 2009).

WHAT ARE THE OPTIONS FOR MANAGING THE ASSESSED RISK?

Guidance in the management of the assessed risks within the framework of ICAM will promote two broad objectives. These are: the development of resilience in coastal communities for coping in emergency situations (Section 7) and the reduction or mitigation of risk through strategic management (Section 8).

The treatment of coping strategies covers issues of public awareness and emergency preparedness, including criteria for warning systems, evacuation plans and standard operating procedures for utility and civil protection organizations. The Guidelines cover the transmission of warnings to end-users. They aim to promote communications synergy with other early detection and warning centres and emergency communications networks, as well as compatibility with other emergency services, both nationally and internationally. They emphasize the requirement for awareness and education as cost-effective means of minimizing hazard-related risks.

The recommendations for best practice in mitigation cover the principles of hard and soft engineering responses to potential hazard impacts aimed at reducing exposure; also non-structural, adaptive actions including the rehabilitation and, where appropriate, the relocation of vulnerable communities and key infrastructure facilities, land-use planning and implementation, and tools such as building code regulation and the role of insurance as a financial instrument in coastal land use and development. Coastal land-use planning is a key component of ICAM. There are many ways in which risk can be reduced by effective and appropriate land use. This applies to all the hazard events dealt with in these guidelines, both the catastrophic inundation events caused by tsunamis, storm surges and its atmospheric forcing (e.g. tropical cyclones) and extreme wind-forced waves (with or without land-water floods), and the long-term, progressive or creeping processes of coastal erosion and sea-level rise. The development of residential areas and utility infrastructure, for example, beyond inundation zones or away from land prone to coastal erosion is an obvious ideal for which to strive. But some authorities and communities may have no alternative but to occupy land prone to inundation. For such cases, the Guidelines aim to provide advice on risk reduction through protection and accommodation, for example, through the construction of engineered defences or emergency refuges.

HOW CAN HAZARD-RELATED RISK MANAGEMENT BE MORE EFFECTIVE?

The experience of the responses to recent coastal hazard events and their ensuing disasters, notably the Indian Ocean tsunami of 2004 and the storm surges associated with Hurricane Katrina in 2005 and Cyclone Nargis in 2008, has highlighted a lack of knowledge of hazards and a poor awareness of vulnerability. Also, it has highlighted dysfunctional institutional structures and systems which have hindered the translation of such knowledge and awareness as does exist into responses that are effective in reducing risk. These shortcomings apply not only to the development of preparedness and emergency response procedures but also to the ways in which coastal communities could, through improved governance within the ICAM framework, reduce their own exposure and vulnerability to the hazards by strategic mitigation measures.

To be successful, the management of the risks demands levels of cooperation and coordination between all the involved agencies which are difficult to achieve, even in developed countries. The Guidelines recognize the problems of coordination at all levels in the warning and response systems. Particular attention is paid to the mechanisms of coordination among the national and local authorities and their component organizations involved in the various aspects of hazard-related risk assessment and management, whether for potentially catastrophic events or long-term, progressive hazard processes.

The practical application of risk knowledge in actions for risk reduction may be improved by strengthening the involvement and co-ownership of the user 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.

Civil protection emergency response and relief procedures are already well established in many countries, particularly where natural hazard events are the norm. Intergovernmental relief organizations such as the United Nations International Strategy for Disaster Reduction (UN/ISDR) also have well-tried procedures that are appropriate to natural hazard impacts in developing countries. These guidelines draw from these established practices, but modify or supplement such procedures in order to address the specific circumstances of coastal hazard impacts.

Whatever the level of risk, there is likely to be some potential for risk reduction, the overarching objective of 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 hazard 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 ways of reducing risk in respect of these hazards which are sustainable and can be embedded in the culture of those communities. Of prime importance is the need to achieve sustained coordination of effort among the many stakeholders, whether in the assessment of risk, the planning and implementation of mitigation measures, or the emergency response. The Guidelines are intended to promote and facilitate this objective, by promoting the mainstreaming of hazard awareness and risk mitigation within ICAM. 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.

GUIDE FOR READERS

The Guidelines are presented as a sequence of procedures for consideration by coastal managers, policy- and decision makers. This sequence and its feedback possibilities are illustrated in Fig. 1.2.

Following this Introduction, Section 2 describes the full framework of the ICAM process and indicates the way in which the assessment and mitigation of coastal hazards and risks may be embedded in that process. The Section presents the four phases of ICAM, each with its respective procedural steps. Each step is described, including its purpose, its key considerations, the challenges that it poses and its anticipated outputs. It then elaborates on key steps included in the phases of the ICAM process: I – Preliminary Identification; II – Preparation of Plans in ICAM; III Implementation and IV Consolidation/Replication/Expansion.

Section 3 describes the coastal hazards covered. Section 4 provides guidance on the identification of baseline and background data on the hazards and describes procedures for hazard assessment, monitoring and forecasting. These procedures relate to Step 2 of the "Preliminary Identification" phase (I) of the ICAM process (Fig. 1.1).

Sections 5 and 6 relate to Step 1 of the "Preparation of Plans within ICAM" phase (II), in which social and environmental assessments are carried out. Section 5 addresses the subject of the vulnerability of coastal communities exposed to the hazards, exploring the various dimensions of that vulnerability and providing information on the procedures for making vulnerability assessments. Section 6 sets out the procedure for assessing the risks by integrating the data from the hazard and vulnerability assessments and considers the incorporation of those assessments in the Management Plan.

Sections 7 and 8 relate mainly to the "Implementation" phase (III), although with extension into Phase IV (Consolidation/Replication/Expansion). Section 7 addresses the development and maintenance of awareness of, and emergency preparedness for, rapid-onset hazards, with the aim of reducing the risks that they pose. Section 8 describes the options for strategic risk mitigation responses to all of the coastal hazards, including those creeping hazards which act progressively over the long term. It also describes, with the assistance of decision-support tools, the wide-ranging possibilities for risk reduction through measures such as land-use planning and regulation.

Data requirements, information sources and selected bibliographies are given as appropriate at the end of each section. A more comprehensive bibliography follows Section 8. Sections 4–8 each include a text box in a light blue tone highlighting the key procedural tasks for the respective sections. Text boxes specially prepared by the principal and contributing authors, illustrating aspects and applications of the Guidelines procedures, are shown in a green tone. Text boxes with supplementary information are shown in a yellow tone.

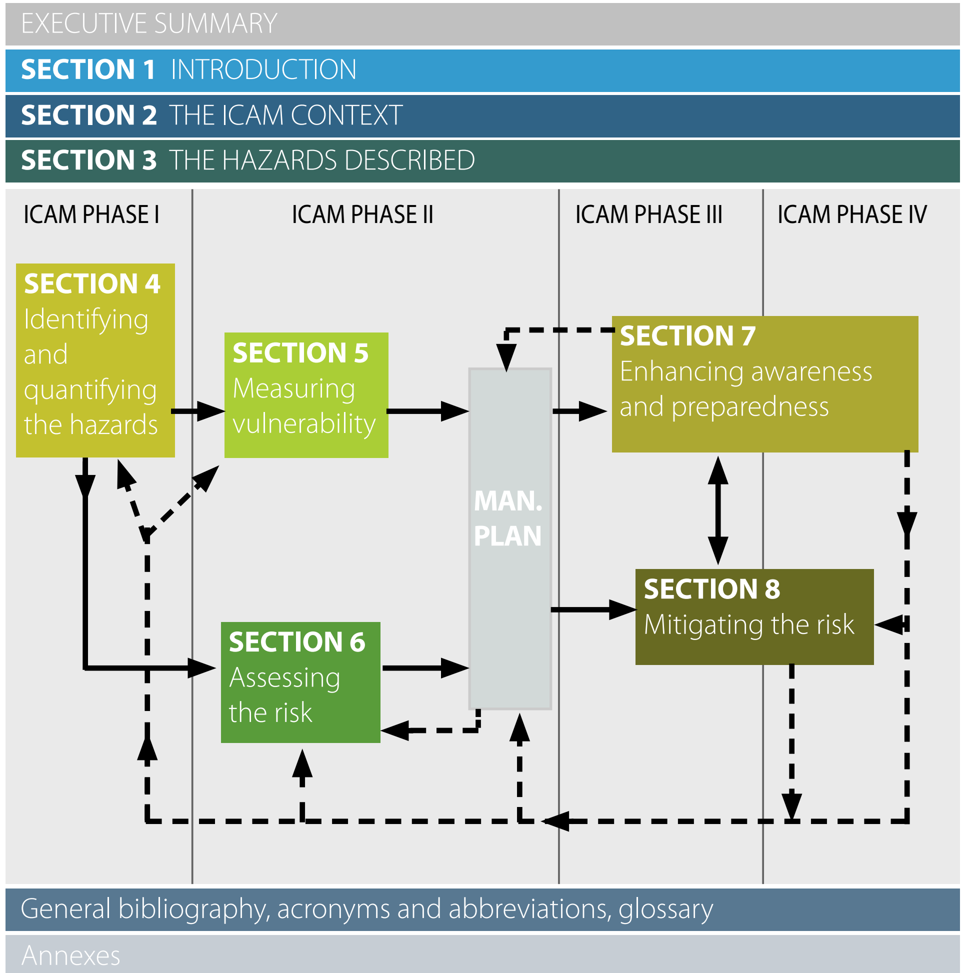

***Fig. 1.2**. The relationship of the Guidelines' sections to four phases of ICAM. Linkages (solid lines) and feedbacks (pecked lines) between Section topics; MAN. PLAN = Management Plan.*

2 THE ICAM CONTEXT

This section describes the multi-phase ICAM process as it relates to the integration of awareness and risk mitigation in respect of the coastal hazards covered by these guidelines

2.1 PHASE I – PRELIMINARY IDENTIFICATION

Purpose

Identify an existing ICAM or other applicable framework where coastal hazard management goals and objectives could be incorporated. Identify background data on coastal hazards and drivers that can be used to promote effective coastal hazard management.

Key considerations

Phase I usually consists of two steps:

- identifying an ICAM framework; and
- identifying background or baseline data.

The following specific questions should be asked during this phase.

Step 1 – ICAM Framework:

Is there a coastal management programme or plan in place that could be modified to incorporate coastal hazard management goals and objectives?

The ICAM process promotes an integrated plan for the protection and development of coastal resources. Identifying suitable planning mechanisms where coastal hazards can be incorporated to achieve an "integrated plan" is an essential first step. A region does not have to have a formal ICAM programme in place to successfully integrate coastal hazard management into their coastal planning processes. Other existing planning documents such as land-use plans, emergency response plans and other development plans can also be modified to consider coastal hazard impacts in a more comprehensive and integrated manner – the essence of ICAM.

Are there external drivers to promote coastal hazard management?

External drivers can include international, national or regional directives related to coastal management. External drivers can also include a recent "focusing event" such as a significant storm event that raises the awareness of coastal hazards and the need to develop effective management plans and policies to minimize future hazard impacts. Identifying external drivers like these can help shape the coastal hazard management approach and gain support for integrating coastal hazards within existing planning processes. An example of an external driver is the European Union's recently adopted Floods Directive (see boxes 2.1 and 6.3).

BOX 2.1 The European Union Floods Directive

The European Union Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007. This Directive requires EU Member States to assess whether water courses and coastlines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas, and to take adequate and coordinated measures to reduce this flood risk. This Directive also reinforces the rights of the public to access this information and to have a say in the planning process.

More information is available at: (http://ec.europa.eu/environment/water/flood_risk/index.htm)

BOX 2.2 Coastal Zone Management Act promotes hazards management in the United States

In the United States, the Coastal Zone Management Act (CZMA) calls for all coastal states to 'minimize the loss of life and property caused by improper development in flood-prone, storm surge, geological hazard, and erosion-prone areas and in areas likely to be affected by or vulnerable to sea level rise, land subsidence, and saltwater intrusion, and by the destruction of natural protective features such as beaches, dunes, wetlands, and barrier islands, minimize loss of life and property caused by erosion and sea level rise while continuing to protect our natural coastal resources' (CZMA 16 U.S.C. § 1452(2)(B)). Since its inception in 1972, the CZMA has been an important driver promoting coastal hazard management at the state and local level. After hurricanes Katrina and Rita struck the Gulf of Mexico coast in 2005, there has been a renewed national focus on coastal hazard management and resiliency, as the country is reminded of the devastation coastal hazards can have and the importance of advanced planning.

More information is available at: (http://coastalmanagement.noaa.gov/czm/czm_act.html)

Is there public and political awareness of coastal hazards?
There is a strong imperative to improve awareness of coastal hazards. The impacts of these hazards are increasing due to many factors, such as increasing population, changes in coastal land use, losses of natural coastal protection through human intervention, and changes in rivers and their catchments. Attempting to move forward with the incorporation of coastal hazard management into existing coastal management or planning processes without strong political and public support can be very difficult. Identifying where additional outreach and education is needed up-front is key to the success of this process (see also Section 7 for a more in-depth discussion on outreach and awareness campaigns). The U.S. Coastal Zone Management Act (see Box 2.2) and the Mediterranean Protocol on Integrated Coastal Zone Management (Box 2.3) are steps in the promotion of hazard management through political awareness.

Step 2 – Background or baseline data
What historical and baseline data are available on coastal hazards, including data on socio-economic and environmental impacts?

Before policy makers can embark on Phase II, it is critical to identify and collect as much available baseline data related to coastal hazards within the region of interest as possible. These data can include historical shoreline change data, frequency and severity of past hazard events, coastal population, economic productivity, critical infrastructure, etc. For a fuller description of data requirements and sources see sections 4.8 and 5.9.

Challenges

Key challenges to the preliminary identification phase can include the following:

- There may be a lack of existing drivers that resonate with the community and will motivate them to improve hazard management planning.
- There may be a lack of an existing ICAM or similar process to incorporate coastal hazard management elements.
- There may be a lack of public and political awareness of coastal hazards and their potential impacts.
- Baseline information on coastal hazards may be lacking.

Outputs and results

Key outputs and results associated with this phase may include:

- identified external drivers to motivate the community to develop or modify a plan to address coastal hazards;
- identified ICAM or other planning mechanism that can address coastal hazards;
- assessment of the level of public and political awareness of coastal hazards; and
- assessment of the baseline data available on coastal hazards.

2.2 PHASE II – PREPARATION OF PLANS IN ICAM

Purpose

Preparation of plans for coastal hazard management goals and objectives as part of ICAM refers to the development of goals, objectives and policies, and the selection of concrete strategies and sets of actions to produce the desired mix of goods and services from the coastal area over time. It is a decision-making step involving the ability to anticipate future events, a capability for analyzing and evaluating situations, and a capacity for innovative thinking to derive satisfactory solutions.

Key considerations

Phase II usually consists of three steps:

- social and environmental assessments through analysis and forecasting;
- definiton of goals, strategies, and development of desirable and possible scenarios, identification of institutional, social and environmental conditions, resources and data available; and
- preparation of the management plan based on ICAM principles, goals and objectives.

Step 1 – Social and environmental assessments

The goal of the first step – the assessments – is to provide an analytical basis for the establishment of goals and objectives and definition of management strategies for sustainable development in the coastal area. This stage is strongly issue-oriented and not necessarily aimed at producing a detailed diagnostic. The procedures for assessing vulnerability and risk are described in sections 5 and 6. The following question is important.

Are the physical and socio-economic aspects related to coastal hazards included in the ICAM plans and regularly assessed?

Vulnerabilities and risks in respect of coastal hazards should be determined through vulnerability assessment and risk assessment studies. These studies should analyse physical and socio-economic aspects of the vulnerabilities and risks. It is also critical to assess the level of awareness of the coastal population and decision makers on the risks associated with the hazards, as well as the impacts these hazards may have upon human life and economic resources over a long timeframe.

BOX 2.3 Mediterranean Protocol on Integrated Coastal Zone Management

Countries have started to consider the issue of coastal hazards and risks as an emerging one in ICAM. A very positive example showing responsible behaviour is coming from the Mediterranean, where in January 2008 countries adopted and signed a Protocol on Integrated Coastal Zone Management. This is the first example in the world of the regional legislation on ICAM. Once the Protocol is ratified, the Mediterranean countries will have to adjust their national legislation accordingly. In the Protocol, there is a specific part (IV) dealing with risks affecting the coastal zone. Article 22 of the Protocol, which relates to natural coastal hazards and risks, states: 'Within the framework of national strategies for integrated coastal zone management, the Parties shall develop policies for the prevention of natural hazards. To this end, they shall undertake vulnerability and hazard assessments of coastal zones and take prevention, mitigation and adaptation measures to address the effects of natural disasters, in particular of climate change.'

More information is available at: (http://www.pap-thecoastcentre.org/razno/PROTOCOL%20ENG%20IN%20FINAL%20FORMAT.pdf)

Step 2 - Scenarios

The purpose of the second, prospective, step is to provide basic direction for coastal sustainable development. Some key questions in this step follow.

Have different options for the impacts of the coastal hazards been considered?
Once the coastal hazards and risks in the respective coastal area are identified, the projection of their impacts on the coastal area should be made. These impacts are then analyzed in a wider context of the forecast of future demand for goods and services from coastal resources. Then the alternative cross-sectoral scenarios are prepared. The scenarios chart the alternative courses of action based on potential changes in population, land-use structure, urbanisation, infrastructure, conservation, economic activities, and other aspects of coastal development. The scenarios have to be evaluated against a number of criteria, one of which is related to coastal hazards and risks (see Section 6). This stage is an iterative one, because the generation of coastal development scenarios is run in parallel and in interrelationship with the definition of goals and objectives. Goals are general development and environmental guidelines that should be followed in the course of the ICAM process.

Are stakeholders being involved in the decision-making process for a management plan including coastal hazards?
Public participation in goal formulation is essential in their realization. Since goals secure the strategic guidance of the process, it is important that they are presented clearly and explicitly, and that they are not contradictory. Goals can be broken down into a number of compatible objectives. The objectives should be operational, in a quantitative form where possible, and should be short term compared with the longer-term time horizon of the goals. Goals and objectives related to hazards and risks should be integrated with other coastal development goals and objectives. The need for mitigation of their eventual impacts on coastal economic sectors (fisheries, tourism, shipping, industry, urbanisation, etc.) should be clearly stated (see Section 8).

Step 3 – Management Plan

The goal of the third, planning, step is the integration of sectoral and cross-sectoral management strategies and policies. This step is based on the existence of a high level of inter-dependence among these strategies and on the need for their implementation in a coordinated way.

Is there a shared long-term vision for the coastal area?
A typical integrated strategy should pay attention to the pattern of future activities in the area once the decision on the most preferable scenario is being taken, and indicate the intended changes in the physical, economic, social and environmental life of the coastal area as a result of the implementation of desired policies. The document to be completed in this stage might be called the Integrated Coastal Master Plan (ICMP) or similar plan.

Can adequate human, technical and financial resources concerning coastal hazards be mobilized to implement the ICAM plan?
Implementation of the ICAM plan requires considerable institutional and financial resources. The objective of the ICMP is to create conditions for making operational decisions in the implementation step of ICAM. The plan proposes, inter alia, concrete operational measures to mitigate the risks in respect of coastal hazards. These measures may be of a strategic nature, such as zoning schemes which indicate, for example, evacuation routes and points; economic incentives and disincentives aimed at stimulating the preferable urbanisation patterns; conservation measures aimed at preserving natural habitats which may have a role in coastal defence. They may be of a locational nature, such as definition of setback lines to prevent future damages to coastal property; or structural measures aimed at stabilization of the coastline. Implementation requires the securing, training and maintenance of adequate human resources at both the management and the operational level.

Challenges

Key challenges in the preparation phase may include:

- There may be a lack of studies on vulnerability and risk assessments related to sea-level rise and other coastal hazards.
- Stakeholders potentially affected by coastal hazards may be poorly represented in the definition of the ICAM plans goals and objectives.
- There may be no agreed long-term vision for the coastal zone: changes in coastal activities not forecast in the ICAM plan.
- Marine-related coastal risk may not be considered in the regular budgets.
- There may be a lack of managerial and field staff trained in coastal hazards involved in the implementation of ICAM plans.

Outputs

- The coastal plans are regularly assessed regarding the environmental and socioeconomic aspects related to coastal hazards.
- The ICAM plans consider different options for the coastal hazards impacts under different scenarios.
- The ICAM decision-making is open to, and inclusive of, all stakeholders.
- Required expertise on the assessment of marine hazards is present within the institutions in charge of the ICAM initiatives.
- Resources aimed to reduce the coastal hazards risk are maintained or increased.
- An Integrated Coastal Master Plan (ICMP) or similar plan has been approved.

2.3 PHASE III – IMPLEMENTATION

Purpose

The aims of this phase include:

- setting up the necessary institutional mechanisms for incorporating into the ICAM process interests potentially affected by coastal hazards;
- implementing the ICAM plan (or any comparable instrument), including through specific measures and tools to protect life and property from the hazards; and
- evaluating the measures implemented and their effectiveness in reducing the risks.

Key considerations

Specific issues to be addressed during the implementation phase of an ICAM process may be considered within three steps.

Step 1 – Institutional mechanisms

Are there institutional mechanisms in place that allow consideration of hazards-related interests?

Due to its intersectoral and multidisciplinary character, the ICAM process involves a variety of institutions and actors, from the national to the local level, with some degree of responsibility over coastal and marine space and resources. A generic representation of typical roles exerted by different government agencies is shown in Table 2.1. The responsibilities of the different levels of government in reducing risk from natural hazards are generally defined by a legal framework. As for the coastal hazards addressed by these guidelines – tsunamis, storm surges, extreme wind-forced waves, coastal erosion, and sea level rise – national institutions normally involved include:

- Meteorological Service: weather forecasts and warnings;
- Seismology network: seismic measurements;
- Oceanographic network: sea-level measurements;
- Civil Protection: assessment, prevention, and mitigation of risks; evacuation in emergencies;
- Public Works: building and maintenance of coastal defences; and
- Ministry of Environment: monitoring of relevant phenomena.

Coordination may be facilitated by a multi-sector platform for disaster risk reduction. A national policy framework for disaster risk reduction should be in place that influences plans and activities at different administrative levels, supported by dedicated and adequate resources.

The coordination of different sectors and administrative actors represents a challenge for the ICAM process: typically, problems involve overlap or even competition among authorities on responsibilities, and gaps in horizontal and vertical communication. This impedes the sharing of information, implementation of activities, and monitoring and control. The existence and functioning of a coordinating or management body for all the key agencies involved in the ICAM process is a prerequisite to institutional coordination. The existence and functioning of such a body reflect the interests of the different actors with a stake in, and influence on, coastal and marine areas and resources. A coordinating body also ensures the representation of relevant stakeholders and may be charged with the formulation and preparation of ICAM policies, plans and programmes.

It is therefore important that government agencies in charge of the prevention and management of coastal inundation and erosion, as well as the stakeholders and interests that may be affected by such hazards, are represented in ICAM coordinating bodies and mechanisms. One particular goal of such bodies and mechanisms is to find ways to balance the competing demands of different users of the same spaces and resources. Often this will include compromise, through a consensual process, between short- and long-term benefits, such as the regulated use of the coastline for leisure, commercial and residential purposes and its conservation in a sufficiently natural state so as to maintain its service in natural coast protection.

Table 2.1. *Coastal management issues and corresponding administrative responsibilities. Principle hazard-related issues are highlighted. (Adapted from Pavasovic, 1995).*

Government Depts / Issues	National														Subnational		
	Min. Interior	Ministry Defence	Hydr. Service	Ministry Mer. Mar.	Harbour Office	Ministry Environ.	Min. S&T	Ministry P. Works	Ministry Health	Local Health Units	Ministry Culture	Ministry Industry	Civil Protect.	Meteorol. Office	Region	Province	Municip.
Navigation		R	M	R P	Mg												
Fishing				R P	M										P		
Harbours				R P	Mg			C			R						
Marinas				P	R						R				P		P Mg
Water quality				M		R M	M		R M	M					P R		Mg C
Rural/urban wastes						R			R	M					P	M	C Mg
Industrial wastes						Mg			R	M							
Eutrophication				M	M	P M Mg	M			M							
Coastal erosion			M		C	M	M	P C							P		C Mg
Flood risk	R		M		M W	M		C					W Mg D	M W Mg	D	D	D
Tsunamis			M		M W								W Mg D	M W Mg	W	W	W
Weather			M										W Mg D	M W Mg			
Tourism		R		R	Mg						M				P		R Mg
Urbanization											M				R P	M	C Mg
Parks and reserves				P R		P R Mg									Mg		Mg M
Archaeol. sites							M				R				P	R	Mg M
Military uses		P R C Mg															
Mapping			P Mg M		M												
Offshore activities				R Mg								P R					

C: construction D: defences Mg: management M: monitoring P: programming R: regulation W: warning

BOX 2.4 Building capacity through IOC to arrest degradation of coastal resources

Science-based strategies can deliver immediate benefits in terms of livelihoods but the key to their successful development resides in the support they receive locally. Since developing states have many immediate problems to address, support for marine sciences research and monitoring remains a low priority. IOC is therefore raising awareness of decision-makers that marine sciences are a cost-effective investment worthy of local support. Simultaneously IOC is also focusing its efforts to strengthen institutional capacities by transferring leadership, proposal-writing and team-building skills that will allow regional and national institutes to effectively network in addressing local problems without external aid. Such efforts could also spur participation in addressing the critical global marine challenges of the 21st century.

More information is available at: (http://www.ioc-cd.org/index.php?option=com_content&task=view&id=12&Itemid=28)

Step 2 – Implementation

Does specific human/technical capacity exist at the local level?

Specific expertise is required at the level of the agencies in charge of implementing the ICAM initiative, i.e., a sufficient number of staff with adequate experience devoted to ICAM and, specifically, to coastal hazards (see Box 2.4).

Is there adequate funding to implement the ICAM plan inclusive of its provisions concerning the hazards?

Adequate and sustained financial resources need to be allocated and readily available to support management activities and interventions to address coastal hazards. This entails proper financing and cost evaluation of relevant measures (see Section 8.3), with a clear agreement on where the responsibilities for funding lie. Who is going to fund what?

Are initiatives being undertaken to raise public awareness of the hazards?

In the implementation of measures to address marine hazards, a crucial role is played by educational and awareness programmes that raise public awareness of coastal hazards (see Section 7).

Which mechanisms are in place to implement the measures?

Among the most-used instruments to reduce damage from coastal hazards are building setbacks combined with buffer zones. The traditional function of protection of buildings could be positively combined with the maintenance and creation of physical space for leisure and tourism uses with economic implications, and the maintenance or rehabilitation of natural defences such as coastal dunes and vegetation. The maintenance of public access to the shore can also favour the use of evacuation routes (see sections 7 and 8).

Step 3 – Evaluation

Has the effectiveness of the measure put in place been proven?

To consolidate and replicate the plan under Phase IV there must be evidence of changing behaviour and reduced risks after the implementation of the plan.

Challenges

Key challenges in the implementation of an ICAM initiative may include:

- There may be insufficient scientific and technical expertise, as well as technology, and an inadequate link between science, policy makers and managers.
- There may be limited public awareness and knowledge of the potential damage from coastal hazards.
- There might be a dominance of short-term economic interests that could impede the acceptance of measures (e.g., restrictions on building in proximity of the shoreline).
- Enforcement may be lax.

Outputs and results

Key outputs and results associated with this phase may include:

- Adequate representation of interests affected by the hazards in institutional arrangements is ensured (official composition of coordinating bodies).
- Required expertise on the assessment of the hazards is present within the institutions in charge of the ICAM initiatives (staff and external experts, on-the-job training programmes).

- Educational programmes and campaigns to raise public awareness of coastal hazards are implemented (number and type of initiative, target populations, funds). University and agencies programmes are officially incorporating the hazard-related risks in their curricula.
- Measures which are put in place to reduce potential damage from the hazards (e.g., building setbacks) are respected (trends in infringements, fines, etc.).

Sections 7 and 8 of these guidelines deal with key aspects of the Implementation Phase: the awareness of the risks and emergency preparedness; and the strategic mitigation of the risks. The content of these sections extends to cover aspects of Phase IV (figs 1.1 and 1.2).

2.4 PHASE IV – CONSOLIDATION/REPLICATION/EXPANSION

Purpose

The aim of this phase is to:

- consolidate the ICAM plan on a long timescale by replicating the implementation, taking into account the learned good practices and correcting the detected mistakes;
- incorporate new knowledge and technology related to coastal hazards;
- adapt the plan to new situations in continually changing scenarios.

Key considerations

Specific issues in this phase may be considered in three steps.

Step 1 – Consolidation

Is the ICAM process sustainable in the long-term?

It is important to address the coastal hazards by achieving low-impact mechanisms and moderate maintenance costs to be sustainable in the long term. Furthermore, regular funding, stable institutional mechanisms as well as long-term political compromise are necessary.

Have good practice and guidelines been developed to address coastal hazards?

Progress can be assessed through the following features:

- good practice and guidelines for addressing hazards produced;
- monitoring system should be in place covering:
  - sea-level/shoreline change (Global Sea Level Observing System, GLOSS; remote sensing)
  - evolution of shoreline habitats;
- change in coastal uses; and
- indicators reflecting adoption of mitigation measures by the local population and institutions.

Step 2 – Replication

Has the ICAM approach been replicated in other parts of the coastal area?

It is important to extend the plans to neighbouring coastal zones. Coastal hazards must be addressed taking into account the physical characteristics of the coast and not the administrative and political structure of the coastal zone. Plans should be replicated and extended along the coastal zone (see Box 2.5).

BOX 2.5 Implementation of ICAM in Italy

In Italy, the ICAM approach at the regional level has been pioneered by Liguria Region with the Coastal Master Plan, adopted in the 1990s and applying to a coastal zone defined by the 200-metre contour and the 100-metre isobath in 63 coastal municipalities. The Coastal Master Plan includes among its priorities the protection of the shore from coastal erosion and beach nourishment to support the use of the coastal zone for tourism and leisure. It relies on the division of authority on coastal defence, beach nourishment, protection and observation of the marine and coastal environment, and maritime domain among the Region, coastal provinces and coastal municipalities, under the general coordination of the Region, and through planning instruments at regional (coastal spatial plans), provincial level (watershed management plans), and municipal level (beach plans) (Regional Law 28 April 1999, No. 13). Such an approach has been progressively adopted by other Italian coastal regions, including Abruzzi,

Emilia Romagna, Latium, Sicily, and Tuscany.

More information is available at: (http://www.regione.liguria.it/MenuSezione.asp?Parametri=4_10_14_1_$4_10_14_1_$Piano_della_costa$4_10_14_1_-0$costa1.htm$)

Step 3 – Adaptation and expansion

Has the ICAM plan been revised and adapted to changing conditions?

The coastal zone is continuously changing because of trends of increasing population and the consequences of climate change. ICAM plans should be continuously adapted to the new scenarios.

Are local ICAM processes contributing to national efforts to address the hazards?

The management of coastal hazards should be incorporated in a regional/ national strategy that should help to support the development of the plan by adequate means.

Challenges

Key challenges in the consolidation of an ICAM initiative may include:

- Measures to reduce the hazard-related risks need to be effective.
- Risk not considered in the regular budgets – there is no investment in infrastructure to prevent or constrain the hazards.
- The coastal hazard-related threats, vulnerabilities and political climate may be specific to each location, so may be difficult to replicate without modification.
- Local governments may be unwilling to adopt land-use measures to protect against hazards without strong mandates from higher level governments.

Outputs and results

Key outputs and results associated with this phase may include:

- risks in respect of the coastal hazards decreased;
- resources aimed to reduce the risks are maintained or increased;
- experience from the implementation of the plan is distilled into good practices and guidance documents;
- the plan is increasingly being extended to neighbouring coastal areas and a data and information network is established; and
- the percentage of national coastal area addressing the coastal hazards in the ICAM context is increased.

SUGGESTED ADDITIONAL READING

FAO. 1998. *Integrated coastal area management and agriculture, forestry and fisheries: FAO guidelines*. Rome.

Pavasovic, A. 1995. The status of integrated coastal and marine management and the demand for coastal management practitioners: Mediterranean and Black Sea regions. B. R. Crawford, J. S. Cobb, Ch. L. Ming (eds). Educating Coastal Managers: Proceedings of the Rhode Island Workshop, March 4–10, pp. 15–29. W. Alton Jones Campus, University of Rhode Island.

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UNEP/MAP/PAP. 2008. Protocol on Integrated Coastal Zone Management in the Mediterranean. Available at: http://www.pap-thecoastcentre.org/razno/PROTOCOL%20ENG%20IN%20FINAL%20FORMAT.pdf (Accessed 16 February 2009.)

UNESCO. 1997. *Methodological Guide to Integrated Coastal Zone Management*. IOC Manuals and Guides, No. 36. Paris, UNESCO.

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UNESCO. 2006. *A Handbook for Measuring the Progress and Outcomes of Integrated Coastal and Ocean Management*. IOC Manuals and Guides, Vol. 46; ICAM Dossier, No. 2. Paris, UNESCO. Available at: http://unesdoc.unesco.org/images/0014/001473/147313e.pdf (Accessed 16 February 2009.)

UNESCO. 2009. *Tsunami risk assessment and mitigation for the Indian Ocean; knowing your tsunami risk – and what to do about it*. IOC Manuals and Guides, No. 52, Paris, UNESCO.

3 THE HAZARDS DESCRIBED

The hazards described in these guidelines are of two main types in respect of their impacts on coastal areas. They include those with rapid onsets – tsuna-mis, storm surges and extreme wind-forced waves – and those which occur cumulatively or progres-sively over a much longer timescale (also known as "creeping hazards") – sea-level rise and coastal ero-sion (Table 3.1). This section defines and describes the characteristics of all these hazards.

3.1 TSUNAMIS

The word "tsunami" comprises the Japanese words "tsu" (meaning harbour) and "nami" (meaning "wave"). A tsunami is a series of travelling waves of extremely long length and period, usually generated by disturbances associated with earthquakes occurring below or near the ocean floor. Volcanic eruptions, submarine landslides, and coastal rock falls can also generate tsunamis, as can a large asteroid impacting the ocean. The speed of a tsunami's propagation is directly related to the depth of water over which the wave passes. In the deep ocean, a tsunami travels at speeds in excess of 700 km/hr and may have a wavelength of several hundred kilometres. Fig. 4.2 illustrates the travel times of such propagation. The height of a tsunami in the deep ocean is small. In the Indian Ocean event of 2004, the height (peak-to-trough) of the tsunami, measured by satellite in the deep ocean, was only about one metre.

Table 3.1 *The coastal hazards defined*

Hazard		Definition
Rapid-onset hazards	Tsunami	A series of ocean waves generated by displacement of the ocean floor from an earthquake, volcanic event landslide (including submarine landslide) or large asteroid impact.
	Storm surge	A temporary rise in sea level caused by an intense storm and the associated low barometric pressure and strong onshore winds.
	Extreme wind-forced waves	Extreme instances of waves (sea-state) generated by winds somewhere in the ocean, be it locally or thousands of kilometres away.
Cumulative, progressive or "creeping" hazards	Long-term sea-level rise	Global sea-level rise due to thermal expansion of the oceans and the increased melting of land-based ice.
	Coastal erosion	A loss of coastal land, caused by wave action, tidal currents, wave currents or drainage that can be enhanced by each of the other hazards.

While some tsunamis travel over several hours across an ocean before impacting a shore (far-field tsunamis, also known as teletsunamis or distant tsunamis), those generated from sources adjoining shorelines (near-source or local tsunamis) may have travel times of only a few minutes before they impact.

As a tsunami enters shallow coastal waters, it slows down, its wavelength shortens and its height increases. The wave energy is compressed into a shorter distance, creating a series of potentially large waves with speeds of 30–80 km/hr. On their impact at the coast, these waves may have maximum heights (peak-to-trough) in excess of five metres. The arrival of a tsunami wave at the coast may be presaged by a fall in coastal sea level which may temporally expose an unusual expanse of nearshore seabed.

When a tsunami wave inundates a low-lying coastal land area, it creates strong landward currents which exert potentially destructive forces on anything in its pathway. Anything moveable may become entrained. Following the peak of the inundation, its drainage forms strong seaward currents – the draining waters being charged with debris of all sorts (potentially including people) that may be carried far out to sea. Such is the force of some tsunami impacts, that the inundation can reach a height above the wave height at the shoreline. More commonly, on flat ground maximum water levels diminish inland, so that the "run-up" at the inland limit of inundation is lower than the maximum height attained along the way. The run-up is the maximum height of the tsunami inundation – the difference between the elevation of maximum tsunami penetration (the inundation line) and the mean sea level at the time of the tsunami (Fig. 3.1). Often the run-up can be several times larger than the tsunami wave height. On steep coasts the water runs up much like the swash of an ordinary wave on a beach.

For a more detailed overview of tsunamis, the UNESCO-IOC International Tsunami Information Centre (ITIC) brochure "Tsunami, The Great Waves" and the "Tsunami Glossary" are recommended reading (Intergovernmental Oceanographic Commission, 2008a, b).

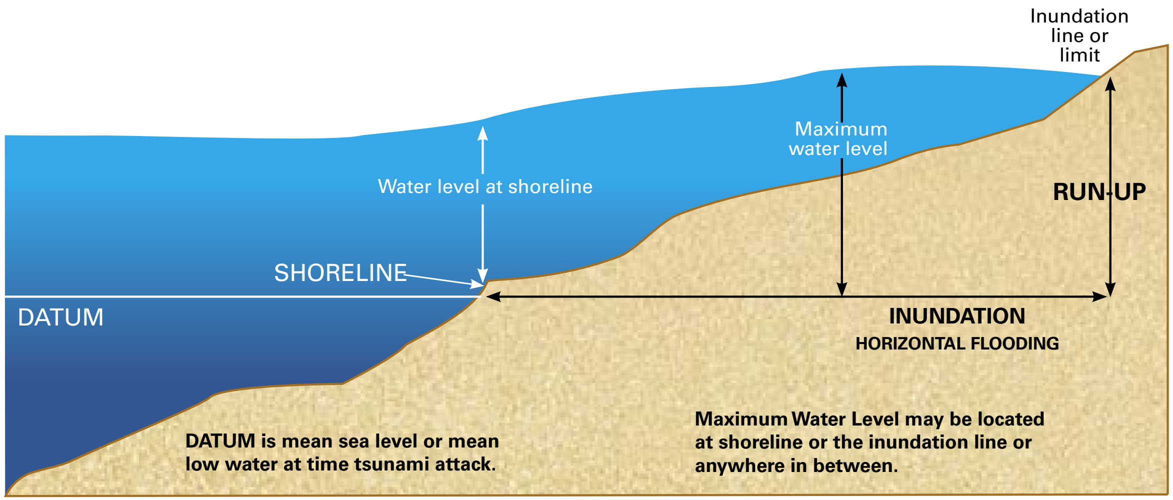

Fig. 3.1 *Tsunami impact at the coast: an explanation of terms.*

Source: UNESCO-IOC International Tsunami Information Centre (ITIC) with modification. (http://ioc3.unesco.org/itic/categories.php?category_no=167)

It is very difficult to attribute a probability to a tsunami impact at the coast. The long intervals between events require data extending over hundreds of years. While databases such as the National Oceanic and Atmospheric Administration (NOAA)/World Data Center (WDC) Historical Tsunami Database (figs 3.2 and 3.3) and the Novosibirsk Tsunami Laboratory Historical Tsunami Database for the World Ocean exist (see Section 3.7), their included data range from high quality instrumental recordings to anecdotal observations. Because of the lack of long-term, systematic observations, it is possible to obtain only approximate recurrence intervals. For most regions of the world, the catalogues of tsunami events cover a period of only 300–500 years. Within the Mediterranean Sea and the Northwest Pacific regions there are older dated records. In many other regions significant events are known to have occurred, many through the recognition of tsunamigenic sand deposits in backshore environments, but not all have been accurately dated, making it difficult to compile comprehensive event summaries. The regional distribution of these events is summarized in Table 3.2.

The uncertainty in evaluating tsunami coastal impacts can be reduced by examining the probabilities of the tsunami source events. Because most tsunamis are earthquake-generated, probabilistic earthquake hazard studies are useful in assessing tsunami hazards. Most earthquake activity occurs along the subduction zones between converging tectonic plates in the Earth's crust, but many other areas are also subject to earthquakes which may generate tsunamis.

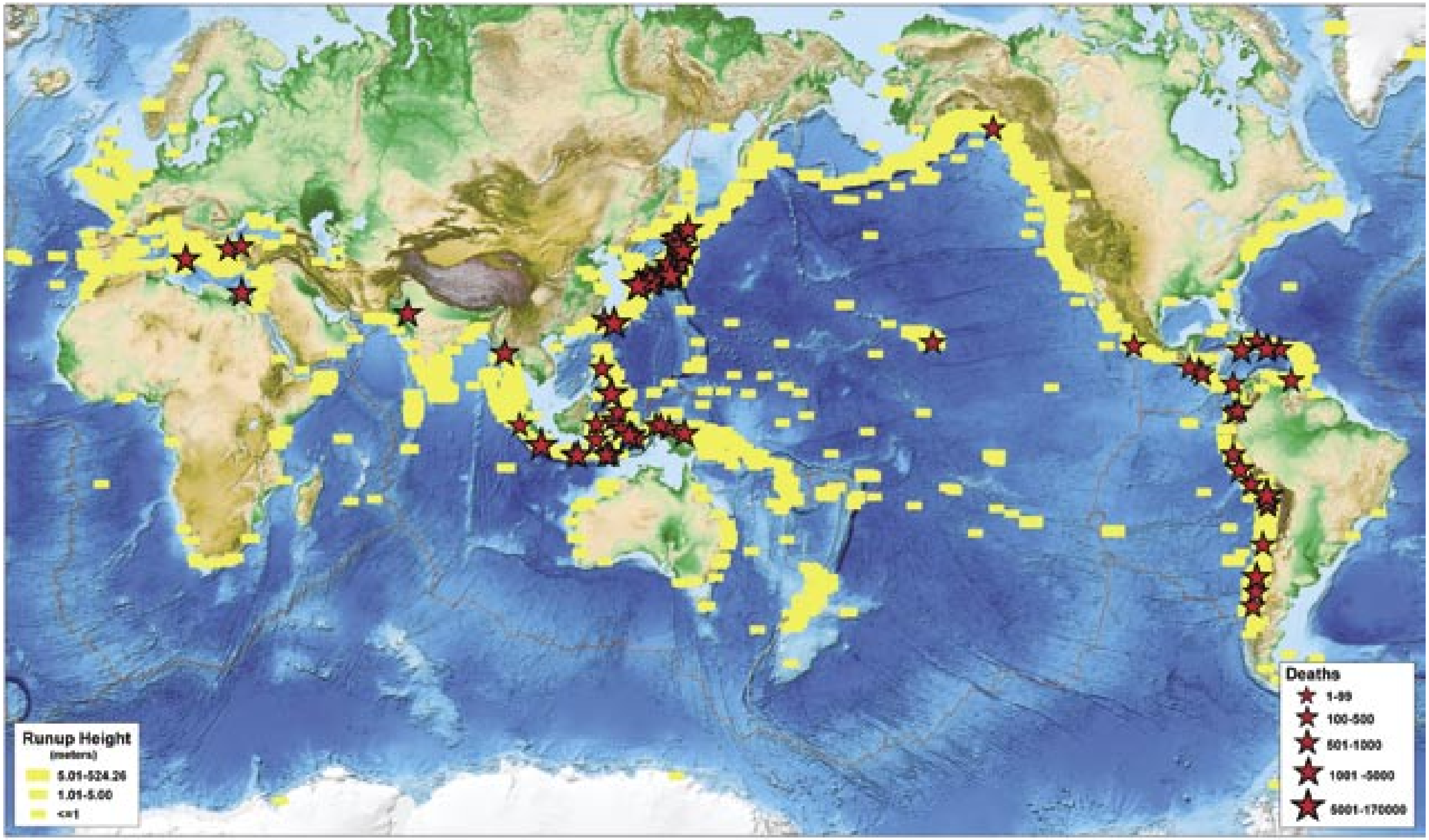

Fig. 3.2 *Distribution of verified tsunami run-ups from the NOAA/WDC Historical Tsunami Database.*

Source: U.S. NGDC. (http://www.ngdc.noaa.gov/hazard/tsu_db.shtml)

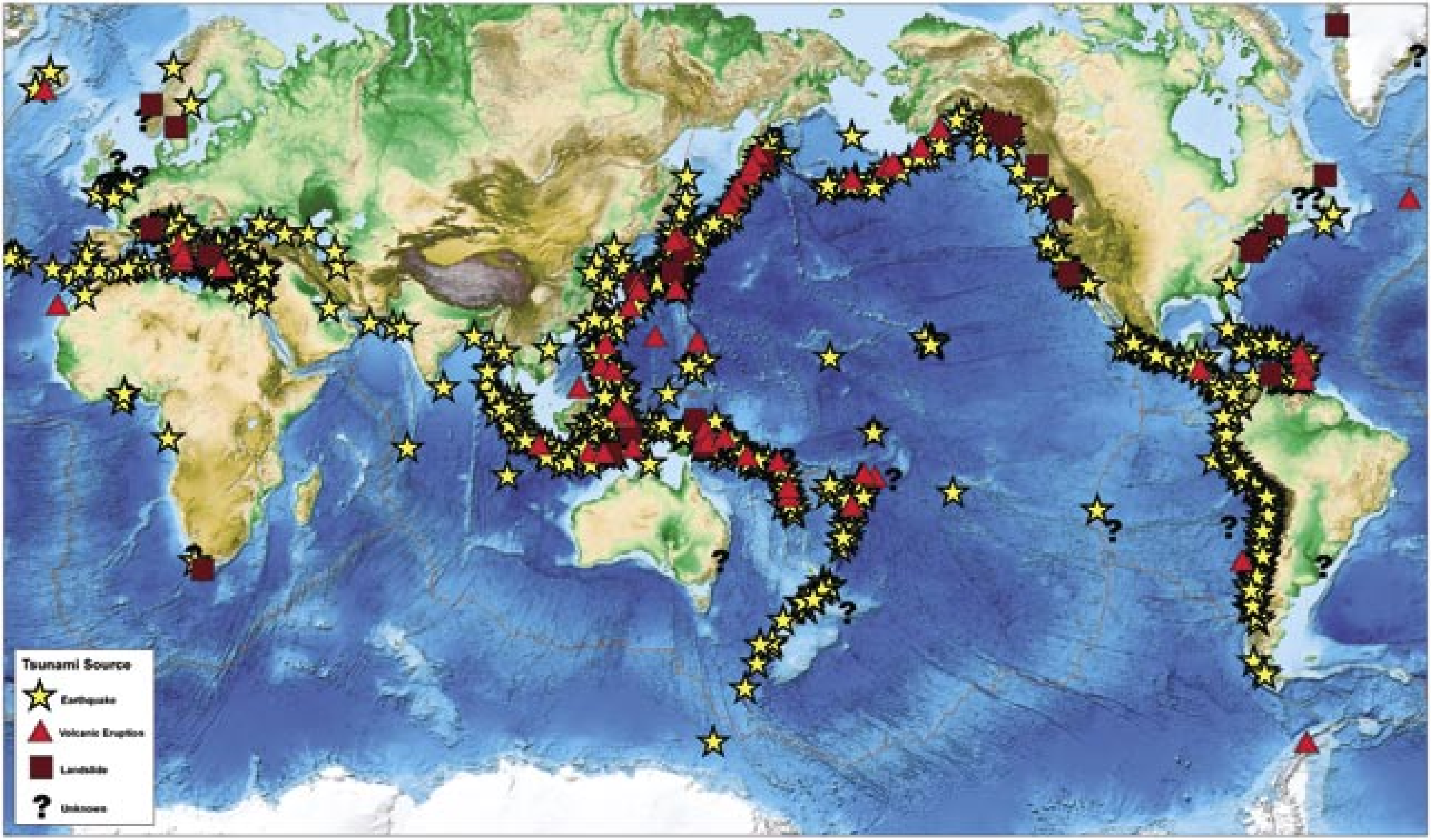

Fig. 3.3 *Verified tsunami sources 2000 B.C.–2008 from the NOAA/WDC Historical Tsunami Database*

Source: U.S. NGDC. (http://www.ngdc.noaa.gov/hazard/tsu_db.shtml)

BOX 3.1 Tsunami facts

- The speed of a tsunami is directly related to the depth of water the wave is passing over; it travels at speeds in excess of 700 km/hr in deep (mid-ocean) water.
- In coastal areas, when there is strong and prolonged shaking from an earthquake, this is a warning that a tsunami may have been generated.
- A sudden lowering of water level at the shoreline is sometimes the first indication that a tsunami is approaching.
- The tsunami run-up on shore is often two to three times higher than the nearshore wave height.
- The height of tsunami run-up can vary significantly over distances as short as a few kilometres along shore.
- Tsunamis can propagate around continents, islands (e.g., Sri Lanka in the Indian Ocean tsunami of 2004), headlands, etc.
- A tsunami event comprises a series of waves; the first wave may not be the largest.
- When a tsunami inundates low-lying coastal areas, the force of the water can destroy buildings and other man-made or natural structures; when the water recedes, currents sweep debris and people out to sea.

