UNESCO-IOC WORKSHOP ON TSUNAMI RISK ASSESSMENT
FOR THE INDIAN OCEAN
Dubai, UAE, 4-6 October 2007

FINAL REPORT

1. SUMMARY

The purpose of the workshop was to form the basis for the development of tsunami risk assessment guidelines for use by Indian Ocean countries as input to tsunami warning and mitigation activities. The workshop agenda is in Annex I. Workshop presentations were made by specialists and practitioners from Indian Ocean countries (Australia, Indonesia, Sri Lanka, Thailand, India, Oman, United Arab Emirates, Kenya, Mozambique and South Africa) as well as selected international experts from outside the region (Japan, US, Germany, Denmark). Specialists included geologists, geophysicists, coastal and structural engineers, and social scientists.

The first part of the workshop was devoted to presentations by tsunami risk assessment experts on: 1) tsunami sources, with a focus on large earthquakes from subduction zone earthquakes in the Indian Ocean; 2) tsunami wave propagation and inundation, focusing on numerical modelling issues; 3) estimation of physical, social and economic vulnerability of communities; and 4) counter measures and mitigation options for reducing the impacts of tsunamis.

The second part of the workshop provided an opportunity for countries to present risk assessment case studies which covered a wide range of approaches from scenario impact studies of individual communities to post-disaster studies from the 2004 tsunami. Presentations were made by Australia, Sri Lanka, Indonesia, South Africa, Kenya, Japan, and Iran. These studies illustrated the range of approaches and issues that are being addressed across the region.

The final portion was devoted to developing an outline for the risk assessment guidelines and identifying key issues that must be addressed. Break-out groups were organised for each of the four elements of risk assessment discussed on the first day. Participants identified the required data and methods of analysis, and major sources of uncertainty and gaps in knowledge. They also considered the attributes of different approaches for first-order reconnaissance studies or simplified scenario analyses, versus the development of a more comprehensive probabilistic analysis that might be required to form the basis for land-use planning or to justify costly mitigation activities.

2. OUTCOMES:

- A document providing guidelines for tsunami risk assessment methodology will be developed over the next year, with a first draft due prior to the ICG/IOTWS-V meeting in Malaysia in April 2008. John Schneider (Vice Chair of WG3) will coordinate development of the document with each of the 4 sub-group leaders, also with input from WG 4 (Tsunami Modelling) and WG 6 (Response and Mitigation).
UNDP (UN Development Program) sees the development of these guidelines potentially forming the basis for a consensus approach to multi-hazard risk assessment internationally, especially for application to developing countries. UNDP has indicated an interest in contributing resources for this work.

The workshop identified approaches for improving the design and performance of end-to-end warning systems using risk assessment and system analysis methods. Issues include identifying bottlenecks in issuing warnings, developing communications networks and strategies for delivering messages, and developing optimal evacuation routes.

With this workshop, the working group now has the breadth of expertise across hazard and risk issues, as well as good representation from Indian Ocean countries for case-study applications and knowledge sharing.

Key gaps requiring more research were identified especially in palaeotsunamis and in estimating tsunami vulnerability (physical, socio-economic, and environmental). A sector-based approach to vulnerability was proposed and supported by the participants. Lack of shallow bathymetry and coastal elevation data is also a clear gap throughout the region.

WAPMERR has offered to provide some support for a risk and tsunami modelling workshop sometime toward the end of 2008. They have also indicated their willingness to contribute detailed imagery and exposure data for use in assessing the impacts of natural hazards in urban areas throughout the world.

3. SUMMARY OF PRESENTATIONS

3.1 Welcome Address
The welcome address was given by Mr Adel Karas, World Agency of Planetary Monitoring and Earthquake Risk Reduction (WAPMERR), sponsors of the workshop. He thanked the participants for coming to Dubai to attend the workshop, and also thanked the workshop organisers.

3.2 Introduction to the ICG/IOTWS
Mr Tony Elliott, Head of the ICG/IOTWS Secretariat, presented an overview of the origins and role of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS). He described the ICG/IOTWS and how it functions, and provided an overview of the roles of the six technical working groups.

3.3 Introduction to the activities of WG3 and linkages to other Working Groups
Dr. Sam Hettiarachchi, Chair of ICG/IOTWS Working Group 3, gave an introduction to the current activities of the working group. He also spoke about linkages with the other working groups and the need to work more closely with Working Group 4 (Modelling, Forecasting and Scenario Development) and Working Group 6 (Mitigation, Preparedness and Response).

3.4 Expected outcomes from the workshop
Mr Sanny Jegillos from UNDP confirmed the UNDP’s involvement in Risk Assessment and the ICG/IOTWS Working Group 3. The key issues for UNDP are: understanding disaster risk, reducing the effect of poverty, and reducing disaster risk. A coherent risk assessment approach is essential in reducing disaster risk, and UNDP is very interested in continuing to work with WG3.

Dr Sam Hettiarachchi, Chair of ICG/IOTWS Working Group 3, provided an outline of the expected outcomes from the workshop. The workshop builds on work already achieved at the previous workshop in Bandung in July 2007. The key outcome will be an agreed outline for the methodology and guidelines for tsunami risk assessment.
4. **RISK ASSESSMENT**

4.1 **Risk Assessment-Overall Summary of Definitions, RA in the context of Disaster Risk Reduction, Hazard/Vulnerability/Risk Map**

Dr. John Schneider and Dr. Juan Carlos Villagran presented a summary of definitions and outlined the general concepts associated with risk assessment and vulnerability. Dr Schneider gave an overview of risk methodology used in Australian tsunami risk assessment studies including assessment of tsunami hazard, tsunami exposure and vulnerability, tsunami impact and risk, and mitigation options.

