EAP DRM KnowledgeNotes
Disaster Risk Management in East Asia and the Pacific
Working Paper
Series No. 25
63414

TSUNAMI RISK MANAGEMENT IN THE CONTEXT OF THE PACIFIC ISLANDS

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THE GENERAL CONTEXT

Tsunamis can be devastating. The 2004 Indian Ocean and 2011 Tōhoku disasters provide frightening examples of the power of tsunamis. The Pacific has long been recognised as a place where tsunamis occur - the “Pacific Ring of Fire” (PRF) contains regions of volcanoes and large earthquakes associated with tectonic plate motions that are ideal breeding grounds for tsunamis.

The Pacific Ocean covers an area of 30 million km^2. Some 22 Pacific Island countries and territories (PICTs) are dotted throughout the Pacific and are vulnerable to varying degrees, to the effects of tsunamis generated locally, regionally and distantly[1].

We are all familiar with the large, trans-oceanic (‘distant’) tsunamis that occurred repeatedly in the 20th and 21st centuries in the Pacific (e.g., 1946 and 1957 Aleutian; 1952 Kuril-Kamchatka; 1960 Chile; 1964 Alaska and 2010 Chile events). These events are conspicuous in that they all originated in circum-Pacific locations, but less well-known local and regional sourced events are also significant. Tsunamis (local, regional and Pacific-wide) in the Pacific have claimed numerous lives, caused widespread damage to coastal infrastructure and heavily impacted natural ecosystems (Box 1). Large and destructive events can take years (perhaps decades) to recover from and can seriously affect long-term sustainable development – especially in rapidly developing economies.

- This is recognised by PICTs in their awareness of the need for tsunami risk mitigation measures. In particular, they recognise the need for improved community awareness and standard operating procedures (SOPs) for international and in-country communication of tsunami warning[2].

This working paper series is produced by the East Asia and Pacific Disaster Risk Management Team of the World Bank, with support from the Global Facility for Disaster Reduction and Recovery (GFDRR). The series is meant to provide just-in-time good practice examples and lessons learned from projects and programs related to aspects of disaster risk management.

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Box 1. Notable Pacific tsunamis and examples of their impacts and lessons learned[3]

2011: 11 March, Japan	Earthquake: Pacific-wide
2010: 13 April, Cook Islands	Submarine Landslide: Local*
2010: 27 February, Chile	Earthquake: Pacific-wide
2007: 1 April, Solomon Islands	Earthquake: Regional
2003: 25 September, Japan	Earthquake: Local
2001: 23 June, Peru	Earthquake: Local
1999: 26 November, Vanuatu	Earthquake: Local

2009: 29 September, Samoa, American Samoa, Tonga

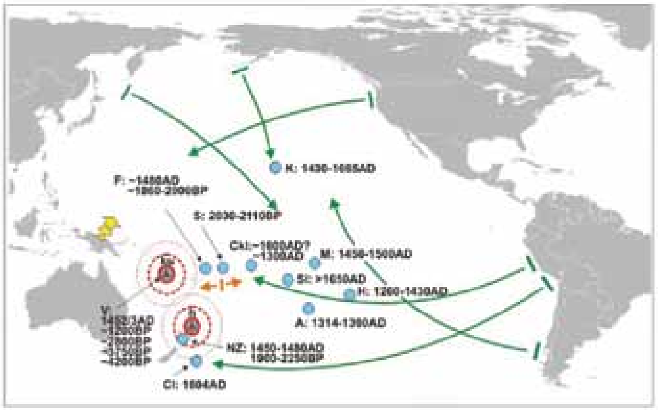
Impacts: 192 deaths; destruction of coastal infrastructure, etc.
Lesson: good community awareness and evacuation planning saved lives; heed natural warning signs

1998: 17 July, PNG

Impacts: 2,205 deaths; destruction of coastal settlements
Lesson: Local tsunamis require careful response planning (e.g. need for vertical evacuation options), heed natural warning signs

*Notable for the fact that this is currently not in NGDC database

Whilst this current state of awareness is encouraging, our understanding of the medium to longer-term (hundreds to thousands of years) recurrence of these events is limited. We know almost nothing about the tsunami record for PICTs, nor the frequency and magnitude of locally and regionally sourced tsunamis in particular, as opposed to pacific-wide events. Given the general vulnerability of PICTs already noted, the lack of a detailed and well-dated long-term record of *all* sources and events stands as a significant obstacle for the development of comprehensive tsunami risk mitigation measures[4] (Figure 1). Successful 'tsunami disaster risk reduction' efforts require as a fundamental building block, a reasonable and reliable estimate of tsunami risk[5].