Most tsunamis large enough to cause coastal damage are destructive only regionally (distances less than 1000 km) or locally (distances less than 100 km). Only six times in the last 100 years have earthquakes produced tsunamis which had heights (peak-to-trough) greater than five metres at distances greater than 5000 kilometres. These events were the Kuril Islands (1923), Aleutians (1946), Kamchatka (1952), Aleutians (1957), Chile (1960) and the Indian Ocean tsunami (2004). In the twentieth century there were 925 documented tsunami events worldwide: 296 of the tsunamis (294 occurring in the Pacific) had maximum recorded coastal heights of one to five metres (approximately 2.5 events per year) and 95 of them (78 in the Pacific) had maximum recorded coastal heights in excess of five metres. Tsunamis generated by subaerial or submarine landslides and explosive volcanic eruptions can be extremely destructive locally (e.g., Krakatau in 1883, with 36,000 fatalities) but do not disseminate much of their energy far from their sources. Unlike an earthquake- or landslide-generated tsunami, there is generally a period of increased volcanic activity prior to the explosive volcanic eruption, a warning of potential tsunami generation.

BOX 3.2 A tsunami source region off north-western America

Even as recently as 20 years ago, the importance of the Cascadia Subduction Zone (CSZ) along the west coast of the U.S.A. and Canada (40°N–50°N) as a tsunami source region was unrecognized. Through research of tsunami events in Japan and tsunami sediments on the west coast of the U.S.A., it was determined that a mega-tsunami originated from the CSZ in January 1700. Additional research has now identified eight major CSZ events during the last 3 000 years (Atwater et al., 2005).

On-going research and better measurement tools in recent years have enabled government organizations and researchers to identify more historical tsunami events (Box 3.2). Many of these are small events that could not be identified in older analogue records, and, prior to recording instruments, could not be identified by visual observation. Of the documented events, 46% occurred in the twentieth century, 30% in the nineteenth century and only 24% before that. This does not necessarily mean tsunamis are becoming more frequent. It means that the historical record of tsunami events greatly underestimates the number of tsunamis that have occurred over the last several thousand years. Most of the largest damaging events have been captured, but some moderate events, capable of being regionally or locally destructive, have not.

3.2 STORM SURGES

In most regions of the world, storm surges are more frequent than destructive tsunamis and thus are a more predictable coastal hazard. They occur typically in winter, forced by extra-tropical (ET) storms, and in summer to early autumn, by tropical cyclones (TC) (Box 3.3). They have the greatest impact in shallow seas and low-lying coastal areas, where they may be very destructive (Fig. 3.4).

Information on the global geographical distribution of tropical cyclones, including their frequency and intensity, is provided in the WMO Global Guide to Tropical Cyclone Forecasting (see Fig. 3.5).

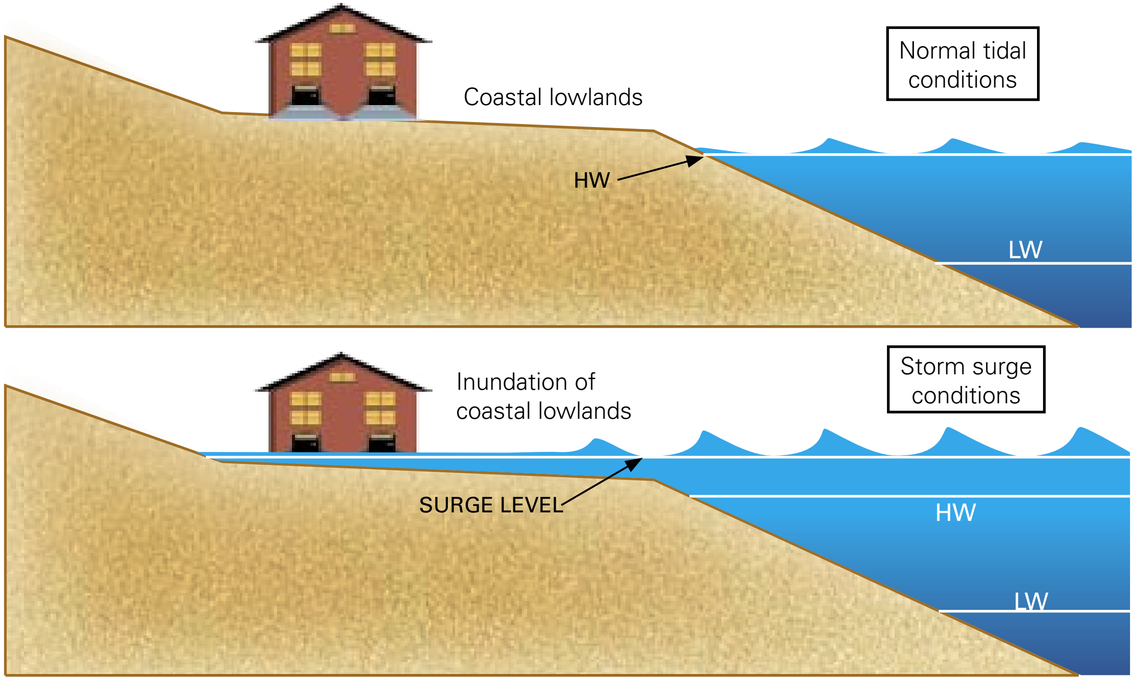

***Fig. 3.4** Storm surge conditions resulting from a Tropical Cyclone (TC) or Extra-tropical Storm (ET) compared with normal tidal conditions HW = High Water; LW = Low Water.*

BOX 3.3 Tropical Cyclones and Extra-Tropical Storms

Tropical cyclones (TCs) are small in geographical extent and very intense. They are characterized by a low pressure system centre and convection that produce strong wind and heavy rain. The rotation of the Earth is also important, hence they are not generated in the equatorial belt - ±5° latitude. They are also able to produce high, wind-forced waves and damaging storm surges. TCs develop over large bodies of warm water and feed on the heat released when moist air rises and its contained water vapour condenses. When TCs approach the coast, they can produce high flood levels within a coastal region extending over several tens of kilometres. TCs are known as hurricanes (U.S.A.), typhoons (Northwest Pacific; the Japanese refer to them also as "reppus"), depressions (Indian Ocean, Bay of Bengal and Arabian Sea), willi-willies (Australia), baguios (Philippines) and asifat (Arabia). Their geographical distribution is shown in Fig. 3.5.

Extra-tropical (ET) storms extend over hundreds of kilometres around a region of very low atmospheric pressure. They may affect large stretches of coastline for several days. The largest storm surges occur when prolonged, strong winds blow along the coast and force water shoreward when, in the northern hemisphere, the shoreline is on the right of the wind direction and, in the southern hemisphere, on the left. Due to the storm's long duration, elevated water levels are enhanced during periods of high tide.

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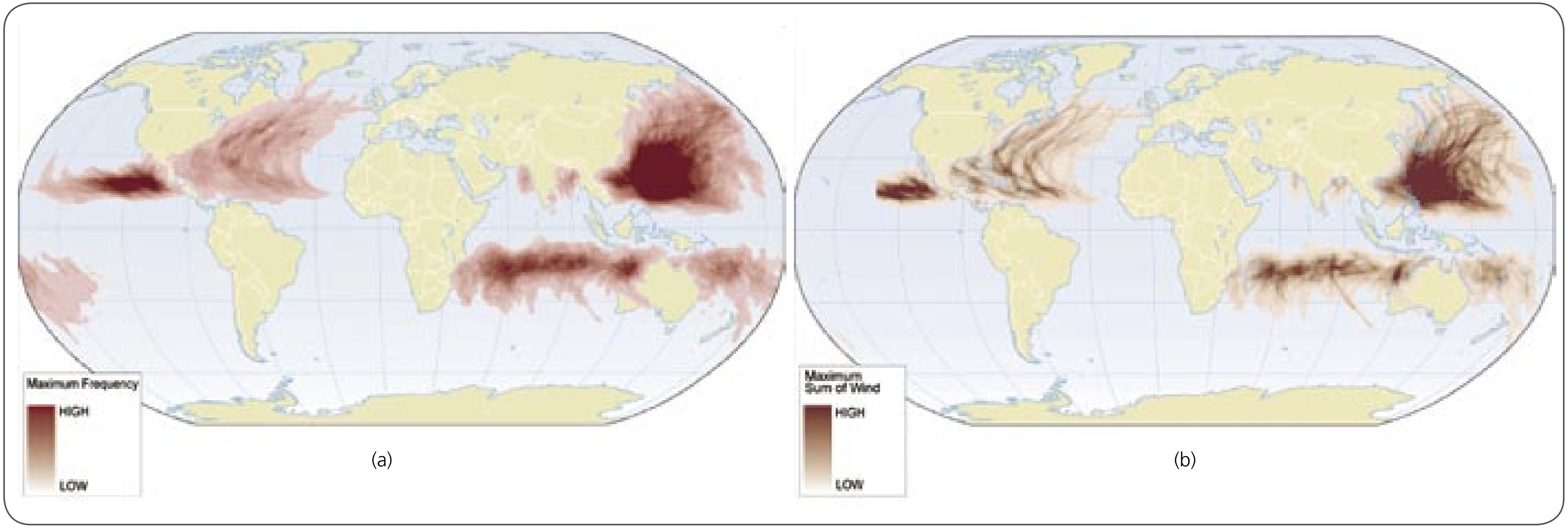

Fig. 3.5 *Global geographical distribution of tropical cyclones (1979–2003) – (a) frequency; and (b) wind sum.*

Sources: UNEP/DEWA/GRID-Europe ((a) http://www.grid.unep.ch/data/download/tc_freq.gif and (b) http://www.grid.unep.ch/data/download/tc_wsum.gif)

BOX 3.4 Heights of storm surges

Until recently the largest storm surge on the U.S.A. Gulf Coast, with a maximum surge height of 7 m, was produced by Hurricane Camille in August 1969. Hurricane Katrina in 2005 produced an 8.2 m storm surge, which penetrated up to 10 km inland and up to 20 km along bays and rivers. The worst storm surge, in terms of loss of life, was the 1970 Bhola cyclone and, in general, the Bay of Bengal is particularly prone to storm surges. The cyclones of 1970 (Bhola), 1991 (Tropical), 1999 (Orissa) and 2007 (Sidr) are some of the examples, producing maximum storm surges of 7.8, 8.8, 8.1 and 8.4 m respectively. Cyclone Nargis (2008) was one of the worst cases in terms of loss of life and properties in Myanmar, although the maximum recorded surge height was around 4 metres (Fig. 3.6).

Storm surges are widely distributed geographically, and their amplitudes and times of occurrence vary considerably. In these guidelines, a storm surge is the elevation of water generated by weather systems above (or depression below) the normal astronomical tide. A storm tide, on the other hand, is the total elevation (including the astronomical tide) above or below a standard datum. Extreme low-water surges are known as negative surges, and, while not generally destructive, they can be a navigation hazard in harbours and coastal areas.

The ocean's response to a weather system in shallow coastal waters is quite different to that in the deep ocean. When a weather system is moving over a water body, there are essentially two forcing fields – the atmospheric pressure gradient and the stress of the wind on the water. In deep waters, far from a coast, the rotation of the earth causes the surface wind stress from a weather system to create a rotating mound, or vortex of water. This is pushed towards the coast – a phenomenon referred to as "wind set-up" – causing a pile-up of water at the coast that becomes a storm surge. In deep waters, the increase in ocean surface elevation is due to the hydrostatic uplift in response to the low central pressure (known as the "inverted barometer" effect) and is relatively small. As the weather system approaches a coast, dynamic effects become pronounced. Shallowing local bathymetry and continuous wind stress substantially amplify the surge height. Unlike tsunamis or short-wavelength, propagating wind-waves, a translating surge wave does not break in shallow waters.

The size of a weather system, its translation speed, its residence time on the continental shelf and its track with respect to the coast, together with local bathymetry and coastal topography all play significant roles in surge generation and the consequent flooding of coastal lowlands (boxes 3.4 and 3.5). The case of Cyclone Nargis and its storm surge impact on the Irrawaddy delta area of Myanmar serves as an example (Fig. 3.6). The surge usually consists of a single passing wave that elevates or depresses (negative surge) the normal tide height. However, because of its long wavelength, the impact on the water level can persist for several hours. In some special situations, especially for cyclones moving parallel to a coast, secondary waves or resurgences can form behind the main surge. Although there are several complicating factors in association with the ocean-coastal state, the amplitude of the storm surge is generally inversely proportional to the water depth. Thus, the shallower the water, the greater is the surge amplitude. Interactions with tides, river flow and wind-forced waves can also modify the storm surge amplitude (see Section 3.6).

Surges can be computed directly at coastal tide gauges (e.g., the GLOSS sea-level network) by subtracting the predicted astronomical tide from the observed water-level record. High water mark (HWM) surveys are also used to identify and, where possible, flag the inland water levels of storm surges. Identifying and qualifying HWM and determining how well these marks represent the peak is often subjective and can depend upon the type of mark (e.g., debris, seed, mud, or stain), the spread or thickness of the mark, and whether the mark was created in a protected environment (such as the interior wall of a building), or an unprotected environment (such as an exposed bridge piling or fence post).

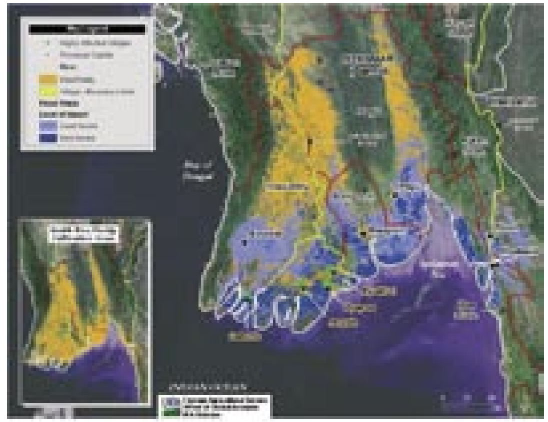

Fig. 3.6 *Cyclone Nargis storm surge inundation analysis map: Myanmar, May 2008*

Source: U.S. Department of Agriculture, Foreign Agricultural Service (http://www.pecad.fas.usda.gov/highlights/2008/05/Burma_Cyclone_Nargis_Rice_Impact.htm)

3.3 EXTREME WIND-FORCED WAVES

In contrast with tsunamis and storm surges, wind-forced waves (usually called 'sea-state' or 'wind-waves') are almost always present at sea. These waves, typically with periods of one to 30 seconds, are generated by winds somewhere in the ocean, be it locally or thousands of kilometres away.

The largest wind-forced waves, known as swell waves, occur typically in the open ocean. However, they can cause significant damage to exposed coasts. Fig. 3.7 shows the January and July climatology of significant wave height (SWH) covering the World Ocean from 80°S to 80°N for the period 1958–2005 (spatial distribution of SWH). In the North Atlantic mid-latitudes, the highest SWH is observed in January. In the South Indian Ocean and South Pacific the highest SWHs are identified

BOX 3.5 Storm surges in north-west Europe

The Baltic, being virtually an enclosed sea and subject on occasion to severe storms, is subject to large surges. In 1924 St. Petersburg was flooded by a surge 4 m high. The North Sea, with its southern extremity almost closed, responds readily to northerly winds; the vulnerable coastlines of the German Bight, eastern England and more particularly the Low Countries have been inundated repeatedly by great surges. The storm surge of 1953 resulted in many deaths in The Netherlands and England. The Hamburg disaster of 1962 was more localized, mainly affecting the German Bight and the River Elbe, where the surge reached more than 3 m in height.

in July. Locally, in the western Arabian Sea, high July values of SWH were observed. Changes in wind patterns as a part of global climate change are widely anticipated, and these will ultimately alter wave regimes. Indeed, evidence indicates that wave heights have been changing over the last 40 years, although a link to global warming is yet unproven.

In deep waters, wave heights (crest-to-trough) of over 15 metres are not unusual. These waves break in water depths of approximately 20 metres. In shallow waters, the heights and directions of waves are modified by the bathymetry. If the nearshore waters are deep and the shore itself is a near-vertical cliff rising from deep water, then waves can reflect from the cliff instead of breaking. They may also overtop the cliff causing extensive damage immediately inland. When combined with the water levels increased by a storm surge, extreme consequences may result (see Coincident hazard events, this section).

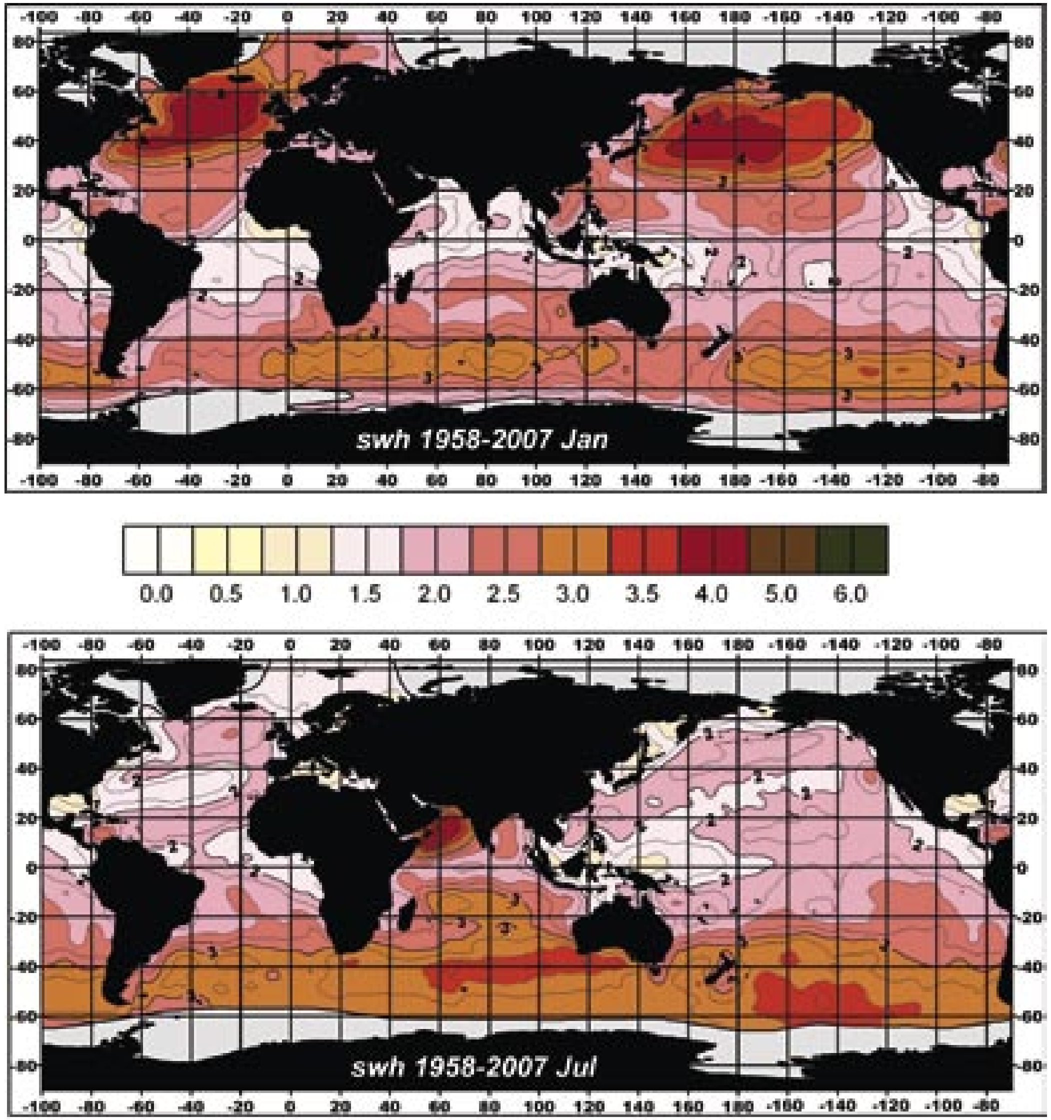

***Fig. 3.7** Climatology of significant wave height (SWH) over the Global Ocean for the period 1958–2005 Upper panel – January; Lower panel – July; derived from visual wave data.*

Source: Global Atlas of Ocean Waves (based on Voluntary Observing Ship (VOS) observations). (http://www.sail.msk.ru/atlas/)

Damage to coastal structures arises from prolonged exposure to swell waves, which causes erosion of foundations and undermining of coastal structures. This is especially a danger with large, slow-moving weather systems and in circumstances of coincident high tidal states (Box 8.7). If the coast has an extensive and shallow continental shelf, the swell waves will break well offshore and cause only minor residual shore effects. New wind waves can reform over the continental shelf, but their heights are limited by the shallow water. Breaking waves at the shore often force water inshore, leading to a phenomenon known as wave set-up. For shallow beach frontages, such wave set-up can significantly increase the impact of storm surges. Local obstructions, such as angled sea-walls or small inlets can focus the wave energy into a small region with dramatically increased effects.

The simplest method to characterize waves is to make visual observations of height and period. A traditional source of wave information in deep ocean has been the Voluntary Observing Ship (VOS) Program (Fig. 3.7), and, at the coast, from coastal stations. JCOMM has engaged in the development of a database of extreme wave events, which provides a useful reference to various studies and applications, including modelling, monitoring and predicting extreme events and their impacts.

3.4 SEA-LEVEL RISE

Sea-level rise is a progressive or "creeping" hazard that is affecting most of the world's coasts. Low-lying coastal areas, including deltas (Fig. 3.8) and many Small Island States (SIS), are particularly impacted (see Box 5.6). The two major causes of global sea-level rise are thermal expansion of the oceans and the increased melting of land-based ice. Thermal expansion is expected to contribute more than half of the average rise, but land ice will lose mass at an increasing rate as the century progresses.

According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, there is strong evidence that global sea level has risen gradu-

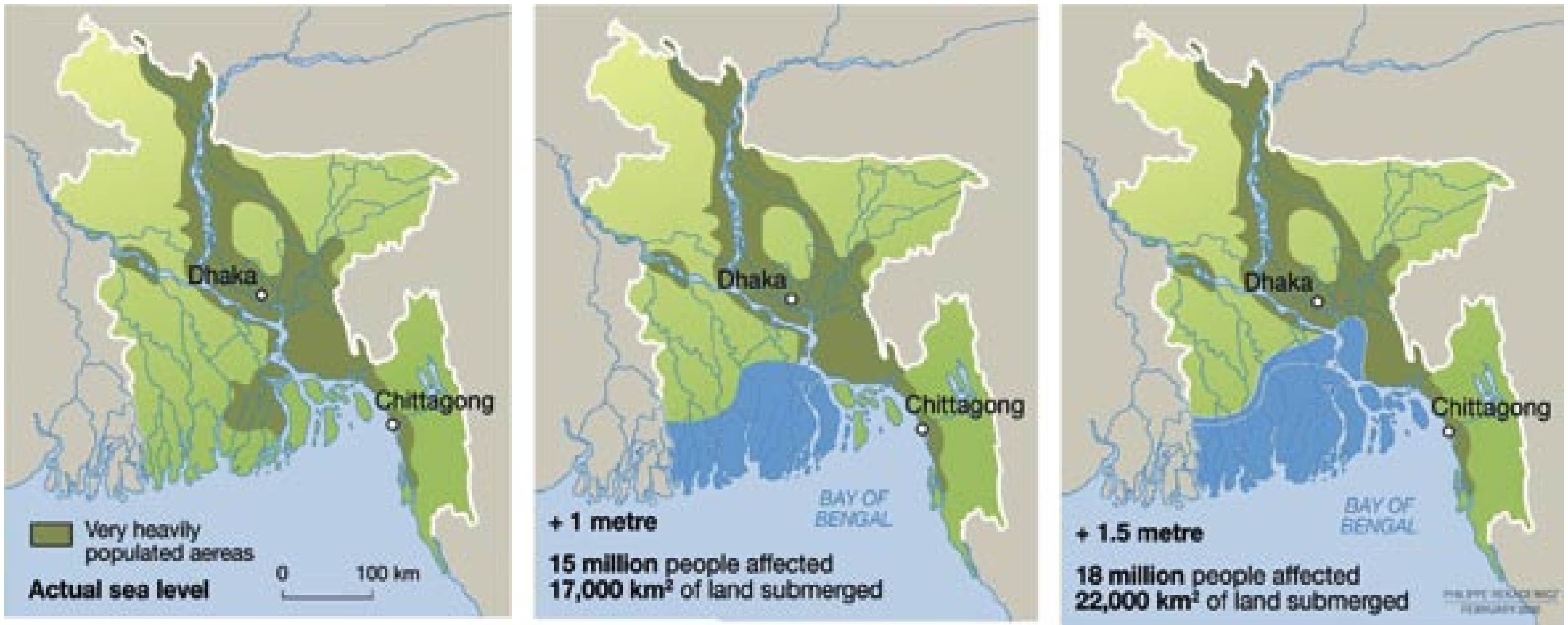

Fig. 3.8. *The potential impact of sea-level rise on Bangladesh*

Sources: Dacca University; Intergovernmental Panel on Climate Change (IPCC). Cartographer: GRIDA. Courtesy UNEP/GRID-Arendal. (http://maps.grida.no/go/graphic/impact-of-sea-level-rise-in-bangladesh1) ally over the past century and that it is currently rising at an increased rate. A number of researchers have estimated with reasonable agreement a global sea-level change rate over the past century of 1.7 ± 0.5 mm/yr. Because of local tectonic and environmental conditions, local rates of sea-level rise can be greater than this, or can even indicate a lowering of mean sea level (MSL) relative to local reference points.

A recent increase in the rate of sea-level rise has been observed by satellite altimeters, which have also provided new insight into the complex geographical patterns of sea-level change. The current rate of rise computed from these data (1993–2003) is indicated to be 3.1 ± 0.7 mm/yr. By 2090 the global sea level is expected to be 0.22 m–0.44 m above the 1990 level and to be increasing by about 4 mm per year (IPCC SRES scenario A1B).

Rising sea levels will increase the frequency of coastal flooding, exacerbate coastal erosion and worsen the impacts of tsunamis, storm surges and extreme wind-forced waves. While the long-term impacts of a rising MSL are significant, it is the rapid-onset, extreme events that affect coastal communities most directly. A global analysis of sea-level data at 141 stations showed evidence of a worldwide increase in extreme sea levels since 1975. However, as with the global rate of change of MSL, there are regions where a global indicator is less useful than a regional indicator. Unlike MSL, statistics on extreme tide conditions are not always rigorously compiled, meaning that in many instances annual extremes and trends due to changing climatic conditions are not always known (see Box 3.6).

Measurements of sea-level change rely on networks of permanent water level stations throughout the world. Most of these stations were established to support maritime commerce and are therefore located in major harbours and predominantly in the northern hemisphere. This shortcoming has been alleviated in recent years through satellite altimetry data, which provide a more complete global picture, and signals not masked by the effects of estuaries and local tectonic activity. Although some sea-level records are more than 100 years-long, the majority of station records extend over less than thirty years, making difficult the detection of long-term trends. Global, long-term sea-level data may be accessed from the PSMSL and GLOSS data holdings (see Section 3.7).

In addition to the projected rates of sea-level rise, inter-annual and inter-decadal effects need to be considered in their impact on storm surges. For example, sea-level records in the Northeast Atlantic exhibit a clear relationship to the air pressure and wind changes associated with the North Atlantic Oscillation (NAO). Changes in these regional "norms" could have a significant effect on the magnitude and frequency of storm surges. In the Pacific and elsewhere, the El Niño-Southern Oscillation (ENSO) is a prominent source of inter-annual variability in weather and climate and can temporarily raise sea levels for periods of several months.

It is important to recognize the importance of historical and present-day tide gauge networks for much of the sea-level data contained in global, regional and national databases. It is also important to recognize the importance of maintaining and expanding these

BOX 3.6 Storm surges and extreme water levels: present and growing threats

Astronomical tides are caused by the pull of the sun and the moon and do not normally produce problems in themselves as they occur so regularly. Storm surges are produced by the weather due to low barometric pressure and wind stress on the sea surface. The landfall of major tropical storms can produce surges of many metres elevation, combined with significant wave activity, such as occurred in Hurricane Katrina, U.S.A. in 2005, and Cyclone Nargis, Myanmar in 2008. Around north-west Europe, surges are smaller but when they coincide with the highest astronomical tides, devastating floods can result as occurred in the U.K. and The Netherlands in 1953 and the German Bight in 1962.

In general, good flood defences are now provided for populated areas around north-west Europe's coasts, and the risk of flooding is quite low. However, the risk is dynamic and needs to be constantly reviewed. For example, sea-level observations made at Newlyn, England between 1916 and 2000 indicate that a level of +3.1 m is reached on average once every 50 years. With a 0.2 m rise in MSL, that level will be exceeded on average approximately once every four years. The impact of rising sea levels at Newlyn is a useful illustration of how changes in MSL change the chances of extreme sea levels. Unfortunately, in many parts of the world, observational data are insufficient to estimate return periods for either present or future extreme sea levels.

Fred Stephenson. See also Box 8.2

networks to provide accurate water-level data for both rapid-onset events and sea-level rise. In addition to improved water-level instrumentation, new tools such as GPS and satellite imagery are also providing information which increases our understanding of these natural hazards.

3.5 COASTAL EROSION

Most of the world's low-lying, sandy shorelines have retreated during the past century and sea-level rise is one underlying cause. In the U.S.A., one half or more of the Mississippi and Texas shorelines have eroded at average rates of 2.6–3.1 m/yr since the 1970s, while 90% of the Louisiana shoreline eroded at a rate of 12.0 m/yr. In Nigeria, local retreat rates up to 30 m/yr are reported.

Globally, sea-level rise will intensify erosion of coastal land comprising beach and delta plains, also of cliffed coasts composed of soft rock, although in all these cases the local response is likely to depend on the degree of protection afforded by beach sediments.

In the Canadian Arctic, some parts of Beaufort Sea coastline are presently eroding at rates in excess of 5 m/yr. With changing climatic conditions, larger areas of the Arctic Ocean are ice-free in summer and are remaining ice-free for longer periods. Along low-lying coastlines, this will increase the impact of storm surges and increase the rates of coastal erosion.

3.6 COINCIDENT COASTAL HAZARD EVENTS

An important aspect of hazard assessment is a consideration of the probability of two or more hazard events occurring simultaneously. Also, the risk of flooding due to a storm surge or a tsunami is strongly affected by the state of the tide. A storm surge or extreme wave hazard which strikes a coastal area at the time of an extreme high tide will be a significantly greater flood risk than a similar event which occurs at the time of a low tide. Because tidal fluctuations are well known in most coastal areas, and because storm surges are fairly common events, it is possible to estimate extreme levels by computing joint tide-surge probability.

In coastal flood plains and estuaries, there is the potential for river flooding and storm surges to occur simultaneously. Deltas are widely recognized as being highly affected by changes in sea level and by changes in freshwater runoff from the land. During the annual hydrometric cycle of most rivers there is a freshet period when flooding can occur. If, during this period, there are high water-levels due to extreme high tides and/or a storm surge event, this high water will act like a dam to downstream river flow, forcing the water to find other courses and possibly overtopping or destroying dykes and flooding low-lying areas. Generally storm surges resulting from tropical cyclones do not coincide with river flooding from the same cyclone. However, the corresponding coincidence with extra-tropical storm surges is not uncommon.

3.7 GLOBAL DATA SETS AND OTHER INFORMATION SOURCES

Data sources and general guidance information listed by hazard type

Tsunamis

IASPEI. 2002. Summary of, New Manual of Seismological Observatory Practice. GeoForschungsZentrum Potsdam, 2002. Available at: http://www.ioc-tsunami.org/files/Neam_meeting3_bonn/SOP%20IASEI%20manual%20rev%20070131%20%282%29.doc (Accessed 16 February 2009.)).

Intergovernmental Oceanographic Commission. 2008a. Tsunami, The Great Waves, Revised Edition. Paris, UNESCO, illus. IOC Brochure 2008-1. 16 pp. Available at: http://ioc3.unesco.org/itic/contents.php?id=169

Intergovernmental Oceanographic Commission. 2008b. Tsunami Glossary, 2008. Paris, UNESCO. IOC Technical Series, 85. Available at: http://ioc3.unesco.org/itic/contents.php?id=328

IOC unified tsunami website (IOC Tsunami Home). Available at: http://www.ioc-tsunami.org/ This website provides information on the IOC tsunami programme, the Regional Tsunami Warning Systems (RTWS) and the National Contacts for RTWS.

Novosibirsk Tsunami Laboratory Historical Tsunami Database for the World Ocean. Available at: http://tsun.sscc.ru/On_line_Cat.htm

UNESCO. 2009. *Tsunami risk assessment and mitigation for the Indian Ocean; knowing your tsunami risk – and what to do about it*. IOC Manuals and Guides, No. 52, Paris, UNESCO.

U.S. NGDC. NOAA/WDC Historical Tsunami Database. Available at: http://www.ngdc.noaa.gov/hazard/tsu_db.shtml
This database contains information on tsunami events from 2000 B.C. to the present in the Atlantic, Indian, and Pacific oceans; and the Mediterranean and Caribbean seas. It provides two related search facilities. The "Tsunami Run-up Search" provides information on locations where tsunami effects have occurred (Fig. 3.2). For specific locations these data include arrival date and time, travel time, maximum water heights, horizontal inundation distances, deaths, injuries, and damage. The "Tsunami Source Event Search"

provides information on tsunami sources. These data include location, date, and time, event magnitude, maximum water height, total number of deaths, injuries and damage for the event (Fig. 3.3). The database is easy to access and use. In addition to information on individual tsunami events, it contains tsunami images, tide-gauge records, tsunami publications and links to other useful tsunami sites.

Storm surges

Europa. 2007. Atlas of Flood Mapping. Annex 2. Handbook on good practice on flood mapping in Europe. Available at: http://ec.europa.eu/environment/water/flood_risk/flood_atlas/index.htm

JCOMM. (in preparation). JCOMM Guide to Storm Surge Forecasting. Further information available at the JCOMM website: http://www.jcomm.info This guide describes numerical methods used for storm surge prediction; a review of such methods and the current available operational storm surge forecasting, including ensemble forecasts.

WMO. 1993. Global Guide to Tropical Cyclone Forecasting, document TCP-31. Available at: http://www.wmo.ch/pages/prog/www/tcp/Publications/listofpub.html This guide provides information on the global geographical distribution of tropical cyclones, including their frequency and intensity.

Examples of storm surge inundation maps:

North Carolina, U.S.A.: Available at: http://www.hurricanetrack.com/ncstormsurge/comaps.html

Extreme wind-forced waves

Global Atlas of Ocean Waves (based on VOS observations). Authors: S. K. Gulev, V. Grigorieva (P. P. Shirshov Institute of Oceanology, Russian Academy of Science) and A. Sterl (Royal Netherlands Meteorological Institute, De Bilt). Available at: http://www.sail.msk.ru/atlas/

This Atlas is the result of a co-operative project, funded by European Union (INTAS grant 96-2089) "Intercomparison of ocean waves from in-situ measurements, voluntary observing ship data, remote sensing, and modelling".

GOOS – the IOC Global Ocean Observing System. Available at: http://www.ioc-goos.org/

JCOMM. (in preparation). Extreme Wave Database – a database of extreme wave events, which provides a useful reference to various studies and applications, including modelling, monitoring and predicting extreme events and their impacts. This database provides a comprehensive source of all instrumented wave measurements (in-situ and remote-sensing) for known extreme wave events (both recent historical events and on-going). Further information available at: http://www.jcomm-services.org/JCOMM-Extreme-Wave-Data-Base.html

WMO. 1998. Guide to Wave Analysis and Forecasting. A detailed review of the existing wave models. 170 pages.

Sea-level rise

GLOSS: The Global Sea Level Observing System (GLOSS) is an international programme conducted under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the WMO and the IOC. GLOSS aims at the establishment of high quality global and regional sea-level networks for application to climate, oceanographic and coastal sea-level research. The main component of GLOSS is the "Global Core Network" (GCN) of 290 sea-level stations around the world for long-term climate change and oceanographic sea-level monitoring. Available at: http://www.gloss-sealevel.org/

PSMSL – Permanent Service for Mean Sea Level. Proudman Oceanographic Laboratory, N.E.R.C. United Kingdom. The PSMSL was established in 1933, and is the global data bank for long-term sea-level change information from tide gauges. The PSMSL collect data from several hundred gauges situated all over the globe. The global network of tide gauges that contribute data to the PSMSL can be viewed using Google Earth. Available at: http://www.pol.ac.uk/psmsl/datainfo/

UNESCO. 2006. Manual on Sea Level Measurement and Interpretation, Volume IV- an update to 2006. IOC Manuals and Guides, No. 14; JCOMM Technical Report, No. 31; WMO/TD, No. 1339, 80 pages. Available at: http://www.pol.ac.uk/psmsl/manuals/manual_14_final_21_09_06.pdf (Accessed 16 February 2009.) Includes information on methods for estimating extreme sea levels.

University of Hawaii Sea Level Center - UHSLC web site: Available at: http://ilikai.soest.hawaii.edu/uhslc/status.html

General ocean data

IODE – the IOC's International Oceanographic Data and Information Exchange was established in 1961 to enhance marine research, exploitation and development by facilitating the exchange of oceanographic data and information between participating Member States and by meeting the needs of users for data and information products. Available at: http://www.iode.org/

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Fritz, H. M., Borrero, J. C., Synolakis, C. E. and Yoo, J. 2004. Indian Ocean tsunami flow velocity measurements from survivor videos. *Geophysical Research Letters*, No. 33, L24605.

Gower, J. 2007. The 26 December 2004 tsunami measured by satellite altimetry. *International Journal of Remote Sensing*, Vol. 28, No. 13, pp. 2897–2913

Gusiakov, V. K. 2008. Tsunami history - recorded. A. Robinson and E. Bernard (eds), *The Sea*, Vol. 15. Harvard University Press, Cambridge, U.K., pp. 23–53.

Harris, D. L. 1956. Some problems involved in the study of storm surges. NHRP Report, No. 4, U.S. Weather Bureau, 30 pages.

Henderson-Sellers, A., Zhang, H., Berz, G., Emanuel, K. and Grey, W. 1998. Tropical cyclones and global climate change: a post-IPCC assessment. *Bulletin of the American Meteorological Society*, Vol. 79, No. 1, pp. 19–38.

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4 IDENTIFYING AND QUANTIFYING THE HAZARDS

ICAMPHASES	I	II	III	IV
	STEP 2			

This section aims firstly to provide countries with guidance on assessing of the likelihoods of their coasts being impacted or otherwise affected by each of the hazards. Secondly, it sets out methodologies for countries to appraise frequencies of recurrence (or rate of occurrence) of the hazard events and the magnitudes of those events. Thirdly, it describes how countries can determine the likely geographical extents of the hazards' physical impacts – the hazard exposure in their coastal management areas under specified scenarios.

4.1 IS THERE PUBLIC AND POLITICAL AWARENESS OF THE HAZARDS?

The inclusion of coastal hazard management (including hazard assessment) within an existing or new coastal area management plan presupposes support through public and political awareness and concern in respect of the hazards. The development of such awareness forms part of Step 1 of Phase I of the ICAM process. Awareness may be enhanced by, e.g., first-hand experience or media coverage of damaging events; also by external drivers at the regional level, such as the European Union's Floods Directive (see sections 2 and 6).

4.2 WHAT BASELINE KNOWLEDGE IS NEEDED?

Baseline knowledge of the coastal hazards (Table 3.1) – their origins, the locations and areas most prone to their impact, their frequencies and magnitudes, and their observed and potential physical impacts – is essential to the development of effective Integrated Coastal Area Management (Section 2.1). Evaluation of the hazards forms a fundamental part of the broadly based acquisition of background information and baseline data within Phase I of the ICAM process (figs 1.1 and 1.2). An awareness of the distribution of potential hazards and their causes is a key part of this evaluation (Table 4.1).

The coastal hazards covered by these guidelines and described in Section 3 comprise rapid-onset events, including tsunamis and storm surges, and the creeping hazards of global sea-level rise and coastal erosion. Historical and contemporary records clearly show which countries are prone to the rapid-onset hazards, while maritime countries worldwide are generally aware that the creeping hazards are also issues of concern. Forecasting the magnitude of a potential hazard and its likely frequency (or rate of occurrence in the cases of creeping hazards) is another key knowledge element, permitting countries to appraise the probability (or timescale) of a hazard event.

Knowledge of the physical parameters, drivers and constraints of the coastal hazards, as well as the likely hazard frequency or rate of occurrence, strengthens the validity of estimates of the potential impacts of those hazards on coastal areas. This information is essential to the assessments of the risks in respect of the hazards and, in turn, to the development of an effective Management Plan in Phase II of the ICAM process (figs. 1.1 and 1.2). The IOC has an important role in facilitating these procedures, in particular through capacity building (Box 4.1).

BOX 4.1 Capacity building activities in the Indian Ocean

In many tsunami-affected countries, one of the main impediments to accurate calculation of tsunami inundation and run-up is the lack of adequate coastal bathymetric data. These remain key inputs for tsunami modelling and one of the critical sources of uncertainty affecting model results. For this reason, strengthened capacity to collect accurate bathymetric data is a fundamental aspect for many countries' preparedness to tsunamis and other ocean-based extreme events such as storm surges.

COAST-MAP-IO is contributing to developing this capacity in the 12 following countries: Bangladesh, Comoros, Kenya, Madagascar, Maldives, Mauritius, Mozambique, Myanmar, Seychelles, Sri Lanka, Tanzania, and Thailand. Implementation began in March 2007 with assessment missions in 10 of the countries to collect information on key partners, their priorities and needs, and existing capacities and data.

The COAST-MAP-IO kick-off meeting took place in October 2007 and an approved work plan was successfully implemented during 2008. Six different workshops on bathymetric data collection, processing and management, and inundation map construction were organized and conducted by Indian National Hydrographic School, Indian National Centre for Ocean Information Services (INCOIS) and the Training and Education Centre Hydrography at the Alfred Wegener Institute in Germany. Sixty-five specialists were trained. Hardware and software for inundation map construction were supplied to all 12 countries involved. Capacity building in coastal bathymetry was considerably enhanced.