5. **TSUNAMI HAZARD**

5.1 **Presentation of the Outcome of the Tsunami Hazard Workshop held in July in Bandung**

Dr Brian Atwater presented the outcomes from the Tsunami Hazard Workshop held in July 2007 in Bandung, Indonesia, hosted by the Bandung Institute of Technology. The main recommendations from the workshop were as follows:

1) Balance the need for hazard mapping with the need for fundamental data
2) Assess Indian Ocean Tsunami Hazards – capture uncertainties, update regularly and work with emergency managers and planners to apply the results appropriately
3) Support assessments with geology, geodesy and written history

5.2 **Historical Tsunami Catalogue and Databases**

Dr. Slava Gusiakov presented the tsunami catalogue and database developed in conjunction with WAPMERR. The database is only really complete for the past 100 years due to a lack of data from all but the largest events prior. However, major events from the past 500 years have been captured using historical records in some places. Dr Gusiakov also presented an overview of the historical development of methods for measuring tsunami intensity.

5.3 **Probabilistic Tsunami Hazard Modelling**

Dr. Hong Kie Thio gave an introduction to Probabilistic Tsunami Hazard Analysis, and compared it with Scenario Modelling. He demonstrated that probabilistic tsunami hazard maps can be used to predict tsunami wave heights for a given return period, and how disaggregation can be used to show variation in source sensitivity between different target regions. Logic trees are used at the start of the process to build uncertainties into the model.

5.4 **Inundation Modelling**

Professor Philip Liu presented an overview of current research on tsunami dynamics and tsunami hazard mitigation, including deep water propagation and inundation. Tsunami modelling involves making several assumptions, including instantaneous sea floor displacement, and assuming that water is not compressed. Inundation modelling requires consideration of wave and flow characteristics including sediment-laden flows.

Following Professor Liu’s presentation, Mr Tony Elliott, Head of the ICG/IOTWS Secretariat, presented an overview of the aims and current activities of ICG/IOTWS Working Group 4 (Modelling, Forecasting and Scenario Development). He described the history of the working group, which was originally one group with WG3. He then discussed the regional goals and terms of reference for the group and how this fits with the work currently being conducted by WG3.
6. VULNERABILITY

6.1 Introduction to Vulnerability- Concepts of Dimensions of Sectors, Scale of Consideration and Susceptibilities-Human and Functional Vulnerability

Dr. Juan Carlos Villagran gave a presentation on the concept of vulnerability and how it can be applied to tsunami risk assessment. Vulnerability is hard to define, and there are over 40 definitions. Quantification requires solid statistical data, which is difficult for events like tsunami and volcanic eruptions because of lack of historical information and long return periods. Data suggests that death rates of women and children are higher so mitigation efforts must take this sort of thing into account.

6.2 Physical Vulnerability

6.2.1 Building and Infrastructure Presentation 1

Dr. Priyan Dias gave a presentation on measuring the effect of tsunamis on buildings and other infrastructure. He presented an overview of research conducted at various institutions around the world, and described how some of these methods have been applied in Sri Lanka. Vulnerability curves demonstrate that buildings constructed from permanent materials (bricks, concrete etc) withstand greater inundation depths. Such information is useful when considering the type of post-tsunami reconstruction in vulnerable areas.

6.2.2 Building and Infrastructure Presentation 2

Dr Ken Dale gave a presentation on case studies undertaken in Australia, showing how risk and vulnerability are being calculated for various built environments, including housing and other infrastructure. He also showed how an engineering damage model can provide input for a macroeconomic model to analyse long term economic impact of hazards such as tsunami.

7. COUNTERMEASURES AGAINST TSUNAMIS

7.1 Methods which Promote Successful Evacuation

7.1.1 Early Warning, Set Back, Hazard Maps, Evacuation Routes

Dr Juan Carlos Villagran presented a case study of evacuation plans developed for the city of Galle, Sri Lanka. Vulnerable groups were identified, and the evacuation plans for these groups were individually developed. Other measures included distribution of education material, posting of evacuation signs and maps, and coordination with the Disaster Management Center.

7.1.2 Planning and Mitigation of natural Disasters Through Network Modelling

Dr Ruwanpura presented a case study of a stochastic scheduling network for tsunami early warning in Sri Lanka, comparing alternative stages of the system. It can be used to assess different systems and the probabilities of each system distributing a warning within a certain time. The tool is especially useful in analysing bottlenecks in the system.

7.1.3 Applications of Remote Sensing

Dr Slava Gusiakov gave a presentation on the Parametric Data Manager for the Global Tsunami Database. He demonstrated how to access the historical tsunami data, and appealed to the workshop participants to send any additional information which could add to the database. He also demonstrated the built in modelling software which allows calculation of tsunami travel times.
7.2 Tsunami Impact Mitigation Methods

7.2.1 Artificial Methods
Dr. Shiego Takahashi, Director of the Tsunami Research Center, PARI Japan, gave a presentation on Structural Countermeasures in Japan. Dr Takahashi started his presentation with an overview of historical tsunami events in Japan. He then described some of the structural countermeasures including seawalls, tsunami gates, artificial high ground, tsunami breakwaters, and showed videos of scaled physical model experiments conducted in Japan.

7.2.2 Natural Methods
Dr. Subandono Diposaptono gave a presentation on natural barrier methods in Indonesia. Structural methods are not favoured for many reasons, including cost and the disruption caused to the marine ecosystem. Instead, Dr Subandono proposed that coastal forests could be used as ‘soft’ barriers for tsunami, with the additional benefits of improving the local environment. His research is based on studies of the mitigation effect of coastal forests, and numerical modelling of probable tsunami heights in each region.