A - Austral Islands, CI - Chatham Island, CkI - Cook Islands, F - Futuna, H - Henderson Island, K - Kauai, Hawaiian Islands, M - Marquesas archipelago, NZ - New Zealand, S - Samoa/American Samoa, SI - Society Islands, V - Vanuatu

Figure 1: The Pacific Ocean with examples of local, regional, and distant tsunami sources.

Yellow oval = local source (earthquake & submarine landslide – Papua New Guinea 1998), **Red triangle** = regional source (submarine caldera collapse – Kuwae (ku), 1452/1453AD; Healy (h), c.1280-1350AD); **orange line** = regional source 29/9/2009 South Pacific earthquakes; **green lines** = regional/distant sources, representative subduction zone segments from various circum-Pacific Ocean country (CPOC) source areas. Light blue filled black circles show locations of PICTs with dated prehistoric tsunami evidence.

Given the general context outlined, this Knowledge Note does the following. It:

- acknowledges the impacts and characteristics of recent damaging tsunamis (with a particular focus on Pacific and PICT events);
- outlines what we understand the 'tsunami risk management framework' to involve;
- outlines the challenges in identifying, assessing and monitoring tsunami risk (using the risk management framework identified as a guide);
- considers the variety of approaches and methods for prevention and mitigation of tsunami disasters; and
- identifies good practice cases and makes a series of recommendations to move tsunami risk management forward.

IMPACTS OF RECENT TSUNAMIS & THEIR CHARACTERISTICS

The majority of tsunamis are thought to be generated by earthquakes below the sea floor. Importantly however, they may also be generated by volcanic eruptions, underwater landslides, asteroid/comet impacts in to the ocean and occasionally, meteorological conditions. However, things are not quite that simple, the Pacific also experiences unusually large tsunamis associated with poorly understood processes operating at subduction zones[6]. These include "tsunami earthquakes" where larger than expected tsunamis are generated by "slow" earthquakes[7] and by earthquakes that simultaneously generate submarine landslides[8].

In September 2009, yet another unexpectedly large tsunami resulting from an unusual earthquake event occurred in the South Pacific[9]. In essence, we are continuing to experience larger tsunamis than anticipated by current numerical modelling scenarios. This is of enormous concern for the Pacific (and PICTs) where attention has largely been focussed on subduction zone events with little or no consideration given to regional tectonic and submarine landslide sources that can be equally important for individual PICTs[10]. This is significant because, local and regionally generated events pose the greatest challenge for effecting warning alerts and ensuring adequate community response (e.g. evacuation)[11].

It is not the purpose of this Knowledge Note to provide a comprehensive analysis of the impacts and effects of tsunamis of various magnitudes. However, in common with other types of natural hazards, tsunamis can cause extensive loss of life and injuries to survivors. Tsunamis destroy and damage public and private coastal infrastructure, lifelines, critical assets and infrastructure, agricultural systems and produce, transport and communication networks, natural ecosystems and the goods and services those systems provide. Major tsunamis can lead to significant economic losses with recovery often counted in years to decades. Even then, a return to economic growth does not compensate for the direct human and economic loss caused by the event.

In the case of the 2011 Great East Japan Earthquake and Tsunami, the final toll will be immense. The number of dead and missing exceeds 23,000 and economists have estimated the monetary loss at 16-25 trillion yen (US$198-310 billion)[12], about 3-5% of Japanese GDP and the effects of the Fukushima Daiichi nuclear plant remain unclear. The take home message from this event is that even for the most well prepared Pacific country for tsunamis, it is impossible to prevent disaster completely and huge damage was occurred although preparedness mitigated losses dramatically.

For PICTs such as Samoa, even a moderate event such as the 2009 South Pacific tsunami caused by an magnitude 8.1 earthquake was its worst natural disaster in at least half a century with nearly 150 dead and 2.5% of the population left homeless. The final physical damage repair bill is expected to be around US$ 85 million (14% of GDP). However, when the additional costs of maintaining basic social services and safety nets for the affected population and the costs for investing in disaster risk reduction during the reconstruction process are considered, total economic cost is equal to about 21% of GDP over the next three to four years[13].

It is also important to remember that tsunamis do not respect geographic boundaries and may cause losses across entire (small) nations or the coastal zones of several countries simultaneously. Impacts and effects often 'ripple' out across connected socio-economic and human-environment systems and transcend scales from the local to the global. For example, the 2009 South Pacific tsunami affected Samoa, American Samoa, Tonga and even caused damage as far away as the Wallis and Futuna archipelago[9,14].