Dmitri Travin

Key considerations

Coastlines around the world differ in their degrees of exposure to the various hazards. Thus, some countries are much more prone to tsunamis or to storm surges than others, and, even within countries, some coastal areas are more prone than others. For geographically complex coasts, the magnitude of a hazard event may vary considerably at the local scale depending on the specific land and sea-bed features, including natural and man-made coastal defences (see Box 6.1).

For each designated ICAM management unit, whether at the national, district or local level, it is necessary to determine:

- Which specific hazards are likely to affect the coast, and which particular parts of the coast are likely to be most affected?
- What are the probabilities of occurrence of specific hazard events (their likely frequencies and their likely magnitudes, or their rates in the cases of the creeping hazards)? (see Table 4.1)
- What are the limits of coastal land likely to be affected by those events – by inundation, by erosion?

Storm surges and extreme wind-forced waves have return periods which can be forecast in months or years with reasonable confidence based on historical data and assuming the generating forces change little with time. However, recent observations showing changing oceanic and atmospheric conditions contribute uncertainty to our analysis of these extreme events. The evaluation of the "creeping" hazards of coastal erosion and sea-level rise, being based largely on instrumental or observational monitoring over a range of timescales, can also be achieved through access to local, regional and global monitoring data. The evaluation of tsunamis, conversely, may be problematic in many coastal areas around the world, particularly where return periods may be measured in centuries. A further challenge in hazard appraisal lies in the evalua-

Table 4.1. *Characteristics of the hazards creating coastal inundation*

HAZARD	Tsunami	Storm surge	Extreme wind-forced waves	Long-term sea-level rise	Coastal erosion
Cause(s)	Earthquakes (80%), volcanoes (6%), landslides (3%), meteorological conditions (1%), 10% unknown origin	Weather systems – tropical cyclones (TC) and extra-tropical storms (ET)	Weather systems – wind stress, tropical cyclones (TC) and extra-tropical storms (ET)	Climate change – warming of world oceans, melting land-based ice	Wave action, tidal currents, wave currents or drainage; sediment discharge reduction due to river flow and land-use changes
Geographical distribution	Pacific Ocean (62%), Mediterranean (22%), Atlantic Ocean and Baltic Sea (10%), Indian Ocean (6%)	Global, but greatest impact in shallow seas and low-lying coastal areas	Global, but greatest impact in shallow seas and low-lying coastal areas	Global, but with some variation in rates due to local geological processes	Global, but greatest impact in low-lying coastal areas
Frequency	Decades to centuries	Annually to decadal, typically in winter (Extra-tropical storms, ET) and summer to early autumn (tropical cyclones, TC)	Annually to decadal, typically in winter (ET storms) and summer to early autumn (TC)	Ongoing but accelerating	Ongoing but accelerating; typically worst in winter (ET storms) and summer to early autumn (TC)
Magnitude	Run-up ranges from cm to several metres	Typically 1–2 m; up to 9 m for ET storms	Typically 1–2 m; up to 18 metres	Average global rate is +1.7 ± 0.5 mm/yr; + 4 mm/yr by 2090; local subsidence increases rate of rise	Several m/yr in many areas; up to 30 m/yr
Duration	Hours to one day or more	A few hours to a few days	Hours to several days	Ongoing	Ongoing
Type of impact	A series of inundation and drainage surges; possibly catastrophic	Single-event inundation; possibly catastrophic	Multiple, localized inundation and drainage surges	Progressive rise of mean sea level and high water extremes with serious long-term consequences	Progressive changes in the coastline
Limits (predicted) of area likely to be affected	Local run-up limit for specified wave amplitudes predicted by modelling	Flood limit for specific surge level and possible effect of river freshet by hydrological modelling	Flood limit for specified wave heights predicted by terrain modelling	Mean high water mark predicted by terrain modelling with allowance for extreme events	New shoreline positions predicted from long-term trends
Warning time (for response)	Travel time – minutes to 12 hours or more	12 hours to 2 days	1–3 days	Decades	Decades – major erosion events caused by other hazards

tion of "joint probability" events, when two or more hazard events coincide (e.g., extreme waves and storm surge; storm surge with river flooding; storm surge with tsunami; and, for tsunamis generated by local earthquakes, the strong ground motion preceding the flooding may disrupt evacuation routes and affect critical infrastructure).

Questions relating to the hazards that are pertinent to Phase I of the ICAM process include:

- What is the country's capacity to monitor and forecast these hazard events?
- What access does the country have to numerical models and other prediction tools which may provide information needed to identify or delineate hazard-prone areas?
- Are the appropriate coastal topographic and bathymetric data available for the purposes of modelling the physical impacts of coastal hazards?
- What, if any, criteria exist at the local, regional or global scale for categorizing the severity of coastal hazard impacts?

Procedures to address these questions are set out below. Information on existing global sea-level and meteorological observing systems and links to related databases are given in Section 4.8. A fuller listing of data and information sources for each hazard follows the hazard descriptions in Section 3.7. This provides information on authoritative references that describe and explain the measurement systems, the tools used to analyse and validate the data and, in particular, the numerical models and other software tools developed to increase our ability to understand and predict the occurrences and impacts of each of these coastal natural hazards.

4.3 HOW TO ASSESS THE HAZARDS

A thorough assessment of all the hazards that may affect a coastal area is of fundamental importance in the development of the Management Plan. Coastal hazard assessment involves the gathering of data from a variety of sources and processing that data with the help of models (Section 4.4). Sources include the documented historical record of coastal hazard impacts affecting the designated coastal management area; regional data on the origins and propagation patterns of potential hazard-forming conditions (e.g., tropical cyclones, tsunamis); and surveyed nearshore bathymetric and coastal topographic data. Hazard assessment procedures for tsunamis are described in greater detail in guidelines produced as part of the Indian Ocean Tsunami Warning and Mitigation System (IOC Manuals and Guides No. 52; UNESCO, 2009).

Defining the geographical limits of the assessment

The geographical scale of the assessment will depend on the bounds of the management unit within the ICAM process. The assessment may be national or regional, informing policy makers about those parts of a national coastline which are most prone to damaging hazard impacts; alternatively, it may be local in its scope, with the purpose of identifying hotspots of potential impact, e.g., within a municipality or an individual coastal embayment.

Accessing the historical record

Gaining knowledge of past or continuing hazard impact events to have affected a designated coastal area, including their magnitudes and their frequency of occurrence, is a key step in assessing the likelihood of their recurrence. In the case of tsunamis, the record of seismic events may also be crucial. Such knowledge may be anecdotal, from the local community; and it may be derived from national archives or international databases such as the NOAA/WDC Historical Tsunami Database (see Section 3.7, and figs 3.2 and 3.3) or the UNEP/GRID (Global Resource Information Database) (e.g., Fig. 3.5). For coastal erosion or other shoreline change, information on rates of change and long-term trends may be obtained by examination and comparison of old and modern maps and charts, aerial photographs and a time-series of

BOX 4.2 Key tasks for the hazard assessment procedure

- 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.
- Acquire and compile data on nearshore bathymetry and coastal topography.
- Determine the spatial parameters of hazard impact – the exposure (e.g., by modelling or post-impact observation).
- Determine probabilities for hazard scenarios (Section 4.6).
- Display exposure and probability results as hazard maps (Section 4.5).
- Convey results of hazard assessment to risk and emergency managers.

satellite imagery. Geological evidence of tsunami may also help to provide a timescale for assessing the likelihood of tsunami or large storm surge events occurring in the future.

Assessing exposure to rapid-onset events

Appraising the level of exposure of a designated coastline to hazards generated both within the region and far away, notably tsunamis from distant earthquake events and far-travelled extreme wind-forced waves, may similarly be aided by access to international databases of past events. Such an appraisal can also be assisted by the application of models, such as those developed to show the ways in which tsunami waves propagate from their sources across oceans (see below and Fig. 4.2). Travel time calculations have been issued routinely for tsunami events by the Pacific Tsunami Warning Centre. The pre-calculated tsunami propagation database created by the European Commission's Joint Research Centre (JRC) is one of several off-line initiatives which may be helpful in this regard (Box 4.3, Fig. 7.1). National and regional tsunami scenario databases are provided by some of the Tsunami Warning Systems in place (e.g., Indonesia, Japan).

Acquiring coastal survey data

The ways in which the rapid-onset hazards are modified as they approach the shore and inundate coastal land are determined by the nearshore bathymetry and coastal topography and orientation. Whether a potential hazard impact is being assessed by modelling (see below) or by expert judgement without the aid of models, knowledge of the nearshore seabed bathymetry and coastal land topography as well as of existing engineered coastal defences is essential. Ideally this knowledge should extend to geological, as well as topographic and bathymetric, surveys. Information should also cover ecosystems such as coral reefs, mangroves, estuaries, wetlands and sea grass beds, any of which may modify a hazard impact. Human alteration of such ecosystems may also play a role and should be noted. The use of airborne laser mapping (LIDAR – Light Detection and Ranging technique) producing accurate elevation data for coastal terrain and nearshore seabed mapping might be considered (Fig. 4.1). Coastal geological mapping (including coverage of reefs and barrier islands) and sediment budget analyses are the most useful approaches in the assessment of a shoreline's response to sea-level rise and the associated increased wave impact on that shoreline. At this detailed scale, bathymetric features change year-by-year and the consequences of this must be appraised as a source of uncertainty.

Determining the inundation parameters

Delineation of the inundation parameters for a specified hazard scenario is a key task in the assessment of the rapid-onset hazards and sea-level rise. The limit may be determined for each hazard by documented evidence or by anecdotal accounts, or estimated by inundation modelling (see below). The inundation parameters – the inundation limits, run-up, water depth, flow velocities – provide the spatial and dynamic information relating to the selected hazard scenario. They indicate the levels of exposure to which coastal communities and their assets may be subjected in such a hazard event. They are essential elements in the compilation of hazard maps (Section 4.5), which will be used in the assessment of vulnerability and risk to coastal communities (sections 5 and 6).

Fig. 4.1. *LIDAR digital surface model for coastal terrain and nearshore seabed mapping This example, showing bathymetric zonation and seabed morphology, is from Watchet in England, United Kingdom*

Source: LIDAR data Copyright Geomatics Group 2008

4.4 USING NUMERICAL MODELS TO ASSIST ASSESSMENT

Knowledge of the nature of the various rapid-onset coastal hazards to which a coastal management area may be prone can be considerably enhanced by the application of mathematical models. These models permit the researcher to gain a more specific appreciation of the likelihood of a hazard event, its timing and its magnitude, as well as a prediction of those parts of the coastline that might be most affected. They are useful for both short-term response and long-term planning purposes. However, it should be noted that there are many uncertainties inherent in the use of predictive models. There may be shortcomings in the quality of the data on which the modelling is based, and, even with good quality data, the use of models requires trained personnel able to interpret and evaluate the results.

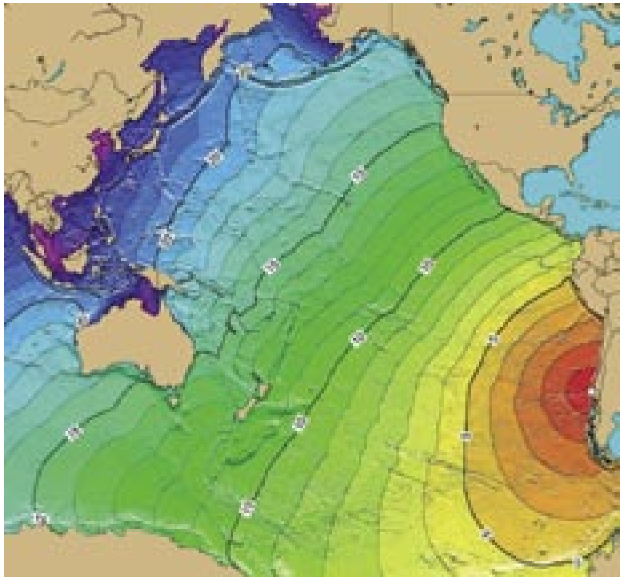

Fig. 4.2*. Tsunami propagation modelling. This modelling output shows travel times (in hours) from the seismic source for the 22 May, 1960 Chile tsunami crossing the Pacific basin.*

Source: Tsunami Glossary, ITIC. (http://ioc3.unesco.org/itic/files/tsunami_glossary_en_small.pdf)

The models for the rapid-onset hazards have two main roles – firstly to assist understanding of the progression or propagation of a real or conjectural hazard towards a shore (in the case of storm surges this is closely linked with meteorological monitoring) (Fig. 4.2); and secondly, to demonstrate how a hazard impact may be modified by a range of physical factors in the coastal zone itself, both the nearshore seabed and coastal land. This permits the preparation of hazard maps showing parameters such as inundation limits (or erosion limits) related to specified hazard magnitudes and timescales. The information in these hazard maps, together with information on the various vulnerabilities of the coastal community (Section 5), will form the basis of the risk assessments to be evaluated in the formulation of the Management Plan.

A numerical model is a mathematical tool where a set of initial conditions (earthquake parameters, tides, meteorological parameters) is entered into a gridded model of a region (bathymetric depths, topographic elevations, shoreline location etc.) to study a hazard event, either to simulate one which occurred in the past, or to estimate the effects of one which might occur in the future. Models provide us with a better understanding of actual events, helping to answer such questions as:

- Why was a tsunami run-up so much higher at a particular location?
- Why were the wave heights larger than expected?
- How strong were the water currents in the harbour?

A model which has been calibrated and validated using one or more of the well documented events can be used to estimate the effects of potential future events or combinations of events.

A numerical model is based on a set of mathematical equations (e.g., shallow-water equations) that represent the behaviour of the real-world event being modelled. There are a number of possible constraints (computing capacity, inaccurate input or boundary conditions, model resolution, model parameters, etc.) that can limit the accuracy and appropriateness of a model.

The following summary of the present state of numerical modelling for coastal hazards will enable coastal stakeholders to develop more detailed and specific questions, and to enhance their understanding of the modelling output.

Tsunami modelling

Tsunami models are used for early warning, inundation forecasting and tsunami hazard assessment. Tsunamis have very long wavelengths that are much larger than the water depth of the medium where they spread and so shallow water equations are used to model their propagation. In deep water the phase speed is a simple function of gravity and depth, which makes the computation of tsunami travel times (TTT) easy and fast (see Figure 4.2). These ray-tracing techniques, useful for early warning, neglect the non-linear effects close to the coast and so tend to provide estimates of TTT that are shorter than reality.

To estimate the tsunami wave height and currents from the open ocean to the coastal waters, the tsunami models solve numerically the non-linear equations for shallow water wave propagation using appropriate knowledge of the bathymetry. Despite the fact that most models use a simplified 2D approach, integrating along the vertical, the computation of ocean wide tsunamis is very time consuming and cannot be used for early warning or forecasting, particularly for areas close to the tsunami source. To circumvent this difficulty, large databases of pre-computed scenarios are established (see Box 4.3).

To compute nearshore wave heights, currents and coastal inundation the numerical models require detailed bathymetric and topographic information with a common vertical reference datum. Many of the codes used for tsunami propagation can also provide inundation scenarios, dealing with the additional difficulties nearshore: wet and dry nodes/cells change in time, hydraulic jumps can be established, fluid must move around obstacles, bottom roughness becomes dominant. A complete modelling solution from source to inundation has to deal with different resolution grids. All 2D models suffer the same limitations due to the approximation used, they cannot resolve vertical convection, and they cannot simulate breaking waves or 3D turbulence. Inundation models are usually applied to small areas, which makes the computation fast, given the adequate boundary conditions. This makes them suitable for use in inundation forecast in real-time warning systems. At a simpler level appropriate to the regional scale, remote sensing techniques can be applied to the prediction of inundation (Fig. 4.3). For further information on tsunami modelling, the reader is referred to the companion guidelines on tsunami risk assessment and mitigation (UNESCO, 2009).

It is important that all numerical models for tsunami propagation and inundation developed by government organizations and universities be tested using historical data associated with well documented tsunami events, such as Okushiri (1993) (Box 7.2) and Papua New Guinea (1998) (Figure 7.1).

The results from models that have not been validated can jeopardize a government's response to the tsunami hazard and result in incorrect information being given to emergency managers and coastal communities. The tsunami community recognizes the importance of this benchmarking and validation, as well as the need for peer review and thorough documentation. Even with these safeguards in place, however, the prediction of off-shore and even on-shore tsunami heights based on a detailed knowledge of bathymetry and source parameters may, in practice, be imperfect. The NOAA publication "Standards, Criteria, and Procedures for NOAA Evaluation of Tsunami Numerical Models" (Synolakis et al., 2007) provides a useful reference document (Section 3.7).

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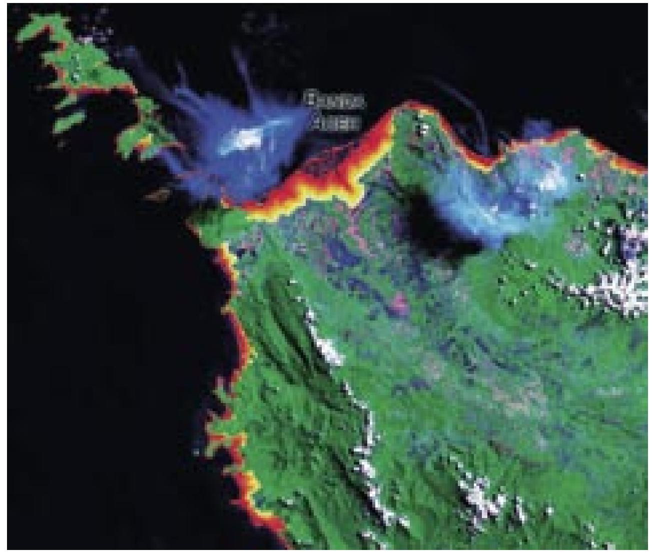

***Fig. 4.3**. Tsunami inundation modelling using satellite imagery Landsat satellite image of northern Sumatra. Modelled inundation depths for a 20-metre tsunami are shown in shades of red to yellow. A GIS model was developed to estimate the extent to which coastal land is likely to be inundated by tsunamis. Based on a digital elevation model, water flow from the coastline inland was calculated iteratively using ArcGIS Spatial Analyst 9.1 application tools. Assuming tsunami run-ups of 5 m, 10 m, and 20 m, tsunami inundation zones were modelled for most of the world's coastlines. The hazard maps were developed for the risk management purposes of the insurance industry but could also be used by governments as a basis for land-use planning..*

Sources: Modelling - L. Dolezalek, Munich Re Group; Satellite image - courtesy NASA 2000, bands 7, 4, 2.

BOX 4.3 JRC Tsunami Assessment Modelling System (see also Fig. 7.1)

The Tsunami Assessment Modelling System was developed by the European Commission's Joint Research Centre, in order to serve tsunami early warning systems such as the Global Disaster Alerts and Coordination System (GDACS) in the evaluation of possible consequences by a tsunami of seismic origin. The JRC system includes three main components: a) the global scenario database; b) the on-line calculation system; c) the Tsunami Analysis Tool.

The Global Scenario Database (GSD) is a set of 136,000 calculations performed in eight months of calculations using a modified SWAN [1] model, using a grid of 10,500 possible epicentres (with a 0.5 x 0.5 degrees interval) determined using historical tsunami event epicentres. Calculations for each magnitude between 6.5 and 9.5 have been performed. This database (2 TBytes) is ready to give a first immediate estimate of the tsunami consequences as soon as the earthquake epicentre is known. The scenario database identifies the locations potentially affected as well as the predicted wave height. The overall database is accessible online through a web interface (user/password required) or can be used locally for a quicker access through the TAT software.

Source: JRC Tsunami Assessment Modelling System

The epicentres (yellow) correspond to the tsunami scenario database. For every single point, 13 calculations with magnitudes in the range 6.5–9.5 have been calculated. A total of 136,000 calculations are available.

The Online Calculation System (OCS) uses the same model as the scenario database but it is automatically initialized with the real earthquake parameters (epicentre and magnitude). The calculations start as soon as an earthquake with potential tsunami consequences is identified and the calculation time is in the order of 30–40 minutes. These results are not very different from those of the GSD, but they should be more accurate because of being initialized with the real parameters.

The Tsunami Analysis Tool (TAT) is the software that allows quick visualization of the results of the scenario database and on-line calculations and compares them with real, online sea-level measurements.

The JRC system is now operationally serving the GDACS system and, soon after any event with possible tsunami consequences, the calculations from the GSD and from the OCS are automatically freely available on the web site http://www.gdacs.org. JRC is open to support any other early warning systems: as an example, an agreement has been recently established to support Portugal's Institute of Meteorology for the development of the Portugese Tsunami Early Warning System through the use of the scenario database and the Tsunami Analysis Tool. To this purpose the scenario database has been enlarged to include some areas in the Atlantic Ocean.

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JRC. (http://tsunami.jrc.it/model/index.asp)

Often the only way to determine the potential inundation and run-up from either a far-field or a local tsunami is to use numerical modelling, since data from past tsunamis are usually insufficient. Models can be initialized with potential worst-case scenarios for the tsunami sources, or for the tsunami waves just offshore to determine corresponding worst-case scenarios for inundation and run-up. Models can also be used with smaller sources to understand the severity of the hazard for the less extreme but more frequent events. This information provides a basis for creating hazard maps such as potential inundation maps, which can inform the risk assessment process and the preparation of tsunami and storm surge evacuation maps and procedures (see sections 6 and 7.4). Potential inundation maps can be used to represent a range of possible hazard scenarios (Fig. 4.6). These maps are analogous to the "flood risk maps" required to meet the European Union's recently adopted Floods Directive (sections 2.1 and 6.3).

Numerical modelling is also an effective way to estimate the currents produced by tsunamis in harbours and bays, and in areas likely to be inundated. These horizontal currents entrain an array of moveable objects and may produce large, fast-moving debris fields. Fig. 4.4 shows the maximum predicted currents in Esquimalt Harbour (Canada) following a modelled Cascadia Subduction Zone event. In this instance the maximum modelled currents are in excess of 5 m/s. Video footage of the 2004 Indian Ocean tsunami in the streets of Banda Aceh, more than 3 km from the open ocean, indicated that the tsunami flow velocities were within the range 2–5 m/s. Modelling also enables researchers to see how bathymetric and natural or man-made topographic

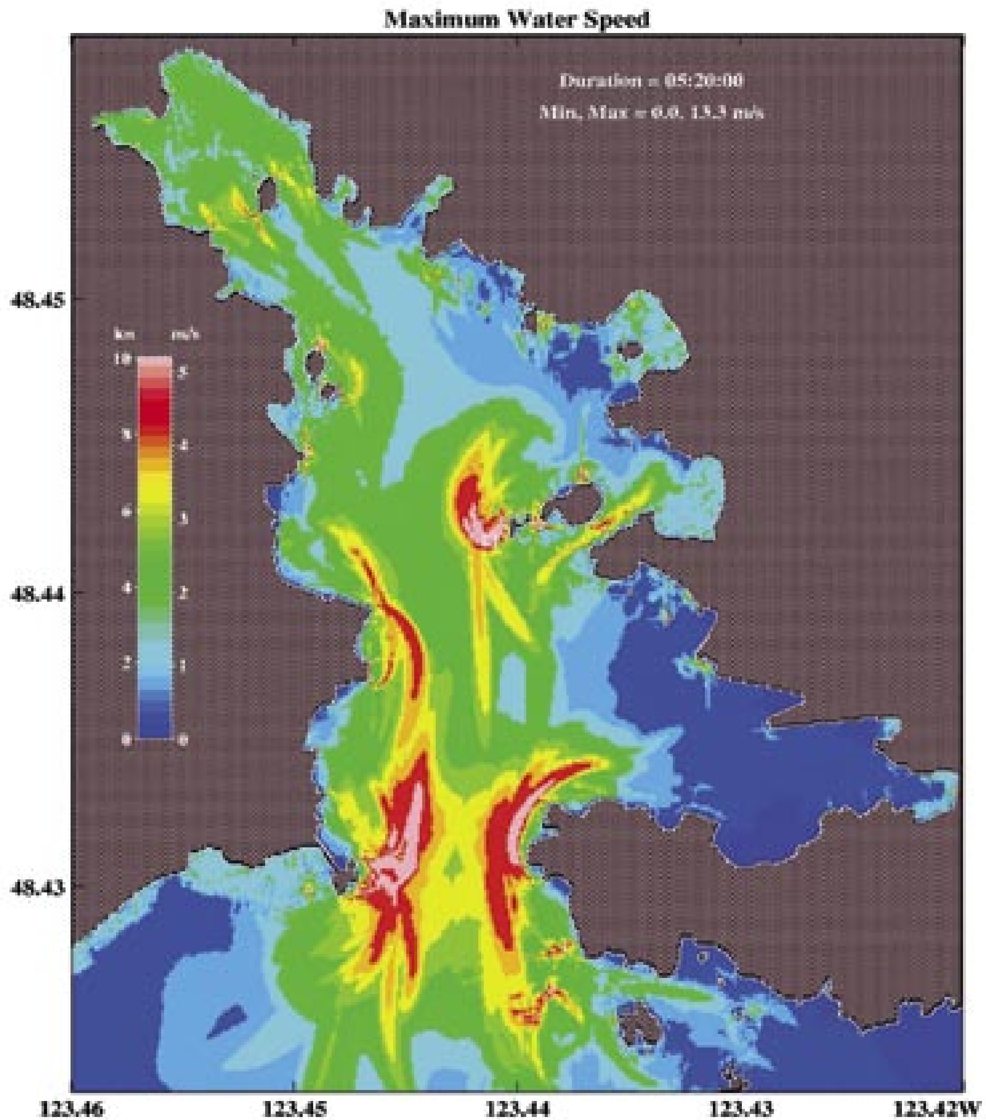

Fig. 4.4 *Modelled maximum inshore currents from a tsunami. This modelled event was triggered by fault slip at the Cascadia subduction zone during an earthquake of moment magnitude 9.0.*

Source: Cherniawsky, J. Y., Titov, V. V., Wang, K. and Li, J-Y. 2007. Numerical simulations of tsunami waves and currents for southern Vancouver Island from a Cascadia megathrust earthquake. Pure and Applied Geophysics, Vol. 164, pp. 465–492. Courtesy Birkhäuser Verlag AG.

features can significantly increase (or moderate) the run-up height at specific locations.

Detailed preparatory modelling has been carried out for only a small fraction of the coastal areas. Sufficiently accurate modelling techniques are now readily available, but the correct use of these models requires trained staff as well as detailed bathymetric and topographic data for the areas being modelled. Bathymetric multibeam surveys and topographic LIDAR surveys (Fig. 4.1) can provide the detailed nearshore information required for effective modelling (Section 4.4), but most coastal areas still have older and less precise bathymetric and topographic coverage. Practitioners requiring information on available tsunami models should contact their national oceanographic organizations. The IOC tsunami website provides information on the IOC-coordinated Regional Tsunami Warning Systems (RTWS) and the National Contacts for those RTWS.

Storm surge modelling

Before the computer era, the techniques used for storm surge prediction were analytical, empirical, graphical (nomograms) and statistical (regression relations). Statistical and empirical methods are still applied, utilizing historical data to develop a forecasting technique by regression or other statistical approaches. Unfortunately, in most regions the large database of wave height information required for such approaches is non-existent. Now, however, numerical methods are the widely used approach for storm surge prediction. A review of such methods and the current available operational storm surge forecasting systems, including ensemble forecasts, will be given in the forthcoming JCOMM Guide to Storm Surge Forecasting (Section 3.7).

A numerical surge model requires a geo-referenced database consisting of nearshore bathymetry and, if inland inundation is to be computed, the coastal topography surrounding the cyclone's landfall location. Typically, a storm surge model takes the cyclone's track, its size, atmospheric pressure, wind speed and predicted tides as basic input, to which local bathymetry and topography may be added.

Storm surge forecasting depends strongly on cyclone (or ET storm) wind forecasting and its uncertainty. Collating the several possible cyclone conditions from the many into a composite potential of surges is a demanding task. Since each computer run gives an envelope of highest waters in a basin for the life history of a cyclone, it is a simple computer task to determine, from a particular family of tracks, the highest possible surge at all coastal locations of concern. The resulting composite is called a Maximum Envelope of Waters (MEOW) (Fig. 4.5). To generate the composite sets of MEOWs, known as MOMs ("Maximum of Maximums"), the maximum surge value from the entire family of cyclones at each grid square of a basin is saved, regardless of which cyclone was responsible. The resulting composite of peak surges makes up a MOM. This provides an easily accessible summary of the possible surge flooding, given the uncertainty in the current forecast situation.

Extreme wind-forced wave modelling

Sophisticated techniques exist for wave forecasting. Most require computing facilities, together with an input database for bathymetry, calibration and testing that are well beyond the resources of many National Meteorological Services. A detailed review of the existing wave models is given in the WMO Guide to Wave Analysis and Forecasting.

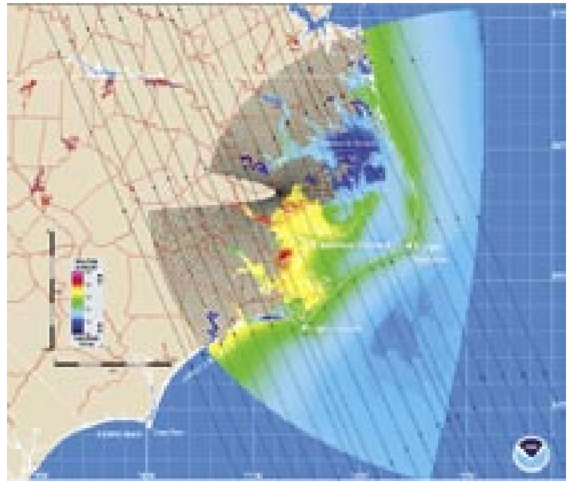

***Fig. 4.5** Modelled maximum surge elevations for a Category 3 hurricane.*
This event was simulated by the NOAA SLOSH (Sea, Lake and Overland Surges from Hurricanes) model, for a Category 3 hurricane making landfall at a forward speed of 15 m/s in the Pamlico Sound basin of North Carolina. The values shown, representing the "maximum envelope of waters", were obtained by running several similar hypothetical storms onshore along parallel tracks (shown by black arrows).
Source: Courtesy of NOAA/National Hurricane Center.

Modelling inundation due to sea-level rise and coastal erosion

Long-term, progressive inundation that may be expected as a consequence of global sea-level rise can be modelled simply on the basis of coastal topographic survey data. These data may be available or acquired by traditional survey techniques or by the application of, for example, LIDAR technology to obtain a digital terrain model of the coastal land (see Section 4.4, Fig. 4.1 and boxes 5.8 and 6.1). Sea-level data from around the world show that there are regional and local variations in the rates of change. Adjustments may be needed in estimating inundation in coastal areas that are tectonically active (especially those in earthquake zones) or subject to subsidence, either because of natural sedimentary consolidation (e.g., deltas) or because of oil and gas or water extraction. In some circumstances such adjustments may be far greater than the amount of global sea-level rise. In deltaic areas further adjustments may be needed to take account of sedimentation during flood episodes that progressively elevates the land surface.

The likelihood of future coastal flooding involves not only the expected MSL rise but also changes in tides and meteorological conditions. These three factors combined affect the total observed sea level. There are a number of methods for calculating how frequently a specific level will be exceeded. These methods include, but are not limited to, annual extremes analysis (requiring many years' data) or joint tide-surge probability estimates (see Section 4.6). A fuller discussion of methods for estimating extreme sea levels is given in the IOC Manual on Sea Level Measurement and Interpretation (UNESCO, 2006, Section 3.7).

Modelling coastal erosion can be a complex process on account of the many variable parameters. These include changes of sea level, changes in the magnitude and direction of wave forcing on exposed shores (perhaps as a consequence of global climate change), changes in the supply and maintenance of beach sediments (sand or shingle) that provide shoreline protection. The potential for erosion is also determined by the nature of the coastal hinterland (e.g., rocky terrain or a sandy beach plain) that may become exposed by the wasting of beach materials. Although physical shoreline regimes tend to change with time and may alternate seasonally and interannually between erosion and accretion, it may be possible by reference to historical survey data and anecdotal information to establish long-term trends of value in making projections of shoreline retreat.

4.5 DISPLAYING HAZARD INFORMATION

Hazard maps are an effective means of documenting and communicating the extents, depths, forces and probabilities of inundation in respect of the various hazards, both rapid-onset and creeping. They show physical, hazard-related parameters displayed on a topographic survey base. Thus, they carry information about the levels of exposure to which a coastal community and its assets might be subject in the event of a hazard impact.

For rapid-onset hazards, the maps may show the inundation limits for the selected event magnitudes (figs 4.6 and 4.7) and, potentially, the water depths at maximum inundation (Fig. 4.8). They can also show information on expected water flow velocities during inundation and subsequent drainage. For the creeping hazards, the information comprises inundation (or erosion) limits at specified timelines, given observed rates of sea-level rise (or shoreline retreat due to erosion).

The hazard maps are also a means of indicating the likelihood or probability of inundation at a specified location, within a specified time frame, for a specified hazard scenario as detailed in Section 4.6. The display of probability "zones", e.g., high, medium and low, may be considered for the chosen scenario.
Subsequently, the hazard maps with their information about potential exposure and probability may be integrated with maps conveying information about the vulnerability of coastal communities (Section 5.7). This integration yields risk maps carrying information for the risk assessment (Section 6.3) and, in

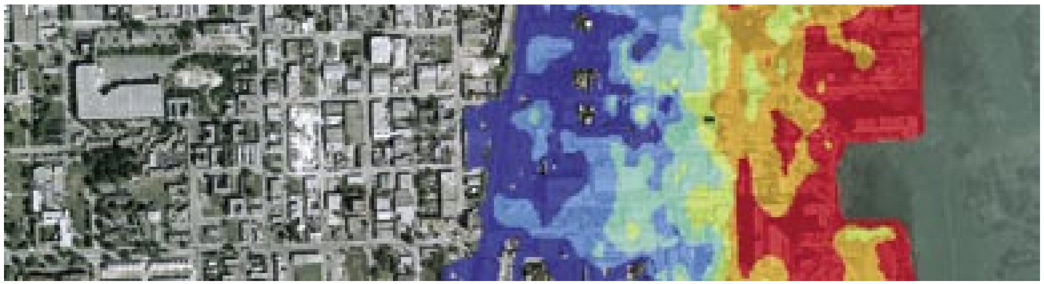

Fig. 4.6 *Inundation modelling of a storm surge impact.*
This model simulated a Category 5 hurricane generating a surge height of 7 m impacting Miami, U.S.A. The colour scale is based on modelled inundation depths: Blue = <1 m; Green = <2 m; Yellow = <3 m; Orange = <4 m; Red = >4 m. Atlantic Ocean to Right of image.
Source: Courtesy Ambiental Technical Solutions, Ltd. (www.ambiental.co.uk).

turn, for emergency preparedness and risk mitigation (sections 7 and 8). The use of Geographical Information System (GIS) technology is appropriate for the representation of geospatial information relating to the risk assessment process. The creation of "layers" of thematic information within a GIS provides a versatile means of comparing and, as required, compounding parameters from a wide range of data plotted to a common topographic base.

4.6 ASSIGNING PROBABILITY LEVELS TO THE HAZARDS

The observational data and modelling products obtained in respect of the various coastal hazards provide indicators of the likelihood, or probability, of a damaging hazard event occurring in the management area within a specified time interval.

The usual way to express the probability of occurrence of a rapid-onset hazard is by the average number of events expected per year or by its return period. For example, if, on average, two damaging storm-surges impact a coast every 10 years, then the probability of occurrence in one single year is 20% and the return period is five years. The simplest statistical model to describe the occurrence of such events is the binomial distribution, the same as is applied to the throwing of coins.

Using this law, and the data from the example above, we can estimate that the probability of occurrence of exactly one storm-surge in a 5-year period is 41% but the probability of occurrence of at least one event in the same 5-year period is 67%. Such a probability could be expressed in qualitative terms, i.e., there is a "high" probability of occurrence of at least a single

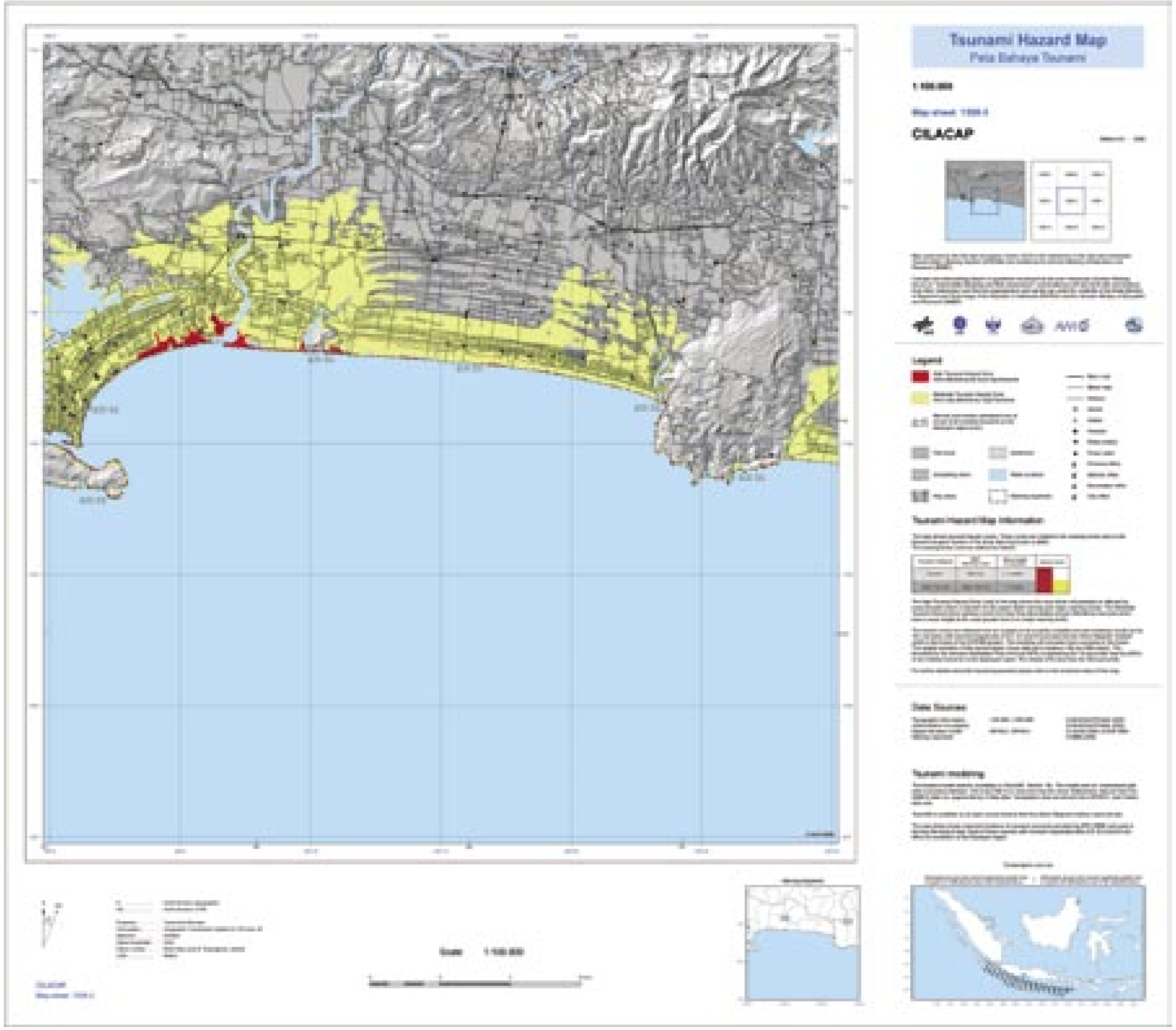

Fig. 4.7 *Tsunami hazard map at a local scale.*
This map (at 1: 100,000 map scale) covers the city of Cilacap in Java, Indonesia. It shows tsunami hazard impact zones (high=red; moderate=yellow) calculated using a multi-scenario approach. The zones comply with the tsunami warning levels issued by BMKG Indonesia in order to directly relate the tsunami warning information to hazard impact zones. Additionally, the tsunamigenic sources, which cause a tsunami impact on land for this coastal area, are shown on the map (bottom right-hand corner).
Source: GITEWS Project. Courtesy DLR, AWI.

Fig. 4.8 *Inundation map showing maximum flood inundation depth caused by a sea flooding event This example is of Rotterdam in The Netherlands; "Waterdiepte" means "water depth".*
Source: Europa, 2007, Atlas of Flood Maps: Netherlands. (http://ec.europa.eu/environment/water/flood_risk/flood_atlas/countries/pdf/netherlands.pdf)

event in the 5-year period. These probabilities can be scaled-up to the longer periods used for planning, e.g., 100 years (see Box 8.1). In this case the probability of occurrence of exactly 20 storm surges in 100 years is only 10% but the probability of occurrence of at least 20 events in 100 years is high, 54%. This could prove to be an underestimate if sea-level rise is taken into account.

For events that are very rare, like destructive tsunamis, since the yearly occurrence is very low, we may use instead the Poisson distribution to describe its simplest statistical properties. For example, if on some coast the return period for a damaging storm surge is 200 years, the yearly frequency is 0.5 % and the probability of occurrence of at least one event in any 10-year period is 5%, which can be considered "low". When the relevant events cannot be considered independent (like destructive tsunamis) or when the probability changes with time (e.g., due to global warming), then more complex statistical models have to be used for hazard assessment.

Similar criteria of probability may be applied to extreme wind-forced waves and tsunamis. While wind-forced wave and storm surge events are driven by meteorological forcing that is to some extent predictable, most tsunami events reflect sudden displacements of the earth's lithosphere. The locations of such displacements may be generally predictable on the basis of geological understanding, but their timings, in the context of a 100-year management planning cycle, are certainly not. In some ocean regions like the Pacific, records show that close to as many as 100 damaging tsunami impacts have occurred (though not necessarily affecting the same coastal management areas) over the last 100 years. Thus, on a regional basis, this number of events could indicate a "high" probability of occurrence within a 100-year planning window. Elsewhere, records may show that damaging tsunami events are be separated by hundreds of years, indicating a "low" probability.

The probability of a rapid-onset event has an inverse relationship with its magnitude. Thus, for many parts of the world, the probability of a high magnitude event occurring within a coastal management planning timeframe may be low. But the consequences of such an event, if it does occur, may be nonetheless devastating, as manifest by the Indian Ocean tsunami of 2004.

The probability of occurrence should be assessed for each of the rapid-onset hazards. This could cover events in a range of different magnitude scenarios. Consideration should also be given to the possibility of two or more rapid-onset hazards occurring at the same time at the same location – the issue of the "joint probability" of coincident hazard events (Section 3.6). Coincidences of storm surges and extreme wind-forced waves are of particular concern, also of storm surges and river floods in estuaries, although the latter are not included in the hazards featured in these guidelines. Tidal regimes may also be important at the local scale. On meso- to macro-tidal coasts, the impacts of rapid-onset hazards that coincide with high tidal states, particularly during Spring tides, may significantly increase the scale of inundation. The probability of the occurrence of such coincident events may be low, but their consequences could be devastating.

Considering the creeping hazards, the probability of inundation (or land loss) is a function of the rate of sea-level rise (or erosion). Because these rates can usually be established with reasonable confidence (by observation aided perhaps by modelling), the probability of the creeping hazard impacting a specified location within a specified timeframe may established with corresponding confidence.

No rigid criteria are proposed in these guidelines for defining thresholds between "high", "medium" and "low" probabilities of occurrence, or indeed whether additional probability classes are appropriate. Nor do the Guidelines express a view on the usefulness of a "percentage probability" scheme rather than a "qualitative" one in the process of risk assessment (Section 6). In practice, the choice of approach may be governed by the quality and amount of available observational and modelling data.

4.7 CHALLENGES AND OUTPUTS

Challenges

The principal challenges are:

- to improve the distribution (geographical coverage), data quality or timeliness of the observation networks; and
- to improve the analysis and interpretation of the data, and to provide new or improved data products.

Outputs

The possible information outputs, based on the background and procedures described in this section and feeding the vulnerability and risk assessment processes in Phase II of the ICAM process, are listed below.

Tsunamis

- a listing of all known tsunami events to impact the region;
- analysis of pre-calculated tsunami propagation patterns for likely earthquake sources;
- country map showing coasts most prone to potential tsunami impact;
- analysis of prone coasts to locate inundation hotspots based on coastal facing direction, nearshore bathymetry, coastal topography, defences, etc.;
- hazard maps for various credible tsunami scenarios showing exposure parameters including inundation limits, run-up, flow velocities, etc.; and
- probability levels for a range of tsunami scenarios.

Storm surges

- a listing of all known storm surge events to impact the region, in conjunction with associated meteorological event information;
- country map showing coasts most prone to potential storm surge impact;
- analysis of prone coasts to locate inundation hotspots based on coastal facing direction, nearshore bathymetry, coastal topography, defences, etc.;
- inundation maps for various surge magnitudes and tidal conditions, showing HWMs, taking existing defences into account; and
- probability levels for a range of storm surge scenarios.

Extreme wind-forced waves

- a listing of all known extreme wave events known to impact the region;
- country map showing coasts most prone to extreme wave impact;
- analysis of prone coasts to locate inundation hotspots based on coastal facing direction, nearshore bathymetry, coastal topography, defences, etc.;
- extreme wave inundation maps for various wave magnitudes and tidal conditions taking existing defences into account; and
- probability levels for a range of wave scenarios.

Sea-level rise

- analysis of sea-level data from regional tide gauge network, with any local modifying data included; and
- predicted shoreline positions at forward timelines (e.g., 25 yr; 50 yr; 100 yr).