8. NATIONAL APPROACHES AND CASE STUDIES ON RISK ASSESSMENT

8.1 Australian Experience
Dr John Schneider of Geoscience Australia presented some results of modelling using the ANUGA model, which is available for download at sourceforge.net/projects/ANUGA. He then presented a case study from Western Australia. Three ‘worst case’ scenario earthquakes on the Java-Sumatra subduction zone were modelled, and six communities were identified as being at risk. The studies were conducted with good communication between scientists and emergency managers to enable production of an emergency response plan.

8.2 Japanese Experience
Dr Shiego Takahashi from PARI, Japan, presented a case study of tsunami risk assessment for Kushimoto town in Japan. There is a very high probability (99%) of a large earthquake and tsunami event impacting on this area within the next 30 years. He described the various efforts for mitigation of tsunami disaster being undertaken by local government. Difficult evacuation areas are identified, and plans made for mitigation options.

8.3 Case Study - Sri Lanka
Dr. Sam Hettiarachchi from the University of Moratuwa in Sri Lanka presented an Assessment of Risk and Investigation of Countermeasures for Tsunami Hazard in a Case Study for the Port City of Galle. Extensive numerical modelling has been conducted, and information from these models has been used to introduce mitigation options. The greatest threat to Sri Lanka is from earthquakes in the northern section of the Sumatra subduction zone, with less threat from earthquakes to the south near Java. Evacuation maps are prepared with consultation from the local communities.

8.4 Case Study - Indonesia
Dr Eko Yulianto from the Indonesian Institute of Earth Scientists (LIPI) gave a presentation on the Joint Indonesian-German Working Group on Vulnerability Assessment and Risk Modelling. He showed some numerical modelling and palaeotsunami studies for South Java, as well as describing some community preparedness activities.

Dr Gunter Strunz from the German Aerospace Agency presented some results from the Joint Working Group on Vulnerability Analysis and Risk Modelling conducted in Indonesia. Broad-
scale risk assessments are being conducted for the whole Indian Ocean coast region in Indonesia, and three areas have been selected for a more detailed study. A decision tree process is being used as a conceptual framework for the risk assessment.

8.5 Case Study - Kenya
Mr John Tychsen from the Geological Survey of Denmark and Greenland presented a risk assessment case study for Kenya. Numerical models were developed to simulate the effects of the 2004 tsunami, calibrated against tide gauge measurements from the event and eye witness accounts. Topographic data was collected using aerial photographs and extensive ground checking, and matched with older bathymetry data. Several scenarios were presented, showing effects at high tide and low tide. Following the numerical modelling, a socio-economic assessment was conducted to determine the damage expected from various scenarios.

8.6 Case Study – Iran
Dr Mohammed Mokhtari, Director of the National Center for Earthquake Prediction, Iran, gave a presentation on the Makran subduction zone, its historical seismicity, and structure derived from seismic reflection data. Low seismicity in the western part of the subduction zone suggests that it may be segmented, which has implications for tsunami risk.

8.7 Case Study - South Africa
Prof. Andrzej Kijko from the Council for Geoscience in South Africa presented a tsunami frequency evaluation. South Africa has 23 seismic stations, five of which are dedicated to the tsunami warning project. There are plans to extend the tsunami warning project with another 8 stations soon to be established. Verbal information about past tsunami events is being collected from communities, in an attempt to quantify the historical tsunami frequency in South Africa. However, this information is often unreliable, so a statistical model is suggested to evaluate the probabilities.

8.8 Case Study – Numerical modelling
Dr Philip Liu presented a numerical model developed to show wave impacts on the lee side of a cylindrical island, with a larger than expected runup due to the waves wrapping around the island and colliding on the far side. He also showed some numerical modelling of landslides which attempts to characterise the resulting waves. Different rheologies are also being modelled. He then showed some numerical models for possible scenarios in the South China Sea, demonstrating the risk to Philippines, Taiwan, and China.

9. DEVELOPMENT OF GUIDELINES FOR STANDARDISED METHODOLOGY
The participants separated into four breakout groups to discuss different components of the Risk Assessment methodology. Group leaders were identified to be responsible for reporting outcomes of the discussions. The four breakout groups were:

Group A: Source regions (geology, seismology). Leader: Hong Kie Thio
Group B: Impact regions (engineers). Leader: Gunter Strunz
Group C: Vulnerability issues. Leader: Juan Carlos Villagran
Group D: Mitigation issues. Leader: Priyan Dias

The four groups were asked to address the following criteria for their area of expertise:

- Assess Data requirements/Gaps
- Techniques/Models/Attributes
• Accuracy/Uncertainty

The groups assembled in the meeting room following the breakout sessions, and presented the results of their discussions. Each group leader agreed to be responsible for preparing a draft outline summarising the group’s discussions. The draft outlines are available in Annex II.

10. CLOSING SESSION
The workshop was closed by Dr Sam Hettiarachchi, Chair of ICG/IOTWS Working Group 3. He thanked the sponsors for providing funding and logistical support for the meeting, and thanked all the participants for their input into the workshop, especially those who have agreed to contribute to the development of the draft guidelines for tsunami risk assessment methodology.
ANNEX I

UNESCO-IOC WORKSHOP ON RISK ASSESSMENT
Dubai, UAE, 4-6 October 2007

Agenda

DAY 1 (4th Thursday)