WHAT DOES 'TSUNAMI RISK MANAGEMENT' INVOLVE?

It is important to outline what is understood as the 'risk management process'. By this, we mean, what steps are followed to understand and quantify the risk so that appropriate, context-specific, actions can be undertaken to reduce risk. Individual countries and organisations will use their own variations of a risk management standard, but all such standards comprise the same basic elements. Essentially, risk is defined by a simple equation:

Risk = hazard x vulnerability

First, identify the tsunami **hazard**. The hazard must then be quantified. Once the hazard has been quantified and the characteristics determined, a range of possible scenarios can be selected for analysis. Such scenarios will likely be selected from a probabilistic assessment of the hazard. For any given scenario of interest, the likely effects of the tsunami may be assessed. To do this, first the exposure of people, infrastructure and assets (e.g. agricultural systems, communication and transport networks, etc) in the forecast inundation zone must be identified and then, critically, their **vulnerability** to harm evaluated. Once this is done, loss may be estimated by risk managers. Once likely loss is known for an event of a given magnitude and probability, decisions can be made about the appropriate **risk** management/mitigation options to follow.

Clearly, experts from different discipline fields will be involved in generating data associated with each step of this process. For example, generally speaking, earth scientists are involved in the identification and characterisation of the tsunami hazard (from not only earthquakes but all possible tsunamigenic sources). Numerical modellers, oceanographers and coastal engineers will model the tsunami from source to inundation. Social and human scientists and engineers will work to evaluate exposure and vulnerability of relevant people, infrastructure and assets, and a range of experts such as risk managers, engineers, social scientists, economists, geographers, etc. might be involved in the quantification of the probable maximum loss (PML) associated with the scenario. Lastly, risk managers have the task of integrating all these datasets and decision makers determine how best to mitigate the risk identified. All this should happen and the risk management actions should be in place before the next tsunami occurs.

CHALLENGES IN IDENTIFYING, ASSESSING & MONITORING TSUNAMI RISKS

There are a number of important challenges that exist in relation to identifying, assessing and monitoring the risk from tsunamis. We discuss these in relation to each element of the risk management process identified in the previous section.

The first point is our limited understanding of tsunami sources – the hazard assessment. Prior to the 2004 Indian Ocean disaster, few (if any) had imagined the possibility of extremely large (Magnitude 9+) earthquakes along the Sumatra subduction zone. The geophysical constraints of the subduction system and its capacity to generate such large events were not fully recognised. In many ways this problem hinges on a key issue related to assessing the tsunami hazard for any region – a lack of context. Until we have a better understanding of how subduction zone geology/geophysics constrains maximum earthquake size, or we can be sure that our knowledge of the tsunami record is complete, we must assume that any subduction zone can generate a large tsunamigenic earthquake. We should therefore strive to improve understanding of past (historic and prehistoric) events in order to better understand our future.

One recently developed method to undertake quantitative tsunami hazard assessment is the Probabilistic Tsunami Hazard Assessment (PTHA) that is based on numerical simulations of what are believed to be ‘plausible’ tsunami scenarios. Such an assessment has been conducted for SOPAC (Secretariat of the Pacific Community, Applied Geoscience and Technology Division) member countries[15]. This approach accounts for large earthquake occurrence on all subduction zones, even those that are not known to have generated large tsunamis. However, these deal almost exclusively with reasonably simple subduction zone source scenarios using historical data as their primary contextual source. The nature and extent of larger events are in general extrapolated from these historical data coupled with a rudimentary understanding of the geophysical properties of the fault zone in question. Scant consideration is given to Traditional Environmental Knowledge (TEK) about past events and geological data concerning prehistoric tsunamis[16].

While this approach offers a ‘general picture’ of the tsunami hazard, it falls short of offering a comprehensive representation of the problems faced by PICTs. There is currently almost no grasp of local and regional volcanic-related tsunamigenic sources and processes in the Pacific (e.g., eruptions, caldera collapse, flank collapse etc). For example, an eruption at Ritter Island, PNG in 1888 produced a significant local volcanic tsunami and the 1452/1453AD eruption at Kuwae, Vanuatu produced a catastrophic region-wide tsunami only recently recognised in the geological record[4,16]. Many PICTs are still volcanically active and form part of the PRF, while those not directly associated with it are generally either linked to hot spot volcanism, mid-ocean ridges, or past tectonic activity. Perhaps most importantly, because most PICTs are volcanic in origin they rise up steeply 1000's of metres from the seafloor and as such are susceptible to tsunamigenic landslides[10] (see Box 2).

