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Tsunami planning and preparation in Western Australia: application of scientific modelling and community engagement

Hall, Stevens and Sexton explain how a leading-edge tsunami impact assessments project combines science, technology and spatial data.

Abstract

Tsunami planning and preparation in Western Australia (WA) has been shaped by a collaborative project between the Fire and Emergency Services Authority (WA) and Geoscience Australia. The project has led to the development of tsunami impact assessments in communities identified as vulnerable to tsunami inundation. Tsunami preparation and emergency response plans have been initiated, based on community engagement workshops to increase stakeholder awareness of the science and risk of tsunami. The project has integrated data and expertise across State and Federal government bodies to build safer communities in WA.

This tsunami project demonstrates the advantages of combining science, technology and spatial data to achieve a leading edge risk assessment.

Introduction

The tragic events of the Indian Ocean tsunami on 26 December 2004 highlighted shortcomings in the response and alert systems for the threat of tsunami to Western Australia's (WA) coastal communities.

The relative risk of a tsunami event to the towns, remote indigenous communities, and infrastructure for the oil, gas and mining industries was not clearly understood in 2004. Consequently, no current detailed response plans for a tsunami event in WA coastal areas existed.

The Indian Ocean tsunami affected the WA coastline from Bremer Bay on the south coast, to areas north of Exmouth on the north-west coast, with a number of people rescued from abnormally strong currents and rips, personal belongings were reportedly inundated by wave activity at some beaches. More than 30 cm of water flowed down a coast-side road in Geraldton on the mid-west coast, and Geordie Bay at Rottnest Island (19 km off the coast of Fremantle) experienced five "tides" in three hours, resulting in boats hitting the ocean bed a number of times.

Vivid images of the devastation caused by the 2004 event across a wide geographical area changed the public perception of tsunami and demonstrated the potential enormity of impact from this low frequency, but high consequence natural hazard.

The source location of the Indian Ocean tsunami event, the Sunda Arc, is widely recognised as a high probability area for intra-plate earthquakes. WA's close proximity to the area demands a better understanding of tsunami risk through modelling of the potential social and economic impacts on communities and critical infrastructure along the Western Australian coast. Under WA's emergency management arrangements, the Fire and Emergency Services Authority (FESA), has responsibility for ensuring effective emergency management plans are in place for tsunami events across the PPRR[1] framework.

To improve community awareness and understanding of tsunami hazard and impact for Western Australia, FESA established a partnership with Geoscience Australia (GA) to utilise their considerable scientific expertise to develop numerical modelling capabilities, three-dimensional visualisations and GIS-based decision making tools for tsunami impact on selected WA coastal communities. Modelling has been completed for the north-west communities of Broome, Port Hedland, Dampier, Karratha, Exmouth and Onslow. These locations were selected following a probabilistic tsunami assessment for WA conducted by Burbidge et al, 2007 and combined with anecdotal evidence of community

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[1] Prevention, Preparedness, Response and Recovery (PPRR).

impact experienced from the Boxing Day 2004 tsunami. A second phase is now focussed on selected coastal communities from Carnarvon to Busselton including a number of Perth metropolitan coastal locations.

The best available scientific data has greatly assisted in shaping local land-use and emergency response planning. It also provides a tool to assist emergency responders in the event of a tsunami alert and guides community awareness programs undertaken by FESA. This project highlights the need for high-quality elevation datasets to support tsunami research.

Methodology

The tsunami project for Western Australia consisted of two parts:

- the scientific process, which considered the tsunami risk and;
- the preparation and emergency response required for a tsunami event, which involved community engagement workshops with stakeholders, to define the science and risk of tsunamis.

The project objectives were to:

- identify coastal areas that may be at risk from tsunami inundation;
- identify emergency managers and responders who require extra knowledge of the risk and challenges of tsunami;
- facilitate the local tsunami emergency response planning for each local government to be affected by tsunami;
- define differing roles and responsibilities of the emergency managers and responders;
- develop and implement a communication plan to raise stakeholder awareness of the potential impacts of tsunami; and
- enhance planning requirements under WA Emergency Planning legislation.

The Scientific Process

The scientific process adopted in this project followed the standard natural hazard risk methodology. This methodology starts with developing an understanding of the source and likelihood of the hazard. These factors are then combined with vulnerability and exposure models, to estimate potential risk. The process was underpinned by the needs of emergency managers and reviewed regularly through strong communication and interaction between FESA and GA.

The methodology adopted to assess tsunami risk is based predominantly on computational modelling. The methodology can be described by the following five key components:

1. A source model that describes the likelihood of a tsunamigenic source (earthquake, landslide, volcano or asteroid) initiating a tsunami of a given size and shape at a given location;
2. A tsunami deep-water propagation model to propagate the wave from the source to the shallow water off the coast of interest, typically 100m water depth. The results of this stage can be used to produce a tsunami hazard map for the region;
3. An inundation model to determine the run-up (maximum elevation above sea level reached by the wave) and inundation distance (maximum distance from the coast reached by the wave) at a given locality on the coast;
4. A vulnerability model that characterises the nature and magnitude of the damage that a structure will experience from a wave of a given amplitude and velocity, and;
5. An exposure database for the area of interest. Combining the hazard, inundation, vulnerability and exposure data together (steps 3 to 5), formed a tsunami risk assessment for the area concerned.