Coastal erosion

- country map showing extent of coasts prone to erosion (or accretion);
- maps (including geological features) of erosion hotspots showing information on former shorelines where appropriate;
- analysis of coastal erosion rates with supporting information on sediment budgets; and
- predicted shoreline positions at forward timelines (e.g., 25 yr; 50 yr; 100 yr).

General

- hazard maps for specified, credible hazard scenarios showing exposure parameters of coastal land affected (inundation limits, run-up limits, erosion, water depths at maximum inundation, inundation and drainage flow parameters).

4.8 DATA REQUIREMENTS AND INFORMATION SOURCES

The following table identifies data sets and sources that may be useful in realizing the hazard assessment products as described in this section. The data sets and other sources of information and guidance are listed and described more fully by hazard type at the end of the previous section (Section 3.7).

Table 4.2 *Information sources for hazard assessment*

Products	**Variables and standards**	**Sources**	**Global programmes and data sets**
Tsunamis			
Seismic event probability assessment	Frequency, magnitude, location	National seismological institutes, international providers, e.g., USGS	NOAA/WDC Historical Tsunami Database (http://www.ngdc.noaa.gov/hazard/tsu_db.shtml) Novosibirsk Tsunami Laboratory Historical Tsunami Database for the World Ocean (http://tsun.sscc.ru/On_line_Cat.htm)
Tsunami probability assessment	Open ocean wave height	Satellite altimetry; DART buoys	
	shoreline wave height, inundation limit run-up	Local records, anecdotal accounts, geological evidence	
Bathymetric data, coastal topographic data	Bathymetry, land topography, existing defences	Hydrographic charts, LIDAR survey, digital terrain modelling	General Bathymetric Chart of the Oceans (GEBCO) (http://www.gebco.net/) NGDC-ETOPO, land and oceans http://www.ngdc.noaa.gov/mgg/global/global.html SRTM, land and oceans http://topex.ucsd.edu/WWW_html/srtm30_plus.html DNSC05, land and ocean ftp://ftp.spacecenter.dk/pub/BATHYMETRY/
Tsunami models	Propagation, ocean wave height, shoreline wave height, inundation run-up	National oceanographic institutes	JRC Tsunami Propagation Model (http://tsunami.jrc.it/model/); ANUGA - https://datamining.anu.edu.au/anuga; See listing in UNESCO, 2009
Inundation maps		Satellite imagery Modelling, surveying, local records, anecdotal accounts	COAST-MAP-IO Project, Improving Emergency Response to Ocean-based Extreme Events through Coastal Mapping Capacity Building in the Indian Ocean http://www.ioc-cd.org/
Storm Surges			
Cyclone and ET storm probability	Location, magnitude, frequency	Meteorological records	WMO-IOC JCOMM Guide to Storm Surge Forecasting (in preparation) (http://www.jcomm.info/)

(Continued next page)

Surge probability	Location, magnitude, frequency	Meteorological and oceanographic records	
Bathymetric and coastal topographic data	Nearshore bathymetry, coastal topography, existing defences	Hydrographic charts, LIDAR survey	
Surge models	Location, magnitude	Meteorological and oceanographic institutes	WMO-IOC JCOMM (http://www.jcomm.info/)
Inundation maps		Satellite imagery, modelling, surveying, local records, anecdotal accounts	COAST-MAP-IO Project, Improving Emergency Response to Ocean-based Extreme Events through Coastal Mapping Capacity Building in the Indian Ocean (http://www.ioc-cd.org/)
Extreme wind-forced waves			
Wave probability	Location, magnitude, frequency	Meteorological and oceanographic records	WMO-IOC JCOMM (http://www.jcomm.info/) Voluntary Observing Ship (VOS) Program (http://www.weather.gov/os/marine/pmo_vos.pdf) IOC-WMO-ICSU GOOS (http://www.ioc-goos.org/) JCOMM Extreme Wave Database (in preparation) Global Atlas of Ocean Waves (http://www.sail.msk.ru/atlas/)
Inundation maps		Modelling, surveying, local records, anecdotal accounts	
Sea-level rise			
Sea-level change probability or rate	Sea surface height	Tide gauges, buoys, satellite imagery, altimetry	IOC GLOSS (http://www.gloss-sealevel.org/) PSMSL (http://www.pol.ac.uk/psmsl/datainfo/) University of Hawaii Sea Level Center (http://ilikai.soest.hawaii.edu/uhslc/status.html) IOC IODE (http://www.iode.org/)
Coastal erosion			
Erosion probability or rate	Shore/hinter-land geology and geomorph-ology, Shoreline positions over time, changes in physical forcing Human interventions	Geological and geomorphological surveys / maps, Time-series aerial photographs and satellite imagery, climate change and sea-level change forecasts, beach sediment monitoring	EUROSION (http://www.eurosion.org/)

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5 MEASURING VULNERABILITY

ICAM PHASES	I	II	III	IV
		STEP 1		

This section aims to guide the determination of the social, physical, economic and environmental vulnerabilities of coastal communities who may be affected by the possible impacts of inundation. It identifies the data requirements that are appropriate to the scale the management unit and the specific thematic dimension of vulnerability (see Section 5.5). It describes how these data may be gathered then processed to provide vulnerability levels for defined inundation scenarios.

Procedures for vulnerability assessment in respect of natural hazards are documented in publications such as those of ISDR. While many aspects of the vulnerability of coastal communities to coastal hazards are common to community vulnerability to natural hazards in general, the section highlights consequences of hazard impacts of particular relevance to coastal areas.

5.1 VULNERABILITY IN AN ICAM CONTEXT

A vulnerability assessment forms a major part of the broadly based social and environmental assessments that make up the first step of Phase II of the ICAM process – the Preparation of Plans. Together with the evaluation of the hazards, as described in Section 4, it can be further developed to a risk assessment, e.g., through special aggregation or combination methods (Section 6), to be considered by policy makers in the formulation of the Management Plan, or the modification of an existing Management Plan (figs 1.1 and 1.2, and Section 2.2).

Many coastal areas lack vulnerability assessment programmes. While some hazard maps, land-use plans, emergency response and development plans may exist, there may be no comprehensive knowledge of vulnerability for the defined coastal management unit. Proper and comprehensive assessment of the vulnerability of coastal communities to coastal hazards is a necessary tool in risk assessment and, in turn, for the promotion of emergency preparedness and strategic risk reduction through the Management Plan.

Vulnerability assessment facilitates three main goals within ICAM:

- assessing the risks to coastal communities in respect of the various hazards;
- enhancing vulnerability awareness and crisis management capacities (e.g. effective and people-centred early warning with a priority on the most vulnerable groups, evacuation, relief) (see Section 7); and
- providing a sound basis for developing long-term disaster risk and vulnerability reduction strategies, including measures for adaptation (e.g. institutional adaptive capacity, land-use planning) (sections 7 and 8).

Key considerations

In these guidelines, the term "vulnerability" refers only to the state or structure of coastal communities (including their social structure, physical assets (buildings), economies and supporting environment) that make them more likely to be affected or harmed by an event or danger due to one or more of the coastal hazards. Vulnerability informs about the consequences (losses, damage) of possible hazard events. It is about hazard reception. Properly assessed and, if appropriate data permit, quantified, it is the key to estimating the risks to coastal communities of both rapid-onset (possibly catastrophic) and creeping (progressive) coastal hazard events.

The assessment of vulnerability is hazard-specific. For example, the vulnerability of a coastal community to inundation from progressive sea-level rise is very dif-

BOX 5.1 The vulnerability of the city of Alexandria, Egypt, to the impacts of tsunamis, storm surges and sea-level rise

The Mediterranean Sea has high incidence of tsunamis. The activity is partly a consequence of tectonic activity in the eastern Mediterranean between the Hellenic and Cyprus arcs. The southern Mediterranean, in particular, has been hit by tsunamis several times in recorded history. Two big tsunami disasters have affected the Nile Delta and the city of Alexandria – on 21 August 365 A.D. and 8 August 1303 A.D. respectively (the consequences of earthquakes of magnitude about 8). Much of Alexandria, once a major Greek and Roman port, was destroyed in the 21 August 365 A.D. event, with the deaths of at least 50,000 people (Stanley and Jorstad, 2005).

Box 5.1: The city of Alexandria, sited between the Mediterranean Sea (top) and the partially reclaimed Lake Maryut.

Picture source: NASA Earth Observatory. Astronaut photograph taken July 27, 2003.

Alexandria is one of the largest cities in the eastern Mediterranean with a population that exceeds four million, over 35% of them living in slum areas. It hosts the largest harbour in Egypt and is considered that country's second largest economic centre, hosting over 40% of its industry and 50% of its petroleum industry. The city is also an important summer resort, with over a million visitors during the season.

The city is located on and between two ridges nearly parallel to the sea shore with an elevation not exceeding 12 m. Mainly, however, the city lies only 1–2 m above sea level, with many areas below sea level. To the south of the city lies Lake Maryut, a shallow lake with an average depth of about one metre. The distance between the lake and sea varies between a few kilometres and 300 m in the area closest to the Mediterranean. Expansion of the city has been progressing over the last few decades by landfilling the lake. Recent trends of urbanization on landfilled areas constitute a serious challenge to the groundwater resource in some low-lying areas.

Alexandria has a moderate climate. Historically, storm surges have occurred during the winter, though with almost no damage. However, in recent years surges have been much stronger and have caused damage to new shoreline structures. The impact on Alexandria of long-term changes of sea level has been worked out quantitatively using remote sensing and GIS techniques, assuming scenarios of sea-level rise of 0.3, 0.5 and 1.0 m and taking into consideration expected land subsidence. Results indicate significant inundation and high risk to the community with the loss of 200,000 jobs over the next 50 years.

Despite a history of tsunamis, the increasing likelihood of inundation from storm surges, and the expansion of the city into vulnerable zones, there is so far no institutional capability for an early warning system, nor are there plans for introducing and promoting climate change policies in the planning of future development. For such a large and historic city, it is important that an effective early warning system covering the eastern Mediterranean and its coastal areas should be established as soon as possible.

Mohamed El Raey

ferent to that of the same community to inundation by a catastrophic tsunami impact. Vulnerability comprises a wide range of factors or parameters. Individual factors that contribute to vulnerability – and thus the aggregated vulnerability – are dynamic. They are prone to change over time because of changing (usually increasing) coastal population as well as changing economic developments, social structures and environmental states (e.g., due to climate change). Socio-economic factors may have a major influence on a community's vulnerability to the hazards and its capacity to cope with them. Because of its multifaceted nature, vulnerability is difficult to measure. Its analysis must be adapted to specific objectives and scales as well as to the context of the coastal area.

Because emergency preparedness and mitigation strategies within the Management Plan should be based on a continuing strategy of vulnerability and risk assessment, vulnerability assessment is an integral and continuing part of the ICAM process. The vulnerability assessment contributes to a better understanding of risk factors and, in turn, facilitates a reduction of those risks. In general, it is not the hazard events themselves that cause the greatest threat to human life and property, but the compounding of these events with conditions which enhance vulnerability on land. Such conditions may be due, for example, to inappropriate land use and inadequate contingency planning. In many areas, the intensive human alteration of coastal environments has already reduced the capacity of natural systems to cope with stresses and shocks. Disasters in coastal areas occur only if hazard events strike vulnerable communities.

The importance of an awareness of the vulnerability of coastal communities to coastal hazards became obvious during the tragedy of the Indian Ocean tsunami of 2004. Damage to the coastal populations, economies, social structures and environments of the affected countries reflected not only the tremendous magnitude of the hazard impact but also poor awareness among the coastal population of its vulnerability to tsunami impacts.

Overall, vulnerability assessment is a powerful tool that contributes to decision support within ICAM. Because climate and societal changes are making it increasingly difficult for coastal communities to avoid these hazards, more attention must be paid to vulnerability reduction, in addition to improving the coping and adaptive capacities of coastal areas (see sections 7 and 8).

Traditionally, the focus of risk reduction in respect of the various hazards has been on physical science aspects (events and exposure) and on technical solutions (e.g., structural measures such as flood embankments, more resistant buildings) rather than on social factors. Today, however, environmental, developmental and global change research lays emphasis instead on the coupled human-environmental aspects of vulnerability. Taking account of the requirements and principles of the ICAM process and the latest developments within contemporary vulnerability and risk research, there is a need to approach the assessment of vulnerability across disciplines and sectors. Such an holistic approach, integrating natural and social sciences, is described in Box 5.3, and an example of its application specifically to tsunami risk assessment is given in Box 5.5.

BOX 5.2 Community vulnerability to storm surges and tsunamis in the Indian Ocean

Inhabitants of low-lying coastal areas in the tropical cyclone zones are particularly vulnerable to the often large storm surges generated by these storms. Bangladesh is a country that is particularly prone to surge impacts, with more than 500,000 lives lost during the past 200 years. A storm surge in the Bay of Bengal in November 1970, with a maximum surge height of 9 m, killed at least 250,000 people, while a surge in 1991 killed about 140,000 people. In May 2008, the 4-metre-high surge of Cyclone Nargis caused the deaths through drowning of at least 86,000 inhabitants of the Irrawaddy delta in Myanmar (Fig. 3.6).

In tsunami events, most fatalities tend to occur within one hour of the tsunami travel time from the source, and almost all within 3 hours. The Indian Ocean tsunami in 2004 was exceptional, with large numbers perishing beyond these limits. The most severe tsunami events have a potential to be extremely destructive, causing a large number of fatalities, heavy property damage and extensive disruption to commerce and social life. In most events, major damage is confined to the nearby coast, but in a few instances (e.g., Sumatra, 2004) tsunamis can be destructive over several kilometres inland. People on vacation on tsunami-prone coasts may be particularly vulnerable. The Indian Ocean tsunami in 2004 killed more than 540 Swedish tourists and ranks as Sweden's worst natural disaster in terms of the deaths of its nationals.

Alessandra Cavalletti

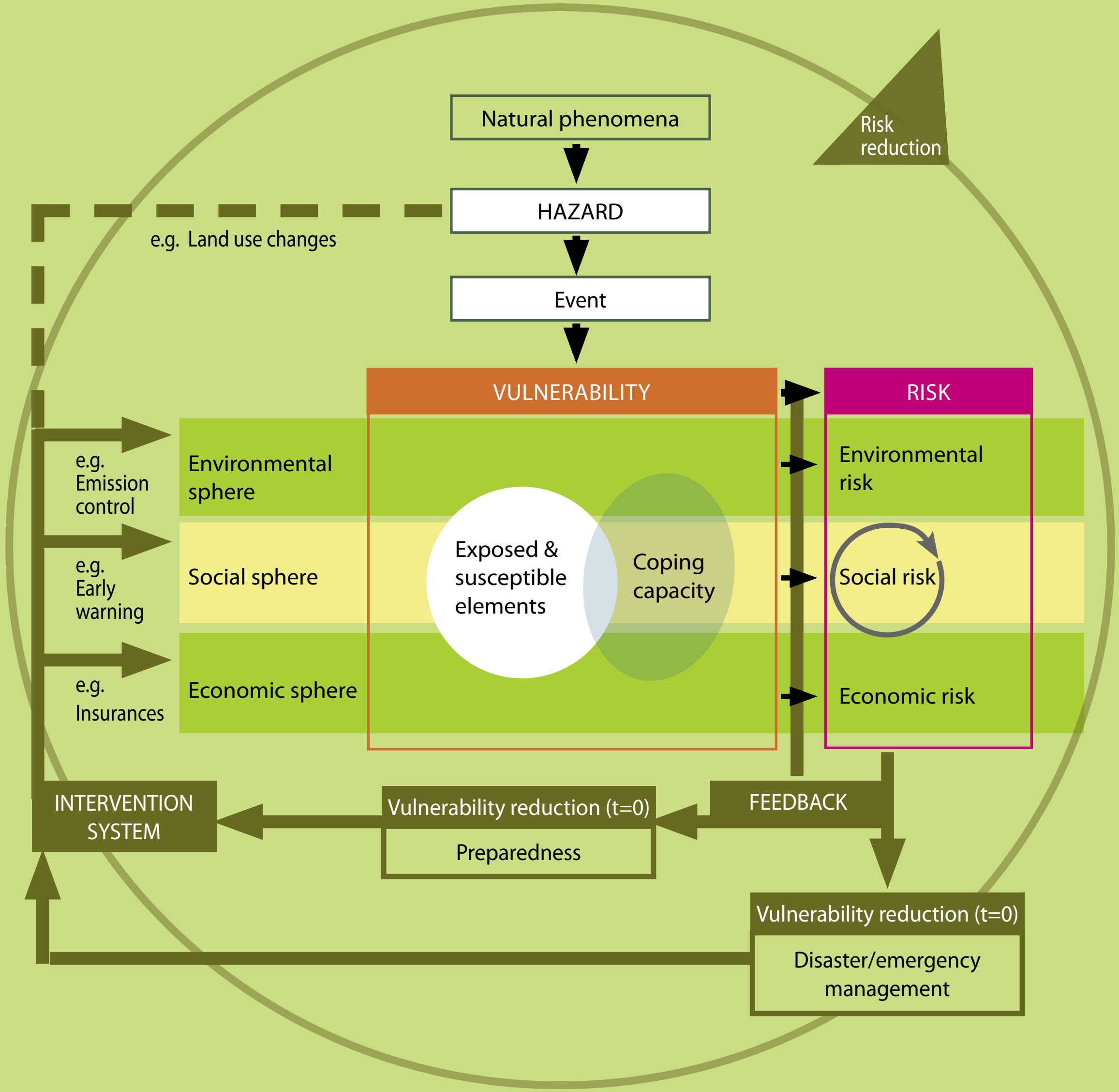
BOX 5.3 **An holistic approach to vulnerability assessment, integrating natural (including engineering) and social (including economics) sciences – the BBC conceptual framework**

The BBC framework aims at exploring the linkages of the socio-economic spheres (who is vulnerable; e.g., social groups and institutions) and the physical-natural spheres (what is vulnerable: e.g. built environment, critical infrastructures, and economic sectors). Thus, by addressing the three pillars of sustainable development, the framework clearly indicates the link between vulnerability assessment and sustainable development. It emphasizes the fact that vulnerability is defined through exposed and susceptible elements on one hand, and the coping capacities of the affected entities (for example social groups) on the other. This means that focusing on deficiencies is not enough. Additionally, the framework shows that it is also important to address the potential intervention tools that could help to reduce vulnerability in the social, economic and environmental spheres, such as early warning (see Section 7). In this regard the framework promotes a problem-solving perspective.

The BBC framework stresses the importance of being proactive in reducing vulnerability before an event strikes the society, economy or environment. The assessment of options for introducing preventive measures, e.g., moving parts of a city out of its exposed zone, aim not only at saving lives but also at saving disruption of sustainable livelihoods – the desired outcomes of a preventive intervention system (BBC framework). In this context, the accepted residual risk is a matter of political negotiation on the basis of hazard and vulnerability assessment and must be addressed within the ICAM process (see Section 2).

Jörn Birkmann

Sources: Birkmann (2006), based on Cardona (2001) and Bogardi and Birkmann (2004).



5.2 HOW TO ASSESS VULNERABILITY

A vulnerability assessment involves the definition of its geographical and temporal scales, and its geographical limits; gathering and compiling geo-referenced data on a wide range of parameters relating to the various dimensions of vulnerability (see Section 5.5); classifying those data in terms of levels of vulnerability then producing vulnerability reports and vulnerability maps in respect of each hazard that may potentially impact the designated coastal management area. Allied to these tasks is an assessment of the deficiencies in institutional preparedness in respect of hazard impacts.

Various tools and procedural recommendations exist for the assessment of vulnerability. Procedures specifically for tsunamis are described in risk assessment guidelines produced as part of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS; UNESCO, 2009).

BOX 5.4 Key tasks in the vulnerability assessment procedure

- Define the geographical scale and limits of the assessment, using e.g., geographically determined hazard exposure limits (Section 4) or other information on specific vulnerabilities or regions that are covered by the coastal management strategy or plan.
- Define the temporal scale of the assessment – this may be a rolling scale.
- Gather geospatially referenced data on human and social, physical and economic and environmental parameters (asset mapping) using, e.g., GIS technology; gather data on deficiencies in institutional preparedness.
- Translate these data into levels of vulnerability with regard to the exposure to each hazard; assess as separate vulnerability dimensions or as aggregated vulnerability, taking all dimensions into account.
- Assess deficiencies in institutional preparedness, particularly in respect of early warning and impact response.
- Produce vulnerability map(s) and reports for the designated coastal management area.
- Communicate the vulnerability and preparedness assessments to all involved in the ICAM process.

5.3 DETERMINING THE SCALES OF THE VULNERABILITY ASSESSMENT

Initial tasks in the assessment of vulnerability are to establish the temporal and geographical scales of the assessment. It is important that the chosen geographical scale allows the study of the different characteristics and dimensions of vulnerability.

The geographical scale at which to conduct a vulnerability assessment may be at the "macro scale" (regional level) or at the "micro scale" (local level). The chosen scale depends on the required resolution and the extent of the designated coastal management area. Additionally, the goal and user groups within the ICAM process (local to national authorities such as disaster management, spatial planning or water resources management agencies) need to be involved in the assessment process. Local and national disaster management agencies require different information about risks according to their specific functions, e.g., coordinating or carrying out emergency management (e.g., early warning, evacuation) or long-term risk and vulnerability reduction (e.g., land-use planning). Multi-disciplinary and multi-dimensional vulnerability assessments produce spatially distributed information at the macro- or micro scale.

At the macro scale, a methodology for vulnerability evaluation could be, for example, an analysis of satellite imagery combined with an analysis of population and socio-economic parameters. The assigned vulnerability levels of the coastal area are based on natural, as well as anthropogenic, parameters. Parameters to be taken into account within the context of hazard exposure (as derived from the hazard mapping) include the coastal population and their social structure, land use, the built environment (including major critical infrastructure, such as electricity and water supply), coast-related economic activities and the coastal environmental assets.

At the micro scale, an assessment should capture vulnerability information specific to individual groups within communities, their buildings, livelihoods, etc. The assessment can allow a more precise understanding of a community's susceptibility to a potential hazard event, including the impacts on different economic sectors and social groups, and the fragility of critical infrastructure. High resolution, micro-scale assessment should be performed for areas with greatest hazard exposure.

Exposure information derived from the hazard assessment process – for example, scenarios of sea-level rise or potential inundation areas of tsunamis or coastal storm surges – may be used to define the geographical limits of the assessment. However, one could also consider the identification of geographical limits using administrative boundaries which encompass different social groups, critical infrastructures and land-use patterns that might be impacted by coastal hazard events. It is crucial that both the natural science and the social science perspectives are taken into consideration.

Vulnerability is a dynamic state. Trends in vulnerability should be considered in order to forecast future risks that might affect emergency planning and strategic mitigation, or indeed be a consequence of any planning and mitigation that has already been undertaken. The temporal scale should relate also to the identified hazard. Assessing vulnerability to a rapid-onset hazard needs a short-term timescale quite different to the long-term view appropriate to sea-level rise or coastal erosion. The temporal scale of the assessment should thus relate to the policy maker's needs.

The temporal scale of the assessment of vulnerability depends on the different tools and data used for the assessment, as well as on the assessed elements or processes at risk (people, buildings and critical infrastructure, economic activities, environmental services). The assessment of vulnerability using census data should, if feasible, encompass a short- or medium time span to assess the current situation and to understand major trends in demography and socio-economic development (e.g., through data covering the last 10 years). Overall, the temporal scale of the assessment needs to take into account the function of the assessment and the application process. If the assessment is intended to serve as a continuous monitoring tool within the ICAM processes, the temporal scale is not limited. If the assessment is to help identify actual vulnerability hotspots, then it can be based on available data or data that can be gathered within a short- or medium time span.

Overall, the capture of data that allow the identification of changes and interactions is recommended. For example, it might be instructive to draw attention to the temporal changes in vulnerability of settlement structures in the coastal area or the demographic changes that have occurred as a result of changes in exposure within the last 20 years. This is especially true if the ICAM strategy focuses on the development of future guidelines and development goals for the next 10–20 years. Furthermore, the assessment needs to select a temporal scale appropriate to the specific subject of analysis. If, for example, the vulnerability to creeping environmental changes should be documented, the time horizon of these creeping changes needs to be considered. If the assessment aims to focus on climate change vulnerability, the timescales of the IPCC scenarios should be considered and potential socio-economic changes or projections could be developed. In order to ensure the applicability of the approach, the most appropriate temporal scale must reflect the specific tools and intervention instruments, as well as the data and the time available to conduct the vulnerability assessment.

5.4 GATHERING GEO-REFERENCED VULNERABILITY DATA

The use and application of geospatially referenced data are useful and recommended, particularly if the vulnerability assessment aims to contribute to a better understanding of interactions between hazard scenarios and human wellbeing or livelihoods. With current GIS technology it is possible to overlay a natural hazard map on the socioeconomic conditions or settlement structures, showing which people and assets would be impacted and what their degree of vulnerability might be. These maps could even be used within the ICAM process to discuss, with exposed communities, a potential response (by improving preparedness or through mitigation) to these respective hazards.

The mapping of social, economic and environmental conditions and trends in relation to potential hazard exposure can be a powerful tool to underline the need for vulnerability reduction before an event strikes the coastal community or region (See Box 5.11 and Fig. 5.1). Overall, it is important to note that not all the information and assessment results need be mapped. Additional vulnerability information that cannot be adequately geo-referenced can instead be documented and explained in reports.

5.5 APPRAISING THE DIMENSIONS OF A COMMUNITY'S VULNERABILITY

In order to assess or evaluate the aggregated vulnerability of a coastal community to specific coastal hazards, thematic dimensions (or spheres) of community vulnerability in respect of the hazard should be identified (see boxes 5.4 and 5.8). The important dimensions which should be taken into consideration within ICAM include:

- human and social;
- physical and economic; and
- environmental.

Physical vulnerability, relating to buildings (also referred to as structural vulnerability) and economic vulnerability may be treated separately, if preferred.

BOX 5.5 Tsunami risk assessment of coastal areas in Indonesia in the context of Early Warning – the GITEWS Project (see also boxes 5.3 and 5.9)

GITEWS project aims for the implementation of an effective Tsunami Early Warning System for the Indian Ocean, mainly off-coast Indonesia. It is strongly connected to IOC-coordinated IOTWS activities in the region. The system integrates terrestrial observation networks of seismology and geodesy with marine measuring sensors, satellite technologies and pre-calculated simulation scenarios. An effective early warning system plays a key role in disaster risk reduction of low-frequency but extreme events like tsunamis. For enhancing its effectiveness, vulnerability and risk assessments play a key role, contributing significantly to disaster risk reduction. The knowledge about exposed elements, their susceptibility, and coping and adaptation mechanisms is a precondition for the development of people-centred warning structures, local specific evacuation planning and recovery policy planning.

Consequently, the following fundamental dimensions of risk are quantified:

- The probability of occurrence, the magnitude, and the spatial distribution of the hazard intensity (hazard assessment, see Section 4).
- The susceptibility and degree of exposure of vulnerable elements (population, economy, physical spheres and regions affected) to a stressor or hazard.
- The ability to respond (coping) and recover from the disastrous impact of a hazard.

Generally, the concept was established to monitor and quantify the spatial vulnerabilities within the timeline of disaster occurrence. That means that, at each location, the properties or deficiencies related to potential tsunami impact – people and critical facilities exposed, warning (e.g., people's ability to receive and understand a warning), response (e.g., people's decision to evacuate, people's capability to evacuate), and emergency relief and recovery (e.g., people's ability to restore their livelihoods) – are addressed and quantified. Hence, the development of risk assessment components reflects temporal stages within disaster management (warning chain, response and recovery phase). Consequently risk assessment in the frame of the GITEWS project contributes to two main tasks (Post et al., 2008a, b):

- enhancing 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 (e.g., evacuation and land-use planning, see sections 7.4 and 8.3).

The risk assessment methodology was developed with respective Indonesian partners within a joint Indonesian-German working group for risk modelling and vulnerability assessment. The risk assessment, modelled on the BBC holistic framework (Box 5.3), is being conducted at two scales with different purposes: firstly, information for early warning and decision support conducted at a sub-national level covering the entire coastal area of Indonesia facing the Sunda Trench; and second, addressing the provision of sound information for disaster management and risk reduction at the local level (e.g., support for spatial planning). The latter is being conducted within three pilot areas (Padang in Sumatra, Cilacap in Java and Kuta in Bali) (see Fig. 6.1). At the sub-national scale, risk specific information, mainly in form of maps, is being developed and provided to respective users.

Beside this, relevant risk assessment information is stored and available within the decision support system of the Tsunami Early Warning Center in Jakarta. Here, risk information is visible as maps at different scales, and risk assessment information is available considering specific tsunami events (e.g., expected tsunami impact area, people and critical facilities exposed, potential safe areas, response capability, people affected and tsunami risk index) as tabulated data.

More detailed analysis is being carried out at the local level within the GITEWS pilot areas. Additional information – detailed tsunami inundation modelling and improvement in hazard assessment, spatially detailed dynamic population distribution (day and night population patterns), social response capability, detailed evacuation modelling including vertical evacuation possibilities, potential infrastructure and building damage to different tsunami intensities and livelihood rehabilitation capacity – are addressed at this assessment level. The respective risk assessment products are being developed taking into consideration specific local planning needs in the context of disaster management.

Besides generating risk assessment products at local and sub-national levels, the established assessment methodologies are integrated into guidelines and methodological documents. The work is embedded in capacity building activities (e.g., training, workshops) in order to facilitate use and updating of tsunami risk assessment products.

Joachim Post, Stephanie Wegscheider (DLR);
Jörn Birkmann, Niklas Gebert (UNU-EHS).

Source: GITEWS Project. Courtesy DLR, UNU-EHS.

BOX 5.6 The vulnerability of Small Island States to sea-level rise and coastal erosion

The communities of small islands, especially low-lying atolls, are widely recognized as being threatened by marine hazards, with long-term sea-level rise (and other climate change) being a major concern which was addressed in a dedicated section of the IPCC Fourth Assessment Report (AR4). Small island states are concentrated in three broad regions: the Caribbean, the Indian Ocean and the Pacific Ocean. This vulnerability reflects a high exposure, limited data, little local expertise to assess the dangers, and a low level of economic activity to cover the costs of adaptation, and often the (local) retreat option (Section 8.2) is not viable due to limited space. Any long-term rise in sea level could have catastrophic effects in many island states with widespread flooding in the more low-lying islands such as the Maldives, Kiribati and Tuvalu. Even the 'high' islands in island regions appear threatened, as human activities are concentrated in the hazardous areas around the coast. Hence it is important to identify critical thresholds of change beyond which there may be collapse of the ecological (e.g., coral reefs) and social systems on these islands. These threats raise the spectre of a planned relocation (retreat) to safer locations, sometimes in other countries, with international implications.

Robert Nicholls

Source: IPCC, 2007: Chapter on Coastal Systems and Low-lying Areas, and Chapter on Small Islands.

Flooding caused by a high tide at Funafuti, Tuvalu, February 2006.

Picture: © Monise Laafai

BOX 5.7 ICAM taking coastal hazards into account: the case of Bangladesh

The coast of Bangladesh is known as a zone of vulnerabilities as well as opportunities. It is prone to natural disasters including tropical cyclones, storm surges and river floods. The combination of natural and man-made hazards, such as erosion, high arsenic content in groundwater, waterlogging, earthquake, water and soil salinity, various forms of pollution and the risks from climate change, have adversely affected lives and livelihoods in the coastal zone and slowed down the pace of social and economic developments. In 2005, the Government of Bangladesh implemented a new concept of Integrated Coastal Zone Management, by adopting a Policy Note on coastal management (http://www.iczmpbangladesh.org/rep/czpo/czpo_eng.pdf) and establishing the Program Development Office (PDO-ICZM). The main output of the PDO-ICZM is the Coastal Development Strategy (CDS), that is based on, and integrates, the following:

- establishing a coastal zone policy;
- setting up a priority investment programme;
- improving community capacities to enhance livelihood;
- enabling institutional and legal environment; and
- establishing an integrated coastal resources knowledge base.

Three indicators have been considered for determining the landward boundaries of the coastal zone of Bangladesh. These are: influence of tidal waters, salinity intrusion and cyclones/storm surges. Nineteen districts of the country are being affected directly or indirectly by some or all of these phenomena. The districts are considered directly vulnerable to natural hazards. The exclusive economic zone (EEZ) is regarded as the seaward coastal zone. The main goal of the Bangladesh's Integrated Coastal Zone Management is to 'create conditions in which the reduction of poverty, development of sustainable livelihoods and the integration of the coastal zone into national processes can take place'. The Government has formulated this coastal zone policy that would provide general guidance to all concerned within the 19 coastal districts for the management and development of the coastal zone, enabling coastal people to pursue their life and livelihoods within a secure and conducive environment.

Alice Soares

The human and social dimension

Social vulnerability is multi-faceted. It changes both spatially and over time. Major transformations of the population's size, its economic condition and social characteristics make this dimension particularly dynamic. Age, income, health and education are basic features affecting the physical and economic condition of an individual. Different levels of education and income are likely to reflect different levels of knowledge about hazards and risk. Poor people might be vulnerable because their financial assets and resources are limited and their income and work may be seasonal. Poor, women-headed households, ethnic minorities and elderly people are commonly among vulnerable groups. Knowledge about the possibility of coastal hazards and their impacts is also is a key for vulnerability reduction. Migrants and holidaymakers who have no experience of such hazards are often among the most vulnerable to their impacts (see Box 5.2).

When assessing the social/human dimension of a community's vulnerability, it is important to identify its specific characteristics. The following parameters should be given particular attention:

- population density;
- population gender (i.e., percentage of women);
- children, disabled and/or elderly people (percentage);
- mean income;
- knowledge of coastal hazards;
- time and duration of living in coastal areas;
- level of education;
- access to warning information;
- power relations; and
- access to resources that might help to build resilience.

The main questions to be answered in assessing social vulnerability are summarized as follows:

- How many people are living and/or working within the zone(s) of potential inundation?
- To what extent are people protected from hazard impact?
- Which social groups are most vulnerable to the coastal hazard impact?

Physical and economic dimension (including critical infrastructure)

Procedures for the assessments of potential economic losses are quite advanced and often link losses to specific land-use types, building structures or economic activities exposed to the various coastal hazards. The methodologies tend to focus mainly on the economic values exposed and their damage functions, the latter relating to observed damage to an inundation parameter, such as the water depth. Damage functions are a method of linking hazard to damage or loss.

In contrast, procedures for the assessment of the vulnerability of critical infrastructure have yet to be developed. Many domestic and commercial operations cease to function without the services of critical infrastructure – particularly energy supply, but also water and sewerage services (Box 5.8). Interestingly, such infrastructure is commonly located in hazard-prone coastal areas and may therefore be particularly vulnerable. This dimension of vulnerability needs to be taken into account when dealing with both business continuity and the susceptibility of economic activity in hazard-prone zones. The functioning of critical infrastructure (heating, piped water, sanitation, etc.) is also important for many daily activities of coastal communities and is therefore a key issue when dealing with the disruption of livelihoods and daily activities. Emergency response and disaster recovery can be hindered by hospitals and other infrastructure being critically affected.

Main questions to be answered in assessing physical and economic vulnerability are:

- What is the capital value at risk within the potential exposed zone?
- What is the likelihood that physical assets (buildings) will be damaged and the capital value lost?
- To what extent is infrastructure protected from hazard impact?
- How vulnerable are critical infrastructure services provided by critical infrastructures?
- Who is most dependent on these critical infrastructure services (facilities such as hospitals or economic sectors such as a glass factory)?
- How is economic vulnerability changing over time?
- Have physical structures been improved to reduce the potential economic damage due to coastal hazards?

BOX 5.8 Critical infrastructure

A country's critical infrastructures consist of those physical and information technology facilities, networks, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of citizens, or the effective functioning of governments. Critical infrastructures extend across many sectors of a country's economy, including banking and finance, transport and distribution, energy, utilities, health, food and water supply and communications, as well as key government services.

Environmental dimension

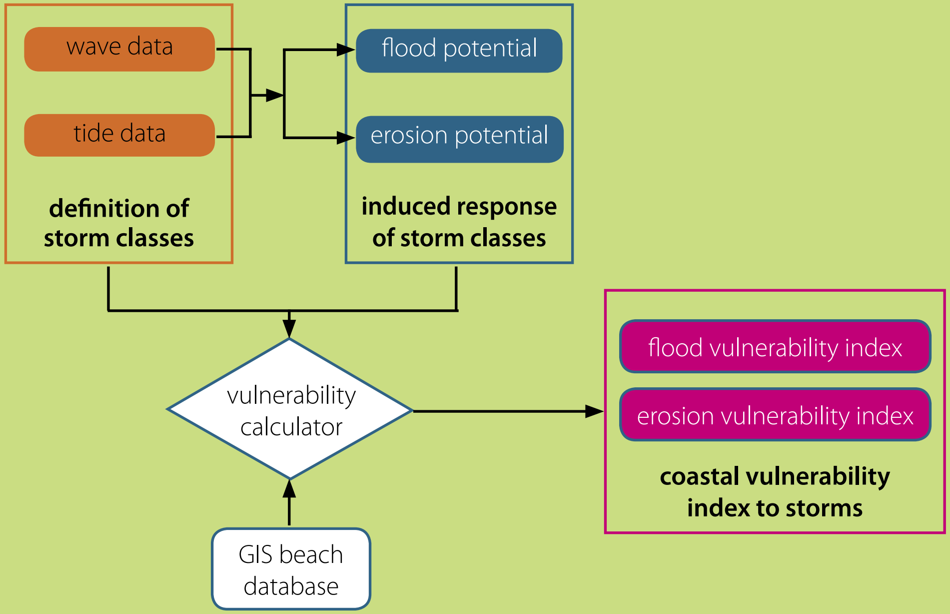
The assessment of environmental vulnerability is necessary to evaluate the short-, medium-, and long-term environmental damage that could be caused by coastal hazard events and to achieve an awareness of the environmental resilience of the designated areas (boxes 5.9 and 5.10).

Environmental resources and the environmental services on which coastal communities depend can be severely degraded not only by catastrophic inundation but also by gradual long-term sea-level rise. One of the most important resources that can be impacted is fresh water (both surface water and groundwater) that is used for drinking and agriculture in many coastal regions. Sea-level rise and major marine inundation, as well as reduced freshwater discharge from rivers in delta regions, can cause serious salination of these resources with major implications for human health, livestock and agriculture.

On the Gulf Coast of the United States, waves and currents generated by hurricanes are capable of moving large amounts of sand. During the most extreme wave events, changes can occur across the width of an entire barrier island. Beach erosion, dune erosion, overwash, island breaching, marsh erosion and coastal cliff erosion have been observed, reshaping the coastline and destroying buildings and infrastructure, highlighting the importance of the environmental dimension of vulnerability.

BOX 5.9 Coastal environmental vulnerability assessment to storms at regional scale

framework to estimate the coastal environmental vulnerability to storm impacts at a regional scale has been developed and tested on the Catalan (NW Mediterranean) coast. It consists in a five-step procedure (see figure, right): (i) characterization of the forcing – storm classification – in the study area; (ii) evaluation of the induced beach response – measured in terms of inundation and erosion; (iii) coastal zone characterization – GIS database comprising data on all the beaches along the Catalan coast; (iv) definition of a coastal vulnerability index to storms – a composite of two partial vulnerability estimations, the flood vulnerability and the erosion vulnerability indices, and (v) assessment of the coastal vulnerability.



The selected approach serves to assess the environmental vulnerability to "representative" storms. First, local storms are classified using a 5-class system (weak, moderate, significant, severe and extreme) obtained by using wave power as classification parameter. For each storm class, the induced physical coastal response (erosion and inundation) is calculated separately for representative beach types (sediment grain size and slopes) in the area.

Partial vulnerability indexes have been defined as a function of the ratio between a measure of the magnitude of the induced physical response (inundation and erosion) and the main involved characteristics of the beach (height and width respectively). The response is obtained from statistics of calculations for each process (wave run-ups and surges on the one hand and beach retreat on the other) for all storms within a class. Beach characteristics are obtained from actual values included in a GIS database. This information is also used to decide which value of inundation and erosion estimates should be used (depending on the sediment and slope of the beach). Finally, both indices are integrated into a single composite, reflecting the overall vulnerability by weight-averaging the partial values.

This approach has been applied to assess the vulnerability of the Catalan coast to storm impacts in such a way that, at present, five vulnerability maps exist for all beaches along the 600 km-long coast. This should permit coastal managers to associate a given set of actual or forecasted wave conditions to one storm class and, using the corresponding vulnerability map, to rapidly identify the areas sensitive to such storm conditions. The regional assessment for class-V storms (extreme) indicates that the main contributor to the vulnerability along the Catalan coast is flooding, controlled mainly by wave run-up.

José A. Jimenez and Tonatiuh Mendoza

Principal source: Coastal Vulnerability to Storms in the Catalan coast. More information available at: (http://www.tdx.cat/TDX-0414108-122517)

Within the environmental vulnerability dimension, parameters that need to be taken into account are:

- surface water;
- groundwater;
- soil;
- ecosystem services;
- landscape; and
- dependency of coastal communities on these environmental resources and services.

For each of these parameters, the characteristics that could be affected by the hazard event should be identified. For example, for an inundation event, the "surface water quality component" parameter has to be studied in terms of salinity, the presence of debris and of pollutants. For each selected characteristic (e.g., salinity) the possible impact may be evaluated considering environmental resilience both with, and without, human intervention. Such analysis will facilitate the prioritization of mitigation and rehabilitation measures. Furthermore, it is essential to analyse whether the coastal community is dependant on one resource base – for example, a surface water resource – or whether the community has alternative surface water resources in the hinterland in case the coastal wells become contaminated. Thus the quality and fragility of the environmental resource base as well as the dependence of the community on this resource base determine the overall level of environmental vulnerability (see Box 5.10).

BOX 5.10 Assessing community and environmental vulnerability on the Australian coast

The Australian coastline is one of the longest and most diverse of any in the world, extending for more than 35,000 km around the mainland, with a range of offshore islands and a complex of coral reefs on northern shores. Over 80% of Australia's population live in the coastal zone, focused in metropolitan centres but with rapid expansion on non-metropolitan parts of the eastern and south-western coasts. Coastal settlements are already subject to a number of hazards, most of which are likely to be exacerbated as a result of climate change. Several approaches have been adopted in the different states and territories to assess the vulnerability of shoreline environments and communities to various hazards.

In northern Australia, there are extensive low-lying coastal and estuarine plains that flank the large macrotidal river and estuary systems. Salt water threatens to invade the unique freshwater wetlands that have established over the plains' surface and which are the basis of an expanding tourism industry centred on Kakadu National Park. The extension of tidal creeks has already been observed on several systems, and the vulnerability of the plains has been assessed in terms of several processes. These include shoreline erosion, overtopping of low-lying ridges, incursion of seawater into freshwater wetlands and salt-wedge intrusion further upstream exacerbated by possible reductions of river flow (fig. a).

In South Australia, a similar, geomorphologically-based approach to mapping the susceptibility of coastal landforms to erosion and inundation has been trialled in northern Spencer Gulf, where homogeneous geological/ecological units, with a clearly defined relationship between elevation and substrate, provided a surrogate for the type of coastal processes occurring, that can be used to indicate vulnerability (fig. b).

In tropical Queensland, where there is a series of small towns established on the low-lying plains flanking the mouths of river systems, there are concerns about the potential impact of tropical cyclones. These settlements are already prone to inundation by storm surges. The risks to these communities are anticipated to be exacerbated as a consequence of the likely intensification of storms, superimposed on the trend of gradually rising sea-level. Modelling provides an indication of the probable adjustments to the recurrence of extreme water levels, although the resolution of topographic survey data is generally insufficient to assess the detailed risk to infrastructure. More precise surveys adopting techniques such as airborne LIDAR are needed to complement the surge modelling (fig. c).

In New South Wales, the beaches are subject to massive erosion during storms, particularly in response to east coast cyclones. The cut-and-fill patterns are likely to mask the more subtle response to gradual sea-level rise, and a number of erosion modelling approaches have been developed (fig. d).

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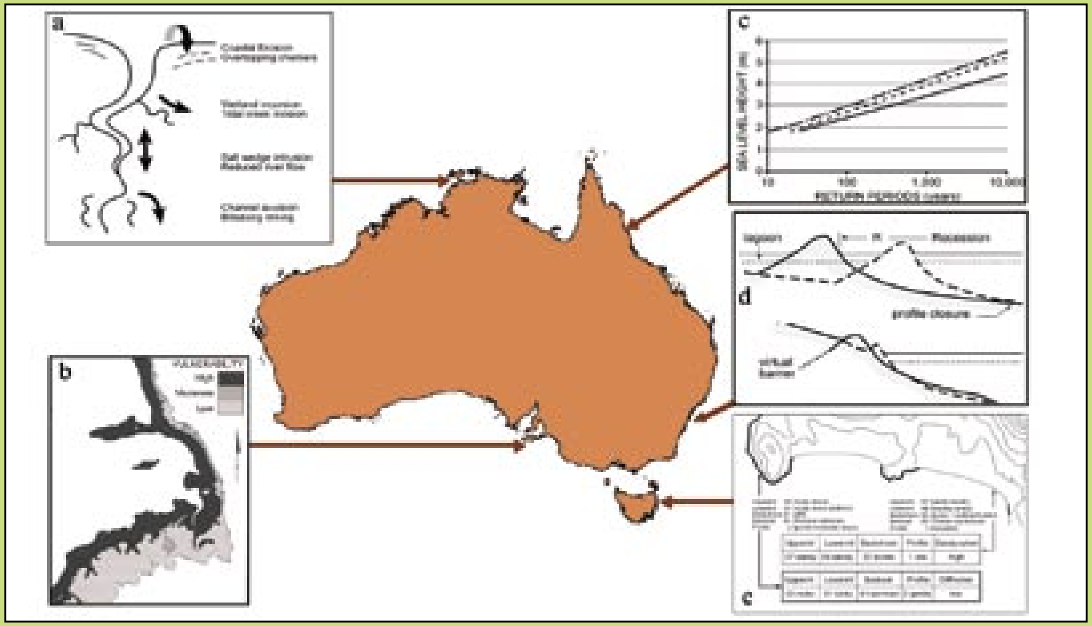
BOX 5.10 (Continued)



In Tasmania, a novel indicative approach to shoreline geomorphology and stability has been adopted, using a line segmentation technique to characterize the shoreline on the basis of form and fabric, assigning attributes to segments which can subsequently be used to define vulnerability classes (fig. e). Recently, this linear segmentation approach, termed the 'Smartline', has been modified and extended on a national basis to the entire Australian shoreline as part of a first-pass assessment of coastal vulnerability. This is the first national approach to coastal vulnerability in Australia.