Box 2. Cook Islands: An example of the disjunct between existing assessments & geological evidence

While recognising that other sources exist, current PTHA data indicate that the Tonga-Kermadec Trench (TKT) is the most significant source of tsunamigenic earthquakes for the Cook Islands with 2000 year maximum amplitudes of around 1.7 m for the northern islands and up to 2.8 m in parts of the southern group. A limited regional threat from the South Solomon and New Hebrides trenches to the west and large earthquakes on the Kuril and Peru-Chile trenches may also represent a distant tsunami threat[16,17].

It is therefore surprising to discover that a locally-generated tsunami (see Box 1) caused by a submarine landslide generated runup heights of up to 12 m on Mangaia10.

Assessing AND monitoring of tsunami risk for PICTs is still in its infancy.

On balance, it seems reasonable to suggest that simple subduction zone events may represent as little as 50% of the potential tsunamigenic sources for some PICTs (e.g. Cook Islands, Kiribati, French Polynesia)[10].

While these challenges are not insurmoutable, and indeed science advances by addressing such issues, for the time being all we can safely say is that we only have a rudimentary knowledge of the risks posed by tsunamis to PICTs.

Even the modelling of moderately simplistic tsunami hazard scenarios is complex - all the way from source (e.g., earthquake, landslide, volcano) to inundation (e.g. water depth, speed, runup). Furthermore, modelling tsunami generation, propagation and inundation faces the challenge of a lack of detailed offshore bathymetry and onshore topography including LIDAR datasets which both act as impediments to producing realistic inundation and runup forecasts. Equally, current inundation models are based on bare earth topography and fail to consider land surface roughness and vegetation, people and infrastructure. Finally, aspects of later arriving and receding waves, and the interaction of debris or projectiles have not been included in many modelling studies.

It is in the reporting of the results and dissemination of the data through peer-reviewed journals and consultancy reports that often a necessary over-simplification takes place with many of the provisos, assumptions and limitations of source event characeteristics and modelling approaches, not being fully considered, clearly explained and justified and/or even overlooked entirely. Further, where such limitations are correctly described and discussed, these often fail to filter through to the emergency management professionals and wider public community for whom these studies are designed to benefit. The task of risk communication is fraught with difficulties and we acknowledge that experts do the best they can in the current circumstances[18]. Information transfer must be effective to ensure that the relevant messages to the different stakeholders are passed on and understood.

The geographic remoteness, high cost of exploration, and a relative lack of scientific interest in Pacific Island tsunami research have tended to act as barriers to detailed in-country PICT studies. Low population numbers and a perceived limited infrastructure exposure have resulted in a general lack of interest in understanding the complex tsunami hazard and risk posed to PICTs. This is unfortunate since much PICT infrastructure, such as wharves and airstrips, is in coastal or low-lying areas, and as such is particularly vulnerable to tsunamis that can destroy the sole means of obtaining essential supplies[4]. Further, to our knowledge, tsunami risk assessments have mostly failed to take in to consideration future sea level rise associated with enhanced anthropogenic climate change. As such, future tsunamis may well be even worse than our current best estimates as inundation may change markedly as sea levels rise. This assumption however, remains to be carefully considered.

The next element of the risk management process that has difficulties and challenges relates to the assessment of exposure and vulnerability. Quantifying PML for any given scenario relies on two fundamental datasets: (1) data about who and what are 'exposed' to potential harm; and (2) an effective method for estimating the vulnerability (and resilience) of those exposed people and assets (so called 'vulnerability assessment').

Assessment of exposure is reasonably simple but is often hampered by a lack of detail. Population census surveys are often only undertaken once every five or ten years and in rapidly developing countries, population numbers can increase quickly – especially in urban and peri-urban centres. As such, having reliable estimates of human exposure can be challenging including knowing the absolute numbers of adults and children, elderly and disabled, etc. For example, after the 1998 PNG tsunami, authorities were unclear as to how many people had actually died (and their demographic composition) because they did not know how many people lived in some of the affected communities at the time.

Similarly, knowing the exposure of the built environment can be limited, especially where government records of development planning and approvals are incomplete or non-existent. However, limited knowledge of the physical exposure of the built environment can be overcome using modern satellite and air survey/photographic techniques. For example, freely available imagery and data through open access platforms such as OpenStreet Map can provide a reasonable mechanism for understanding building exposure. Another example is the Pacific Catastrophe Risk Assessment and Financing Initiative that has established a substantive risk exposure data base comprising of population, buildings, infrastructure and crops for risk modelling. The initiative is implemented jointly by SOPAC/SPC, the World Bank and the Asia Development Bank and data is being launched in August 2011[19].