1.0 INTRODUCTION TO THE WORKSHOP
1.1 Welcome Address- (8.30-8.40)
Adel Karas, World Agency of Planetary Monitoring and Earthquake Risk Reduction (WAPMERR), sponsors of the workshop
1.2 Introduction to the ICG/IOTWS-(8.40-8.50)
Mr Tony Elliott, Head of ICG/IOTWS Secretariat
1.3 Introduction to the activities of WG3 and linkages to other Working Groups-(8.50-9.00)
Dr. Sam Hettiarachchi, Working Group 3, ICG/IOTWS
1.4 Expected outcomes from the workshop – (9.00-9.30)
Mr Sanny Jegillos, UNDP
Dr Sam Hettiarachchi, Chair of ICG/IOTWS Working Group 3

2.0 RISK ASSESSMENT
2.1 Risk Assessment-Overall Summary of Definitions, RA in the context of Disaster Risk Reduction, Hazard/Vulnerability/Risk Maps-(9.30- 10.10)
Dr. John Schneider and Dr. Juan Carlos Villagran de Leon

BREAK (10.40-11.10)

3.0 TSUNAMI HAZARD
3.1 Presentation of the Outcome of the Tsunami Hazard Workshop held in July in Bandung-(10.10-10.40)
Dr John Schneider, Geoscience Australia

LUNCH (1.00-200)

3.2 Historical Tsunami Catalog and Databases (11.10-11.40)
WAPMERR and Dr. Slava Gusiakov
3.3 Probabilistic Tsunami Hazard Modelling-(11.40-12.15)
Dr. Hong Kie Thio, URS, USA
3.4 Deterministic Tsunami Hazard Modelling-(12.15.-12.50)
Dr. Slava Gusiakov

LUNCH (1.00-200)

3.5 Inundation Modelling-(2.00-2.35)
Mr Tony Elliott, ICG/IOTWS Secretariat
Professor. Philip L-F. Liu, Cornell University, USA

4.0 VULNERABILITY
4.1 Introduction to Vulnerability-
Concepts of Dimensions of Sectors, Scale of Consideration and Susceptibilities-
Human and Functional Vulnerability (2.35-3.15)
Dr. Juan Carlos Villagran de Leon, UNU

BREAK (3.40-4.10)

4.2 Physical Vulnerability
4.2.1 Building and Infrastructure Presentation 1- (4.10-4.35)
Dr. Priyan Dias, University of Moratuwa
4.2.2 Building and Infrastructure Presentation 1- (4.35-5.00)
Dr. Ken Dale, Geoscience Australia

DISCUSSION (5.00-5.30)

DAY 2 (5th Friday)

5.0 COUNTERMEASURES AGAINST TSUNAMIS
5.1 Methods which Promote Successful Evacuation
5.1.1 Early Warning, Set Back, Hazard Maps, Evacuation Routes (8.30-9.00)
Dr. Juan Carlos Villagran de Leon, UNU
5.1.2 Stochastic scheduling Network for Tsunami Planning and Hazard Mitigation (9.00-9.30)
Dr. Janaka Ruwanpura, Schulich School of Engineering, University of Calgary
5.1.3 Applications of Remote Sensing (9.30-10.00)
Dr. Slava Gusiakov, WAPMERR

BREAK (10.00-10.30)

5.2 Tsunami Impact Mitigation Methods
5.2.1 Artificial Methods (10.30-11.00)
Dr. Shiego Takahashi, PARI Japan
5.2.2 Natural Methods (11.00-11.30)
Dr. Subandono Diposaptono, Indonesia

DISCUSSION (11.30-12.30)

LUNCH (12.30-2.00)

6.0 NATIONAL APPROACHES AND CASE STUDIES ON RISK ASSESSMENT
6.1 Australian Experience (2.00-2.30)
Dr. John Schneider, Geoscience Australia
6.2 Japanese Experience (2.30-3.00)
Dr. Shiego Takahashi, PARI Japan
6.3 Case Study - Sri Lanka (3.00-3.30)
Dr. Sam Hettiarachchi, University of Moratuwa, Sri Lanka

BREAK (3.30-4.00)

6.4 Case Study - Indonesia (4.00-4.30)
Dr. Eko Yulianto, Indonesian Institute of Earth Sciences, Indonesia
6.5 Case Study - Kenya (4.30-5.00)
Ms. Beatrice Akunga, Fisheries Institute, Kenya, and Dr. John Tychsen, GEUS
DAY 3 (6th Saturday)

6.0 NATIONAL APPROACHES AND CASE STUDIES continued
6.6 Case Study – Iran (9.00-9.30)
Dr Mohammed Mokhtari, National Center for Earthquake Prediction, Iran
6.7 Case Study - South Africa (9.30-10.00)
Prof. Andrzej Kijko, Council of Geosciences, South Africa

BREAK (11.00-11.30)

7.0 DEVELOPMENT OF GUIDELINES FOR STANDARDISED METHODOLOGY
(11.30 onwards)

LUNCH (1.00-2.00)

DEVELOPMENT OF GUIDELINES FOR STANDARDISED METHODOLOGY cont…

8.0 CLOSING SESSION (5.15-5.45 pm)
ANNEX II

GUIDELINES ON RISK ASSESSMENT

Group_A: Tsunami Sources

Goal: Identify and quantify tsunami sources and avert surprises. Subduction related sources were found to be at more priority at the current time. However, it was consensually agreed that other sources may be important, in both the near and far source possibilities, but were not addressed in the below summary.

Customers: Who are the users of the Tsunami Source Database may include Working Groups 4, 1, 2, 5, 3, and loosely 6. In addition, beyond the field of tsunami other beneficiaries of this information are insurance companies, structural engineers, and others.