Colin D. Woodroffe and Nick Harvey

5.6 HOW TO DETERMINE THE LEVEL OF VULNERABILITY FOR EACH DIMENSION

The information acquired about the various dimensions of vulnerability should be merged, if feasible, to create an integrated vulnerability map showing the hotspots of vulnerability. This requires the normalization and weighting of different indicators as well as the development of vulnerability levels and classes that allow the integration of very different types of information and GIS layers.

One example is to aggregate several indicators into a useful and meaningful aggregated indicator. In the case study of Indonesia (Box 5.11), "Access to Information and Knowledge" encompasses four indicators. Furthermore, logical, verbal argumentative or statistical methods can be used to group and combine indicators and to merge them into a single index that can be illustrated and shown in a vulnerability map. If the community has not developed its own goals and standards to classify vulnerability, the most reasonable approach to derive different levels of vulnerability is the spatial comparison between different regions. Regions with a high percentage of elderly people and children, and with limited access to information, health facilities and education might be defined as more vulnerable than those where people have a lower percentage of elderly and children as well as a better access to information (early warning), education and health facilities.

The development of vulnerability levels can also be supported by using statistical methods, such as an analysis of the variance or a factor analysis to identify appropriate thresholds and classes of high, medium and low vulnerability. Most important is the identification of certain patterns and more vulnerable areas compared to less vulnerable. While for every assessment the indicator value might differ slightly, the spatial distribution and comparison of the information is crucial.

Alternatively, the use of other logical approaches or a participative tool to decide on the most important indicators and the weighting among them could be considered. Even results of single indicators could be documented regarding different areas, thus showing a relative vulnerability – the differences between the areas. The most important indicators could also be derived by using a regression analysis to identify those variables that have the most significant influence on the overall picture. What is important at this stage is that, in the assessment, the results of single indicator analyses and also the aggregated index results are documented, plus the methods used to arrive at these results. The assessment should first be carried out separately for each of the vulnerability dimensions. Simple equal weights could be applied to combine, e.g., the social and economic vulnerability layers.

It would be desirable to develop thresholds for social, physical and economic, and environmental vulnerabilities within the ICAM process. However, in most areas, precise goals which could serve as thresholds for the classification of vulnerability and non-vulnerable conditions do not exist. In lieu of such goals, a pragmatic approach is the development of relative vulnerability, taking into consideration the variance of vulnerability between different parts of the coastal area examined, or within different social groups or critical infrastructures.

From a methodological point of view, different methods could be used to derive levels and classes of vulnerability. One of the most common would be the differentiation of the areas or groups in two or three vulnerability classes – thus one could outline green, yellow and red areas of vulnerability. Furthermore, statistical methods such as the calculation of the standard deviation could be used to identify thresholds for levels of vulnerability. The results of the reliability test and standard deviation could be used to define the range of classes that ensure that the actual values can be grouped into classes which show major differences. It would depend on the end-product whether, for example, all the different levels of vulnerability are shown in a map (with the option of including 6–8 classes and levels of vulnerability), or whether the aggregation and illustration of vulnerability levels should be limited to the three colours of a traffic light – red, orange and green (see Fig. 5.1).

Beside the justification of the classes used to distinguish different levels of vulnerability, it might also be helpful to assess vulnerability trends and to examine whether in the past these trends reached different vulnerability levels. Particularly if one aims to evaluate actions and interventions with these vulnerability indicators, the levels and vulnerability classes need to be relatively sensitive to changes due to these interventions. If a general overview of vulnerability in a larger coastal area is required (the macro scale), cruder vulnerability levels such as low, middle and high might be sufficient. Lastly, the development of vulnerability levels will also depend heavily on the specific element at risk. For example, for social groups different methods are needed compared to critical infrastructures.

To compare and derive vulnerability levels for critical infrastructure and their various components – e.g., within an electricity network – the network structure itself, the transformers and the various network stations, etc. can be assessed and classified using the method of utility functions. In this regard, each component is evaluated according to its value and importance for the whole system. When a component is crucial for the functioning of the entire system, it will get more values as a component that can be replaced by other existing components. For example, if a major transformer station for electricity from high voltage to middle voltage failed and the local transformers and substations were unable to compensate for this loss, then the transformer station from high voltage to middle voltage would be a crucial component when dealing with the critical electricity infrastructure.

Within the framework of the ICAM process, local and regional stakeholders should involve respective companies and agencies or NGOs to discuss the vulnerability thresholds and the classification model used. Overall, due to a lack of specific vulnerability thresholds and goals for vulnerability reduction, the assessment of relative vulnerability seems to be an appropriate, practical way to derive respective vulnerability levels, taking into account the variance within the area or country. In this regard, comparison of the different vulnerability values, for example, different areas within the ICAM region, is recommended; also comparison of the values with national or regional averages. For some indicators, international norms, such as the dependency ratio or norms for the calculation and measurement of illiteracy, can be used. Finally, stakeholders that might be partners within the ICAM process do have an overview of different vulnerability levels. For example, the urban planning authorities in some areas have a catalogue regarding the earthquake and tsunami resistance of different building types. These catalogues can also serve as a basis to derive vulnerability levels for buildings.

5.7 DISPLAYING VULNERABILITY INFORMATION – MAPS, MATRICES AND REPORTS

The results of the classifications of vulnerability levels for each indicator can be plotted on thematic vulnerability maps through GIS software or can be documented in matrices and reports, using different colours for the different vulnerability levels, in order to give a view of the main vulnerability features. GIS software provides a flexible system, which allows each end-user to obtain specific, customised outputs.

If the aim is to inform the local population, it might be useful to minimize the different vulnerability levels to three: green (low vulnerability), yellow (middle) and red (high vulnerability). These colours are commonly self-explanatory and might not need to much additional information. If the maps or reports regarding vulnerability are for a specific end-user, such as for urban planning, additional, more detailed information particularly relevant for planning could be inserted. Similarly, maps for critical infrastructure might need to be more detailed, for use by disaster response agencies which require an appropriate basis for evacuation and preparedness strategies.

Overall, the vulnerability information within ICAM processes should be visually attractive and should encompass different formats, such as maps, matrices and reports. Also, short movies or digital material might be helpful to explain what vulnerability is and which hotspots of vulnerability were detected during the assessment. Displaying vulnerability information should also allow different stakeholders to identify potential ways of reducing vulnerability. Thus the information should be action-relevant and should help to promote the development of strategies to reduce vulnerability. For example, local administrations could be interested in buildings vulnerability, in order to better plan urban development and urban renewal. Insurance companies might need information regarding "physical vulnerability" to set insurance premiums in different areas. Local authorities, emergency management and humanitarian assistance agencies could be interested in socio-economic and environmental aspects of vulnerability to concentrate their efforts – mitigation and prevention strategies – in hotspots of vulnerability.

Many aspects of vulnerability can be mapped and therefore also be combined with hazard information to produce a risk map (Section 6.3). In the development of vulnerability maps, the spatial resolution of these maps should match the end-user needs. If specific information for urban planning, for example, is required, the maps should permit illustration of the most vulnerable areas at 1:100,000 and 1:50,000 map scales (Fig. 5.1). If the assessment is targeted to produce a general overview at a national level, much smaller-scale maps would be appropriate. Furthermore, experience shows that maps for the individual features of vulnerability (socio-economic vulnerability, infrastructure vulnerability, etc.) should be developed in addition to an integrated map, which can usefully outline how vulnerability compares with other regions.

The end-user should be involved when developing specific vulnerability maps. For example, in the GITEWS project in Indonesia, vulnerability and exposure information were integrated into a "response map" that estimates at sub-national and local levels how many people would potentially be able to evacuate themselves to safe areas. Demographic vulnerability features as well as physical vulnerability characteristics were combined.

For a more general vulnerability map, the social fabric of the exposed population, the educational level and awareness about the coastal hazards are key features that can be spatially compared (Box 5.11). It might be also be useful to integrate a physical vulnerability layer that shows areas exposed to coastal flooding in which a vertical evacuation in buildings would be possible (see Fig. 7.3). As a starting point, development of the following four types of vulnerability map is recommended:

- socioeconomic and human vulnerability map;
- physical vulnerability map (vulnerable buildings) (see Box 5.12);
- vulnerability map of critical infrastructure (hospitals, electricity network, schools, etc.); and
- vulnerability map of environmental services (see Box 5.12).

BOX 5.11 Sub-national vulnerability assessment to tsunami risk in Indonesia in the context of Early Warning – the GITEWS project (see also Box 5.5)

The assessment of vulnerability within the GITEWS project aims to compare the vulnerability between different regions at the coasts of Sumatra, Java and Bali, particularly focusing on the aspect of the potential of loss of life during a tsunami event. Tsunami risk assessment is linked to the question of effective, people-centred early warning and evacuation. With this focus, the vulnerability indicators developed follow the assessment guiding questions:

- Do exposed people have access to warning?
- Do they know how to respond to warnings?
- Are they able to reach a safe place in due time (evacuation)?

The complexity of the relevant vulnerability factors contributing to the potential loss of life during a tsunami event requires an integrated assessment approach by including human vulnerability factors (e.g., exposure of the population, age, gender, knowledge and access to information) and spatial and physical vulnerability factors (e.g., the "reachability" of safe places as a function of land use, topography and distance relationships between safe places and settlement areas). The target audience of the vulnerability assessment products are authorities from the local to the national level who need to take knowledge-based intervention decisions for the development and the optimization of the early warning chain, the awareness of the population at risk and the evacuation strategy.

The most crucial challenges of sub-national assessments are data gaps and the attempt to calculate and map locally based vulnerability patterns on a coarse scale. Nevertheless, by utilizing a variety of methods, such as remote sensing and GIS techniques, and the analysis of available national statistical data, important vulnerability information can be generated that allows comparison of vulnerable regions. For the human vulnerability factors, existing statistics in Indonesia (e.g., the Population Census 2000) were utilized and processed. These provided demographic data (distributions of the population at the coastline, gender and age); data regarding the access of households to information (and warnings), represented through the indicators of access to electricity and mobile phones; and data regarding the level of education within a region, representing people's degree of anticipated response to tsunami warnings. For the case of the spatial and physical vulnerability factors, land-use characteristics, street networks, spatial relationships of evacuation infrastructure and population distribution were analyzed by using remote sensing and GIS techniques. The integration of the human and spatial / physical dimensions of vulnerability yield an overall vulnerability index, classified into low, moderate and high vulnerability. The more vulnerable a region is, compared to others, the more likely people are unable to evacuate in due time, thus potentially suffering higher loss of life during a tsunami event.

The study of the sub-national assessment will be complemented by assessments of vulnerability at local scales in the pilot areas of GITEWS. Here, participatory research methods and quantitative household surveys were also conducted jointly.

To outline the usefulness of vulnerability information, preliminary maps of the vulnerability assessment to tsunami risk in Indonesia are shown. The maps provide a first outline on how vulnerability information can be represented in maps at the sub-national level.

Exposure as a factor of vulnerability

The first map (fig. a) shows the degree of population exposure to a tsunami event (people per hectare in the hazard zone). The estimation has two major functions. Firstly, it serves as an indicator that links the hazard and the vulnerability component. Secondly, the indicator is related to the available space for evacuation (pathways and safe place capacity), thus playing an important role for the estimation of the potential of loss of life during a tsunami event (overall vulnerability map). Here, the map shows a major difference between the islands of Java and Sumatra. In Sumatra especially, urban centres are indicated as highly exposed (red), whereas in Java high population densities also occur in rural areas.

Access to information and knowledge as a factor of vulnerability

The second map (fig. b) shows the "access to information and knowledge" in different coastal regions in Indonesia. The red zones indicate a low level of access while green and yellow areas are generally better off regarding people's access to information, their education level and their access to electricity. The map shows that, particularly in Sumatra, the southern part and the islands in front of Sumatra have to be seen as hotspots, while cities such as Padang have

(Continued on next page)

BOX 5.11 (Continued)

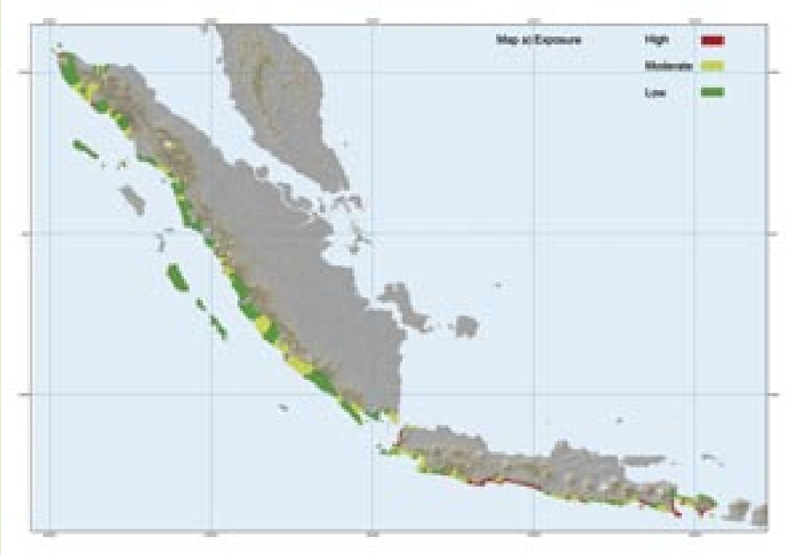


fig. a *Exposure*

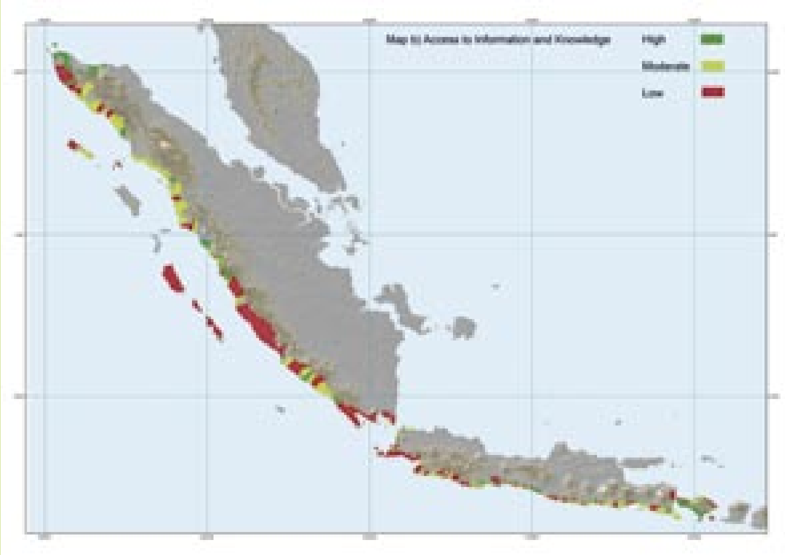


fig. b *Access to information*

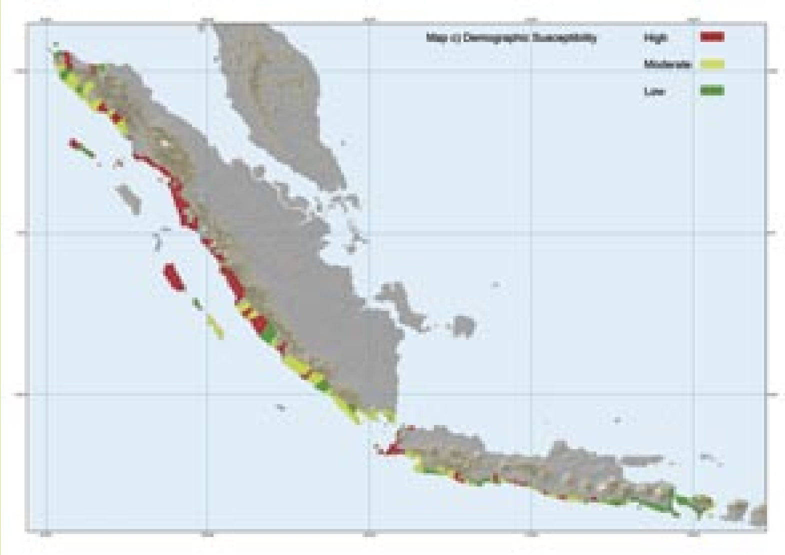


fig. c *Demographic susceptibility*

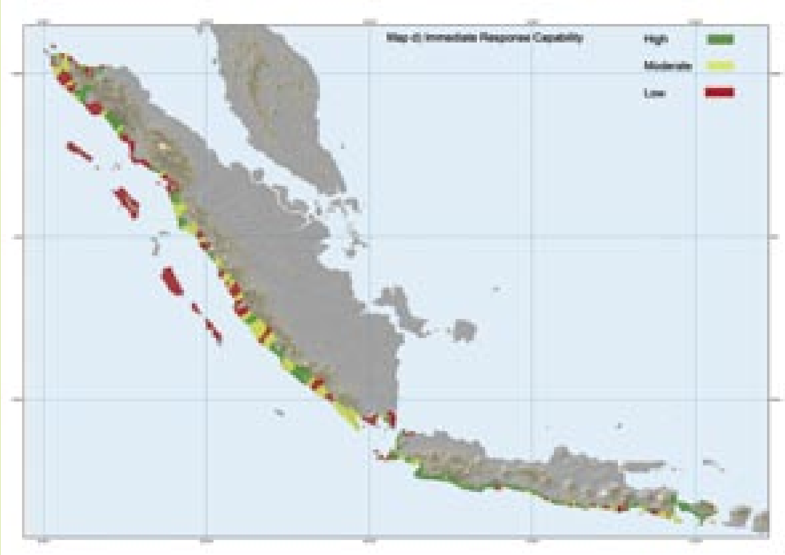


fig. d *Immediate response capability*

(Continued on next page)

BOX 5.11 (Continued)

generally a higher level of access to information and knowledge. In Java, the north-western coastal regions particularly can be identified as a hotspot, while the region of Bali is relatively better off.

Demographic configuration of regions as a factor of vulnerability

Interestingly, the analysis and visual presentation of the demographic susceptibility index (third map, fig. c) shows that, particularly in mid- to north-western Sumatra, there are areas with a significantly higher demographic susceptibility (relatively more elderly, children and women) representing a lower response capacity to manage successful evacuation. The islands in front of Sumatra also show up as a hotspot of demographic susceptibility. In Java, the north-west shows up as a hotspot as well.

Spatial and physical morphology as a factor of vulnerability

With respect to the spatial analysis of the "reachability" of safe places within a given timeslot at the Indonesian coastline, hotspots appear especially on the Mentawai islands off the Sumatra coast and various sub-districts in Sumatra (see fig. d). In Java, especially the western part of the south coast shows rather good conditions for successful evacuation. This is due largely to the cliffed topography in that area.

Aggregated vulnerability

As one preliminary result, an aggregated vulnerability map (see fig. e) was developed, encompassing the indicators used to examine the exposure of people (fig. a), the access to information and knowledge (fig. b), the demographic susceptibility (fig. c) and the physical and spatial factors that influence the capability of people to reach a safe place in due time (fig. d).

The draft map of the aggregated vulnerability index shows interesting patterns. **The islands in front of Sumatra are hotspots of vulnerability**. Furthermore, important sub-national differences are revealed such as the differences within the province of Aceh and the differences between the city of Padang and the

fig. e *Aggregated vulnerability*

area of Padang Pariaman. In Java, the north-western part is significantly less vulnerable than, for example, the south-west. In conclusion, the sub-national vulnerability assessment, in the context of tsunami risk and early warning in Indonesia, reveals that it is not the cities, but the remote and rural areas (e.g., islands in front of Sumatra as well as the north-western part of Java) that are hotspots of vulnerability. The hotspots that the assessment clearly reveals might be a basis to define priority areas for risk reduction efforts, e.g., within the ICAM process.

While these sub-national assessment results are a first analysis about the general situation, more detailed information can be given by the vulnerability maps produced for the local and district levels (see Fig. 5.1), based on qualitative (e.g., Participatory Rural Appraisal) and quantitative data collection methods and processing.

Jörn Birkmann and Niklas Gebert (UNU-EHS), Joachim Post (DLR)

Sources: GITEWS Project. Courtesy UNU-EHS, DLR.

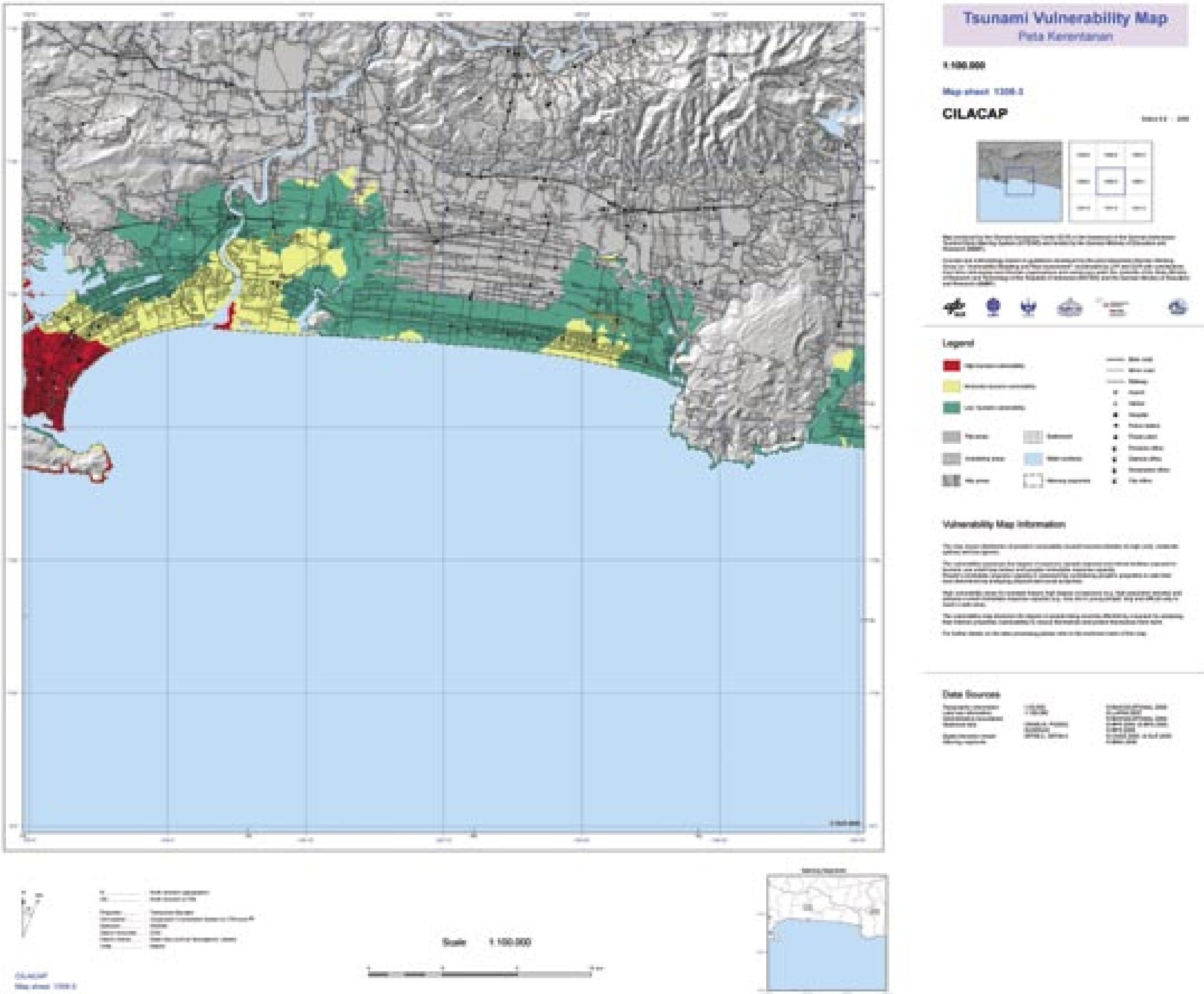


Fig 5.1 *Tsunami vulnerability map at a local scale.*
This map (at 1: 100,000 map scale) covers the city of Cilacap in Java, Indonesia. It shows the vulnerability (high=red; moderate=yellow; low=green) of people towards the tsunami hazard. The map combines information on the degree of exposure and people's ability to respond.

Source: GITEWS project. Courtesy DLR.

BOX 5.12 The CRATER project: Coastal Risk Analysis of Tsunamis and Environmental Remediation

For Thailand's coastal areas with a high population density, a presence of valuable infrastructure, tourism and environmental resources subject to tsunamis, the CRATER project has assessed the potential damage due to tsunami waves. This has provided information for the vulnerability and risk assessment required for the design of prevention and mitigation plans, for the development of protection structures and for appropriate environmental uses of the coastal areas.

The project has involved analysis of the tsunami's effects through hazard mapping and vulnerability and risk assessment and evaluation; it has calculated water levels and current velocities associated with possible tsunami floods. This has enabled the evaluation of vulnerability maps and provided data necessary for rescue planning. Vulnerability has been assessed at regional and local scales for the various dimensions, in particular the environmental and infrastructure (built environment) vulnerability.

Field data and multi-criteria analysis have been used for the vulnerability evaluation and the compilation of vulnerability maps. Two manuals – "Optimization of evacuation plans" and "Creating tsunami vulnerability and risk maps through GIS software" – have been created as specific tools to guide local authorities to assess and evaluate vulnerability within designated coastal areas.

Alessandra Cavalletti

Sources: Cavalletti et al., 2006; Dall'Osso et al., 2006.

The CRATER project is the Italian technical contribution to Thailand's 2004 tsunami-affected area, implemented by experts of the Italian Ministry of Environment and Territory in association with experts from the Asian Disaster Preparedness Centre and the Ministry of Interior of Thailand.

5.8 DEFICIENCIES IN PREPAREDNESS

For the assessment of risk in respect of a hazard scenario, it is also important to consider deficiencies in preparedness which may be manifest as weaknesses of institutions and disaster-risk management agencies. Early warning systems, and evacuation planning and standard operating procedures for emergency response, as described in Section 7, may be lacking or inadequate. Another possible deficiency might be a lack of risk transfer mechanisms, such as insurance. In general, such weaknesses may be grouped into:

- weaknesses in early warning systems and responses in the event of a warning;
- weaknesses related to the emergency response; and
- risk transfer mechanisms facilitating post-impact recovery.

Opinion is divided as to whether such deficiencies in institutional preparedness should be assessed as a contributor to community vulnerability – "institutional vulnerability". The presence of good institutionalised capacities, effective organizations and good governance may be seen as reducing vulnerability. However, it may be argued that, from a policy-relevant point of view, the responsibility concerning preparedness should be placed on those agencies which are in charge of preparedness (National or Local Emergency Committees), while vulnerability should be the responsibility of those who generate it. In these guidelines, the topic of "deficiencies in preparedness" is included within the section dealing with vulnerability assessment.

Main questions to be answered while assessing deficiencies in preparedness are:

- Are there institutions and organizations in place which have the capacity to deal with coastal hazards and vulnerability?
- How are different institutions coordinated towards an integrative vulnerability and risk perspective (perhaps through the ICAM process)?
- Are there warning systems in place and have these been tested?
- What is the warning time for emergency response?
- Are there established procedures for emergency response at national and local authority levels, and have these been tested?
- Are there adequate levels of national, local authority and community awareness of the hazards?
- What is the level of institutional resilience?
- How do these institutions and organizations promote the preparedness and resilience of the most vulnerable groups, economic sectors, infrastructures and environmental services?

- Are there instruments and tools in place to reduce vulnerability and to promote adaptation to a changing climate and more intense and frequent coastal hazards?

A lack of institutional preparedness or a lack of cooperation between different administrative and political levels should be documented and mentioned in an assessment report, which should relate to the vulnerability maps and include additional information about coping and adaptation to the respective hazards. The report could also document how these findings are going to be acknowledged and used within the ICAM process.

Remedial procedures dealing with shortcomings in preparedness are considered in sections 7 and 8.

5.9 CHALLENGES AND OUTPUTS

Challenges

Key challenges to successful assessment of vulnerability can include the following:

- In many coastal areas there is a lack of vulnerability assessment programmes. While land-use plans, emergency response and development plans may exist, there may be no comprehensive knowledge of the vulnerability.
- A thorough assessment of the vulnerability of coastal communities (in all its dimensions) to coastal hazards is an essential element in the preparatory phase of ICAM, an important tool that should be implemented by all authorities in charge of disaster preparedness and risk reduction plans.
- Vulnerability assessment requires knowledge of the community's exposure to a hazard event (see Section 4.3).
- Changes in vulnerability must be expected as consequences of socioeconomic and environmental changes. Future scenarios should be assessed. Vulnerability assessments must be kept under review.

Outputs

Key outputs and results associated with this phase may include:

- an asset database for the coastal area being assessed;
- a preliminary appraisal of vulnerability carried out (perhaps leading to a preliminary risk appraisal, Section 6), so that local authorities and disaster reduction and prevention agencies may appreciate the importance of setting up a plan within ICAM for vulnerability assessment of the designated coastal area;
- in-depth assessments of each dimension of vulnerability for each of the recognized coastal hazards;
- 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 of the different dimensions of vulnerability, and aggregated vulnerability, for each of the recognized hazards;
- vulnerability maps and reports covering future scenarios, taking into account the likely consequences of improved emergency preparedness (Section 7) and mitigation (Section 8);
- a preliminary appraisal of the state of preparedness including early warning practices, evacuation plans, Search and Rescue Operations and risk transfer schemes; and
- communication of the vulnerability and preparedness assessments to all involved in the ICAM process.

5.10 DATA REQUIREMENTS AND INFORMATION SOURCES

Table 5.1 identifies data sources that may be useful in realizing the vulnerability assessment products as described in this section.

Table 5.1 *Information sources for vulnerability assessment.*

Products	Variables and standards	Sources	Global programmes and data sets
Vulnerability maps			
Social	Demographic, gender and educational parameters; access to information and hazard awareness; exposure to tsunami risk (how many people are living in the hazard zone (people per ha.))	Inundation and asset maps; Local Authority census; health and welfare services; tourism organizations; exposure and susceptibility surveys	
Physical and economic	Distribution and value of industry, agriculture and infrastructure; the built environment; public utilities; existing hazard defences	Inundation and asset maps; land-use maps Local and national authorities; utility suppliers; trade and industry organizations including ports, agriculture and fisheries; transport companies; insurance companies; exposure and susceptibility surveys	
Environmental	Distribution and value of habitats supporting human well-being; water supply, groundwater quality	Inundation and asset maps; agriculture and fisheries organizations; water and sewerage utilities; environmental health authorities; exposure and susceptibility surveys	
Other products			
Vulnerability reports	Vulnerability indicators as shown above, plus additional information quantitative or qualitative on coping capacities	National and local statistics; household surveys; additional reports in media and local institutions	There is currently no global standardized data set to measure vulnerability. Perhaps this is even not feasible – hazard specific vulnerability and differences in regions (e.g., Europe versus Asia) have to be taken into consideration.

Early warning	Tsunami early warning system in place; communication links from national warning centre 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; drills and simulations conducted to test the state of readiness of the community to respond to a warning.	Government agencies; NGOs	
Emergency response	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.	Government agencies, NGOs	
Risk transfer	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.	Insurance companies; re-insurance companies; Government agencies; NGOs	

General guidance

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6 ASSESSING THE RISK

ICAM PHASES	I	II	III	IV
			STEP 1	

This section provides guidance in determining the likelihood of specified loss and damage to a coastal community, including its population, economy, supporting environment and its institutional structures caused by the impacts of the coastal hazards.

6.1 DETERMINING RISK IN AN ICAM CONTEXT

The risk assessment is the culmination of the broadly based social and environmental assessment that forms the first step of Phase II of the ICAM process, leading to the preparation of the Management Plan (Section 2.2). As described here, the risk assessment is a qualitative judgement which draws together the baseline and background knowledge gained from the procedures of hazard assessment and quantification (Section 4) and the results of the vulnerability assessment (Section 5). Evaluation of the risk information is a key procedure in the creation and maintenance of the Management Plan (figs 1.1 and 1.2).

Key considerations

In these guidelines, the term "risk" refers to the likelihood of danger and loss due to coastal hazards as it may affect coastal communities (including their buildings, economies and supporting environment). The assessment of risk is hazard-specific – for example, the risk to a coastal community from progressive sea-level rise may be very different to that to the same community from a catastrophic tsunami impact. Just as there are different dimensions of vulnerability for a coastal community, so there are corresponding dimensions of risk. Thus the assessment may deliver a range of risk information, depending on the specific hazard and community aspects considered. The probability estimates for each hazard type and its defined scenario are combined with measures of a community's vulnerability to derive and map the risks associated with these hazards.

BOX 6.1 Tsunami risk assessment and mitigation for the port city of Galle, Sri Lanka

Many coastal cities of Sri Lanka, including the historic port city of Galle, were severely damaged by the Indian Ocean tsunami of 2004, with a large loss of human lives. This was due to the magnitude of the hazard and high vulnerability of the coastal community, which was inadequately prepared.

The tsunami waves which reached the offshore waters of Galle were primarily waves diffracting around the southern coast of Sri Lanka. The city lies beside a wide bay and a natural headland on which is located the historic fort. In the vicinity of the headland, the wave energy became concentrated due to diffraction. These waves were reflected by the vertical solid walls of the fort and propagated around the headland. The canal on the western side was a facilitator in conveying the massive wave and associated flow towards the city centre. To the east, the tsunami moved along the bay. The waves, which were increasing in height due to reduced water depths, were further amplified by modified shoaling processes arising from reduced wave crest width to accommodate the bay shape, a phenomenon identified as local enhanced exposure to the tsunami hazard. Poorly constructed buildings, infrastructure and inadequate drainage increased vulnerability. Preparedness against the tsunami hazard was non-existent leading to a very high risk situation.

In order to safeguard lives and protect infrastructure in the future, a risk assessment case study was undertaken for the city. The study comprised field surveys, mathematical modelling for hazard assessment, investigations on vulnerability and the development of mitigation measures. Field surveys were carried out to collect data on inundation height, the direction of the first tsunami wave and the overall tsunami hazard. The area studied was divided into a 250 m x 250 m grid. People living within the respective areas of each grid square were interviewed. The results of the study were used to identify safe areas and safe buildings, evacuation routes and refuge areas, and locations for evacuation route signage.

For a number of source scenarios selected for the Sunda/Java trench, modelling was carried out using deterministic numerical models. General coarse-grid modelling was carried out for the coastal region in the southern parts of the island and detailed fine-grid modelling, including tsunami run-up and inundation was carried out. High resolution nearshore bathymetric data, obtained for the port, were used for study, along with high resolution topographic data obtained from LIDAR surveys (Fig. 4.1) of the coastal zone carried out after the tsunami. The results of the modelling and field surveys were used for the preparation of a hazard map and in the determination of evacuation routes.
There are many countermeasures that could be adopted within the framework of ICAM, in planning for a tsunami and other coastal hazards that accompany high waves. These include engineering interventions such as protection structures and regulatory interventions in the form of extension of the existing 'setback' defence line. These need to be supplemented with public awareness on disaster preparedness, efficient evacuation procedures, incorporating, if necessary, planned evacuation structures that effectively integrate with the overall planning process.

A Master Plan had been developed before the tsunami for the expansion of the port. In order to maintain healthy exchange of tidal flow for the conservation of an existing coral reef system, the design incorporated an offshore detached breakwater, which coincidentally has all the characteristics of an effective tsunami breakwater. By implementing this project with a slightly extended offshore breakwater in the direction of the Galle Fort, the city will have the benefit of a tsunami breakwater as part of a port development project. Mathematical modelling confirmed its effectiveness. A revetment armoured with either rock or concrete needs to be constructed along the coastline to supplement the tsunami breakwater. These measures would also be effective against wave attack arising from surges and extreme wind-forced waves that have a greater probability of occurrence than an extreme tsunami wave. Measures to reduce vulnerability and improve preparedness were identified.

Physical modelling on a large scale was used to investigate specific tsunami impacts and the effectiveness of countermeasures. Two-dimensional physical modelling was carried out to understand the effectiveness of bio-shields (reefs, sand dunes and coastal vegetation). In addition, physical modelling was carried out on rock-armoured structures to be used in conjunction with bio-shields.

Sam Hettiarachchi

Risk assessment, as described in these guidelines, is a qualitative procedure or judgement which aims to rank the different hazards according to pre-determined thresholds or levels. Where sufficient and appropriate data are available, it may be possible to apply a quantitative, statistical approach to risk assessment.

Risk is commonly defined as “hazard x vulnerability” – the product of the assessed hazard probability level (frequency, magnitude) and the assessed vulnerability level (losses, damage). The preceding sections on quantification of the various hazards in terms of exposure and probability (Section 4) and assessments of vulnerability in terms of its various dimensions and including deficiencies in preparedness (Section 5) provide the bases for risk assessments relating to these hazards. Because the ultimate goal is to reduce risks to acceptable levels, measures to manage the risks, planned or in hand, (sections 7 and 8) also need to be considered.

It is important to understand that the risks are dynamic and will normally increase both as the probabilities of hazardous events increase and as the consequences or vulnerabilities in respect of hazardous events grow. Conversely the risks can be reduced by hazard awareness and emergency preparedness, and strategic mitigation. Given human-induced climate change and the rapid growth of coastal populations and their assets, levels of risk in respect of the coastal hazards are generally increasing.

6.2 HOW TO MAKE A RISK ASSESSMENT

Risk assessment is a logical outcome of the processes involved in hazard and vulnerability assessments. As with those assessments, it assumes the definition of its spatial and temporal scales, and its geographical limits. It entails the integration of geo-referenced data on hazard exposure and probability with the results of the vulnerability assessment (Section 5). The integrated output is classified in terms of the levels of risk for each vulnerability dimension (or for aggregated vulnerability) for each hazard, and may be expressed in risk maps and reports for the designated coastal management area. The assessment procedure specifically for tsunamis in the Indian Ocean region is described in guidelines produced as part of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS; UNESCO, 2009).

Risk assessment in respect of coastal hazards within ICAM should consider all the relevant hazards and dimensions of vulnerability. Each dimension of vulnerability – human and social, physical and economic and environmental (Section 5.5) – has a risk level in respect of each of the hazards. An assessment of risk needs to be more than just a snapshot of risk under present (baseline) conditions. The assessment needs to address how risk might change with changing vulnerability, including existing and planned preparedness and mitigation measures.

Successful mitigation (sections 7 and 8) will reduce risk by constraining the hazard and/or reducing the vulnerability (including improving preparedness). However, environmental changes such as sea-level rise will progressively increase the risk. It is also important to recognize that risk may increase over long periods due to unintended consequences of mitigation, such as an increase in the density of habitation and assets in newly protected but potentially exposed locations, particularly behind dykes and other defences. The implications of all these long-term trends need to be considered within the risk assessment process.

The timescales considered in risk assessment will vary from one country to another, but it is worth noting that there is a move to longer assessment

BOX 6.2 Key tasks in the risk assessment procedure

- Define the geographical scale and extent of the assessment, using determined geographical hazard limits (Section 4).
- Define the temporal scale of the assessment.
- Integrate geospatially referenced hazard exposure information and probabilities with assessed vulnerability using, e.g., GIS technology.
- Translate integrated hazard and vulnerability output into levels of risk for each vulnerability dimension in respect of each hazard; assess risk for separate vulnerability dimensions or aggregated, taking all dimensions and deficiencies in institutional preparedness into account.
- Produce risk map(s) for the designated coastal management area in respect of selected hazard scenarios.
- Analyze and evaluate uncertainties.
- Assess future risk(s) taking preparedness and mitigation measures into account (sections 7 and 8).
- Communicate risk assessment to policy- and decision makers.

periods due to the long-term implications of many mitigation measures and the recognition of the dynamic nature of risk. Hence, some countries are explicitly considering a 100-year timescale, or even longer, for risk assessment (Box 8.2).

6.3 DISPLAYING RISK INFORMATION

Risk maps (Fig. 6.1) are useful decision-support tools for several different stakeholders in the Management Plan, e.g., local administrations and authorities, disaster planners, insurance companies. Different stakeholders can use these maps not only for emergency planning, but also for reducing potential damages and losses through logical and sustainable urban planning (see Box 6.3).

The availability or acquisition of reliable risk assessment information from this stage of Phase II in the ICAM process is essential to the formulation of an ICAM Management Plan that takes the coastal hazards into account. This applies both for the rapid-onset hazards as well as those creeping hazards which affect the coastal community over the much longer timeframe (Phase III, Step 1). The risk assessments for all aspects of the community, both at the present time and in scenarios for the years to come, are essential elements feeding into the second stage of Phase II of ICAM. In this stage, strategies are developed and defined. These take into account present and future social and environmental conditions, economic pressures, financial and human resources for implementation and available data. This process is the precursor to the formulation of the Management Plan (Step 3 of the Preparation Phase, Fig. 1.1), from which the strategy for the management of the coastal hazards, as described in sections 7 and 8 of these guidelines, will be determined.

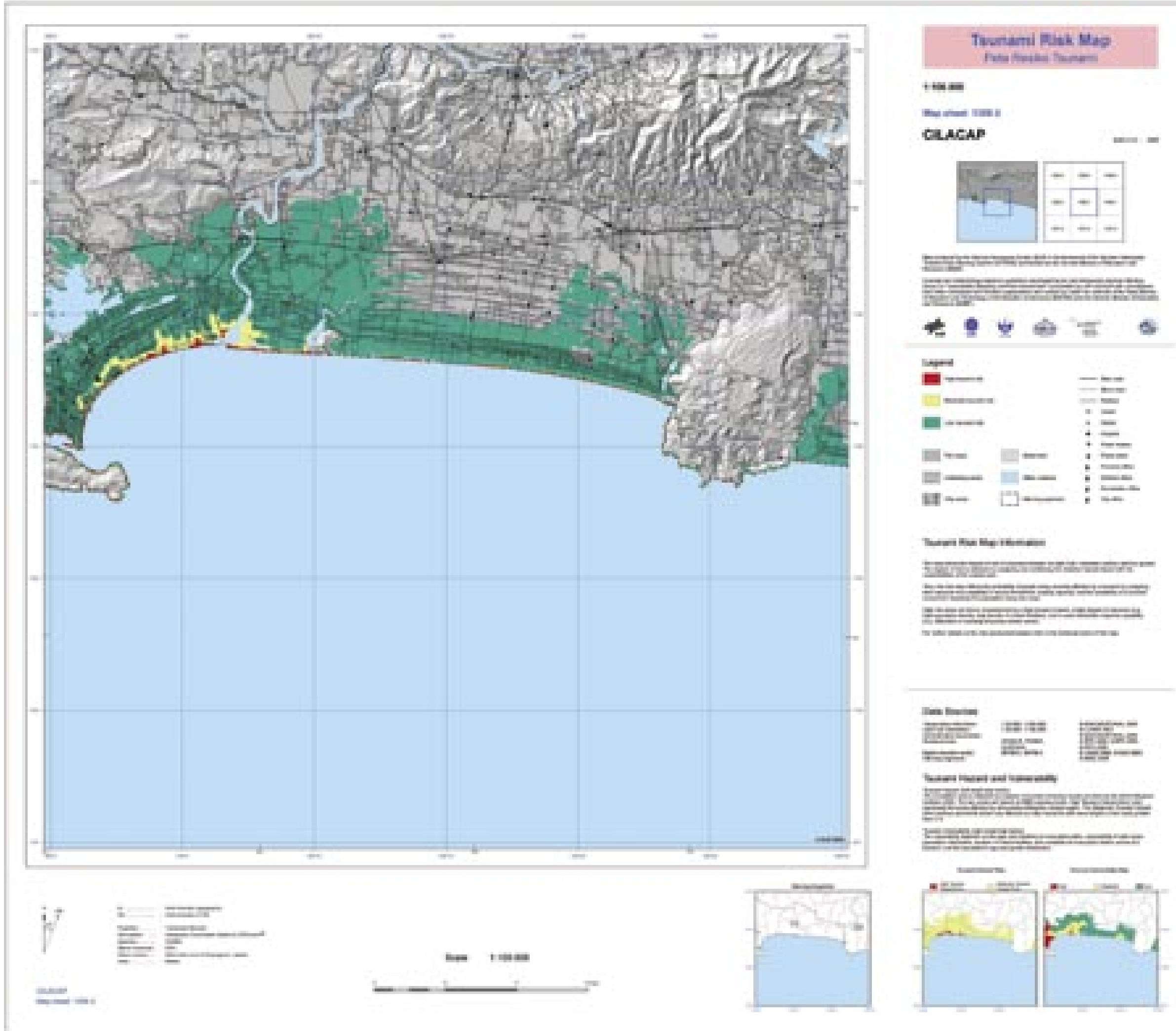


Fig. 6.1 *Tsunami risk map at a local scale*

BOX 6.3 The EU Floods Directive, 2007: Timelines for actions by EU Member States

- Preliminary Flood Risk Assessments required to be completed by 2011
- Flood Risk Maps required by 2013
- Flood Risk Management Plans focused on prevention, protection and preparedness required to be in place by 2015
- The Directive applies to inland waters as well as all coastal waters across the whole territory of the European Union. (see Section 2.1)

Source: WISE – Water Information System for Europe, European Commission (http://ec.europa.eu/environment/water/flood_risk/index.htm)

6.4 CHALLENGES AND OUTPUTS

Challenges

Key challenges to successful assessment of risk can include the following:

- Acquiring the fullest possible information on hazard probability (for selected scenarios for each of the recognized hazards, Section 4) and on vulnerability (Section 5). These are essential prerequisites for a meaningful assessment of risk to coastal communities, including their economies, their supporting ecosystems and institutions.
- Appropriate data and resources for carrying out the risk assessment may be limited.
- Risk assessments should be carried out for future scenarios as well as existing conditions so that likely socioeconomic and environmental changes may be taken into account.
- Uncertainties must be clearly identified within the risk assessment.