Assessing the vulnerability of the built environment is another issue altogether. The translation of data about what is physically 'exposed' to tsunami inundation into what is 'vulnerable' to damage and loss is an area of science that has only been properly explored in the last 10 years or so.

Significant efforts are underway to develop, test and validate (using post-tsunami building damage assessments) semi-quantitative and quantitative engineering models for tsunami damage assessment. Such models (in keeping with seismic, flood and wind hazards) are attempting to integrate damage functions and fragility curves established from empirical field evidence of damage sustained by differently engineered structures in real disasters. Such models may then be applied in a forecast sense to estimate damage and loss.

Notwithstanding the difficulties faced by engineers in establishing and validating such models, their application in forecast assessments is limited by the need for detailed datasets of the built environment at a high-resolution (building-by-building) scale. That is, what built environment characteristics are relevant for estimating vulnerability (e.g., building materials, number of floors, design standards, etc.).

Studies of the September 2009 South Pacific tsunami, as well as work by other agencies have made significant advances in constructing and validating building fragility curves to aid in built environment vulnerability assessments by undertaking post-tsunami damage assessments of 'typical' Pacific structures[20]. This work is critical since it has demonstrated the value of the Papathoma Tsunami Vulnerability Assessment (PTVA) Model that is currently, to the best of our knowledge, the only detailed model available to estimate building vulnerability to tsunamis[21,22].

The PTVA Model has been tested and applied in several locations including Australia, the Pacific coast of the USA, Greece, Italy, Malaysia, India and Sri Lanka and appears to be the most promising approach to such infrastructure vulnerability assessment. The challenge in its use however, lies in its 'data hungry' inputs (e.g. building type, construction materials, number of floors, ground floor plan layout, etc)[23,24].

Following on from the above, there are significant challenges associated with calculating replacement costs for physical infrastructure across PICTs. Without standard methods/approaches and with widely variable costs in each country, it is not a simple process to estimate final PML or replacement costs. Also, in supply-limited post-disaster situations, building material costs can escalate rapidly diminishing the relevance of pre-event estimates. The strength of this methodology though is that loss metrics have an associated probability of occurrence. A risk manager can therefore determine what return period level of loss they would like to consider such as the 1:100 or 1:500 year event. However, one of the weaknesses of this approach is that it assumes a comprehensive knowledge of the country's tsunami hazard that as previously noted is rarely, if ever, achieved.

Lastly, we recognise the value of using indigenous or traditional building practices as a possibly sustainable and affordable best practice. Further research should be done to consider the viability of incorporating lessons learned in Indonesia, Southeast Asia, and Japan into recovery planning and construction.

In terms of monitoring risks, we would suggest that after each major tsunami has occurred, relevant authorities should carefully review lessons learned and the knowledge generated by post-event analyses in order to determine if our understanding of the risk has changed.

APPROACHES FOR PREVENTION & MITIGATION

Prevention and mitigation of natural hazards is a standard element of the risk management process. However, in the context of tsunamis it is simply not possible to 'prevent' them from occurring. As such, risk management has to focus entirely on mitigating the effects of events when they occur.

Tsunami mitigation: - what does this mean? In practice, mitigation for PICTs will have several elements. These include having:

- Detection, monitoring and early warning systems (regularly maintained and tested to ensure they are operational);
- Science-based tsunami hazard maps showing flooding impact (where, when, how big), locations of important facilities (infrastructure, lifelines, evacuation sites or safe areas, police/fire/hospitals, etc);
- Educated, prepared and responsible coastal communities (and relevant stakeholders). All segments of the population are addressed, including young and elderly, women, physically and mentally-challenged, religions, languages, culture;
- Disaster preparedness information that is a required part of school curricula, e.g. a scaffolded school curriculum that reinforces and creates the appropriate educational messages throughout a student's time in the education system and one that serves to underpin other community awareness initiatives;
- Infrastructure and planning that is tsunami risk aware – e.g., coastal setbacks, coastal landscape parks, open ground floor plans, building constructions styles; sea walls, breakwaters, barriers and natural berms; coastal forest/mangroves and buffer vegetation; where appropriate, no build zones are designated or coastal communities are transitioned inland or to higher ground.
- Whole-of-government (and cross-sectoral) risk and multi-hazard warning and disaster management plans and policies that are mutually supportive;
- An informed and proactive tourist industry that ensures not only the safety and well-being of their clients, but also safeguards the sustainability of a PICTs GDP (tourism is the largest and fastest growing sector in the Pacific. It is estimated that tourism income in the Pacific is around US$2 billion per year and represents a significant part of the GDP of PICTs [e.g. 2/3 of Palau's economy], port and harbour facilities for tourism and trade need to acknowledge marine risks)[25]; and
- Annual memorial/hazard awareness days.