Data Needs: guided by WG4 requirements

1. Source Geometry (slip, dip, ruptures)
2. Magnitude range (M_{max})
3. Recurrence, available from slip rates, geology, seismic data, past events, plate models.
4. Recurrence model (Slip Rate, recurrence)
5. Scaling relation (Magnitude versus area Length, Width)
6. Integrate over entire source zone
7. Slip distribution
8. Segmentation models (variable rupture models)

Data Gaps:

In the following sources:

1. Java (Southern Sumatra, Lesser Sunda)
2. Makran
3. Arkan

Data Gaps are:

a. M_{max} (1-3)
b. Recurrence Intervals (all, except W. Sumatra)
c. Source Geometry (3,2)
d. Segmentation Models (all): variation in rupture dimensions
e. None-subduction tsunami sources

Methods: (objective to fill database gaps)

a. GPS measurements of strain accumulation to address which part is locked, particularly for 1-3.
b. Passive Seismic Monitoring: this would provide valuable information on the source geometry, especially for the least known sources such as Makran, Arkan).
c. Earthquake and Tsunami Geology potentially past 8,000 years of possible M_{max}. Examples include near source (example: land level changes, uplifts, evidence of land shaking indicated by liquefaction, and turbidities) and far field (example: depicted by tsunami deposit).
d. Written Histories, none-European: this would assure not to neglect local indigenous information which may be more valuable and perhaps crucial.
e. Other geophysical data measurement that may include active seismic data, potential field data (gravity & Magnetic), and bathymetry data.

Note: 1-4 will contribute to segmentation models

**Products:**
1. Tsunami Source Database, updated periodically every five years, by a traveling scientific committee under the UNESCO umbrella.
Group B: Hazard Assessment

Hazard assessment has to fulfill the needs of the different groups, which will be using the outcome and results of the hazard analysis. These “target groups” are e.g. the administrations, which are responsible for:

- Early Warning (Warning Centers)
- Emergency Response and Evacuation (Emergency Services),
- Mitigation: e.g. establishment of countermeasures against tsunamis (technical, e.g. design of structures, or natural methods, e.g. forestation)
- Development Planning: site planning of critical infrastructure, set-back for development, etc

The requirements of these different applications fields have to be considered in the definition of the hazards maps.

Moreover, the final results have to be communicated to the people. Therefore, hazard assessment has to provide on the one hand, scientifically sound and detailed maps (or information products) and customized, and on the other hand simplified maps for the local communities.

Methods for Inundation Modeling

Simple (“interim”) approach

In cases where no inundation model is available, which can be used for numerical modeling of the tsunami inundation, a simplified approach can be applied. This simplified approach is based on the following input data:

- Distance to the coastline
- Terrain elevation
- Characterization of topography (dams, barriers, forests, etc)

The result of this analysis is a map of Inundated Areas. The User Groups, which can benefit from this product, are e.g. the emergency services.

Comprehensive, scenario-based approach

This approach is based on numerical modeling. Numerical models for inundation modeling are based on the following input data:

- Source scenario
- Bathymetry
- Topography
- Tidal information
- Bed resistance, surface roughness
- Large structures, breakwaters, dams

The results of this numerical modeling are:

- Map of Inundated Areas (for certain return periods)
- Maximum Inundation height
- Maximum water velocity
- Duration of flooding
- Arrival time
Data requirements and availability

Data requirements
(see above)

Data availability and accuracy
Topography (digital elevation models):
- Global: SRTM (3” resolution)
- National: Topographic maps (mostly 1:50.000 scale)

Bathymetry:
- ETOPO2, GEBCO, C-Map
- Navigational charts

Data gaps
The most critical data gaps are
- Near-shore bathymetry
- Coastal topography
- Characterization of sea-floor conditions

Hazard maps and hazard assessment products
Describe the above mentioned outputs in more detail, give examples from existing hazard maps and provide
Group C: Vulnerability

Emily Mudge
Beatrice Akunga
Ken Dale
Sanny Jegillos
Adel Karas
Mussa Mustafa
Juan Carlos Villagrán

INITIAL COMMENTS:
Definitions, Methodologies
There is recognition that there is no consensus on definitions regarding vulnerability, nor on methods regarding how to assess it. There are methods for assessing damage to structures, casualties and economic cost which have been developed for other hazards and can be adapted to tsunami risk assessment.

Data sources, gaps
While data exists in a variety of formats (databases, satellite images, surveys); the identification of data sources and gaps will be approached once methods are selected to assess vulnerability at the minimum and advanced levels.

Uncertainties
It is difficult to assess the uncertainties regarding the results of models to assess vulnerability, especially for application to social vulnerability. Uncertainties can be quantified with respect to the vulnerability of structures, casualties and cost, but in general data are poor and are difficult to generalize from one location to another.

MINIMUM APPROACH: VULNERABILITY BASED ON EXPOSURE

<table>
<thead>
<tr>
<th>Component</th>
<th>Parameter</th>
<th>Data Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOCIAL:</td>
<td>People</td>
<td>Tsunami impact map (2004); identify benchmarks to establish geographical exposure (exposure area in terms of distance from shore)</td>
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<tr>
<td></td>
<td>All individuals considered as vulnerable</td>
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</tr>
<tr>
<td>ECONOMIC:</td>
<td>Assets; Land-use:</td>
<td>Surveys, imagery, analysis of economic value of infrastructure in exposed area.</td>
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<tr>
<td></td>
<td>- Commercial</td>
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<td></td>
<td>- Residential</td>
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<td>- Agricultural</td>
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<td>- Public utilities</td>
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<tr>
<td>ENVIRONMENT:</td>
<td>Industrial, hazardous materials; Agriculture Marine</td>
<td>Surveys, imagery</td>
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<td>DEFICIENCIES IN PREPAREDNESS:</td>
<td>End-to-End Early Warning approach; Technical aspects Human aspects Media/communications Awareness campaigns Local structures for response (committees)</td>
<td>Surveys: - Preparedness plan tsunami-specific - Focal points at local levels. - Evacuation routes - Awareness material adapted to local conditions and available in local languages</td>
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ADVANCED APPROACH: VULNERABILITY BASED ON SUSCEPTIBILITY: 3 classes