Outputs

Key outputs and results associated with the risk assessment may include:

- assessments of risk for each dimension of vulnerability, or aggregated vulnerability, produced in respect of each of the recognized coastal hazards (scenarios with defined probabilities);
- risk maps and reports produced relating to the different dimensions of vulnerability for each of the recognized hazards, taking deficiencies in preparedness into account, covering the designated coastal areas, whether at the regional or the local scale;
- risk maps and reports covering future scenarios produced, taking into account the likely effects of improving emergency preparedness (Section 7) and strategic mitigation (Section 8); and
- risk assessment outputs effectively communicated to all levels involved in the ICAM process. The assessments are vital inputs to the policy-making process within ICAM, determining the nature and level of response (Management Plans) with the aim of reducing risk.

6.5 DATA REQUIREMENTS AND INFORMATION SOURCES

The following table identifies data sources that may be useful in realizing the risk assessment products described in this section. It highlights the dependency of the risk assessment process on the hazard and vulnerability assessments described in sections 4 and 5 of these guidelines.

Table 6.1 *Information sources for risk assessment*

Products	Variables and standards	Sources	Global programmes and data sets
Risk maps and reports for each identified hazard in respect of population, economics, environment and deficiencies in preparedness	Assessed probability for each hazard type	See Section 4	
	Assessed vulnerability parameters in respect of each hazard type	See Section 5	

General guidance

UN/ISDR. 2004. *Living with Risk: a Global Review of Disaster Reduction Initiatives*. United Nations International Strategy for Disaster Reduction. Geneva, UN Publications. Available at: http://www.unisdr.org/eng/about_isdr/bd-lwr-2004-eng.htm

UNDP. 1992. *An overview of disaster management, 2nd edn*. Washington, D.C., United Nations Development Programme.

UNESCO. 2009. *Tsunami risk assessment and mitigation for the Indian Ocean; knowing your tsunami risk – and what to do about it*. IOC Manuals and Guides, No. 52, Paris, UNESCO.

Selected bibliography

Thywissen, K. 2006. Core terminology of disaster reduction: a comparative glossary. J. Birkmann (ed.), *Measuring vulnerability to natural hazards: towards disaster resilient societies*. United Nations University Press, Tokyo, pp. 448–496.

7 ENHANCING AWARENESS AND PREPAREDNESS

ICAM PHASES	I	II	III	IV

This section sets out guidance on the procedures to reduce the risks to coastal communities through awareness and preparedness. It describes good practice both in the technical provision and communication of early warning of the rapid-onset hazard events and in the development and maintenance of preparedness for emergency response to such hazard events at all levels of the community. These measures address deficiencies in preparedness, the assessment of which is described in Section 5.8, and which may have contributed to a community's level of risk in respect of hazard impacts. Together with Section 8, the section describes procedures which address these topics within the Implementation phase (III) and Consolidation/Replication/Expansion phase (IV) of the ICAM process (Fig. 1.1; sections 2.3 and 2.4).

Procedures covering preparedness for tsunamis are also described in guidelines produced as part of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS; UNESCO, 2009).

BOX 7.1 Key tasks to enhance awareness and preparedness

- Identify an appropriate early warning framework.
- Raise awareness of the risk at all levels in the community.
- Establish the key operational requirements of the early warning system.
- Prepare all levels of the community for emergency responses.

7.1 IDENTIFYING AN EARLY WARNING FRAMEWORK

The provision of early warning facilities to coastal communities is a key part of the development of the preparedness of those communities for coping with the rapid-onset, potentially catastrophic hazards. The other crucial part of community preparedness is knowing what to do in the event of an alert being received from a Regional Watch Centre and a warning being issued by a National Warning Centre. The planning and practising of emergency evacuation and of procedures for dealing with vulnerable people and utilities infrastructure are priorities in establishing preparedness. These plans and procedures will be incorporated in the Management Plan, which has been informed by the hazard, vulnerability and risk mapping information produced by the assessment procedures described in sections 4 to 6.

Experience over recent years regarding the impacts of coastal hazards in developed and developing countries alike has shown that inadequate preparation for, and response to, emergency situations has contributed to widespread damage and loss of lives and livelihoods. In some instances these shortcomings have been due to a lack of warning through poor regional detection and communication systems. In many cases, however, they have reflected inadequate awareness, planning and coordination on the part of national and local authorities, agencies, and people exposed to such hazards. In some cases, such inadequacies have resulted in catastrophic human losses which could and should have been avoidable. A particular challenge for local authorities and agencies is to create and maintain an awareness of rapid-onset hazard events that, in many parts of the world, may recur only after intervals spanned by many generations.

Key considerations

Key questions that should be asked by all countries in the ICAM context are:

- Is there an adequate preparation for, and response to, coastal hazards?
- Why is this important?
- Who and what are risk?
- What could be the consequences of inaction?

The assessment of deficiencies in preparedness has been addressed in Section 5.8. Such deficiencies certainly contribute to a community's risk in respect of the coastal hazards, while, in the opinion of some experts, they are also direct contributors to vulnerability and should be accounted for within the vulnerability assessment. Whatever view is taken, awareness of the hazard-related risks and preparedness for them form essential parts of IOC's "end-to-end" early warning system programmes in respect of coastal hazards. These systems incorporate the early warning system (EWS) framework developed and adopted by the United Nations International Strategy for Disaster Relief (UN/ISDR) through their Platform for the Promotion of Early Warning (PPEW). The PPEW framework is applicable to all natural hazards and integrates four distinct elements:

- awareness of the risk;
- technical monitoring and warning service;

BOX 7.2 Raising awareness of disaster risk reduction – recommended steps

Awareness campaigns need to include a wide variety of activities focused on various audiences and implemented by different actors.

To develop an appropriate awareness campaign strategy, a country needs to:

- secure continued resources for implementing awareness campaigns;
- determine which communication channels will appeal to the widest range of stakeholders, to ensure the campaigns reach women and other high-risk groups;
- seek to engage and inform different age groups so as to build sustained understanding across generations;
- establish relationships for the involvement of media professionals and other commercial and marketing interests; and
- engage respected local officials, religious and community leaders, and women's and other special interest groups, in order to disseminate information and encourage participation.

Measures that can support effective implementation of an awareness campaign include:

- selecting and undertaking activities that will appeal to target groups - such as educational campaigns in schools and community centres, community fairs, annual commemorative events or festivals, and neighbourhood safety drills and simulations;
- promoting activities that enable school-aged children to influence parents;
- encouraging private and commercial enterprises to raise awareness among their employees, and create incentives for employees' wider involvement in awareness campaigns, through such activities as sponsorships and advertising opportunities; and
- organizing workshops, forums and educational activities for communities at local, social and cultural facilities.

Basic principles of awareness programmes:

- Programmes to be designed and implemented with a clear understanding of local perspectives and requirements, descriptive materials reflecting local conditions.
- All sections of society to be targeted, including decision makers, educators, professionals, members of the public and individuals living in threatened communities.
- Different types of messages, locations and delivery systems are necessary to reach the various target audiences.
- Sustained efforts are crucial to success, although single activities such as commemorative disaster reduction events and special issue campaigns can be useful if they are part of a larger, consistent programme.

Source: UN/ISDR, 2007

dissemination of meaningful warnings to those at risk; and
- public awareness and preparedness to act.

7.2 RAISING AWARENESS OF THE RISK

The principal issues and activities relating to raising awareness of the need for hazard-related risk reduction are addressed below. They are relevant to all levels of governance within countries, notably among the coastal communities at risk. These include the identification of the audiences that need to be reached and the formats and means to communicate the risk to them. Behind all of these activities lies the need for a solid base of political support, laws and regulations, institutional responsibility, and trained people. Specific questions are considered below.

What is the main goal for the risk-awareness process?

The goal behind any risk-awareness process is to promote among people, their leaders and decision makers an acceptance of the value concerning the management of hazards in order to reduce the risks of future catastrophic losses. The ISDR recommended campaign strategy to raise awareness of the need for hazard-related risk and disaster reduction is given in Box 7.2.

What means and formats should be used to communicate the risk?

These should be tailored to the proposed target audience. In the context of decision-making and disaster preparedness, risks are usually represented by means of maps and matrices with complementary text (the outputs of procedures detailed in Section 6). Recommended measures to be conveyed to the general public for raising the level of awareness are listed in Box 7.2. In addition, there are needs to:

- sustain the social memory concerning events which have very long return periods; and
- promote awareness concerning safe areas and evacuation routes.

Is there a specific format to communicate the hazard?

Communication of the hazard to those at risk should be conducted in a plain language or languages (including local languages) that are clear and understandable. This must take into consideration local experience and education, traditions, and culture. In addition, the range of communication formats and channels must be tailored to the capacities and limitations of the community at risk, in terms of the media being used.

How can public be aware of coastal hazards?

Posters and leaflets can be employed, as well as publications in mass media such as newspapers, magazines and the Internet (see boxes 7.4, 7.5 and 7.6). It is important to consider the intended level (national, provincial, municipal, or local) at which the proposed risk maps will be employed.

BOX 7.3 Okushiri Tsunami: Community response and mitigation measures at Aonae

Japan has a long history of destructive tsunamis and, in response to that significant threat, has developed effective tsunami warning and mitigation procedures. Most events have occurred along the seismically active Pacific Ocean coast of Japan – the Sea of Japan is not so active, seismically. However, a magnitude 7.8 earthquake occurred in the Sea of Japan on 26 May 1983. This earthquake generated a tsunami which struck Okushiri Island 20 minutes after that earthquake, with a maximum wave height of 1.2 metres. As a result of that tsunami and the high level of tsunami awareness throughout Japan, the residents of Okushiri Island were aware of the tsunami hazard and had a tsunami response plan.

On the evening of 12 July 1993, an earthquake of magnitude 7.8 occurred in the Sea of Japan southwest of Hokkaido Island. This earthquake was felt by the residents of Okushiri Island and many people, in spite of the late hour (10.17 p.m. local time), immediately took appropriate action and moved to higher ground inland. Although the JMA District Meteorological Observatory issued a tsunami warning 5 minutes after the earthquake event, the first tsunami wave reached Okushiri Island less than 5 minutes after the earthquake, sweeping away many people and homes in the Aonae District on the south coast of the island. Those homes not destroyed by the tsunami were destroyed by fires, fed by fractured gas lines and toppled fuel containers.

In the town of Aonae, the tsunami run-up was 5–10 metres. Although most of the community was able to evacuate safely, 114 persons were killed. The people who were killed were either unable to evacuate quickly enough or, based on the 1983 event, thought they had more time to evacuate. In some instances, individuals left their homes, but then returned and were caught by the tsunami.

As a result of this catastrophic tsunami, government funding was provided to construct/raise the local sea wall and tsunami embankments, install sluice gates on four rivers (which will automatically close one minute after an emergency announcement following an earthquake event), and reinforce some slopes as tsunami prevention measures. In support of improved emergency response, government constructed an evacuation platform at the fishing port (it is 6.6 metres above sea level and can hold about 440 evacuees), distributed a disaster prevention handbook, and supported the purchase of an emergency broadcast receiver by every household. In addition, the Japan Meteorological Agency developed an "earthquake emergency report" that is designed to issue a tsunami warning two minutes after an earthquake.

Evacuation platform at Aonae port

The residents of Okushiri Island had an emergency response plan in place and had undertaken mitigation measures prior to the 1993 tsunami. However, those preparations were not adequate. Since that time the various levels of government have taken steps to further protect the island from tsunamis, though at considerable financial cost.

Fred Stephenson

Picture source: Laura Kong, ITIC

BOX 7.4 Societal impacts of storm surge and mitigation strategies in Far North Queensland, Australia

Far North Queensland is in Australia's Tropical Cyclone-prone region. Over the last 50 years, landfalling tropical cyclones have been relatively infrequent, although many, like TC Larry in March 2006, have been severe. Potentially the most dangerous threat from tropical cyclones is storm surge. With the Great Barrier Reef running along much the coast the region is one of Australia's prime tourist destinations and, in recent years, has experienced rapid and sustained development and population growth.

In the late 1990s, weather and emergency services managers became increasingly concerned that the region's growing number of coastal residents were complacent about the tropical cyclone risk and it was evident that they were not responding to advice to be well prepared for the cyclone season.

In an effort to understand the community at risk and define and understand the community hazard-related risk perception, a series of surveys of community residents and school children were conducted. The results of these surveys confirmed that, while there was some community-wide understanding and knowledge of tropical cyclones, the residents' awareness of storm surge and their perception of the risk associated with landfalling tropical cyclones were generally very limited. Many residents mistakenly believed a local myth that the regional geography and topography, together with the close proximity of the Great Barrier Reef, provided a natural protection from tropical cyclone and storm surge impacts. It was also found that most householders did not know how high above sea level their properties were, and that many had a false confidence that their homes were in safe locations, because they had been built with local government building approvals. Community and school hazard education programmes and materials were found to be limited in local detail and often poorly delivered.

It became apparent that, rather than being complacent about the tropical cyclone and storm surge risks, many in the community had, based on flawed and biased information, decided they were not at great risk and needed to take only minimal precautionary action. Warnings messages and defensive action advice were therefore unlikely to be well acted upon.

The Australian Bureau of Meteorology operates within the context of a Total Warning System and works closely with partner organizations and emergency services to develop and deliver warnings messages that are communicated effectively. This means that the warnings information is accurate and timely, that it is delivered in a range of formats via a range of media, that terminology is understood and appropriate, and that it is received by an informed and receptive community that is able to personalize the risk and take effective defensive actions.

With the greater knowledge and understanding of community beliefs and perceptions of tropical cyclones and storm surge, The Bureau of Meteorology, together with partner agencies, has now developed warnings services and focused education campaigns that address the identified community and industry needs, describing the hazards and explaining the risks. This strategy includes:

- Workshops with stakeholders and the public at the beginning of the cyclone season.
- The production of print material ranging from fridge magnets with simple defensive action messages to comprehensive booklets, many locally specific in detail.
- Information provided on Bureau and partner organization websites.
- Contributions for inclusion in school curricula.
- The production of 'Stormwatchers' – an interactive children's game, initially on a CD and more recently available on the Bureau's website (fig. a).
- Targeted industry seminars with particular emphasis on the region's tourist industry.
- Maps that identify areas of relative storm tide risk for the local residential community have been produced and distributed by Local Government authorities (fig. b).
- The introduction of the Queensland Storm Tide Warning System to support policy, community and individual decision-making. This involves a collaborative arrangement between the Bureau of Meteorology and key State and Local Government counter-disaster groups. When there is a threat of tides exceeding Highest Astronomical Tide (HAT), the Bureau provides two types of warning to these key stakeholders:

BOX 7.4 (Continued)

- preliminary advice of threat up to 24 hours ahead;
- detailed warnings including quantitative storm tide estimates issued from 12 hours before the event;
- a storm tide warning graphical product (the 'totem pole') to assist disaster managers to interpret the sea-level heights given in the text of the storm tide warning by the Bureau. This illustrates the predicted storm tide with reference to the National Storm Tide Mapping Model (fig. c).

• Qualitative reference to the storm tide threat is included in public cyclone warnings.

Follow-up surveys across the region confirm the combined effects of the introduction of the well-structured and directed awareness and education campaigns and the implementation of the Queensland Storm Tide Warning System. These have raised public awareness of, and supported improved public response to, tropical cyclones and, more particularly, the storm surge threat. This seems to be evidenced by the fact public perception of the risk is now less biased. In 1996 52% of the population believed the area to be naturally protected from Tropical Cyclone impact, while by 2002 this had fallen to just 7 per cent. Response to Bureau warnings has also improved. In March 2004 coastal communities impacted by Severe Tropical Cyclone Larry complied with directions from emergency services to evacuate, their decisions to leave their properties based on their informed understanding of the risk of storm surge.

Residents in communities at risk need to be empowered to make sound and well-informed decisions about the level of hazard-related risk they face and the defensive actions they need to take to protect themselves, their households and their communities. This is an effective primary disaster mitigation strategy that can be achieved when community needs are defined and understood, and addressed with the provision of specific and targeted information.

Linda Anderson-Berry

fig. a *Stormwatchers – an interactive electronic tropical cyclone and storm surge game. An education resource for primary school students.*

Source: (http://www.bom.gov.au/storm_watchers_game/)

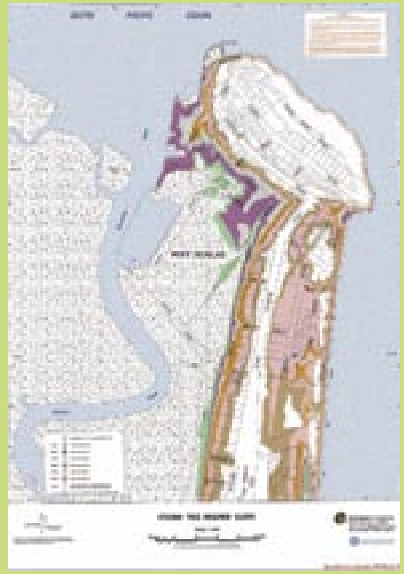


fig. b *Local area storm surge maps illustrate areas at risk of inundation and help raise community storm surge awareness.*

Source: National Storm Tide and Mapping Model for Emergency Response, 2002; Issued by the Queensland Government, the Australian Bureau of Meteorology and Emergency Management Australia.

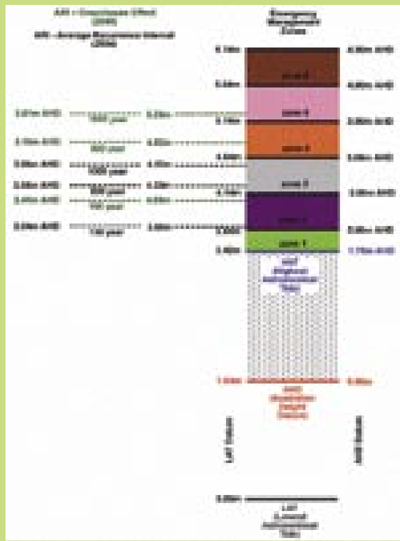


fig. c *The 'totem pole' – a graphical storm tide warning graphical product developed to assist disaster managers, emergency services and response agencies to interpret the sea-level heights given in the text of the storm tide warning by the Bureau.*

Source: Tropical Cyclone Storm Tide Warning-Response System Handbook, Eighth Edition, 2008; Issued by the Queensland Government State Disaster Management Group and the Australian Bureau of Meteorology.

BOX 7.5 Road signage for hazard awareness

In Indonesia, road signs are used to warn of the tsunami hazard. These have been designed by a local NGO – KOGAMI – for the coastal city of Padang. They have been printed in the local language to promote awareness on the levels of hazard. Hazard levels were defined by this NGO in terms of elevation of the land with respect to mean sea level.

Road sign describing the tsunami hazard in Padang, Indonesia

Is there a connection between public awareness and frequency of the hazard?

One issue to consider when communicating both the hazard and a particular hazard-related event relates to the population's previous experiences of such events. Storm surges and extreme wind-forced waves are more frequent than tsunamis, and thus coastal people may already be aware of these hazards and how to manage such events. However, worldwide, tsunamis are basically less known, thus strategies must be devised to promote awareness of such events.

Are there special target audiences?

Special communication efforts may be desirable for:

- children living in coastal communities who should be made aware of the hazards from an early age; and
- tourists visiting coastal areas who may be unfamiliar not only with the hazards but also with the local geography and language (see Box 5.2).

7.3 ESTABLISHING KEY OPERATIONAL COMPONENTS OF AN EARLY WARNING SYSTEM

This section describes the key operational aspects and components required for an effective coastal hazard warning system. These include data requirements, equipment, products, telecommunications, outreach strategies and tools that comprise a full, people-centred system. Technical monitoring and warning services for coastal hazards, operated by technical and scientific agencies in many countries, are playing an important role in minimizing fatalities, injuries, and material and property losses.

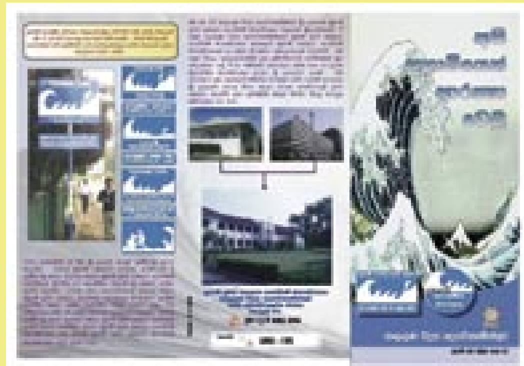
An early warning system usually comprises seven components:

- earth data observations;
- data and information collection;
- hazard event detection;
- hazard warning system decision support;
- warning and other products;
- dissemination and notification; and
- anticipated response.

Some aspects of the first three of these components have been considered in sections 4 to 6 of

BOX 7.6 Informing communities about an Early Warning System

Because tsunamis are very infrequent in some parts of the world, the efforts relating to the implementation of a tsunami early warning system need to be supported with awareness campaigns that illustrate all aspects of the system, including signs in coastal areas indicating evacuation routes, safe areas, and other pertinent information concerning the system. It is also important that visitors to tsunami-prone coasts are adequately advised of the potential hazard.



Leaflet describing a tsunami early warning system in Sri Lanka

Source: UNU-EHS.

An EWS may encompass specific aspects related to the generation and dissemination of information, its flow and management, and reliable and redundant means of communication. Legal and institutional aspects and standard operating procedures should also be considered. Allocation of the necessary resources for all tasks to be executed is crucial; without which those agencies which are assigned new responsibilities within the EWS may not be able to execute them. In addition, institutional mandates may need to be revised and modified to incorporate newly assigned tasks in the context of such EWS.

Successful end-to-end systems require cooperation and commitment of all stakeholders. Stakeholders should be aware of all procedures within such systems. These comprise:

- Partners – usually other government and non-government organizations that play some role in the detection, warning, and preparedness processes. These include:
  - Domestic and international data providers;
  - Government and private entities (including the mass media) that serve as communications conduits for product dissemination;
  - Government and private sector groups that train and educate other Regional Watch Centre (RWC) and National Warning Centre (NWC) partners and customers; and
  - Business and economic groups, such as coastal hotel operators.
- Customers – usually groups and individuals that rely on the Regional Watch Centres (RWCs) or National Warning Centres (NWCs) and their partners for timely and accurate alerts and warnings, for protection of their lives and the opportunity to minimize the impact on their property. Customers include:
  - the general public;
  - Non-governmental organizations (NGOs) and other private sector groups that must respond to events; and
  - Government agencies that must respond to events.

Following the Indian Ocean tsunami of 2004, IOC has facilitated the global expansion of tsunami early warning systems (see Foreword). This expansion builds on the experience of the Pacific Tsunami Warning System (PTWS) that has been operational since 1965. Three additional warning and mitigation systems are in the course of development, co-ordinated by IOC. These cover the Indian Ocean region (IOTWS), the Mediterranean, North-East Atlantic and Connected Seas region (NEAMTWS) and the Caribbean (CARIBE-EWS). Associated with the IOTWS is the GITEWS project (Box 5.5), which aims for the implementation of an effective Tsunami Early Warning System for the Indian Ocean, with an emphasis on Indonesia.

Reference guides relating to existing warning systems for tsunamis, storm surges and wind-forced waves associated with tropical cyclones and extra-tropical storms are listed in Section 7.6. Awareness materials for tsunamis are published by IOC-ITIC (International Tsunami Information Centre) and are available on-line (see Section 7.6).

Earth data observations

Earth data observations are a critical component of an EWS. In an end-to-end EWS, the first indication of a potential coastal hazard is provided by a rapid detection and characterization of its generating event (i.e., earthquakes or tropical cyclones and extra-tropical storms, typically monitored by governmental agencies, such as the National Seismological and Meteorological services, respectively, and research agencies). Critical seismic, atmospheric and sea-level data must be received rapidly at a watch centre (RWC) to be of significant use in the early warning process.

There are now networks of deep-ocean gauges in the Pacific and Indian Ocean regions, and a network of gauges is presently being installed in the eastern Indian Ocean. For tsunamis, the observed deep-ocean data can be used to select an appropriate modelled scenario which provides estimates of expected wave heights at nearshore locations as well as predictions of anticipated inundation in areas where detailed coastal and inundation models exist (see Section 4.4). This methodology has been tested several times in recent years (in the Pacific) and has been shown to be very effective in predicting, e.g., tsunami wave heights and propagation times, and, by doing so, allowing NWC staff and emergency managers to make appropriate decisions about the risks to coastal communities. The Case Study of the 2003 Rat Islands tsunami (Box 7.7) provides additional information in this regard.
Precursors to a hazard event may be present but sometimes not taken into account. This may be because they are unrecognized or because there is no recognized institution in charge of monitoring such precursors at the national or local levels. As cases in point, the exodus of animal wildlife from the seashore and the withdrawal of the sea from the shore minutes before the Indian Ocean tsunami of 2004 hit coastal areas in Indonesia, India, and Sri Lanka, were not recognized by many local people as tsunami precursors.

Collection of data and information

Communications are the lifeblood of a multi-hazard warning system. All aspects of operations, from collecting data to disseminating warnings to developing community connections, depend on effective communications. The timely collection of data and information from nationally maintained and international earth data observation networks is a crucial task of national and regional centres. Several telecommunications connections are required to retrieve data and information needed to detect a potential coastal hazard. Some data are available in real-time on the Internet and through satellite downlinks. Data from nationally maintained networks often require alternate communications paths such as landlines, wireless telephone, or radio. These data are of little value to the centres if they are not received in time to permit analysis. Such communication requires the use of international networks, in particular the WMO Global Telecommunications System (GTS) and the WMO Information System (WIS). It is important to recognize the role of these WMO networks (in situ and space-based) of national and regional observing systems, data dissemination systems (see below), data archives and predictive modelling tools, particularly for storm surge early warning and forecasting. Without these data, observations and transmissions there could be no early warning. Models by themselves cannot provide useful forecasts without real-time data; they are not a substitute for observations.

The centres should also acquire, in the most effective and efficient way, real-time data and information released by other advisory and warning centres and observatories. Information should be acquired from other national centres and posted on Internet web sites, the GTS/WIS, and other alternate public and non-public information sources (see Section 7.6).

Hazard event detection

The phenomena which may trigger or otherwise contribute to a hazard event – earthquakes, tropical cyclones and extra-tropical storms, in particular – are the subjects of continuous monitoring by national and international organizations. Analysis of the derived data permits the forecasting of hazard events. In addition, complementary data sources may be used to forecast or verify whether hazard events, such as tsunamis or storm surges, may have been generated. This requires the incorporation of seismic, atmospheric and sea-level data from the communications channels into an integrated observing system, and analysis of this information as input to the decision-making support component. Forecast models (e.g., inundation models) and user-friendly mapping tools, as described in sections 3 and 4, must also be used and developed at the NWC to assist in making quick decisions in response to the receipt of information bulletins and alerts from RWCs.

BOX 7.7 **A tsunami warning case study: the Rat Islands tsunami in the Pacific**

Hilo, on the island of Hawaii, is a coastal community highly vulnerable to the effects of tsunamis. This community was hit by a destructive tsunami in 1946 when a magnitude 8.1 earthquake near Unimak Island, in the Aleutian Islands, produced a tsunami with wave run-up heights of almost 8 m at Hilo and as much as 12 m at other locations on the island. At Hilo, 96 people were killed and more than 400 structures were destroyed. On May 22 1960, the tsunami from a magnitude 9.5 earthquake off Chile struck Hilo with a maximum run-up height of 10.7m. The harbour front of Hilo was destroyed and there were 61 deaths. The destructive effect of these two tsunami events in the Hawaiian Islands and elsewhere ultimately led to the formation the Pacific Tsunami Warning System.

On November 17 2003, a magnitude 7.8 earthquake occurred near the Rat Islands in the Aleutian Islands. Although this earthquake occurred approximately 1000 km west of the 1946 event, there was concern that it could generate a tsunami that would place coastal areas in Hawaii at risk. Traditionally, a tsunami warning is issued based on the earthquake's magnitude and location, and is later confirmed by data from coastal tide-gauge stations. In the case of the Rat Islands earthquake, the closest tide gauge stations were located at Shemya and Adak and would likely detect little or no signal due to their location relative to the maximum wave energy. The closest stations likely to detect the tsunami were located at Midway and in the Hawaiian Islands. These stations would offer little warning for the residents of Hilo and other coastal communities in the Hawaiian Islands. A tsunami warning, if issued but, in the event, unnecessarily, could result in some loss of life and disrupt the economy for a number of hours. If a tsunami warning was not issued and there was a destructive wave, then people in coastal areas would have received no warning and many people could die.

BOX 7.7 (Continued)

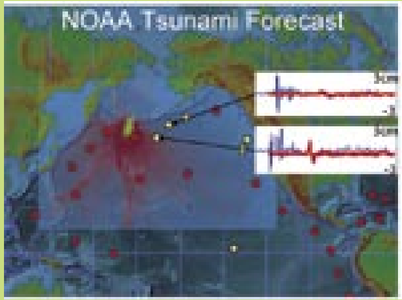


fig. a *Observed and predicted signal at DART gauges*
Graphics: Courtesy NOAA PMEL

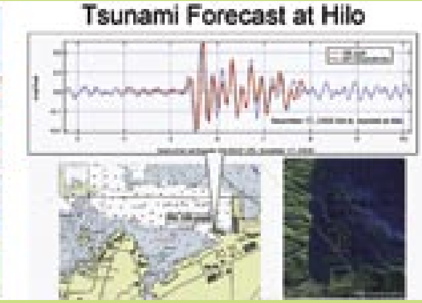


fig. b *Observed and predicted water levels at Hilo, Hawaii*

Fortunately, this event gave scientists at the Pacific Marine Environmental Laboratory (NOAA) in Seattle an opportunity to employ two new tsunami warning tools – data from recently installed DART gauges (Deep Ocean Assessment and Reporting of Tsunamis) in the Gulf of Alaska and new tsunami modelling software known as SIFT (Short-term Inundation Forecasting for Tsunamis, see Section 4.4).

The tsunami generated by the Rat Islands earthquake was recorded by one of the DART buoys southeast of the earthquake epicentre (see fig. a, this box) and this information was transmitted by satellite to the scientists at PMEL. Modelled tsunami waves from a number of tsunami scenarios (similar location and magnitude) were compared with the data observed at the DART buoys to select the propagation model most likely to represent the Rat Islands tsunami. The output from this model was then used to estimate wave heights at nearshore locations throughout the Pacific. It was also used as input for a higher resolution model at Hilo.

The model results indicated that the tsunami was not sufficiently large to issue a tsunami warning for coastal areas in Hawaii. The tsunami data recorded at the tide gauge in Hilo Harbour was in excellent agreement with the modelled predictions (see graph in fig. b, above) and demonstrated the importance of these two new tsunami warning tools in making emergency management decisions which are both knowledgeable and timely. Since that time data from DART gauges and the SIFT process have been used effectively in several other earthquake/tsunami events.

Fred Stephenson

Graphics: Courtesy NOAA PMEL

For example, when an earthquake of sufficient magnitude occurs below the ocean floor or near the coastline, a tsunami warning may be issued based on the magnitude and characteristics of that earthquake, as well as other relevant historical information. At the Pacific Tsunami Warning Center (PTWC), the threshold for issuing a tsunami warning is an earthquake with a magnitude greater than 6.5. Box 7.7 provides a case study on the detection and modelling procedures employed in response to the Rat Islands event in 2003.

Warnings of storm surges and wind-forced waves are issued based on the magnitude and characteristics of the tropical and extra-tropical cyclones. For example, the threshold for issuing a storm surge warning is a category one of the Saffir-Simpson Hurricane Scale, and the threshold for issuing a waves warning is wind speed Force 7 of Beaufort Scale or greater (see "Global Guide to Tropical Cyclone Forecasting", Section 7.6).

Hazard Warning System decision support

Once a coastal hazard is detected and its amplitude forecast, there must be a component to assess the potential impact of that hazard. As detailed in Section 4.2, an appropriate historical database of such hazards should be available, with possible inundation areas under different scenarios of these hazards' occurrences. This is necessary for the issuance of credible warnings that cover only areas actually affected, thus avoiding "false alarms" that lead to unnecessary and costly evacuations.

Tsunami propagation models allow the prediction of the tsunami travel time and wave amplitude once the initial location of the earthquake is fixed. The model, in contrast to other 2D propagation models, is fast and sufficiently precise to be integrated in a Tsunami Early Warning System to give a first estimate of the impact of the tsunami on the coast when the conditions which favour tsunami generation (an earthquake of magnitude > 7 and epicentre in a submarine location) are met. One of several such models is the system developed by the European Commission's Joint Research Centre (JRC) (see Box 4.3 and Fig. 7.1).

As described in Section 4, a large part of these decision-support tools includes local inundation maps for various magnitudes of coastal hazard. These maps are often generated locally, and updated as new technologies (such as better inundation mapping or higher resolution topographic data) become available. Increasingly, it also involves scenarios to produce probabilities of various degrees of impact from the source cause event (earthquake, tropical or extra-tropical cyclone).

Warning and other products

Once the decision is made by a Regional Watch Centre to issue an alert, the regional products should be drafted in a clear fashion, following as closely as possible international standards and formats. Lead times for each type of product should be established and published as Operational Plans and Manuals for each region (see listing of Guides in Section 7.6 for illustrations of product examples). It is the responsibility of national authorities to issue warnings to their coastal populations identified as being at risk.

The nomenclature, definitions and thresholds for the various outputs of existing early warning systems differ from one region to another and even within regions. This important topic is currently under review amongst the international bodies (including IOC) and other agencies involved. Examples of the content of some hazard bulletins are described in the guides and manuals listed in Section 7.6.

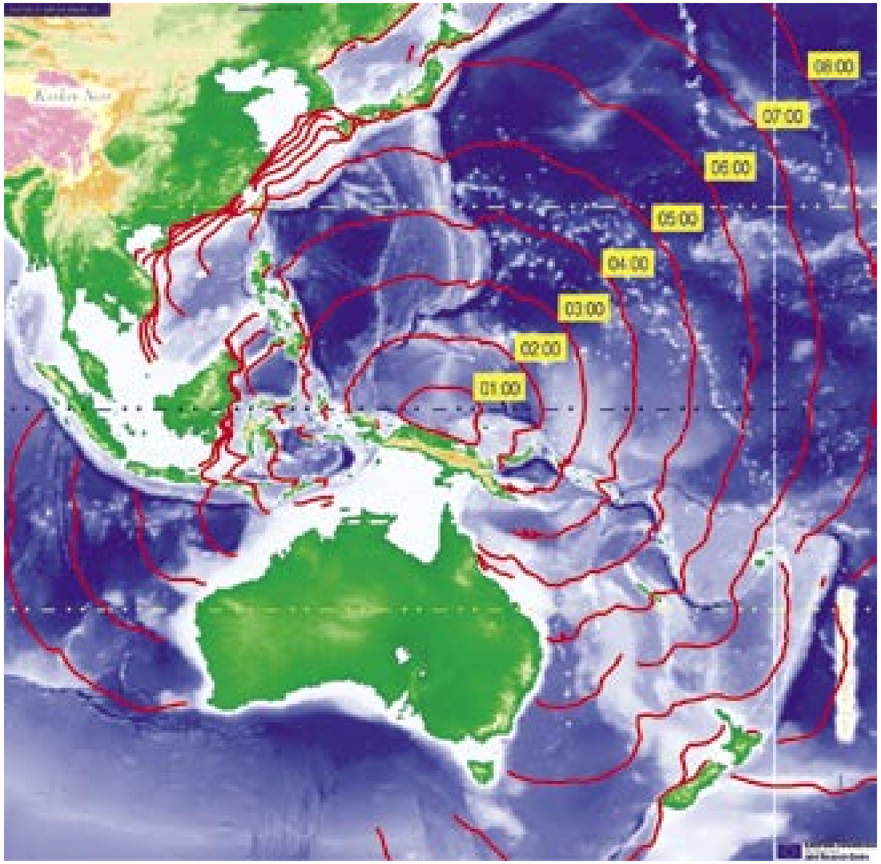


Fig. 7.1 *Preparing for a tsunami event.*
Information from prepared model outputs based on actual or credible tsunamigenic events forms an important part of an Early Warning System. This figure shows the response of the on-line JRC Tsunami model for the Papua New Guinea 1998 Tsunami. Contours show propagation times from the source in hours. Source: Annunziato, 2007. Courtesy JRC.

Dissemination and notification

Bulletin recipients, or national focal points, should be identified and communications methods established as a matter of preparedness. Whenever possible, there should be redundant communications paths to ensure receipt of critical data and complete dissemination of important bulletins. People at risk should be identified at an early stage, in order to ensure that the critical warnings are properly delivered to "the last mile", including to the beach. The entire dissemination process should be tested on a routine basis, and be automated as much as possible to minimize the time required and improve efficiency for warnings provision.

In addition to international dissemination via GTS/WIS, and use of regional, satellite-based dissemination systems, such as the Emergency Managers Weather Information Network (EMWIN), Radio and Internet for the Communication of Hydro-Meteorological and Climate-Related Information (RANET), and GEONETCast (a global network of satellite based data dissemination systems providing environmental data to a worldwide user community), some of the more local communications channels should be used for dissemination. An overview of present satellite emergency communications resources is listed in Section 7.6. Possible dissemination channels include:

- Short Message Service (SMS) of mobile phones;
- electronic or telephonic faxes;
- mass media broadcasting systems consisting of radio, television, and print media;
- public announcement systems using sirens, alarms, and all hazards alert broadcast systems;
- conventional telephones; and
- Internet web pages.

New technologies, like mobile phone emergency radio and cell broadcasting, could improve the reliability and coverage of more traditional channels.

A mechanism to build organizational support and long-term commitment exists through bodies such as committees that bring together stakeholders from warning centres, emergency management and first responders, scientists, other government agencies, non-governmental organizations and the private sector. A committee's mission is to enable and be advocate for policies, procedures, and programmes that are needed to save lives and property from hazard impacts. Examples are the five Tropical Cyclone committees (WMO/ESCAP Panel on Tropical Cyclones, ESCAP/WMO Typhoon Committee, Regional Association (RA) I Tropical Cyclone Committee for the South-West Indian Ocean, RA IV Hurricane Committee, and RA V Tropical Cyclone Committee for the South Pacific and South-East Indian Ocean) that cover all these aspects for tropical cyclones and their consequent storm surges and wind-forced waves. Due to the generally infrequent nature of tsunamis, it is strongly advised that a tsunami warning system be embedded in a multi-hazards framework to ensure sustainability.

A key issue in the dissemination of warnings by NWCs is clarity about who decides on issuing a warning through the media, and who has authority over the media to issue such a warning. The decision maker must be clearly defined and authority delegated, with the chain of command clearly identified and understood by the agencies involved. Because there may be various means to disseminate the warnings to the population at risk in coastal areas, it is important to address the following issues:

- A consensus regarding how the people will be warned in urban and rural areas. Local public radio and television networks, and other potential warning services (as local signs that are often based on previous experience, siren alert, etc.) should be incorporated in such a dissemination process. The dissemination process should have redundancy, so that if one service fails there is still a means to communicate messages. The warning messages need to be confirmed (same message issued from credible sources).
- Highly vulnerable groups need to be warned as quickly as possible so that such groups can be evacuated as soon as possible (children, women, fishermen, communities in coastal areas, densely populated areas such a public markets and plazas, public bus or train stations, and seafronts and beaches). Thus, it is important that such highly vulnerable groups are identified through the vulnerability mapping efforts (Section 5.5).
- A format has to be established for local radio and television stations regarding the wording of warning messages to be broadcast, as well as messages in different languages and generic symbols for tourists.
- The use of the local police department to warn critical service facilities, to guide traffic and to support the evacuation process should be discussed (schools, health centres or hospitals, markets, access roads, coastal roads, mass transport systems).

Mass media such as radio and television are employed to disseminate warnings to geographical areas where the event is expected to impact. Other means to communicate events are the Internet and cellular telephones. While it is important to stress the need for redundancy in the context of communicating events, recent experiences in Latin America and Asia point out that cellular networks are susceptible to saturation during an emergency, making them an unreliable means of communications.

Anticipated Response

The final component in the end-to-end EWS is the action taken by those who will be affected by a hazard warning. Local preparedness and commitment is a critical element for the success of an EWS, because, ultimately, warning systems will be judged on their capacity to save people and minimize losses. Warnings should reach these critical populations and facilities as soon as possible, in order to start the anticipated response. For local (near-source) tsunamis, which in some cases could come ashore within 10 minutes, special reactive measures should be carried out as soon as possible. For distant tsunamis, storm surges or wind-forced waves, which could take hours to reach shore, warning centres and national disaster management organizations have sufficient time to organize evacuations.

7.4 PREPARING FOR EMERGENCIES

Emergency preparedness usually consists of five elements:

- coordinating the response;
- Standard Operating Procedures;
- Emergency Operations Centres;
- evacuation planning; and
- simulations and drills.

The following procedures deal with preparedness to react in case of a hazard event. Note that, again, these procedures relate only to rapid-onset hazards that require immediate response – tsunamis, storm surges and wind-forced waves. Emergency and disaster preparedness involve a whole spectrum of tasks which are intended to ensure government agencies, voluntary and private organizations, and the coastal community at large react to an event efficiently, appropriately and in a timely manner. The aim is to minimize loss of life and property, societal disruption, financial losses, and environmental degradation.

Because the hazards, and in particular tsunamis, can affect several countries at once, regional efforts must be incorporated into national and local efforts headed by Civil Protection agencies and Maritime authorities. It may even be useful to disseminate warnings globally where they concern areas with large tourist influxes. In the case of the 2004 Indian Ocean event, countries in the region with many tourists might have reacted, or been better prepared, for the catastrophe (Box 5.2). At the regional level in Europe, the European Commission is responsible for supporting and supplementing efforts at national, regional and local levels with regard to disaster prevention, preparedness of those responsible for civil protection and intervention in case of an event or disaster. The legislative framework for European Civil Protection has enabled the Commission to establish a framework through its Monitoring and Information Centre (MIC) for effective and rapid co-operation between national civil protection services when mutual assistance is needed (see Section 7.6).

Coordinating the response

Emergency preparedness should lead to a well coordinated response. A major disaster will require an integrated response by different sectors (emergency services, health, agencies in charge of life-lines, public infrastructure, law enforcement, etc.) and at different levels (local, provincial or state, national and international), as necessary. Other partners in a coordinated response could include tourism/hotel and transport organizations. In most countries there are Civil Protection agencies and Maritime authorities which coordinate inter-institutional efforts at the national level, whereas local law-enforcement agencies and local organizations, such as Local Emergency committees, fire brigades and the Red Cross/Red Crescent agencies or other voluntary organizations, handle events at the local level. Inter-institutional coordination is promoted and achieved through the implementation of a variety of measures. In the context of emergency preparedness, three types of procedures are common:

- development of Standard Operating Procedures;
- implementation and use of Emergency Operations Centres; and
- elaboration of evacuation plans, and their subsequent testing and improvement through simulations and drills.

BOX 7.8 Disaster preparedness in the Caribbean and Central America

In the American Hemisphere, the Caribbean Disaster and Emergency Response Agency coordinates efforts on disaster preparedness, focusing on English-speaking island states. In parallel, the Central American Coordination Centre for Natural Disaster Prevention targets all tasks related to disaster reduction, including preparedness. A recently elaborated manual concerning the management of relief aid in case of disasters has been endorsed by the ministries of Foreign Affairs of all six Central American nations and constitutes the protocol under which relief aid must be provided by such countries in case of disasters. The manual aims at correcting the bad practice of having to receive a particular type of aid which may not necessarily be required.

Standard Operating Procedures

In order to avoid improvisations during the response phase, it is important to follow a previously agreed set of procedures. Again, a command chain must be established and recognized, with a clear understanding of who decides on priorities in the decision making process. The procedures, typically labelled as "Standard Operating Procedures" (SOPs), describe the sequence of activities to be executed following a warning or an event. Such procedures include information regarding which agency is responsible for the execution of certain activities, which agencies should provide support in the execution of these activities, what resources will be used to execute them, and any special conditions which should be met if certain tasks are to be carried out or completed. As is to be expected, SOPs must be developed for the different types of hazards which may impact a designated coastal area. Such SOPs are elaborated with the following purposes:

- acknowledging decisions regarding the execution of certain tasks, even without the presence of authorities (the decision to allow the execution of certain tasks is taken well before the event, and is manifested through the SOPs);
- ensuring that tasks are executed in the proper hierarchical order;
- ensuring continuity in case of changes in personnel in various institutions; and
- minimizing improvisations that may lead to inefficiencies or delays in emergency operations (e.g., duplication of effort).