Emerging lessons from the recent Japan disaster suggest the following:

- In risk management, there is always a significant trade-off between risk tolerance and acceptable mitigation in that countries could never afford or may want to choose not to pay the 100% mitigation costs for very infrequent hazardous events, but it should be acknowledged that there are potentially catastrophic consequences associated with underestimating the hazard;
- Complete reliance on physical mitigation measures (such as tsunami sea walls, tsunami forests and tsunami defence gates) is unwise as they may easily be overwhelmed and overtopped[26]. Again, we do rec-

ognise that such measures do lessen the impacts of events in places;
- For many political and practical reasons, 'set back' is frequently unrealistic. As such, exposure cannot be reduced thus increasing the importance of other mitigative strategies such as community education, evacuation planning and practices and vertical evacuation structures.
- There is a need for a paradigm shift in disaster risk management: one that accepts worst case scenarios and includes them in planning and mitigation scenarios. This recognizes the importance of understanding that simple hazard assessments invariably do not contemplate the complexity of the real world.

With specific regard to PICTs, a recent assessment of the tsunami capacity of SOPAC member countries by the Australian Government Bureau of Meteorology (BoM) has been undertaken[2]. This report highlights through a process of consultation, that mitigative options like those we identified above are entirely appropriate. However, of the 14 SOPAC member countries involved in this assessment, 13 or more recommended the need for robust and effective international and in-country SOPs for tsunami warnings and dissemination to make communities aware. Significantly, none of these 14 countries have complete coverage for the effective dissemination of warnings to their national communities and none have comprehensive training programs for their officials involved in tsunami warning and response. This suggests that at present, these PICTs are not as well prepared as they would like, or need to be and that their current tsunami risk mitigation processes are inadequate and limited. However, in April 2010, as a positive sign of developing an integrated approach to tsunami risk management, the Solomon Islands obtained funding to undertake a coordinated, whole-of-government, private sector and NGO approach to tsunami management by completion of a holistic National Tsunami Response Plan.

GOOD PRACTICE CASES

There is no single example of comprehensive good practice. However, elements of good practice have been adopted at international, national and local scales.

- At the international and regional level, the UNESCO-IOC organised two Pacific-wide tsunami exercises in 2006 and 2008 to encourage countries to prepare for the next tsunami. The next Exercise Pacific Wave (PacWave) 2011 will take place 9-10 November as a multi-scenario exercise to allow countries to practice responding to local and regional sourced tsunamis. For PICTs, earthquake sources along the New Hebrides and/or the Philippines Trench can be used. PacWave06, in which 44 countries participated, has been credited with saving lives in the 2009 South Pacific and 2010 Chilean tsunamis.
- At a national scale, prior to the 2009 South Pacific tsunami, the Government of Samoa had developed an effective tsunami early warning system, working with communities to raise public awareness and to practice evacuation drills and exercises. These actions helped to save lives during the 2009 South Pacific tsunami since the population in many cases knew how to respond[14]. In American Samoa, September has been declared as 'Disaster Awareness Month'. During this month in 2010, the disaster management office conducted numerous outreach and training activities for government and non-government agencies and schools, so that by the 29 September, many people knew about tsunamis.
- At a local scale, the Island Council of Mangaia, Cook Islands, has passed a law stating that all new houses should be built inland and uphill away from the coast, in part taking on-board the results of recent geological studies of past tsunamis on the island[27].
- In Guam, American Samoa and the USA, there is a community-based programme called TsunamiReady which requires communities to have redundant warning and alerting communications, tsunami response plans, tsunami hazard and evacuation maps and signage, and active community and school education programmes. Similar efforts are in place in the Philippines and being undertaken in Commonwealth Caribbean countries. These are the essential components of an effective and successful end-to-end tsunami warning.