<table>
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<th>Sectors</th>
<th>Components</th>
<th>Parameters</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Housing Health, Education Industry Energy Agriculture Commerce Banking &amp; Finance Life Lines Tourism Telecommunications Transport</td>
<td>Physical Human/gender Functional Administrative Environmental</td>
<td>Foundation High-rise or Low-rise Children/elderly Women / men Patients, PwD, PrisionersC</td>
<td>In case of low-rise, building materials and construction techniques</td>
</tr>
<tr>
<td>Local, State / Provincial National</td>
<td>Physical Human/gender Functional Administrative</td>
<td></td>
<td>Develop matrices to carry out assessment as part of guidelines</td>
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ADVANCED APPROACH: VULNERABILITY BASED ON SUSCEPTIBILITY: 3 classes

<table>
<thead>
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<th>Government</th>
<th>Components</th>
<th>Data Requirements</th>
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<tr>
<td>Local, State / Provincial National</td>
<td>Physical Human/gender Functional Administrative</td>
<td>Surveys, databases</td>
</tr>
</tbody>
</table>

ADVANCED APPROACH: VULNERABILITY BASED ON SUSCEPTIBILITY: 3 classes

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<th>Population Demographics</th>
<th>Components</th>
<th>Data Requirements</th>
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<td>Age, Gender, Poverty / exposure Ethnicity Culture PwD Dependency</td>
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<td>Surveys, databases</td>
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### Additional comments:

<table>
<thead>
<tr>
<th>Model</th>
<th>Uncertainties</th>
<th>Modeling</th>
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<tr>
<td>Minimum approach</td>
<td>Vulnerability is represented in terms of exposure. It may lead to large uncertainties.</td>
<td>Simple model based on use of census data and surveys.</td>
</tr>
<tr>
<td>Advanced Approach</td>
<td>Vulnerability is represented in terms of 5 types of susceptibilities.</td>
<td>There is a need to develop models linking susceptibilities. A Task Team is proposed to do this. Proposal to tailor model to 3 degrees of vulnerability (Low, Medium, High).</td>
</tr>
</tbody>
</table>

### Tentative work plan:

<table>
<thead>
<tr>
<th>Model</th>
<th>6 months</th>
<th>6-12 months</th>
<th>6 months</th>
</tr>
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<tr>
<td>Minimum approach</td>
<td>Develop framework to assess buffer areas. (6 months)</td>
<td>Complete elaboration of guidelines. (6 months)</td>
<td></td>
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<tr>
<td>Advanced Approach</td>
<td>Gather supporting information from sectors, to acquire input from Task Team in terms of mathematical models. (12 months)</td>
<td>Complete elaboration of guidelines. (6 months)</td>
<td></td>
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</tbody>
</table>
At the outset the group identified and prioritized the sectors in the broader context of mitigation as follows,

1) People – Their lives and safety
2) Physical Infrastructure
3) Land, Agriculture and Fisheries
4) Ecosystems and Environment.

Thereafter the group identified three principal areas which have to be considered in detail under the theme of mitigation and the sectors identified above. Under each principal area the relevant topics were also identified as follows.

1. Hazard Mitigation Planning
   1.1 Hazard Maps
   1.2 Vulnerability Maps
   1.3 Risk Maps
   1.4 Setbacks
   1.5 Land use planning

2. Evacuation
   2.1 Safe zones
   2.2 Evacuation Structures
   2.3 Evacuation Routes
   2.4 Education and Communication

3. Tsunami Impact Mitigation
   3.1 Barriers- Artificial, Natural and Hybrid Solutions
   3.2 Tsunami Resistant Structures- Codes of practice, retrofit and new

The group then discussed in detail each of the items and the outcome is presented below.

1. Hazard Mitigation Planning

   1.1 Hazard Maps
Hazard Maps, primarily relating to inundation, have to be considered for credible scenarios including worst case scenario.

The maps should ideally indicate
- Inundation height
- Run up
- Intrusion Length
- Current velocity and direction
- Arrival times
1.2 **Vulnerability Maps**

Group C will provide information to be included in this section. The following categorization was identified as relevant.

- Human
- Socio Economic
- Physical Infrastructure
- Functional/ Essential services
- Environment

1.3 **Risk Maps**

The Risk Maps will be developed by combining the information from Hazard and Vulnerability Maps.

1.4 **Set backs**

Setbacks to be identified with respect to Risk Maps for Tsunami and other coastal hazards (multi-coastal hazard approach)

1.5 **Land use Planning**

To be determined on Hazard, Vulnerability Risk Maps, Set backs and national policies on planning. The concept of ‘living with risk’ has to be introduced because from a practical point of view mitigation can only achieve specific levels of disaster risk reduction and that too on the availability of funds for mitigation.

2. **Evacuation**

2.1 **Safe zones**

Safe zones to be determined with respect to Hazard Maps, Geographic location (Elevation, distance and available areas for safe zones) and Accessibility.

2.2 **Evacuation Structures**

The need for evacuation structures to be identified with respect to the population at risk and time available for evacuation to safe places, if such places have been identified.

If the Tc represents the critical time for the tsunami to reach a proposed safe place for a worst case scenario and Te(max) represents the maximum time for evacuation, evacuation structures will be required if Te(max) > Tc. In the analysis a safety factor should be included to accommodate any potential delay in the evacuation process. Sometimes evacuation structures may be avoided by having additional routes to the safe zones thereby accommodating reduced density of the human evacuation rate on a given route, leading to high speed of evacuation (reducing Te (max) ).