The implementation of SOPs becomes relevant when institutions in charge of response activities change their personnel for particular reasons. In this context, the SOPs will provide the required continuity, as successors to previous staff members can follow the SOPs regarding the execution of specific tasks. Even when staff do not change, SOPs are very important and need to be tested at regular intervals to ensure essential systems (e.g., communications) and links (contacts and contact information – telephone numbers, etc.) remain valid and functional.

SOPs should be developed by every facility or organisation at risk in the case of the rapid-onset hazard events. SOPs can include tasks to be executed shortly before, during, or after an event to minimize the impact of an event on routine operations, processes or resources; and to ensure the safety of people within the agency through evacuation to safe areas or similar procedures. For example, in the case of schools, SOPs focusing on tsunamis in geographical areas where the earthquake sources are very close to shore should contemplate tasks to be executed after an earthquake, such as the immediate and orderly evacuation of children to safe areas; the management of critical paperwork (class lists and emergency contact information), custodian responsibilities (e.g., turning off gas lines), and teaching resources which may be required after the event to re-start the education process as soon as possible. In case of the police, SOPs may include the designation of specific teams to assist in the evacuation process; management of critical information; the set-up of special security measures in particular buildings or places, evacuation of the premises; and the use of back-up communication systems should the main systems fail.

It is important to stress that in the case of a coastal city, specific SOPs should be developed by each agency, in particular, critical facilities such as the police department, schools, health centres and hospitals, energy and telecommunication facilities, mass transport systems as well as any other agency which may be at risk of being affected by hazard event.

Emergency Operations Centres

Because governments are responsible for the coordination of many aspects regarding any event, a Command Post or an "Emergency Operations Centre" (EOC) should be set up and activated so that government agencies can coordinate operations. These may include evacuation to safe areas, as well as the response after a rapid-onset hazard event. Such a facility allows all relevant agencies to share information, identify needs, and coordinate inter-institutional activities. The advantages of using such a facility are:

- a coordinated approach to solving the problems which arise during and after an event, avoiding the duplication of resources to execute the same task (unless absolutely necessary to complete the task) and avoiding leaving other places without any support;
- a more efficient management of resources available to carry out the response activities, and a more rapid identification of the needs which cannot be met with local resources for subsequent request to authorities at a higher level; and
- a unified information management system, avoiding confusion arising from agencies providing information in mutual isolation.

As expected, such a facility also requires specific SOPs for its activation and standard operations. While the activation of an EOC at any particular level is dictated by such SOPs, the activation of specific agencies within an EOC depends on the severity of the event. In cases where the event is small and contained, possibly only a few agencies are activated. In other cases, it may be necessary to gradually activate additional agencies, again depending on the particular circumstances.

Evacuation planning

An essential element of the response is the evacuation (or self-evacuation) of people and key mobile assets (e.g., vehicles and important information) to safe areas before the impact of a potentially catastrophic event. Evacuation planning begins with an assessment of the types of impact which the hazard can provoke, and of the time available to carry out such evacuation, considering the lead warning time (see sections 4 and 5). It involves the following tasks:

- identification of the people at risk, and their geographical location;
- physical vulnerability of infrastructure which needs to be used for vertical evacuation;
- identification of potential evacuation routes to be used by the different groups;
- identification of safe areas and meeting points.

The installation in prominent places of simple maps carrying internationally recognized signs indicating hazard zones, evacuation routes and safe routes may be considered (Fig. 7.2).

The identification of people at risk and their location allows emergency and disaster planners to develop evacuation plans and strategies tailored to the needs and capacities of those people at risk. The identification of potential evacuation routes and safe areas is carried out using information regarding the dynamic features of the hazard. In some cases it is important to consider vertical evacuation, and therefore, a structural assessment of the buildings to be employed for evacuation purposes is required to ensure that such buildings offer adequate safety to those people who use it to seek temporary shelter (Fig. 7.3).

Fig. 7.2 *Informing communities about hazards and responses.*
Maps should be used to provide tsunami safety instructions and identification of the hazard zones, evacuation routes and safe places.

Source: ISO 20712-1:2008--Water safety signs and beach safety flags--Part 1: specifications for water safety signs used in workplaces and public areas, and from ISO 20712-3:2008--Water safety signs and beach safety flags--Part 3: Guidance for use. Reproduced with the permission of the International Organisation for Standardisation, ISO. This standard can be obtained from any ISO member and from the Web site of the ISO Central Secretariat at the following address: (www.iso.org/isostore). Copyright remains with ISO.

Simulations and drills

Simulations and drills constitute exercises to test and improve the degree of preparedness of an institution or a community to react efficiently and in a timely manner to an event, to test the soundness of SOPs, to improve inter-institutional coordination mechanisms, and to promote awareness regarding how to respond in case of an event of a certain nature. Simulations usually refer to more passive exercises whereby SOPs are put to the test to identify their strengths and weaknesses, but no actions take place

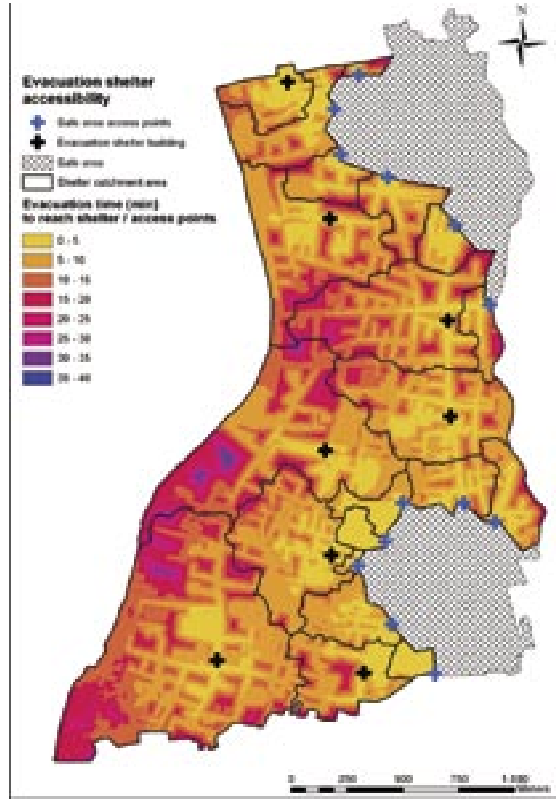


Fig. 7.3 *Evacuation map for Kuta, Bali.*
Map shows the time in minutes (short time=yellow; long time=red, purple) people need to evacuate to vertical shelter buildings or horizontal shelter areas.
Source: GITEWS Project. Courtesy DLR.

in the field. In contrast, drills or exercises refer to field exercises whereby SOPs are put to the test, as well as response capacities in a controlled way. In drills and exercises, mobilization of people and resources takes place. While both simulations and drills follow a similar procedure regarding planning, preparation for the execution is more complex in the case of drills. Unlike the simulation, the drill will involve the mobilization of people. Both simulations and drills can be executed at the level of an institution, such as a single school, for example, or for a group of institutions, a neighbourhood, a city or a region. All participants and others who could potentially be affected need to know that it is only a drill or exercise. Such an inter-institutional drill to test the response capacities of national and local agencies was conducted in Indonesia in December 2006, headed by the Ministry of Science and Technology, RISTEK, and coordinated with the support of the disaster management agency of Indonesia, BAKORNAS. RISTEK is the national agency which has the responsibility to design and implement the tsunami early warning system for that country.

BOX 7.9 Gaps and challenges in response capability in early warning systems

- Lack of multi-agency collaboration and clarity of roles and responsibilities at national to local levels;
- Lack of public awareness and education for early warning response;
- Lack of simulation exercises and evacuation drills;
- Limited understanding of vulnerabilities and of the public's concerns;
- Need for a participatory approach and inclusion of traditional knowledge; and
- Need for long-term risk-reduction strategies

Source: UN/ISDR, 2007

7.5 CHALLENGES AND OUTPUTS

Challenges

The major actors concerned with the different elements of an effective EWS should meet regularly to ensure they understand all of the other components and what information or support other parties need from them. Specific targets to be achieved in establishing a new (or in maintaining and enhancing an existing) end-to-end EWS may include:

- the relative importance of the various coastal risks at national to local scales established and understood;
- risk scenarios constructed and/or reviewed;
- specific responsibilities throughout the chain agreed and implemented;
- past events studied and improvements implemented;
- manuals and procedures developed and maintained;
- communities consulted and information disseminated; and
- operational procedures, such as evacuations, practiced and tested

Challenges in raising awareness of disaster risk reduction may include:

- a limited public awareness and knowledge of the potential damage from the hazards; and
- a lack of appropriate awareness campaigns.

Challenges in establishing and maintaining an Early Warning System for coastal hazards may include:

- a lack of observational data in some critical regions (see Section 4);
- inefficient telecommunication connections;
- inefficient forecasting models and decision-making tools (see Section 4);
- acquiring appropriate topographic and bathymetric data (see Section 4); and
- gaining the commitment of all stakeholders.

Challenges in emergency preparedness may include:

- development of appropriate Standard Operating Procedures;
- appropriate implementation and use of Emergency Operations Centres;
- elaboration of efficient evacuation plans;
- development of inter-institutional efforts at the regional and national levels on disaster preparedness; and
- required elements for establishing new (or maintaining and enhancing existing) end-to-end EWS.

Outputs

These may include:

- an adequate framework for designing and establishing an effective Early Warning System;
- steps for raising awareness of disaster risk management established;
- adequate means and formats to communicate the hazard in place;
- special target audiences identified;
- operational components for an Early Warning System in place;
- adequate means and formats to disseminate the alert established;
- stakeholders identified;
- adequate capacity established to carry out an integrated, inter-institutional response in case of a coastal hazard event;
- functionality of Emergency Operation Centres demonstrated; and
- evacuation planning in place and tested.

7.6 DATA REQUIREMENTS AND INFORMATION SOURCES

***Table 7.1**. Information sources for enhancing awareness and preparedness*

Products	Variables and standards	Sources	Global programmes and data sets
Education and awareness products			GeoHazards International. 2008. Preparing Your Community for Tsunamis: A Guidebook for Local Advocates. (www.geohaz.org) Intergovernmental Oceanographic Commission. 2008a. *Tsunami, The Great Waves*, Revised Edition. Paris, UNESCO, illus. IOC Brochure 2008-1. 16 pp. Available at: http://ioc3.unesco.org/itic/contents.php?id=169 Intergovernmental Oceanographic Commission. 2008b. Tsunami Glossary, 2008. Paris, UNESCO. IOC Technical Series, 85. Available at: http://ioc3.unesco.org/itic/contents.php?id=328 IOC Tsunami Teacher. (http://ioc3.unesco.org/TsunamiTeacher/) UNESCO. 2008. Tsunami Preparedness: Information Guide for Disaster Planners. IOC Manuals and Guides No. 49. (http://unesdoc.unesco.org/images/0016/001600/160002e.pdf)
Rapid-onset hazard Early Warning Systems	Alerts and information on locations, timings and magnitudes of tsunami and storm surge coastal impacts. National warnings of impacts	Regional Tsunami Watch Centres through National Focal Points to National Warning Centres National Warning Centres	IOC-coordinated regional Tsunami Early Warning Systems (RTWS) and National Contacts. (http://www.ioc-tsunami.org/) JRC Tsunami Propagation Model. An on-line procedure is available to calculate a tsunami event. (http://tsunami.jrc.it/model/index.asp) WMO RSMCs for Tropical Cyclones. (http://www.wmo.ch/pages/prog/www/tcp/Advisories-RSMCs.html)
Communications systems			WMO-GTS/WIS (World Meteorological Organization, Global Telecommunications System) (http://www.wmo.ch/pages/prog/www/TEM/GTS/gts.html) EMWIN (Emergency Managers Weather Information Network) (http://www.weather.gov/emwin/index.htm) RANET (Radio and Internet for the Communication of Hydro-Meteorological and Climate-Related Information) (http://www.ranetproject.net/) GEONETCast (a global network of satellite based data dissemination systems providing environmental data to a worldwide user community) (http://www.earthobservations.org/geonetcast.shtml) Satellite Earth Stations and Systems (SES) - an overview of present satellite emergency communications resources, ETSI. (European Telecommunications Standards Institute). (http://www.etsi.org)
Evacuation plans	Evacuation maps with evacuation routes and timings; shelters and refuges; emergency practice drills	Inundation, vulnerability and risk maps; vulnerability hotspots for people and utilities	

General guidance

European Commission, Civil Protection. Available at: http://ec.europa.eu/environment/civil/prote/cp01_en.htm

European Commission, EXCIMAP Evacuation Mapping. http://ec.europa.eu/environment/water/flood_risk/flood_atlas/pdf/flood_maps_ch7.pdf (Accessed 19 February 2009.)

European Commission, Joint Research Centre: JRC Tsunami Propagation Model. An on-line procedure is available to calculate a tsunami event. Available at: http://tsunami.jrc.it/model/index.asp

- http://lunar.jrc.it/tsunami/CurrentEvents/tabid/55/Default.aspx - all the calculations of the online system
- http://lunar.jrc.it/tsunami/GridCalculations/tabid/54/Default.aspx - description of the grid rationale

GDACS: The Global Disaster Alert and Coordination System is a joint initiative of the United Nations and the European Commission, and provides near real-time alerts about natural disasters around the world and tools to facilitate response coordination, including media monitoring, map catalogues and a Virtual On-Site Operations Coordination Centre. Available at: http://www.gdacs.org/

http://www.gdacs.org/tsunami/archive.asp?CMD=GET_ID&TSID=916 An example of an online calculation for an event in Japan (19 July 2008)

IOTWS: U.S. contribution to the IOC-led Indian Ocean Tsunami Warning System. Available at: http://apps.develebridge.net/usiotws/pageaahome.html

PTWS: Pacific Tsunami Warning and Mitigation System. http://ioc3.unesco.org/itic/files/ptws_brochure.pdf (Accessed 19 February 2009.)

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UNESCO. Unified tsunami website – IOC Tsunami. Provides information on the IOC tsunami programme, the Regional Tsunami Warning Systems (RTWS) and the National Contacts for RTWS Available at: http://www.ioc-tsunami.org/

USAID. 2007. *The Tsunami Warning Center Reference Guide*. Available at: http://www.iotws.org/ev_en.php?ID=2897_201&ID2=DO_TOPIC describes a concept of operations for a National Tsunami Warning Centre or Regional Tsunami Watch provider.

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8 MITIGATING THE RISK

ICAM PHASES	I	II	III	IV

This Section outlines the procedures and information that policy makers should consider within ICAM when developing a risk mitigation strategy for the coastal hazards.

8.1 STRATEGIC MANAGEMENT WITHIN ICAM

The ultimate goal of strategic risk management is effective and sustainable risk reduction or mitigation. This entails choosing strategic management 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. Together with Section 7, the section describes procedures relating to mitigation within the Implementation (III) and Consolidation/Replication/Expansion (IV) phases of the ICAM process (figs 1.1 and 1.2; sections 2.3 and 2.4). An example of the need for clear guidance on strategic risk management is illustrated by the case study at Box 8.7.

Key considerations

There is a wide range of methods that can be employed within a risk management strategy to mitigate the impacts of coastal hazards. The terminology used to define these different methods can be confusing, especially when referring to other authoritative sources, such as those on disaster reduction by the UN/ISDR and the IPCC assessment reports, which use the same terms in quite different ways. For the purposes of these Guidelines, the terms of "adaptation" and "mitigation" are essentially synonymous (see Glossary).

Once the risk assessment process is completed (sections 4-6), policy makers should have at their disposal the essential information on the hazards, vulnerabilities and risks within the designated coastal management area. The risk assessment exercise should have considered the cumulative risks of all coastal hazards and acknowledged the different types of risks associated with individual hazards and events.

This knowledge of the hazard-prone areas and the prioritized risks provides policy makers and planners with a basis for developing a risk management strategy to reduce the community's exposure and vulnerability to these hazards. Such a strategy will need to take account of the full range of other coastal area management pressures and considerations, including the wide range of stakeholder interests, in the development of the Management Plan. The strategy will also need to identify responsibilities, both operational and financial. The assurance of adequate funding, whether national or local, is likely to be a key determinant in the successful execution of the plan.

Procedures for mitigation primarily in respect of tsunamis in the Indian Ocean region are also described in guidelines produced as part of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS; UNESCO, 2009).

BOX 8.1 Key tasks and goals for the strategic management of the perceived risks

- Define the temporal and geographical scales of the management.
- Determine the options for strategic mitigation.
- Consider the adoption of a multi-pronged approach to the management response.
- Incorporate other ICAM goals in the response.
- Apply decision-analysis tools in the management process.
- Involve the public in the decision-making processes.
- Identify management responsibilities and sources of adequate funding.

8.2 SELECTING THE STRATEGIC APPROACHES TO RISK REDUCTION

What is the scope and scale of strategic management?

Due to the complexity of coastal hazards and the uncertainties identified through the risk assessment, selected strategies need to be robust. It is very unlikely that a single mitigation approach would be effective by itself. Rather, policy makers will need to develop a portfolio of options to collectively reduce hazard-related risk. There is a need for system-oriented thinking and an adaptive strategy, taking into account the interdependencies and interconnectedness of the various coastal interests.

As sections 4–6 describe, many factors influence a community's vulnerabilities and risks to coastal hazards. These include the location of critical infrastructure, vulnerable populations, and key economic centres, as well as environmental considerations. Therefore, policy makers will need to cater the hazard mitigation response for specific areas based on the level of development, land use and the critical ecosystems present. Where regulation is required, enforcement and control may be a problem. Box 8.6 brings out one example from the U.S. where the law had to be gradually adjusted to accommodate special interests of development or maintenance, etc. There will always be pressure on decision makers to adjust, especially in relation to events which occur only infrequently.

In addition, vulnerabilities change over time as coastal populations grow (or, less commonly, shrink), development and land-use patterns change, and environmental factors, such as sea-level and climatic conditions, change as well. Societal expectations of the goals of risk mitigation may also change significantly over time. Hence, policy makers must recognize that the preferred hazards management options are also likely to change over time. They need to develop their strategies accordingly. The case study in Box 8.3 illustrates this approach based on shoreline management planning in England and Wales.

What are the strategic mitigation options?

Broad risk mitigation strategies available to policy-makers and applicable to all the coastal hazards can be classified into three main types (Fig. 8.1):

- Protection;
- Accommodation; and
- Retreat.

As noted above, unless dealing with a small and/or homogenous coastal management area, policy makers will often implement a mix of these approaches for an effective and practical response. These strategies include both structural and non-structural measures.

Structural measures refer to any physical (natural or artificial) construction to reduce or avoid possible impacts of hazards. Structural measures can range from engineered structures that are added to the landscape to protect development and infrastructure from hazards to buildings that are designed or modified specifically to better withstand coastal hazard impacts. They also include the use of natural protection from, e.g., coastal wetlands or sand dunes.

Non-structural measures refer to policies, regulations and plans that promote good coastal management practices to minimize risks from coastal hazards. Education and outreach campaigns that increase the public's awareness of risks, vulnerability and preparedness responses (as described in Section 7) can also be considered non-structural measures.

"Protection" involves the use of natural or artificial measures to protect landward development and/or attempt to hold the shoreline in its existing position in an effort to reduce hazard impacts. Traditionally, protection against coastal erosion, flooding, storm surge and tsunami inundation has been approached through mitigation by hard structural response. Examples of common protection measures include constructing groynes, seawalls, offshore breakwaters, and bulkheads. In some heavily populated areas susceptible to storm surges, dykes, levees, dams, and flood gates have been built to protect coastal communities during extreme sea-level events. Major cities including London, St Petersburg, Rotterdam, Alexandria, Bangkok, Shanghai, Tokyo and Vancouver, rely on these major engineering initiatives to protect them during storm surge events (Box 8.2).

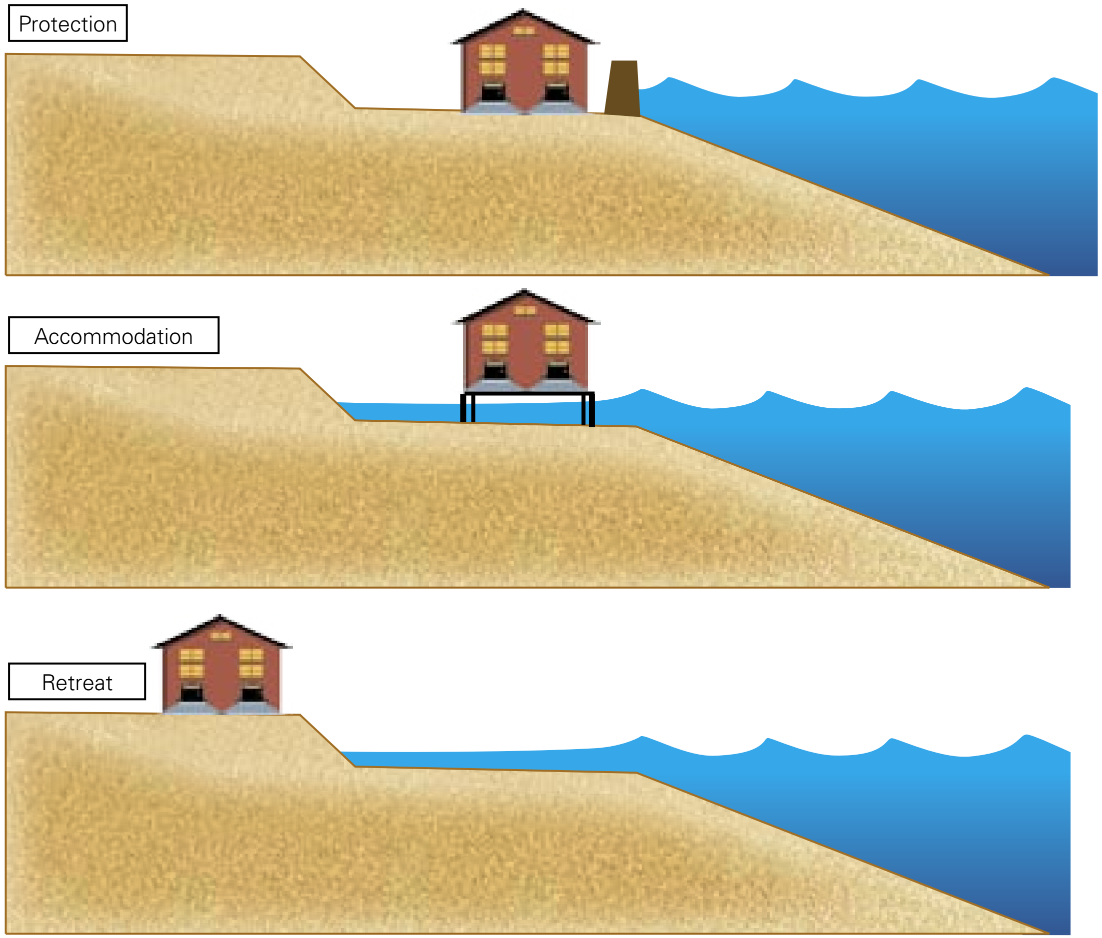


Fig. 8.1. *The three mitigation strategies: protection, accommodation and retreat.*

Source: Based on Bijlsma et al., 1996.

BOX 8.2 Thames Estuary 2100: Planning for future flood risk management in an uncertain future

Following the 1953 East of England coastal floods, the Thames Barrier and associated defence improvements were planned and built over a 30-year period to protect London and the tidal floodplains of South Essex and North Kent. London and the Thames Estuary are currently protected to a high standard (managing the 1:1000-year flood expected at the year 2030). This high standard was justified by the high value of property and strategic infrastructure within the floodplain. At the time of design, an allowance for future increases in sea-level rise was built into the Thames Barrier, although little was known of climate change and the potential for future increases in storm surge driven extreme sea-level events or increases in river flows. This allowance was based on an extrapolation of the evidence of past sea-level rise and downward land movement. In addition, the existing flood defence system is ageing. Because there are now more people and property on the floodplain, the flood risk is increasing and present flood management arrangements need to be reviewed. As a response, the Environment Agency has set up the "Thames Estuary 2100" (TE2100) project. This project will develop a Flood Risk Management Plan for London and the Thames Estuary for the next 100 years, presenting an appraised and adaptable set of costed options to Government in 2010.

TE2100 has developed an approach that will cope with the uncertainties that are presented by climate and socio-economic changes. The estuary supports internationally important wildlife habitats, is a major recruiting ground for North Sea fish populations, an internationally important commercial centre, a port, and home for over 1.25 million people. The TE2100 plan must therefore demonstrate the move from flood defence to flood risk management advocated by Government in their flood and coastal erosion risk management strategy "Making Space for Water". The project is developing and appraising a range of options which will manage both the increasing probability of flooding, i.e., raising existing flood defences, increased operation of the Thames (tidal) Barrier, location of new barriers, restoring floodplains for tidal and fluvial flood storage, as well as options which will manage the consequences of flooding, i.e., working with the spatial planning system to locate and design flood resistant and resilient developments, improve flood awareness of those living and working in the floodplain and improving emergency planning, response and recovery. The plan must also demonstrate how options can be adapted and respond to change through the century and the monitoring of triggers for change, such as sea-level rise, floodplain development, deterioration of existing flood defences, habitat decline, public behaviour and delivery partner response.

The Thames Barrier in operation – view upstream towards the city of London

The TE2100 approach is centred on dealing with the uncertainties highlighted above. The challenge is to ensure that each option is appraised against a range of climate and socio-economic scenarios, which will deliver acceptable flood management. It must also be fully compliant with the requirement of European legislation on habitats, strategic environmental assessment, floods and water framework, to enable the people and wildlife of London and the Thames Estuary to prosper. At the centre of this approach is a framework which will test the suitability of the options against differing futures driven by a range of socio-economic and climate change scenarios. Thus, options can be refined and the most resilient, effective and cost-ben-

BOX 8.2 (Continued)

eficial solution identified. Using this method it will be possible to detect thresholds which will be critical to differing options. For example, modifying the existing Thames Barrier and defences will cope only with a certain level of sea-level rise and increase in storm surge, so there will be a trigger threshold at which other measures (such as flood storage, an outer Barrier or relocation of vulnerable development) must be added.

This approach has been developed from the "Risk, Uncertainty and Decision-Making" Technical Report produced by the Environment Agency for the UK Climate Impact Programme. TE2100 is also working with partners in Holland, Germany and Belgium in the ESPACE Project (European Spatial Planning Adapting to Climate Events) to develop and refine transnational methods. The involvement of stakeholders in London and across the estuary will be critical to the success of the plan and implementation of the selected options post-2010. TE2100 is working with a wide variety of stakeholders, from Government to local estuary user groups to ensure that the final Flood Risk Management Plan will, as far as possible, be compatible with the various interests that the Estuary supports.

An extensive study and consultation programme is underway to enable full understanding of the processes and issues critical to testing and developing options. At this stage, no conclusions have been reached on likely final options, but early findings have been released to keep stakeholders abreast of the project's development and to provide confidence in the approach to key decision makers across the Estuary. A key aspect of planning for an uncertain future has been to advocate and share the aims of the project with key decision makers across the Estuary, particularly those planning new development, to ensure that decisions taken today will provide opportunities to implement the recommended options through the century. A draft plan will be released for consultation in April 2009.

TE2100 will produce a long-term Flood Risk Management Plan for London and the Thames Estuary. Climate and socio-economic change is central to the risk-based approach adopted and the options being considered have been structured around this. The long-term success of the final Plan will be determined to a large extent by how well this strategic approach, which embraces uncertainty, can be adopted by the Environment Agency's implementation partners. Spatial and emergency planners as well as those that live and work on the Estuary will need to ensure that decisions taken today do not restrict TE2100 options for the future, as well as accepting that flooding and the way it is managed are going to change over the century.

Rachael Hill.

Courtesy The Environment Agency, England and Wales. U.K.

While hard structural protection can successfully reduce risk in respect of coastal hazards, such measures have not always been efficiently implemented. In some cases, protection measures may have even contributed towards an increased risk. For example, hard shoreline stabilization can disrupt natural sand movement on the shore, exacerbating erosion rates down-drift from the structure. This is one of the reasons why shoreline management planning based on coastal cells was implemented in England and Wales (Box 8.3).

BOX 8.3 Coastal hazard management planning, including examples from England and Wales

Protection of a coast against erosion and flooding caused by waves, currents, storm surges and tsunamis or any other natural phenomena or human intervention requires a deep understanding of the associated physical processes over a wider coastal region. Irrespective of the source of the hazard, the underlying principles of coast and flood protection methods are similar. In this context, the preparation of a Coastal Hazard Management Plan (CHMP) is an important element of an overall Integrated Coastal Area Management Plan.

Within an ICAM plan, a CHMP represents a coherent set of measures, specified in time and space, to achieve hazard mitigation against existing or anticipated damage from single or multiple hazards. A project monitoring and control system is also incorporated as an important activity within this plan. In view of the dynamic behaviour of the coastline, solutions for a particular location cannot be developed in isolation. There is strong need to consider impacts over a wider coastal region where problems can be exported alongshore. To overcome this, sediment transportation along coastlines and the dynamic equilibrium are assessed via "coastal cells" and "sub-cells" and sediment budget computations.

Coastal cells are self-contained systems for beach-grade sediment, while coastal sub-cells operate reasonably independently of their adjoining sub-cells. Within a coastal cell, coastal erosion and accretion can be understood, defined and explained in terms of the cell's sediment balance (sediment budget). Coastal erosion is a result of sediment budget deficit. The establishment of coastal cells and the quantification of sediment budgets provide an effective platform for ICAM. This procedure provides information of the status of the coastline as well as how it would respond to a given hazard. The approach provides the basis for solutions and also enables the assessment of the impact of a particular solution on its neighbouring coasts.

This philosophy has been adopted in England and Wales, where, historically, coastal flooding and coastal erosion have been treated as separate issues governed by different laws and different parts of government. Since the early 1990s, the management of these two hazards has been integrated under the umbrella of shoreline management based on coastal cells and sub-cells. Defined by the sub-cell boundaries, about 40 shoreline management plans (SMPs) were prepared in the late 1990s covering the entire coast of England and Wales. Within the sub-cells, coastal land use was used to divide the shoreline into homogeneous management units where the response to flooding and/or erosion is uniform. For each management unit, one of four generic and essentially geometric policies was selected:

- Hold the Line
- Advance the Line
- Retreat the Line
- Do Nothing

The technical details of how to achieve these strategic goals are assessed in "coastal strategy" assessments and in more detail the "coastal scheme" design. Since the 1990s, the SMP process has evolved to a comprehensive set of methods assessing (1) coastal processes, (2) coastal defences, (3) land use, and (4) the environment. Recognition of management units (now termed "coastal process units") remains fundamental to the approach, and, in any hazard mitigation study, the coast will similarly have to be divided into homogeneous units in terms of responses. These principles can be transferred to the management of any coastal hazard.

Robert Nicholls and Sam Hettiarachchi

Structural protection responses can also lead to significant adverse socio-economic and environmental impacts. Installing hard shoreline protection structures can destroy important habitats as well as opportunities for public access to the shore. For example, seawalls and bulkheads prevent the landward migration of wetlands, intertidal areas and beaches. As sea level rises or the land in front of the structure continues to erode, ecologically valuable wetlands and intertidal areas that provide important habitat for commercial fish species are lost along with popular tourist beaches. Such losses may have significant impacts on local economies.

Fig. 8.2 *Protection by enhancement of natural features: mangrove.*
Rhizophora apiculata *four months after planting using an innovative planting technique, COMP-PILLOW, for rehabilitating a less eroded site (Category 2) without a front-line wave breaker, Kuala Gula, Perak, Malaysia.*

Source: Raja Barizan, 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

A protection strategy could also include softer engineering options, such as restoring or enhancing natural protective features (e.g., restoring wetlands, stabilizing/rebuilding dunes and re-nourishing beaches), or raising the ground level around coastal villages (Fig. 8.2).

Within the ICAM context, policy makers and planners need to carefully evaluate the long-term implications of the proposed protection measures, fully weighing the socio-economic and environmental benefits and costs of each approach. Even when potential drawbacks are considered, policy makers may select a protection strategy using structural solutions as the only practical option, especially along heavily developed coasts, where vital infrastructure is at immediate risk. Alternatively, hard solutions may be a necessary short-term strategy for communities to "buy time" for more comprehensive or long-lasting but politically difficult solutions.

Lastly, it is important to keep in mind that there is always a risk of failure for protection measures, even if this risk may be very small. Hence, additional mitigation measures, such as establishing hazard warning systems and evacuation plans and routes, should always be combined with protection approaches as an added safety measure (see "Accommodation", below).

"Accommodation" involves adjustments in the way people live and the way in which they develop land in response to coastal hazards. It includes the continued, but altered, use of land, market mechanisms, and building and/or site design practices to reduce vulnerability to coastal hazards. Examples include elevating structures on pilings or fill so they are out of floodplains, constructing elevated flood and cyclone shelters, flood- and wind-proofing buildings to better withstand high winds and storm surges, and changing crops to more flood/salt-tolerant varieties.

Accommodation for tsunamis and storm-induced flooding will commonly include measures such as establishing early warning systems and evacuation routes to encourage population movement to safe locations, when appropriate (Section 7). Successful examples include the extensive cyclone shelter networks and associated warning systems around the Bay of Bengal which, since 1991, have greatly reduced the death toll during cyclone landfall (Box 8.4). In the Maldives, the experience of the 2004 Indian Ocean tsunami is leading to the development of shelters to protect at risk populations from tsunamis.

When developing a risk management strategy, policy makers may realize that attempting to reduce a community's risk from coastal hazards through protection and accommodation approaches would not be feasible in the long-run. Protection and accommodation approaches can be costly to implement and usually require continual maintenance to be effective. Their cost, combined with their inability to permanently protect coastal communities from all hazards, may lead policy makers to adopt the third type of mitigation strategy – "retreat".

BOX 8.4 Coastal cyclone shelters in Bangladesh and in Orissa, India

A cyclone shelter in Orissa, India

Picture source: courtesy of Frank Thomalla

Deltaic areas adjacent to the Bay of Bengal suffer from frequent extreme high tides due to storm surges as well as routine monsoonal floods. In Bangladesh a network of concrete two-storey shelters has been constructed at a spacing of about one kilometre, mainly since the 1991 cyclone. These shelters have space on the ground floor for animals and on the second floor for people, well above recorded water levels. The shelters also have early warning sirens or bells and may have pre-positioned emergency supplies of food and medical supplies. In addition to the shelters, a warning system is in place based on community volunteers which distributes meteorological forecasts to local people in time to evacuate to the shelters. The success of these measures is apparent from the greatly reduced death toll in cyclones. Cyclone Sidr in 2007 was similar in magnitude to the 1991 cyclone, but the death toll in Bangladesh, at 3200 people, was only 2%–3% of that in 1991.

Peter King

"Retreat", which in this context is managed or planned, involves preventing future development in coastal hazard zones and progressively ceding land by moving development away from hazard-prone areas as the opportunity arises or as individual assets come under imminent threat (Box 8.5). Unplanned and ad hoc retreat can also occur as a last resort.

BOX 8.5 Coastal setbacks

Adoption of construction setbacks may pose some resource, institutional and political challenges, but has become a fairly commonplace and feasible approach to promoting adaptation or retreat strategies to cope with sea-level related hazards. Construction 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. Setback lines are often measured from a specific shoreline feature, such as the high-tide line, extreme high water mark, or a dune vegetation line.

UNESCO defines coastal development setback as '...a prescribed distance to a coastal feature, such as the line of permanent vegetation, within which all or certain types of development are prohibited.' This is the standard definition used by many as the starting point to defining the coastal setback. Coastal development setbacks, according to UNESCO, have several functions, namely:

- to provide buffer zones between the ocean and coastal infrastructure, within which the beach zone may expand or contract naturally, without the need for seawalls and other structures;
- to reduce damage to beachfront property during extreme natural events, e.g., hurricanes; to provide improved vistas and access along the beach; and
- to provide privacy for the occupiers of coastal property and also for persons enjoying the beach as a recreational resource.

So far, only in one Regional Sea has a specific legislation regulating this issue been adopted. The Mediterranean Protocol on ICZM, which was adopted in early 2008, has a special provision for coastal setback. Its Article 8 stipulates that the Parties to the Barcelona Convention '...shall establish in coastal zones, as from the highest winter waterline, a zone where construction is not allowed. Taking into account, inter alia, the areas directly and negatively affected by climate change and natural risks, this zone may not be less than 100 metres in width...'

BOX 8.5 (Continued)

A number of countries have also taken steps to safeguard the coastline against natural risks by defining the coastal setback zone. In the United States, as of 2001, nearly two-thirds State and Territorial Coastal Zone Management Programs have developed State/Territory-wide setback requirements for construction along the coast. Of the remaining areas, setbacks have often been adopted and implemented by local/municipal governments. The following types/numbers of setbacks have been implemented; i) three states with a *fixed* setback line; ii) nine states with an *arbitrary* setback distance from a baseline; iii) six with a variable setback distance; and iv) six with a combination of *arbitrary and variable* setback lines. These setbacks are employed for a number of purposes, including protection of beaches and dunes for recreation and hazard mitigation objectives or specifically designed to move structures out of an identified erosion- or inundation risk area.

The Shore Law of Turkey defines the "shore strip" as a zone which has a minimum of 100 m width horizontally, starting from the "shore edge line", according to the amendment dated 1st July 1992. Construction in this zone is extremely restricted. The Cyprus Act of 1959 forbids foreshore construction within a 50-metre-wide coastal fringe. Coastal Development Setbacks in Antigua and Barbuda have been determined for cliffed coasts (the setback is 50 feet) and low rocky shores (the setback is 100 feet). These setbacks apply to all types of development – houses, hotels, villas and commercial buildings, whether of wood or concrete, as well as roads and swimming pools.

Ivica Trumbic

A managed retreat approach typically involves prohibiting development in undeveloped areas and establishing thresholds to trigger demolition or relocation of existing structures threatened by erosion and other hazards. Therefore, this approach usually requires a number of measures to limit new or redevelopment in high risk areas. These include implementing construction setbacks along the shore to ensure development is placed outside high risk areas; adopting zoning controls to ensure that buildings are small enough and constructed in a way to facilitate relocation or easy removal when needed; and instituting relocation assistance and/or buy-back programmes to help with relocation costs or compensate property owners when their property becomes unusable. Although retreat strategies can be politically challenging to implement, in some areas they can be the most effective risk management strategy in the long run. Box 8.6 on rolling easements and easements for retreat explains a relatively new approach to managed retreat.

Table 8.1 provides examples of the types of measures that may be taken within the protection, accommodation and retreat strategies to address specific hazards (tsunami inundation and run-up, storm surge, sea-level rise and coastal erosion). For more in-depth information about the measures presented in Table 8.1, see annexes 1 and 2. Annex 1 describes each measure and provides links to additional information on the measures. Annex 2 identifies the major economic, environmental and political trade-offs for the selected management measures.

Table 8.1 *"Protection", "Accommodation" and "Retreat" strategies – examples of strategic risk management measures for addressing coastal hazards and their effectiveness. (See note at base of table regarding effectiveness)*

MANAGEMENT (RISK REDUCTION) STRATEGIES	Management measures	HAZARDS			
		Tsunami inundation and run-up	Storm surge	Inundation from long-term sea-level rise	Erosion (chronic and episodic)
Protection Constrain hazard impact	• Closure gates, surge barriers/ storm gates		••	••	
	• Dykes (levees)/revetments/seawalls	•	••	••	••
	• Groynes		•		••
	• Artificial headlands		•		••
	• Cliff stabilisation measures				••
	• Offshore breakwaters/reefs	•	••		••
	• Offshore tsunami breakwaters	•			
	• Beach nourishment		••	••	••
Accommodation Modify behaviour	• Enhance natural protective features	•	•		•
	• Shelters, warning systems and evacuation routes	••	••		
	• Building codes	••	••	•	
	• Drainage regulations/policies				•
	• Zoning controls	•	•	•	•
	• Post-disaster redevelopment regulations	••	••	•	
	• Tax and insurance incentives/disincentives	••	••	•	•

Retreat Move away	• Building codes	•	•	••	••
	• Construction setbacks	••	••	••	••
	• Transfer of development rights	•	•	•	•
	• Targeted buyouts/relocation assistance	••	••	••	••
	• Zoning controls	•	•	•	•
	• Tax and insurance incentives/disincentives	•	•	•	•
	• Restricting capital improvements	•	•	•	•
	• Easements, rolling easements			••	••
	• Post-disaster reconstruction prohibition	••		••	••

•• very effective; • somewhat effective
The effectiveness of various measures will depend on the magnitude of the hazard events, especially for tsunamis and storm surges, as well as the robustness of the non-structural approaches implemented.

BOX 8.6 **Examples of rolling easements/easements for retreat in the U.S.A. and the United Kingdom**

To address shoreline erosion and sea-level rise, the state of South Carolina, United States, passed a Beach Front Management Act in 1988, which established a setback line for ocean-front property of forty times the annual erosion rate. When the setback line was drawn, it rendered some lots undevelopable since there was an insufficient area to landward of the setback line to erect a building. It also placed some existing structures entirely seaward of the setback line.

In response to a lawsuit brought by a property owner whose property was "undevelopable" due to the new setback line, the state amended its Beach Front Management Act to allow for a rolling easement on any lot seaward of the setback line. Establishing a rolling easement policy helped the state to avoid the need to compensate landowners for the lost use of their land. The rolling easement allowed lots seaward of the setback line to be developed, but no hard shoreline stabilization structures could be used to protect the property. "Soft" erosion control methods are still allowed, including beach renourishment, building up artificial dunes, and temporarily placing small sandbags around a home. If homes are damaged or destroyed during a storm, they are allowed to be rebuilt as long as high ground still exists. If the lot is submerged during high tide, rebuilding/repairing is no longer allowed.

In the United Kingdom, easements have recently been established for redevelopments on eroding cliff tops in the Isle of Wight. Two new buildings have been allowed. However, the owners forfeit their right to protection and bear the risk of the erosion of their property. Such practices are expected to be more widely applied to eroding cliffs in the United Kingdom.

Allison Castellan and Robert Nicholls

Source: includes Titus, 1998

8.3 DEVELOPING A STRATEGIC RESPONSE TO COASTAL HAZARDS

Considering a multi-pronged approach

Unless dealing with a small and or homogenous management area, policy makers will usually have to take a multi-pronged approach to reducing risks, incorporating many of the protection, accommodation and retreat options available to be most effective. No single approach by itself will be able to address the community's vulnerability to coastal hazards. Once an overall strategy is identified, comprising protection, accommodation, retreat or a combination thereof, policy makers must choose specific measures, such as those presented in Table 8.1, to implement the selected strategy.

Selection of specific measures will depend on a wide variety of factors including:

- the hazard(s) being addressed;
- the geographical scope and level of development of the area to be managed;
- priorities identified through the vulnerability and risk analyses;
- the broader approach(es) being taken (protection, accommodation or retreat);
- the timeframe that is being addressed;
- the existing and potential capacity of the community (e.g., funds, expertise, administrative capacity); and
- the political, legal and socio-economic context.

BOX 8.7 Risk and response: coastal storms and erosion in KwaZulu-Natal, South Africa, March 2007

In March 2007, the entire coastline of KwaZulu-Natal (KZN) experienced exceptionally high waves generated by a cut-off low-pressure system off the coast, which occurred concurrently with equinox Spring high tides. A significant wave height of 8.5 m and a peak wave height of 14 m were recorded.

Although the Highest Astronomical Tide (equinox Spring tide) only occurs once every 18.6 years and had been predicted for the March 2007 period, the coinciding cut-off low pressure system that generated the extreme waves was a meteorological event that was less predictable. Due to the relatively slow increase in wave height leading to the peak of the storm, people had sufficient time to move away from the threat. Once authorities and citizens realized the imminent danger to built infrastructure and private property, it was too late to mobilize and institute temporary protection measures. Even if managers were afforded more time to prepare, the exposed nature and length of the KZN coastline, in conjunction with the intensity of the storm, suggests that most attempts to protect infrastructure against the waves would have been largely ineffective.

Coastal erosion in Kwazulu-Natal, South Africa, March 2007

The March 2007 storm event has resulted not only in the loss of infrastructure and property, but also a reduction in the ability of the shoreline to buffer the coast against the eroding action of the ocean. The removal of sand from beaches and the erosion of the offshore sand bars caused by the storm have triggered severe, localized coastal erosion in the months following the storm. In many cases, the coastal erosion has prevented the reinstatement of public infrastructure and services. The storm event and the ongoing erosion have highlighted the lack of unambiguous management guidelines for dealing with physical hazards and risk at the provincial scale. Although the appropriate legal instruments already exist, the scale of the impact required not only action by the state and managers to act in order to protect infrastructure, but also a similar response from the public. This, however, proved to be impractical on the temporal and spatial scale that was necessary to respond to the exacerbated coastal erosion. The impracticality was attributable to the detailed and time-consuming nature of the Environmental Impact Assessments as a requirement for conducting alterations and reinstatement works whether by municipalities or the private sector.

Initially government response was limited to the actions of the local authorities, but as the threat and widespread impact of coastal erosion increased, both provincial and national government had no choice but to respond to the call from stakeholders and local authorities. The role of National Government in this instance would more than likely be restricted to providing financial resources through the National Disaster Management Fund while the Provincial Department of Agriculture and Environmental Affairs will take a more strategic role in expanding the horizon of the response. This includes the proposal of elevation-based building setback lines (for example, the +10 m MSL contour), the development of guidelines for dealing with erosion in both the short- and the longer-term, and broad principles for living with coastal erosion.