In reality, good practice will have to be 'context specific'. No single model will fit all situations and given the diversity of PICTs, a single approach to good practice would not be appropriate. However, it is still possible to ‘map out’ those concepts we see as contributing to good practice and these include:

- *Whole-of-government willingness to act and work collaboratively to reduce risk;*
- *A commitment to long-term funding of warning and disaster risk management offices* (within an ‘all-hazards framework’). Critical core stakeholders supporting disaster risk reduction are; the scientists providing hazard and risk information, tsunami warning centres providing continuous threat assessment in real-time, and disaster management offices and first responders that are responsible for public safety. These stakeholders must work together and seamlessly in an emergency. An important mechanism for building a strong mitigation program is the establishment of Tsunami Coordination Committees that will oversee tsunami mitigation in a country or jurisdiction;
- *Inter-PICT government and regional cooperation – shared technical and communications infrastructure* (e.g. seismic stations, coastal sea level gauges, deep-ocean DART© buoys, and in the future real-time GPS networks, WMO (United Nations World Meteorological Organization) Global Telecommunications System, RANET communications project, etc.), and information sharing during real events of observations and impacts, will lead to improved tsunami detection and threat assessment across the region;
- *Intergovernmental and regional organisations continue to provide significant contributions to assist countries to build their capabilities for hazard and risk assessment, early warning and dissemination, and awareness and education.* At the United Nations intergovernmental level, the UNESCO-IOC coordinates the global tsunami system that includes, since 1965, the Pacific Tsunami Warning and Mitigation System (PTWS). The UNESCO-IOC’s ITIC (International Tsunami Information Centre) serves as its regional focal point for training, technical assistance, and awareness. Regional organisations such as SPC/SOPAC, support PICTs disaster risk reduction and national disaster management offices, and SPREP (South Pacific Regional Environment Programme) supports PICT national meteorological services under the WMO in their role as national tsunami warning centres. All such organisations contain a wealth of existing experience, knowledge and skill in relation to disaster risk reduction across a range of hazard types and wherever possible, this existing regional experience and knowledge should be utilised;
- *Building of PICT skills and capacities of agencies and especially its staff through training and outreach, especially dedicated, multi-year, sustainable in-country training and outreach on tools, equipment and knowledge.* Engaged and motivated personnel will lead to improved tsunami warning and response efficiencies across the region.

Specific activities and programmes that constitute part of the ‘map’ for reducing tsunami risk include: (1) building sustainable operations for tsunami early warning and alerting and tsunami emergency response through well-known and exercised plans, procedures, and protocols; and (2) education with a focus on adaptive strategies that work for different languages and cultures.

RECOMMENDATIONS & WAYS FORWARD

During the UNESCO-IOC ICG/PTWS-XXIII held in Apia, Samoa, Pacific countries endorsed its 2009-2013 Medium Term Strategy (MTS) to document the essential components and strategies for achieving tsunami preparedness. The PTWS is envisioned as an *“An interoperable tsunami warning and mitigation system based on coordinated Member State contributions that uses best practices and operational technologies to provide timely and effective advice to National Tsunami Warning Centres. As a result, PTWS communities at risk are aware of the tsunami threat, reduce risk, and are prepared to act to save lives.”* The MTS builds from the ITSU (PTWS) Master Plan (1999, revised 2004) that summarises the mitigation of tsunami hazards in the Pacific.

The PTWS MTS is comprised of three Pillars supported by four foundational elements.

The Pillars are:

- Risk Assessment and Reduction: hazard and risk identification and risk reduction

- Detection, Warning and Dissemination: rapid detection and warning dissemination down to the last kilometre
- Awareness and Response: public education, emergency planning and response

The supporting foundational elements are:

- Interoperability: free, open and functional exchange of tsunami information
- Research: enhanced understanding and improved technologies and techniques
- Capacity Building: training and technology transfer
- Funding and Sustainability: resources to sustain an effective PTWS

Within each Pillar, prioritised activities, guided by the PTWS's foundational elements, are to be undertaken with the aim of making at-risk populations safer.

After the PTWS MTS was approved, the PTWS Implementation Plan was developed setting forth Priorities of Action to fulfil the strategy. Thus, PICTs are recommended to adopt the MTS and use the Implementation Plan Priorities as a guide to improving their tsunami preparedness.

During the ICG/PTWS-XXIV in May 2011, a technical workshop was convened to share experiences and lessons learned from the recent regionally-destructive tsunamis (2009 South Pacific, 2010 Chile, 2010 Japan) and to discuss and elaborate on how effective the PTWS, both as a system and individually as countries, has been in providing early, timely warnings to communities at risk. Outcomes from the Workshop are intended to serve as a catalyst for improving the system. The Workshop discussions and outcomes were used to formulate the PTWS Working Group recommendations to the ICG/PTWS-XXIV.