2.3 **Evacuation Routes**

Evacuation routes have to be designed to permit human and vehicle movement to safe places and evacuation structures. The design will be based on the expected volume of humans and vehicles, speed of evacuation and safety. The design will primarily present the number of routes required, the width and the overall safety of the evacuation process. The design must ensure the safe passage of evacuation and risk of failure of the route itself under disaster conditions. Such an approach will
identify weak links which may have to be rectified in advance and also recommend alternative routes in the event of failure of a prescribed route.

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

3. Tsunami Impact Mitigation

3.1 Barriers
Barriers are broadly classified into three groups namely, Artificial, Natural and Hybrid Solutions.

Artificial Methods include,
-Offshore tsunami breakwaters which on most occasions are partial barriers will dissipate a part of the energy of the incoming tsunami wave. These could also be designed as full barriers with the inclusion of a tsunami gate for complete closure.
-High rise seawalls (dykes) is a full barrier against the tsunami wave propagation located on the coastline
-Tsunami gates for tsunami flow prevention are usually installed across rivers and also included in seawalls to close ‘openings in them’ which are used in normal times for access and regular flow of traffic. The closure of the gate will prevent tsunami wave propagation.
-Medium rise seawalls (dykes) are partial barriers against flow and will prevent tsunami wave propagation up to specific design water levels. The design permits overtopping beyond these levels. Therefore in this respect the stability of the barrier during overtopping and issues relating to inland drainage have to be given due consideration.

Natural Methods include,
-Sand Dunes
-Coastal vegetation
-Conservation of coral reef systems

Natural solutions provide cost effective, environmentally friendly solutions for situations where the frequency of occurrence of tsunamis which can cause damage is low. Sand dunes can be used as full barriers where as Coastal vegetation will dissipate part of the tsunami wave energy via turbulent flow through porous structures. It is strongly recommended to adopt Sand dunes in combination with coastal vegetation which enhances stability and performance of dune systems. Coral reefs have the ability of dissipating tsunami wave energy. This is particularly so id tsunami waves reach coastline under low tide conditions where the reefs remain exposed.

Hybrid Methods refer to combinations of Artificial Methods or a combination of natural Methods as well as joint application of Artificial and Natural Methods.

Barriers are physical interventions and in designing them it is necessary to ensure the continuity of sustaining multiple uses of the existing natural environment. From an engineering point of view the
design must be robust, reliable and functional. Due consideration must be given to convenient maintenance and effective operation. Equally it is important to minimize negative impacts on socio economic, livelihood and environmental issues. Priority must be given to good landscaping of the environment. There is a need to explore synergies for the enhancement of commercial activities.

3.2 Tsunami Resistant structures

The coast is an area of high economic activity and it is not possible to transfer all activities to areas that are completely free from potential tsunami hazards. Therefore there is a need to develop Design Guidelines and Construction Manuals for tsunami resistant housing and infrastructure for the benefit of the public and wider usage. It is expected that properly designed structures will be able to withstand to a considerable extent the impacts of tsunami waves with limited damage. For some areas of the coast, safe evacuation areas may be too far away for citizens to reach on foot thus necessitating vertical evacuation structures. Such structures must be able to withstand extreme conditions arising from tsunami wave attack

It is recommended to develop Codes of Practice for the Design of Tsunami Resistant Structures. In this respect two types of guidelines are required.

1) Design Guidelines on Good Practice providing advice on concept, location, layout, orientation, structural configuration, geo-technical considerations and other considerations leading to good design practice. Such designs will enhance the robustness of the structures to withstand tsunami wave attack and other coastal hazards without total collapse or failure.

2) Detailed Design Guidelines providing information on hydraulic and structural loads, geo-technical parameters and detailed design information. The design approach should be based on the concept of design against failure and in this context attention must be focused on Failure Modes and the development of a Fault Tree.

The Overall Design Guidelines could be developed from the experience gained from Damage Assessment from different parts of the country and such assessment should be analyzed in the context of the hydraulic regime which would have been generated by the tsunami at that location. Relevant information from other countries that have been affected by tsunamis will also be very useful for this exercise. It is important that Damage Assessment should cover infrastructure that was (i) Destroyed (ii) Damaged (iii) Survived (least affected).

The proposed Design Guide Guidelines should be applicable to

- Rehabilitation of damaged structures
- Strengthening of existing structures (retrofitting)
- Design of new structures
**ANNEX III**