The damage estimate caused to municipal infrastructure (excluding private landowners), amounts to approximately South African Rand 400 million. This figure is based on the damage assessment report of the Provincial Disaster Management Centre. Other secondary but significant costs include the loss of tourism revenue as holiday rentals and vacation-associated commerce were affected by a negative perception of the state of the beaches. Furthermore, the allocation of municipal funds towards remediation of the damaged beaches and infrastructure were not consistent. Some municipalities, notably eThekwini Municipality, reallocated funds from their operating and capital budgets, resulting in an immediate clean-up response and concomitantly reducing negative public perceptions relating to the state of the beaches. Other municipalities were less willing to compromise on budgets, hoping on Disaster Relief from National Government. Six months after the storm event, the beaches are still perceived to be in a less than satisfactory state, with rubble and damaged infrastructure very visible. This obviously affects occupancy and most other commerce in these tourist-dependent towns.

Louis Celliers and Andrew Mather

Incorporating other ICAM goals

When selecting management measures within an ICAM context, policy makers should also consider, not only the management of risk, but also the potential effects of those measures on critical coastal resources, public access, recreational assets, and other ICAM goals and values. The whole coastal management system at the defined scale needs to be taken into account in deciding on the mitigation approach. For example, policy makers might focus on a retreat strategy with some protection elements such as the development of a special zoning overlay district that establishes a setback for structures along a shoreline. Such an approach might also achieve the benefits of protecting riparian habitat, providing public lateral access and establishing a vegetated zone to protect and potentially improve coastal water quality. Alternatively, for a highly developed area, a protection response should include warnings and evacuation elements to manage residual risk. Further, if the protection degrades coastal ecosystems, habitat creation could also be considered in appropriate locations. The case study in Box 8.8 describes how Pacifica, California, decided to implement a managed retreat policy to address other ICAM issues, such as preserving public access and restoring fish habitat.

BOX 8.8 Hazard mitigation in an ICAM context: the case of Pacifica, California

Pacifica, California had long battled chronic coastal flooding and beach erosion. For decades, the city had employed structural stabilization techniques to armour Pacifica State Beach and channelize San Pedro Creek. Despite these earlier stabilization activities, the city still faced three ongoing impacts: flooding of homes and businesses; erosion at the state beach; and maintaining habitat for an important native fish species, the Steelhead Trout, in the creek.

In 1982, a major flood damaged more than 300 homes, destroying one home completely. Three of the remaining structures were now continually threatened by storm surge and erosion. Community members were concerned that additional shoreline hardening would only accelerate erosion at the state beach – a popular surfing location. The surfing community, led by Pacifica's mayor, favoured a shoreline restoration approach over a proposal to further harden and channelize the creek to reduce hazard-related risk. A state conservancy agency and other partners also preferred the restoration option because it offered additional benefits: improving fish habitat.

In the early 1990s Pacifica, the state conservation agency, and a local land trust worked together to develop a managed retreat strategy that combined relocation or removal of vulnerable structures to reduce flooding and erosion threats, with enhancement of natural protective features and beach nourishment. To begin implementing its strategy, the city partnered with several state agencies and the U.S. Army Corps of Engineers to expand and enhance the tidally influenced wetlands at the creek mouth and restore the eroding creek banks. This restoration enhanced the Steelhead Trout habitat and achieved 100-year flood protection for the community. The restoration approach also had an additional benefit for the community. It was significantly less expensive than other proposals for additional shoreline hardening and flood control measures.

With assistance from the local land trust and the state conservation agency, Pacifica was later able to make targeted buyouts and remove the two most vulnerable homes. They also restored the former home sites to a natural area by renourishing the beach and rebuilding the dunes. In the final phase of the managed retreat strategy, the city plans to relocate the one remaining threatened structure – a restaurant – to the other side of the coastal road.

Creative partnerships involving all levels of government and NGOs helped leverage the public support needed to implement a project that cost millions of dollars and took a decade to complete. Support of local government leaders, particularly the mayor, helped finance the up-front expenses for the project. Ultimately, the planned retreat strategy was made more politically viable because project partners had the capital necessary to purchase threatened structures outright.

Bill O'Beirne and Allison Castellan

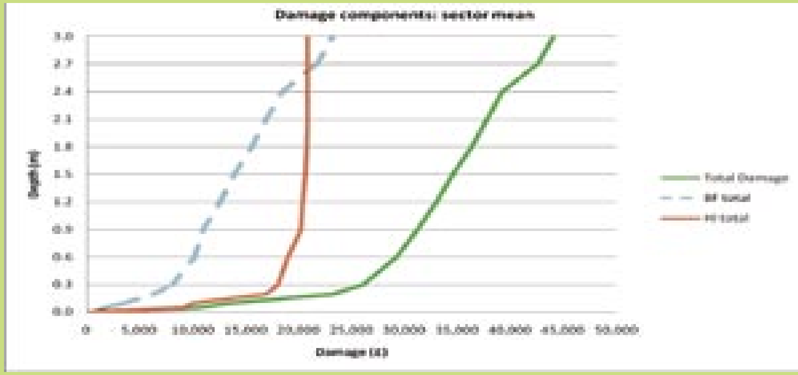
The application of decision-analysis tools

With so many variables to consider, policy makers can find it very challenging to decide which strategy and measures would be best. Decision-analysis tools can be very helpful in evaluating the various benefits and drawbacks of each option. Two examples of decision-analysis tools are benefit-cost analysis and multi-criteria analysis.

Benefit-cost analysis involves comparing the total cost of one or more strategies with the total benefits it would provide (Box 8.9). When the benefits outweigh the costs, the approach would be effective and have an overall benefit to the community. In order to perform a benefit-cost analysis, all costs and benefits must be translated into a common denominator – typically monetary. Ecosystem services must be included in the analysis, for instance, the monetary benefits of protection afforded by coral reefs and mangroves.

BOX 8.9 Benefit-Cost Analysis: the example of England and Wales, United Kingdom

Background: Benefit-Cost Analysis (BCA) is one decision method for assessing whether the costs of an intervention to reduce hazard-related risk, such as a flood defence scheme, are worth the benefits it brings by measuring both costs and benefits in the same (usually monetary) units. In England and Wales, the benefits of a flood alleviation scheme are assessed on an economic, rather than financial, basis so that those benefits represent real economic savings to the nation as a whole, and not financial savings to individual householders. BCA in flood risk management involves setting a "do nothing" baseline option (where there is no existing scheme) or a "walk away" baseline option (where there is an existing scheme). The effects of technically feasible flood alleviation schemes are then compared to the baseline scenario to ascertain the economic benefits of the proposed scheme. Those benefits, with respect to residential and commercial properties, are calculated using the standard national databases funded by the national government.



Damage components of residential sector mean, short duration (BF = building fabric, HI = household inventory)

Property damages: Property damage is estimated for residential and non-residential properties. As an example, the residential depth/damage data estimates potential damage using synthetic flood damage data based on secondary source data. Depth/damage figures are provided for 15 flood depths (ranging from -0.3 m to 3.0 m) and two flood durations (<12 hours and >12 hours). The most detailed standard data is provided for five house types, seven building periods, and for four different social classes of the dwellings' occupants. Where detailed information on the type and age of the properties or the social class of their occupants is not available, weighted averages are provided. The highest-level data available is the sector average for all residential properties; these data are intended for use at the strategic level of appraisal, where only the number of properties in the benefit area may be known. At the lowest level, the damage data are provided at the individual household level; these values may be applied in a full feasibility appraisal. At all levels, the damages are separated into building fabric and household inventory components. The figure below shows the damage components of the residential sector mean.

Benefits of BCA: The approaches outlined above provide a rational and objective method of assessing competing projects under the real situation of finite resources. In England and Wales, the application of BCA has focused flood and erosion investment towards the most beneficial projects from a societal perspective and has assured that government investment provides a real return. In more general terms, structure methods like BCA, or other related methods such as Cost-Efficiency Analysis or Multi-Criteria Analysis, provide processes where the selection of hazard mitigation measures is transparent and consistent.

Edmund Penning-Rowsell and Theresa Wilson

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 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 (Box 8.2).

Table 8.2 presents a general comparison of some of the diverse considerations for selecting measures.

The need for public involvement

Public opinion and wide stakeholder involvement are also valuable tools that should be included in the decision-making process as the risk management strategy is developed (Box 8.2). Public support and buy-in is important for the success of the strategy as it is for ICAM in general (Section 2). 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.

Summary of mitigation strategy

After following the process and weighing the considerations presented in this Section, policy makers should have a basic understanding to develop a risk management strategy that is appropriate for their community and supported by the public. Selecting mitigation responses is not easy and involves a careful analysis of the pros and cons of each measure. However, decision-support tools, such as those described above, together with public feedback can help deter-

Table 8.2. *Summary of socio-economic, environmental and institutional/political trade-offs of various hazard management approaches.* *A fuller discussion of these trade-offs is included at Annex 2.*

Management strategy	Trade-off		
	Socio-economic	**Environmental**	**Institutional/political**
Protection measures			
Closure gates, surge barriers/ storm gates	●●● magenta	●● magenta	● green
Dykes (levees)/ revetments/seawalls	●● magenta	●●● magenta	● green
Groynes	● magenta	●● magenta	● green
Artificial headlands	● yellow	●● magenta	● yellow
Cliff stabilisation measures	●● magenta	●● magenta	● green
Offshore breakwaters/reefs	● yellow ● magenta	● yellow	● yellow
Offshore tsunami breakwaters	● yellow	● yellow	● yellow
Beach nourishment	● yellow	● yellow	● yellow
Enhance natural protective features	● green	●●● green	● magenta
Accommodation measures			
Shelters, warning systems and evacuation routes	● yellow	● green	● yellow
Building codes	● green	● green	● yellow
Drainage regulations/policies	● green	●● green	● green
Zoning controls	● green	●● green	● magenta
Post-disaster redevelopment regulations	● green	● green	● magenta
Tax and insurance incentives/ disincentives	● green ● yellow	● green	● magenta
Retreat measures			
Building codes	● green ● yellow	● green	● yellow
Construction setbacks	● green ● yellow	●● green	● yellow
Transfer of development rights	●● magenta	● yellow	● magenta
Targeted buyouts/relocation assistance	●● magenta	●● green	● yellow
Zoning controls	● green	● green	● magenta
Tax and insurance incentives/ disincentives	● green ● yellow	● green	● magenta
Restricting capital improvements	●● green	● green	● yellow
Easements, rolling easements	● green ● yellow	● green	● green
Post-disaster reconstruction prohibition	● green	● green	● magenta

Socio-economic: ● magenta (high cost); ● yellow (moderate cost); ● green (low cost). If two different colours are used then costs are variable.
Environmental: ● magenta (significant negative environmental impacts); ● yellow (moderate negative environmental impacts, may be balanced with positive benefits); ● green (positive environmental impacts).
Institutional/political: ● magenta (significant institutional/political hurdles); ● yellow (moderate institutional/political hurdles); ● green (minimal institutional/political hurdles).
Note: Socio-economic and environmental impacts as well as institutional and political hurdles are very site- and project-specific. The information presented in this table is intended to be only a very rough guide to policy makers. When making specific decisions about which management approaches to use, careful consideration needs to be paid to site-specific conditions.

mine the approach and measures that would be most effective, given the community's hazard vulnerabilities and risks, as well as their values and resources.

Finally, coastal hazard management, as with any part of the ICAM process (see Section 2) 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 measures. Policy makers and coastal mangers should be prepared to adjust their hazard management strategy over time to make improvements where needed and to be responsive to other socio-economic, environmental, and political pressures and changes that may occur.

8.4 CHALLENGES AND OUTPUTS

Challenges

Key challenges to the strategic risk mitigation phase can include the following:

- overcoming short-term views and concerns to develop a longer-term perspective;
- avoiding over-focus on adaptation for single sectors rather than an ICAM approach which considers all coastal activities and their trade-offs;
- considering all the potential options when retreat is often seen in negative terms by coastal residents, at least initially;
- assessing full cost (direct and external such as socio-economic and environmental impacts, etc.) of the management options in order to select a suite of options that would have the maximum benefit for the minimum cost; and
- assigning management responsibilities and assuring adequate funding.

Outputs and results

Key outputs and results associated with this strategic risk mitigation may include:

- a portfolio of hazard mitigation measures which are consistent with ICAM objectives and, collectively, can manage coastal hazards; and
- a long-term plan for their implementation, including a monitoring programme to assess the effectiveness of the selected strategy.

8.5 DATA REQUIREMENTS AND INFORMATION SOURCES

General guidance

DEFRA. 2006. Shoreline Management Plan Guidance. Volume 1: Aims and requirements. Department of Environment, Farming and Rural Affairs (DEFRA), HMSO, London, 48 pages. Available at: http://www.defra.gov.uk/environ/fcd/guidance/smpgvol1.pdf

National Oceanic and Atmospheric Administration (NOAA). Shoreline Management Toolbox: Policy, Planning and Regulatory Tools. Available at: http://coastalmanagement.noaa.gov/initiatives/shoreline_ppr_overview.html

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Information sources relating specifically to the table at Annex 2 follow that table.

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Table 8.3 *Information sources for risk mitigation*

Products	Variables and standards	Sources	Global programmes and data sets
Risk mitigation strategy implemention	Selected management approach(es); assessment of full cost of management options; incorporation of other ICAM goals; long-term impacts of strategy.	The Management Plan from Phase II of the ICAM process; Benefit-cost analyses; inundation, vulnerability and risk maps; stakeholder/public participation; monitoring programme.	

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Titus, J. 1998. Rising seas, coastal erosion, and the takings clause: how to save wetlands and beaches without hurting property owners. *Maryland Law Review*, Vol. 57, pp. 1279–1399.

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ACRONYMS AND ABBREVIATIONS

BOM	Australian Bureau of Meteorology
CARIBE-EWS	Tsunami and Other Coastal Hazards Warning System for the Caribbean and Adjacent Regions
DART™	Deep Ocean Assessment and Reporting of Tsunami™
DLR	German Aerospace Center
EMWIN	Emergency Managers Weather Information Network
ENSO	El Niño-Southern Oscillation
EOC	Emergency Operations Centre
ET	Extra-tropical storm (or cyclone)
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EWS	Early Warning System
GDACS	Global Disaster Alert and Coordination System
GEONETCast	is a Task in the GEO Work Plan and is led by EUMETSAT, the United States, China and the WMO
GFZ	GFZ German Research Centre for Geosciences (Geo-Forschungs Zentrum), Potsdam
GHDB	Global Historical Tsunami Data Base
GIS	Geographical Information System
GITEWS	German-Indonesian Tsunami Early Warning System
GLOSS	Global Sea Level Observing System
GPS	Global Positioning System
GTS	Global Telecommunications System
HAT	Highest Astronomical tide
HWM	High Water Mark
SMS	Short Message Service
ICAM	Integrated Coastal Area Management
ICM	Integrated Coastal Management
ICMP	Integrated Coastal Master Plan
ICZM	Integrated Coastal Zone Management
IOC	Intergovernmental Oceanographic Commission
IOTWS	Indian Ocean Tsunami Warning and Mitigation System
IPCC	Intergovernmental Panel on Climate Change
ISDR	United Nations International Strategy for Disaster Relief
ITIC	International Tsunami Information Centre
JCOMM	Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology
JMA	Japanese Meteorological Agency
JRC	Joint Research Centre, European Commission
LIDAR	Light Detection and Ranging ground/seabed survey technique
MS	Member States (of the IOC)
MHW	Mean High Water
MSL	Mean Sea Level
NAO	North Atlantic Oscillation
NEAMTWS	Tsunami Early Warning and Mitigation System in the North Eastern Atlantic, Mediterranean and Connected Seas
NGDC	United States National Geophysical Data Center
NGO	Non-Governmental Organisation
NOAA	National Oceanic and Atmospheric Administration (United States Government)
NWC	National Warning Centre
PIC	Pacific Island Countries

PMEL	Pacific Marine Environmental Laboratory (NOAA)
PPEW	Platform for the Promotion of Early Warning
PSMSL	Permanent Service for Mean Sea level
PTWC	Pacific Tsunami Warning Center
PTWS	Pacific Tsunami Warning and Mitigation System
RANET	Radio and Internet for the Communication of Hydro
RTWS	Regional Tsunami Warning System
SME	Small and medium-sized enterprises
SOPs	Standard Operating Procedures
SWH	Significant wave height
TC	Tropical cyclone
TM	Trade Mark
TOWS	Tsunami and Other Marine Hazards Warning System
TTT	Tsunami travel time
RSMC	Regional Specialized Meteorological Centre
RTWS	Regional Tsunami Warning System
RWC	Regional Watch Centre
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
UN/ISDR	see ISDR
UNU-EHS	United Nations University, Institute for Environment and Human Security
U.S.A.	United States of America
VOS	Voluntary Observing Ship Scheme
WDC	World Data Center
WIS	WMO Information System
WMO	World Meteorological Organisation

GLOSSARY

Accommodation: The continued use of land at risk, without attempting to prevent land from being damaged by the natural event. This option includes erecting emergency flood shelters, elevating buildings on piles, converting agriculture to fish farming or growing flood/salt tolerant crops. (Bijlsma et al., 1996)

Adaptation: Adjustment in natural or human systems in response to actual or expected [climatic] stimuli or their effects, which moderates harm or exploits beneficial opportunities. (IPCC, 2001). See also definition of **Mitigation**, below.

Climate change: Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes. (IPCC, 2007)

Coping capacity: The means by which people or organizations use available resources and abilities to face adverse consequences that could lead to a coastal disaster. (UN/ISDR, 2004)

Creeping hazard: A hazard that impacts progressively over the long-term. (Bogardi, 2006)

Early warning: The provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to avoid or reduce their risk and prepare for an effective response. (UN/ISDR, 2004)

Ecosystem: A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth. (IPCC, 2007)

Emergency management: The organization and management of resources and responsibilities for dealing with all aspects of emergencies, in particularly preparedness, response and rehabilitation. (UN/ISDR, 2004)

Exposure: Elements at risk, an inventory of those people or artefacts that are exposed to a hazard. (UNDP-BCPR, 2004)

Hazard: A potentially damaging physical event or phenomenon that may cause loss of life or injury, property damage, social and economic disruption or environmental degradation. A hazard is characterized by its location, intensity, frequency and probability. (UN/ISDR, 2004)

Inundation: The state of flooding of coastal land resulting from the impact of a tsunami, storm surge or other coastal flood hazard. Quantitatively it is the horizontal distance attained by flooding, usually measured perpendicularly to the shoreline.

Inundation line: The line marking the maximum horizontal inland penetration of a tsunami, storm surge or other coastal flood hazard from the shoreline.

Joint probability: The likelihood of two or more hazard events impacting the same coastal area simultaneously.

Land use and land-use change: Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction and conservation). Land-use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. (IPCC, 2007)

Management unit: The geographical area under consideration for the purposes of risk assessment and mitigation. This may be national in scale, or at the district or local levels.

Mitigation: Structural and non-structural measures undertaken to limit the adverse impact of natural hazards. (UN/ISDR, 2004). See also Adaptation.

Non-structural measures: Policies, regulations and plans that promote good coastal hazard management practices to minimize coastal hazards risks

Preparedness: Activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations. (UN/ISDR, 2004)

Probability: The likelihood of a defined hazard event impacting a coastal area.

Protection: Involves the use of natural or artificial measures to protect landwards development and/or attempt to hold the shoreline in its existing position in an effort to reduce hazard impacts. (Bijlsma et al., 1996)

Public awareness: The processes of informing the general population, increasing levels of consciousness about risks and how people can act to reduce their exposure to hazards. This is particularly important for public officials in fulfilling their responsibilities to save lives and property in the event of a disaster.

Rapid-onset hazard: A hazard that impacts over a short time-scale (minutes-hours), sometimes catastrophically. (see Bogardi, 2006)

Relative sea level: Sea level measured by a tide gauge with respect to the land upon which it is situated. Mean sea level is normally defined as the average relative sea level over a period, such as a month or a year, long enough to average out transients such as waves and tides. (IPCC, 2007)

Resilience: The capacity of a system, community or society potentially exposed to hazards to adapt by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures. (UN/ISDR, 2004)

Retreat: Abandonment of coastal area and the landward shift of ecosystems. This choice can be motivated by the nature of assets to be protected. (Bijlsma et al., 1996)

Return period: The average time between occurrences of a defined event. (IPCC, 2007)

Risk: The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between hazards and vulnerable conditions. (UN/ISDR, 2004)

Risk assessment: A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, property, livelihoods and the environment on which they depend. (UN/ISDR, 2004)

Run-up: The difference between the elevation of maximum tsunami penetration (inundation line) and the sea level at the time of the tsunami.

Scenario: A plausible and often simplified description of how the future might develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline. (IPCC, 2007)

Sea-level change: Sea level can change, both globally and locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass of water and (iii) changes in water density. (IPCC, 2007)

Sediment cell: In the context of a strategic approach to coastal management, a length of coastline in which interruptions to the movement of sand or shingle along the beaches or nearshore seabed do not significantly affect beaches in the adjacent lengths of coastline. (Simm et al., 1996)

Significant wave height: The average height of the one-third highest waves of a given wave group. Also called the "characteristic wave height" (Intergovernmental Oceanographic Commission. 2008)

Storm surge: The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. (IPCC, 2007)

Structural measures: Structural measures refer to any physical construction to reduce or avoid possible impacts of hazards, which include engineering measures and construction of hazard-resistant and protective structures and infrastructure. (UN/ISDR, 2004)

Susceptibility: The predisposition to be affected by physical or socioeconomic change, including damage or loss. In these guidelines, "susceptibility" is taken to be broadly synonymous with "vulnerability".

Thermal expansion: In connection with sea level, this refers to the increase in volume (and decrease in density) which results from warming water. A warming of the ocean leads to an expansion of the ocean volume and hence an increase in sea level. (IPCC, 2007)

Tide gauge: A device at a coastal location (and some deep-sea locations) that continuously measures the level of the sea with respect to the adjacent land. Time averaging of the sea level so recorded gives the observed secular changes of the relative sea level. (IPCC, 2007)

Uncertainty: An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. (IPCC, 2007)

Vulnerability: The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. (UN/ISDR, 2004)

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ANNEXES
Annex 1

Table: Descriptions, including effectiveness, of the selected strategic risk management measures listed in Table 8.2, including links to more detailed information (see Section 8.2)

Management strategies	Descriptions and effectiveness of measures	Experience (years)
Protection measures		
Closure gates, surge barriers/ storm gates	Moveable or fixed barriers or gates which are always closed when an extreme water level is forecast to prevent flooding (e.g., the fixed 32 km-long Afsluitdijk which separates the Ijsselmeer from the Wadden Sea in the Netherlands since 1932, or the moveable Thames Barrier completed in the 1980s). For fixed barriers, water is discharged through or pumped over the barrier.	75
Dykes (levees)/ revetment/seawall	Artificial walls (vertical or sloping) used to protect the land or structures behind from the effects of extreme water levels and/or waves. In the past, these have been the most widely used option for coastal and flood defence. High wave reflection can lead to scour at base, which can undermine its structural stability. Often need to place riprap at toe to avoid scour at base, or combine with other beach enhancing measures. In extensive coastal lowlands landward of the defences (e.g., the Netherlands), water management will be critical to avoid flooding from run-off, precipitation and high water tables.	100+
Groynes	Structures placed perpendicular to the shoreline to intercept and trap longshore sediment transport and locally widen the beach and/or control coastal erosion. Often many groynes are placed at regular intervals along the coast. Comparatively easy to construct and their effectiveness may be increased by initially adopting artificial nourishment as required to reduce exporting the erosion to adjacent coasts.	100+
Artificial headlands	Rock structures which protect strategic points or lengths of an eroding coast. The intervening stretches continue to erode, progressively (over many decades or longer) forming an indented coast, and between two headlands, an artificial bay. Temporary headlands can be built with gabions or sand bags, but life expectancy is short (typically 1–5 years). Artificial headlands and the shoreline response remain a research and development topic.	40 (inadvertently 100+)
Cliff stabilisation measures	Even if the base of a cliff is stabilised, the cliff above may continue to degrade if it is too steep, which is the normal case. Hence a range of geotechnical measures can be used to stabilise the cliff, including lowering water tables, grading slopes, vegetation. At the most simple, the measures 'Drainage regulations/policies' under Accommodation below would be used.	100+
Offshore breakwaters/ reefs	Fixed, floating or shallow submerged structures generally built parallel to and at a short distance from the shore. They dissipate, refract and diffract wave energy and change both the longshore and onshore/offshore sediment transport, resulting in sand accumulation landward of the breakwater. In general offshore breakwaters promote the development of wider (more protective) beaches. Can be combined with beach nourishment to reduce "exporting" the erosion to adjacent coasts.	50
Offshore tsunami breakwaters	Fixed, floating or shallow submerged structures designed to cause tsunamis to break and dissipate and reduce their energy and run-up.	??
Beach nourishment	Addition of beach material (usually sand) to widen an eroding coast. Raises the beach to a pre-storm or desired profile. Sometimes uses controlling structures (e.g., groynes, breakwaters, etc). Regular renourishment is required to maintain the desired profile and regular monitoring is required, especially after storms. Sand sources for nourishment should be carefully selected to match existing grain size and composition. The new beach usually provides multiple benefits (e.g., recreational and access services.)	50+

Management strategies	Descriptions and effectiveness of measures	Experience (years)
Enhance natural protective features	Protection and restoration of existing dune systems, coastal wetlands, offshore sand banks, coral reefs, and riparian vegetation, or others natural features. These natural systems provide protection from hazards by dissipating wave energy, storm surge and flood waters. Typically most effective in low-energy environments. In high energy regimes, may need to be coupled with other protection measures to maximize effectiveness.	50
Accommodation measures		
Shelters, warning systems and evacuation routes	Building elevated structures or refuges, providing effective warning systems and establishing evacuation routes can help notify and protect coastal populations from impending coastal hazards.	50
Building codes	Require that buildings in hazard areas are flood and wind proof, and designed to minimizing impacts to other structures if damaged. Commonly involves elevating buildings above most flood and wave impacts as well as other measures. Can be combined with building codes for retreat (see below).	40+
Drainage regulations/ policies	Regulations or policies for buildings and irrigation on top of soft eroding cliffs and bluffs which minimise raising water tables and hence lowering the risk of cliff slope failure. Most effective on cliffs/bluffs with slow marine erosion at toe.	40
Zoning controls	Adoption of zoning or other land use ordinances to limit or restrict the type, density, size, location and construction or redevelopment of structures within identified hazard areas. This can promote accommodation and/or retreat policies and will often be linked to other measures such as building codes. Can be applied regionally or at the littoral cell scale to promote strategic responses, including targeting the most vulnerable areas. Existing buildings are normally 'grandfathered' into the scheme.	40
Post-disaster redevelopment regulations	Defines minimum standards for repair or reconstruction of structures damaged by marine-related hazards that reduce the vulnerability or exposure to these hazards in the future. Includes requirements to elevate and/or flood proof buildings, etc, linking to building codes above. Encourages action for those buildings which are demonstrably vulnerable.	40
Tax and insurance incentives/ disincentives	Can be used to encourage more appropriate or environmentally sound hazard management practices. For example, a lower tax rate or reduced insurance premium can be applied to parcels within a hazard area to reward landowners for implementing approved mitigation measures such as retrofitting structures above what is required by law. Tax breaks can also be given to property owners for donating their land for conservation purposes or for adding a conservation easement to their property to limit development, or establish building setback. Alternatively, mitigation may be accelerated by removing tax credits which act as incentives for unwanted behaviour—for example eliminating tax write-offs for capital losses due to natural hazards for new structures or major additions to existing structures in designated high-hazard areas. Similarly, insurance rates can be adjusted to better reflect the real hazard-related risks and thus potentially discourage development in more hazardous areas. (Favourable tax incentives/disincentives can similarly promote Accommodation. For example, a lower tax rate can be applied to parcels within a hazard area to reward landowners for implementing building codes above what is required by law.)	40

Management strategies	Descriptions and effectiveness of measures	Experience (years)
Retreat measures		
Building codes	To promote buildings designed to be movable. Can be combined with building codes for accommodation (see above).	40+
Construction setbacks	Defined hazard zones where new development or redevelopment is prohibited within a certain distance of the shoreline. In areas subject to shoreline retreat, any setback has a definable 'life' usually related to the design life of the property. The setback distance from a baseline feature (e.g. dune crest, line of vegetation, MHW) can be fixed or variable dependent on the rates of erosion or encroachment of water levels, the timescale for which the setback is designed and the size or type of structures that are to be built. While fixed distance setbacks are easier to implement, they may provide a buffer zone that is too narrow or too wide, depending on the erosion rate. Variable distance setbacks based on the annual erosion rate are more effective but are more difficult to administer due to additional data needs for calculating and regularly updating erosion rates and baselines. In the USA setbacks are often 30 or 50 times the average annual erosion rate, while in Australia they larger, often being 100 times the annual erosion rate with an additional allowance for climate change.	40
Transfer of development rights	A voluntary, market-based mechanism which allows specific development rights to the land within a high-risk hazard area (also referred to as a "sending" area) to be transferred to other less hazardous land (within a "receiving" area). As a result, development within the sending area is restricted while development that exceeds the zoning limits within the receiving area is allowed. This directs development away from high-risk hazard zones. Most effective where the shoreline is relatively undeveloped, and where a viable receiving area is available.	40
Targeted buyouts/ relocation assistance	Acquisition of fee simple interests in land to conserve natural features and prevent development of identified hazard area or providing financial assistance to help relocate structures away from high hazards areas. Targeted buyouts could be for already developed land where the structure is later removed, or for undeveloped land to present development in high risk areas.	40
Zoning controls	As above under "Accommodation", but with a focus on avoiding development.	40
Tax and insurance incentives/ disincentives	As above under "Accommodation", but with a focus on encouraging planned retreat, such as tax breaks for placing conservation easements on land or donating property for conservation purposes.	40
Restricting capital improvements	Prohibits or restricts capital improvements such as road enhancements, sewer, water or electricity expansion into high hazards areas.	40
Easements, rolling easements	Public acquisition of less than fee simple interests in land though a voluntary (or mandatory) legal agreement between a landowner and a land trust or government agency. The "hazards easement" restricts development in some manner in an identified hazard-prone area while leaving the property in private ownership. Rolling easements are a special type of easement placed along the shoreline to prevent property owners from holding back the sea but allow any other type of use and activity on the land. As the sea advances, the public easement automatically moves or "rolls" landward.	10
Post-disaster reconstruction prohibition	Prohibits reconstruction or repair of structures that have been significantly damaged (typically > 50%) during a hazard event. Instead, structures must be demolished within a certain time period.	40

Annex 2

Table: Illustrative descriptions of major economic, environmental and political trade-offs for selected strategic management measures (see Section 8.3 and Table 8.2). A listing of information sources follows.

MANAGEMENT STRATEGIES	TRADE OFFS		
	Socio-economic	**Environmental**	**Institutional/political**
Protection measures			
Closure gates, surge barriers/ storm gates	• The most costly intervention in hazard mitigation – the MOSES barriers in Venice are costed at €3 billion, while upgrade of the Thames Barrier has been crudely costed in billions of pounds Sterling. • But in wealthy locations like London, it can be the most effective solution • Barriers and gates are usually designed to allow continued navigation.	• Closure has major environmental consequences on estuary hydrography and salinity; • Moveable gates limit these impacts	• Always requires considerable engineering studies to design and install well. • In addition to the hardware, effective forecast and warning systems are required which requires significant institutional capacity.
Dykes (levees)/revetments/ seawalls	• Costs can be significant. Costs can vary greatly from an individual small seawall (€270/lin metre) to a large seawall to protect a road at costs up to (€11,200/lin metre). • In high-energy areas, requires additional riprap (€135-180/lin metre) to protect toe of structures. • Prevents beach from migrating inland so loose beach and beach-dependent tourism revenues as sea level rises and beach forward of structure continues to erode. • Significant shoreline hardening can be aesthetically unpleasing, especially for a tourism-dependent economy that values natural shorelines.	• environmental consequences of such shoreline hardening methods.	• Often requires considerable engineering studies to design and install well. • In some areas, beginning to see desire to move away from shoreline hardening due to environmental impacts.
Groynes	• Groynes are moderately expensive (roughly € 4,500/lin m) to install and require additional maintenance. • Can impair public access along the shore or interfere with near-shore navigation by small watercraft.	• Interrupts natural sand movement, causing local scour along the groyne and increasing downdrift erosion.	• A mature technology that is well understood, but engineering studies are required before implementation.
Artificial headlands	• Significantly cheaper than protecting an entire frontage, but experience suggests that costs are ongoing as the headland will require substantial maintenance and extension as the headland and the neighbouring coasts evolve.	• May add new hard rock environments in otherwise soft areas.	• Technology still poorly understood, especially long-term performance under sea-level rise. • Requires considerable engineering studies to design and install.
Cliff stabilization measures	• Usually highly costly, and the benefits are usually fairly localised. • Costs often rise compared to first estimates due to 'geological complexity'.	• Degrades the natural cliff environment, but this would happen due to the associated seawalls anyway.	• Requires careful engineering design and implementation.

MANAGEMENT STRATEGIES	TRADE OFFS		
	Socio-economic	**Environmental**	**Institutional/political**
Offshore breakwaters/reefs	• Can be fairly large structures that are expensive and difficult to construct in near shore waters.	• Can cause down drift erosion • Can displace/degrade near shore habitat where installed but can also create new artificial reef habitat.	• May require considerable engineering studies to design and install well.
Offshore tsunami breakwaters	• Expensive structures able to withstand extreme wave interaction and usually loacted off shore at strategic places such as offshore of river mouths or heavily populated cities.	• May lead to changes in nearshore circulation, currents and coastal processes the impacts of which have to be investigated by modelling.	• Should be carefully designed and where possible integrated with existing development works such as coast protection and harbour works.
Beach nourishment	• Initial costs can be costly (roughly €3- €4/m^3 of sand or €675 to €4,000 /lin m in US) and requires regular sand renourishment (sometimes every 5-10 years or less depending on storm events). However, compared to hard structures, costs are spread more in time. • Flexible approach as beaches adjust naturally to changing conditions. • Losses of sand along the coast and benefit neighbouring beaches. • Costs will likely rise as near shore sand sources disappear. Equally, may not be a practical or economical option for many island nations because sand often is a scarce resource (However, trade in sand is possible – such as existing trade from Guyana to the eastern Caribbean). • Renourished beaches provide recreational amenities that can boost tourism.	• Preserves beach habitat. • Dredging bottom sediments to place on beach can disrupt fish, shellfish, and benthic populations from borrow site and increase sedimentation in water column, impacting nearby coral reefs, etc. • Placing fill on beach can disrupt beach and benthic habitats (bird and sea turtle nesting, etc.), especially if sand grain size/composition doesn't match existing beach.	• Will require considerable engineering studies to design and install. • Determining who should pay for renourishment can be contentious depending on who is the perceived beneficiary (individual property owners, tourist hotels, or the general public). • Regular monitoring is essential.

MANAGEMENT STRATEGIES	TRADE OFFS		
	Socio-economic	**Environmental**	**Institutional/political**
Enhance natural protective features	• Compared to hard stabilization structures, can be a relatively low cost for providing effective mitigation of hazards. Restoration more costly then preserving existing features and can range from moderately expensive (€225/lin metre) for low energy systems to expensive (€2,250/lin metre) for high-energy systems. • Expertise for design and construction of effective restoration projects may be moderately expensive. • May result in lost development revenue due to preservation of natural areas along the shore. • May be difficult to find sources of adequate sediments for restoration • Can enhance tourism and recreational economies. • Aesthetically more appealing than hard stabilization structures.	• Provides enhanced environmental benefits (e.g. habitat preservation/ creation, water quality improvements). • Restoration projects involving fill may disrupt fish, shellfish and benthic populations.	• Regulatory programs in place to ensure preservation of critical natural areas can be administratively costly to implement/enforce. • May need above average expertise in reviewing and permitting restoration projects for hazard mitigation. • Vegetative plantings coupled with low rock sills or small groynes, often termed "living shorelines", are a relatively new technology so may be difficult to find skilled contractor.
Accommodation measures			
Shelters, warning systems and evacuation routes	• Relatively low cost and effective approach to mitigate hazards as demonstrated in diverse countries such as USA and Bangladesh. • Shelters can be built individually, but other aspects of these systems require more collective action.	• Often reduces the need for shoreline stabilisation	• Requires the development and implementation and coordination of quite diverse technologies to be most effective, • Forecast and warning systems need to be centralised and supported by government • Detailed responses to hazardous events can be delegated to more local levels.
Building codes	• More stringent building codes may increase new housing costs but most studies show increase not more than 5%. Effect of more stringent codes on property values less well known. • Retrofitting existing structures to raise them above base flood levels and wave heights can be expensive for homeowners.	• Elevating structures may allow natural features to migrate landward under houses.	• May be politically difficult to adopt due to concerns regarding additional construction costs, and fears that new development will move to other jurisdictions with more lenient codes. • Most easily implemented for new build.
Drainage regulations/policies	• Usually lower cost than cliff stabilisation.	• Minimal effects	• As it slows, but does not prevent erosion, need to expect continuing losses of property.

MANAGEMENT STRATEGIES	TRADE OFFS		
	Socio-economic	**Environmental**	**Institutional/political**
Zoning controls	• When development restricted in high hazard areas, may result in loss of economic development opportunities and or tax revenue for the community.	• Avoids the need for shoreline stabilization structures, thus help maintain natural shoreline dynamics in environmentally sensitive areas.	• Depending on the type of zoning, may be resource intensive to administer. • May need to have authorization and mechanism for local government to establish overlay districts. • Requires good scientific data to identify high-risk hazard areas and environmentally sensitive areas to determine zoning districts or overlay areas which may be difficult and/or costly to obtain. • May be a more politically acceptable strategy compared to measures that prevent all development, however land use controls may still be unpopular as a taking of private property if they limit the type or amount of development allowed in specific areas. • Local governments may be opposed due to the perceived loss of development potential/tax revenue.
Post-disaster reconstruction requirements	• Reduces cost of damages from next storm by requiring repaired/rebuilt structures to meet stronger building codes, so it exploits the post-event renewal cycle effectively.	• Can allow natural shoreline features to migrate inland naturally.	• Easier to administer than a retreat policy by post-disaster reconstruction prohibition (see below), as people are allowed to use their property. • Codes need to be in place before damaging events.

MANAGEMENT STRATEGIES	TRADE OFFS		
	Socio-economic	Environmental	Institutional/political
Tax and insurance incentives/disincentives	• More accurately reflects cost of developing in high-risk erosion areas. • Tax incentives may decrease local government's tax revenues.	• Can promote adoption of other hazard mitigation measures that protect/preserve natural areas along the coast.	• Need good scientific data to determine where the greatest erosion risks are located which may be difficult to obtain. • Can be difficult to enforce and ensure the property owner is still implementing/maintaining the practice to receive insurance/tax break. • Local governments may not support loss of tax revenue through tax incentive programs.
Retreat measures			
Building codes	• Building codes may that promote buildings that are easily relocated.	• Relocation of buildings allows natural processes to occur.	See "Accommodation" above.
Construction setbacks	• Help maintain lateral beach/shorefront access and recreational opportunities, maintaining coastal tourism economies. • May reduce or enhance property values.	• Setbacks often provide protection of natural features (beaches and dunes), which also provide habitat and recreational values/ services. • Can increase water quality benefits by removing development and associated pollution from water's edge.	• May be politically and legally difficult to implement because will restrict or prohibit some development, and may be viewed as a «taking» if the setback causes property to be unbuildable, or significantly restricts the size of the building. • Require good scientific data to assess erosion rates and maintain/ update baselines.
Transfer of development rights	• Administration, data analysis costs may be prohibitively expensive.	• Helps limit development in high risk areas, reduce development impacts on coastal ecosystems within these areas. • Concentrates development in receiving areas, increasing environmental impacts from development within these areas.	• Historically has been particularly difficult to put into practice. • Is a complicated program to develop, requiring technical and legal expertise to collect and analyse data to determine an acceptable development quota for sending and receiving areas and to establish a trading system..

MANAGEMENT STRATEGIES	TRADE OFFS		
	Socio-economic	**Environmental**	**Institutional/political**
Targeted buyouts/relocation assistance	• Can be more cost-effective over the long run compared to hard shoreline stabilization projects that have to be maintained and only prolong a structure's life, not protect it permanently. • Due to high price of coastal property, can be very costly to implement, especially for large or multi-story structures and densely developed shorefronts where many structures would need to be moved. • In highly developed areas it may be difficult to find undeveloped lot to place the relocated structure.	• Maintains natural shoreline processes and thus protects and maintains coastal ecosystems. • Avoids the need for hard shoreline stabilization which can have additional negative environmental impacts (see Protection measures above).	• Due to high costs, can be difficult to develop political support for these types of programs. • Acquisition of selected properties can offset "takings" claims on private property when other retreat policies implemented.
Zoning controls	See "Accommodation" above.	See "Accommodation" above.	See "Accommodation" above.
Tax and insurance incentives/disincentives	See "Accommodation" above.	See "Accommodation" above.	See "Accommodation" above.
Restricting capital improvements	• Can save jurisdictions considerable costs for construction, maintenance and repair of large-scale infrastructure in high-risk areas. • Could potentially reduce economic activity in targeted areas,	• By reducing or prohibiting increase in capital improvements, coastal development densities will typically be lower, decreasing development impacts on the coastal environment.	• May be politically unpopular with municipal governments, development community and some individual landowners. • May run into some legal issues regarding equitable provision of services. • Sends out a clear message to building owners on the nature of the hazards faced.

MANAGEMENT STRATEGIES	TRADE OFFS		
	Socio-economic	**Environmental**	**Institutional/political**
Easements, rolling easements	• Generally less costly than outright land acquisition/buy-outs, or structural stabilization approaches although given the cost of many coastal properties, even easement costs can be substantial. • Can be donated or sold. Incentive programs, such as lower property taxes, can be used to encourage landowners to place easements on high-risk properties. • The restrictions included in the easement may decrease the resale value of the property.	• Depending on the language in the easement, can provide significant protection to coastal habitat. • The prohibition on protection allows ecosystems to migrate inland.	• Voluntary nature of easements may make them more appealing than other more regulatory approaches. • May need to be combined with a strong education and outreach campaign to make sure property owners are aware of erosion control easements and understand their benefits to increase the effectiveness. • Rolling easements may be politically more acceptable because they do not place restrictions on development. • Do not require as much scientific data as some other hazards management approaches. • Rolling easements have not been widely used. Not clear how well they would stand up to legal challenge and easements may be difficult to enforce.
Post-disaster reconstruction prohibition	• Reduces cost of damages from next storm by not allowing buildings to be rebuilt in high hazard areas if they are damaged.	• Can allow natural shoreline features to migrate inland naturally.	• Sympathy for the victims of hazards, desire to rebuild in the face of disaster, and anti-regulatory concerns may make these politically difficult to pass. • Procedures to determine when no-build restrictions kick in (e.g., building damaged > 50%) may be cumbersome and difficult to administer properly, especially when pressured to allow affected property owners to rebuild quickly. • Loss of development potential could trigger legal issues (takings).

INFORMATION SOURCES FOR ANNEX 2

Overview of Protection, Accommodation, Retreat strategies

Shoreline Management Planning

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Groynes

CIRIA. 1990. Guide on the uses of groynes in Coastal Engineering. Report 119, ISBN 0-86017-313-5

Artificial headlands

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No.	Title
1 rev. 2	Guide to IGOSS Data Archives and Exchange (BATHY and TESAC). 1993. 27 pp. (English, French, Spanish, Russian)
2	International Catalogue of Ocean Data Station. 1976. (Out of stock)
3 rev. 3	Guide to Operational Procedures for the Collection and Exchange of JCOMM Oceanographic Data. Third Revised Edition, 1999. 38 pp. (English, French, Spanish, Russian)
4	Guide to Oceanographic and Marine Meteorological Instruments and Observing Practices. 1975. 54 pp. (English)
5 rev. 2	Guide for Establishing a National Oceanographic Data Centre. Second Revised Edition, 2008. 27 pp. (English) (Electronic only)
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7	Guide to Operational Procedures for the IGOSS Pilot Project on Marine Pollution (Petroleum) Monitoring. 1976. 50 pp. (French, Spanish)
8	(Superseded by IOC Manuals and Guides No. 16)
9 rev.	Manual on International Oceanographic Data Exchange. (Fifth Edition). 1991. 82 pp. (French, Spanish, Russian)
9 Annex I	(Superseded by IOC Manuals and Guides No. 17)
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11	The Determination of Petroleum Hydrocarbons in Sediments. 1982. 38 pp. (French, Spanish, Russian)
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16	Marine Environmental Data Information Referral Catalogue. Third Edition. 1993. 157 pp. (Composite English/French/Spanish/Russian)
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18	User Guide for the Exchange of Measured Wave Data. 1987. 81 pp. (English, French, Spanish, Russian)
19	Guide to IGOSS Specialized Oceanographic Centres (SOCs). 1988. 17 pp. (English, French, Spanish, Russian)
20	Guide to Drifting Data Buoys. 1988. 71 pp. (English, French, Spanish, Russian)
21	(Superseded by IOC Manuals and Guides No. 25)
22	GTSPP Real-time Quality Control Manual. 1990. 122 pp. (English)
23	Marine Information Centre Development: An Introductory Manual. 1991. 32 pp. (English, French, Spanish, Russian)
24	Guide to Satellite Remote Sensing of the Marine Environment. 1992. 178 pp. (English)
25	Standard and Reference Materials for Marine Science. Revised Edition. 1993. 577 pp. (English)

No.	Title
26	Manual of Quality Control Procedures for Validation of Oceanographic Data. 1993. 436 pp. (English)
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