For PICTs, the relevant PTWS Working Groups are a Regional Working Group for the South West Pacific, Seismic Data Sharing for the South West Pacific Task Team, Warning Communications Task Team, Exercise Pacific Wave 2011 Task Team, Enhanced Products Task Team, Risk Assessment and Risk Reduction Working Group, and Awareness and Response Working Group.

There are two interrelated, but clear ways forward.

First, we need better science (e.g. geological, geophysical, oceanographic, engineering, social, TEK, historical, environmental, etc.), better integration of the data and communications of these scientific results in an understandable and actionable way to enable meaningful public policy and to convince an often-busy citizen to pay attention to natural hazards and take action to prepare themselves and their community. This is not just about numerical modelling or pure research, but using science to improve decision-making and to ultimately implement a sustainable and practical end-to-end warning and mitigation package.

Second, BUT at the same time, national and local governments and communities need to get better at doing risk management. This can be achieved through improved government policy systems, better warnings, community-wide consultation on awareness and education and an integrated approach to tsunami risk within an all-hazards framework.

These two points have been made in some detail by the recent Australian Government BoM report dealing with PICT tsunami preparedness[2].

To fill in the existing knowledge gaps, our key recommendations are:

1. *Improve basic understanding of the hazard.* This can be achieved by:

- improving our long-term understanding of the hazard by undertaking detailed country-by-country geological, archaeological and TEK investigations of past historic and prehistoric tsunamis in PICTs;
- investigating *all* tsunamigenic sources (e.g. incorporate volcanic- and landslide-related data into regional and national tsunami databases for PICTs);
- using integrated source to inundation numerical modelling that is underpinned by comprehensive geological, historical and TEK datasets to ensure that PTHA are robust;
- undertaking studies of socially-oriented perceptions of tsunami hazard and risk to improve community understanding across the region;
- testing the assumption that PICTs are automatically 'vulnerable' to tsunamis. This is an over-simplistic generalisation. It appears that many PICTs have a built in cultural and system resilience (e.g. Samoa: developed in response to the 2009 South Pacific

tsunami). We need to understand this so that this existing resilience can be protected and enhanced, and current vulnerabilities reduced or eliminated.

2. *Improve governance structures, processes, policies and protocols.* This can be achieved by:

- Ensuring that there is a genuine integration of an all-hazards approach to risk management and better integration of Disaster Risk Reduction (DRR) with Climate Change Adaptation to ensure better outcomes for communities and governments with limited financial and human resource capacity[28];
- committing to ongoing, permanent educational and outreach programs to improve community understanding;
- incorporating other important stakeholder groups in DRR for PICTs (e.g. tourists: tourism is a significant component of the GDP of many PICTs. If tourists are not considered, significant market losses can occur when tourists go elsewhere following a hazard/disaster, thus compounding the problems faced during recovery efforts).

Tsunami risk management needs to adopt a 'coupled human-environment systems framework' in conjunction with the risk management process. Climate change and extreme climate events researchers are already using this approach. The tsunami science community has not yet caught up with other hazard scientists in using this approach effectively. In essence, we are not good at understanding the human and environmental context in which tsunami hazards become disasters nor the resilience within coastal communities and ecosystems and how to preserve and enhance that resilience[29].

3. *Improve communications infrastructure for information sharing and event monitoring.* This can be achieved by:

- Providing basic electronic information access to all communities, especially through the Internet and computers. This is essential for providing knowledge-building opportunities for everyone. Better and faster access at greater bandwidth will allow many more to learn much more, whether it is about tsunamis, hurricanes or other hazards, or about health, agriculture, education, or other day-to-day topics.
- Providing telephonic communications services, whether by fixed line or mobile (voice and/or text), that is affordable to everyone. It should not happen that many run out of mobile phone credits after a disaster, such as happened in Samoa 2009 immediately after the tsunami. Government can work with the telecommunications industry to encourage fair pricing or consider subsidies to allow for greater use.
- Providing robust communications for warning and emergency services, and for transmitting important monitoring (earthquake and tsunami) data to warning centres. Communication before for receiving alerts, during for monitoring impact, and after for declaring 'all-clear' safety and search-and-rescue response to disasters is a critical necessity.

Last, the Australian Government BoM report highlighted that no PICT has a comprehensive grasp of the tsunami risk from end-to-end. Furthermore, no PICT has a comprehensive tsunami risk management framework in place. As such, much work remains to be done and we advocate that many international and regional organisations can play a significant role in addressing the gaps that exist at present.

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