**LIST OF PARTICIPANTS**

<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beatrice Akunga</td>
<td>Kenya</td>
<td><a href="mailto:nyabokeakunga@yahoo.com">nyabokeakunga@yahoo.com</a></td>
</tr>
<tr>
<td>Ali Al-Lazaki</td>
<td>Oman</td>
<td><a href="mailto:lazki@squ.edu.om">lazki@squ.edu.om</a></td>
</tr>
<tr>
<td>Brian Atwater</td>
<td>USA</td>
<td><a href="mailto:atwater@u.washington.edu">atwater@u.washington.edu</a>; <a href="mailto:atwater@usgs.gov">atwater@usgs.gov</a></td>
</tr>
<tr>
<td>Vadim Chesnokov</td>
<td>WAPMERR</td>
<td><a href="mailto:wads@ngs.ru">wads@ngs.ru</a></td>
</tr>
<tr>
<td>Hannah Clements</td>
<td>Australia</td>
<td><a href="mailto:hannah.clement@kbr.com">hannah.clement@kbr.com</a></td>
</tr>
<tr>
<td>Priyan Dias</td>
<td>Sri Lanka</td>
<td><a href="mailto:priyan@civil.mrt.ac.lk">priyan@civil.mrt.ac.lk</a></td>
</tr>
<tr>
<td>Ken Dale</td>
<td>Australia</td>
<td><a href="mailto:ken.dale@ga.gov.au">ken.dale@ga.gov.au</a></td>
</tr>
<tr>
<td>Subandono Diposaptono</td>
<td>Indonesia</td>
<td><a href="mailto:sbdn@cbn.net.id">sbdn@cbn.net.id</a></td>
</tr>
<tr>
<td>Fachrizal</td>
<td>Indonesia</td>
<td><a href="mailto:fahrizal@bmg.go.id">fahrizal@bmg.go.id</a></td>
</tr>
<tr>
<td>Nor Hisham Mohd Ghazali</td>
<td>Malaysia</td>
<td><a href="mailto:hisham@water.gov.my">hisham@water.gov.my</a></td>
</tr>
<tr>
<td>Vyacheslav Gusiakov</td>
<td>Russia</td>
<td><a href="mailto:gvu@sscc.ru">gvu@sscc.ru</a></td>
</tr>
<tr>
<td>Sam Hettiarachchi</td>
<td>Sri Lanka</td>
<td><a href="mailto:sslh@civil.mrt.ac.lk">sslh@civil.mrt.ac.lk</a></td>
</tr>
<tr>
<td>Kruawun Jankaew</td>
<td>Thailand</td>
<td><a href="mailto:k.jankaew@yahoo.co.th">k.jankaew@yahoo.co.th</a></td>
</tr>
<tr>
<td>Adel Karas</td>
<td>WAPMERR</td>
<td><a href="mailto:a_karas@wapmerr.org">a_karas@wapmerr.org</a></td>
</tr>
<tr>
<td>Hong Kie</td>
<td>USA</td>
<td><a href="mailto:hong_kie_thio@urscorp.com">hong_kie_thio@urscorp.com</a></td>
</tr>
<tr>
<td>Andrzej Kijko</td>
<td>South Africa</td>
<td><a href="mailto:kijko@geoscience.org.za">kijko@geoscience.org.za</a></td>
</tr>
<tr>
<td>Philip Liu</td>
<td>USA</td>
<td><a href="mailto:pll3@cornell.edu">pll3@cornell.edu</a></td>
</tr>
<tr>
<td>Igor Marinin</td>
<td>WAPMERR</td>
<td><a href="mailto:igor.marinin@inloje.ru">igor.marinin@inloje.ru</a></td>
</tr>
<tr>
<td>Mohammad Mokhtari</td>
<td>Iran</td>
<td><a href="mailto:mokhtari@iiies.ac.ir">mokhtari@iiies.ac.ir</a></td>
</tr>
<tr>
<td>Emily Mudge</td>
<td>Sri Lanka</td>
<td><a href="mailto:emily@unhabitat.lk">emily@unhabitat.lk</a></td>
</tr>
<tr>
<td>Mussa Mustafa</td>
<td>Mozambique</td>
<td><a href="mailto:mussa_m@inam.gov.mz">mussa_m@inam.gov.mz</a></td>
</tr>
<tr>
<td>Paul Olooo</td>
<td>Kenya</td>
<td><a href="mailto:olooo@meteo.go.ke">olooo@meteo.go.ke</a></td>
</tr>
<tr>
<td>Jascha Polet</td>
<td>USA</td>
<td><a href="mailto:jpolet@csupomona.edu">jpolet@csupomona.edu</a></td>
</tr>
<tr>
<td>CP Rajendran</td>
<td>India</td>
<td><a href="mailto:rajendran_cp@yahoo.com">rajendran_cp@yahoo.com</a></td>
</tr>
<tr>
<td>Janaka Ruwanpura</td>
<td>Canada</td>
<td><a href="mailto:janaka@ucalgary.ca">janaka@ucalgary.ca</a></td>
</tr>
<tr>
<td>Saman Samarawickrama</td>
<td>Sri Lanka</td>
<td><a href="mailto:samans@civil.mrt.ac.lk">samans@civil.mrt.ac.lk</a></td>
</tr>
<tr>
<td>John Schneider</td>
<td>Australia</td>
<td><a href="mailto:john.schneider@ga.gov.au">john.schneider@ga.gov.au</a></td>
</tr>
<tr>
<td>Gunter Strunz</td>
<td>Germany</td>
<td><a href="mailto:Guenter.Strunz@dlr.de">Guenter.Strunz@dlr.de</a></td>
</tr>
<tr>
<td>Shiego Takahashi</td>
<td>Japan</td>
<td><a href="mailto:takahashi_s@pari.go.jp">takahashi_s@pari.go.jp</a></td>
</tr>
<tr>
<td>John Tychsen</td>
<td>Denmark</td>
<td><a href="mailto:jt@geus.dk">jt@geus.dk</a></td>
</tr>
<tr>
<td>Juan Carlos Villagran de Leon</td>
<td>UNU</td>
<td><a href="mailto:villagran@ehs.unu.edu">villagran@ehs.unu.edu</a></td>
</tr>
<tr>
<td>Eko Yulianto</td>
<td>Indonesia</td>
<td><a href="mailto:ekoy001@yahoo.com">ekoy001@yahoo.com</a></td>
</tr>
<tr>
<td>Sanny Jegillos</td>
<td>UNDP</td>
<td><a href="mailto:sanny.jegillos@undp.org">sanny.jegillos@undp.org</a></td>
</tr>
<tr>
<td>Tony Elliott</td>
<td>IOC</td>
<td><a href="mailto:t.elliott@unesco.org">t.elliott@unesco.org</a></td>
</tr>
<tr>
<td>Jane Cunneen</td>
<td>IOC</td>
<td><a href="mailto:j.cunneen@unesco.org">j.cunneen@unesco.org</a></td>
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