The outputs from steps 1 and 2 were critical in allowing FESA to undertake community profiling and identify communities at risk. The outputs consisted of probabilistic offshore tsunami hazard maps that describe the minimum offshore tsunami wave height for a given return period, or conversely, the probability of exceedence for a given wave height, Burbidge et al, 2007[2]. An example of an offshore tsunami hazard is seen in Figure 1 where the minimum offshore wave height has a chance of 1 in 500 years of occurring. Additionally, these outputs also allow the tsunami source to be identified that contributes to that hazard. Combining the inundation, vulnerability and exposure data together (steps 3 to 5), formed a tsunami risk assessment for the area concerned.

The modelling methodology has relied on two separate models; URS for the source model (see Wang et al 2006) and deep water propagation (based on the model of Satake et al 1992) and ANUGA (see Nielsen et al, 2005) for the inundation and impact ashore. The reason why two models are used are twofold; firstly, it is important to understand the offshore hazard separately so that locations can be prioritised for detailed modelling and secondly, it is computationally intensive to use one model to conduct inundation modelling at one location.

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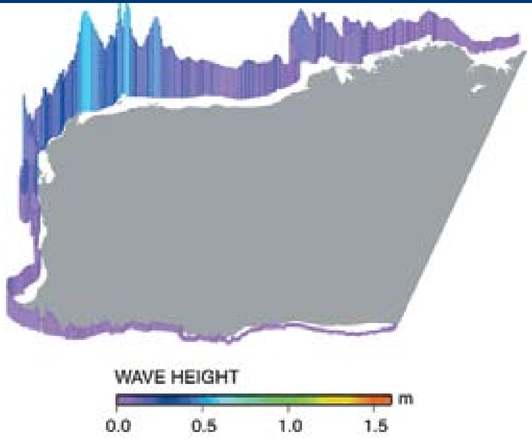
[2] For details on how the probability of tsunami hazard are calculated, see Burbidge et al, 2007.

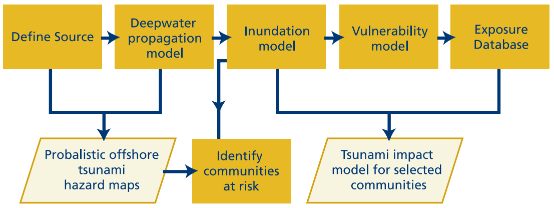
The URS and ANUGA models solve the same wave equations and utilise different computational methods that are advantageous to their prime purpose. Both these models have been validated against benchmark problems and continue to be validated against tsunami events when data is available. Each model requires a range of inputs. The source model component of the URS model requires geophysical inputs such as convergence rates and seismicity information, and the propagation component requires bathymetry grids. The output of the propagation component of the URS model is then an input to ANUGA. In addition, ANUGA requires bathymetry and topography at a much higher resolution than URS as the tsunami propagation behaviour is increasingly complicated in the near shore environment.

Figure 1: Offshore Tsunami Hazard Map describing the minimum off-shore tsunami height with a probability of exceedance of 1 in 500.



FESA used the hazard map to identify communities for detailed inundation modelling and to inform a discussion of the type of event they wished to plan for. FESA decided to plan for the plausible "worst-case" scenario which led to source events with a 1 in 10,000 year return period being selected from the hazard map. Three tsunamis were selected to be representative of the 1 in 10,000 year hazard for the North West Shelf with the larger of these events generated south of Java and the remaining two generated further east in the Sumba section of the Indonesian Arc, see Burbidge et al 2007.

Figure 2: Schematic of modelling process.



The deep-water propagation model was then coupled with the inundation model to estimate the inundation depth and speed and resulting extent. To make an impact assessment, the outputs from the inundation model were then coupled with exposure and vulnerability models to determine the effect on structures. The vulnerability models have been developed for framed residential construction based on limited data found in the literature as well as observations from the Indian Ocean tsunami event. The models predict the probability of collapse for an exposed population and incorporate the following parameters thought to influence building damage; inundation depth at building, distance from the coast, building material (residential framed construction) and inundation depth in house above floor level, Papathoma and Dominey-Howes, 2003. The scientific process is summarised in the schematic shown in Figure 2. However, there is limited data available to develop these models and observations from more recent events are assisting in the ongoing development of these models. Based on this limited understanding, the number of residential buildings is reported in terms of structural and contents losses, rather than damage.

The National Exposure Information System (NEXIS) contains information about building type, construction type, people, replacement value and contents value at buildings level, Krishna and Dhu, 2007. It is built from a number of fundamental datasets, such as Census, Mesh blocks, Cadastre, ABS Housing Survey and the Geo-coded National Address Framework etc. NEXIS-Residential is used to estimate the number of residential buildings affected by a tsunami event. Business or commercial buildings and infrastructure are not considered in this project as this NEXIS component is not yet mature and the vulnerability models are developed for residential buildings only. The input datasets are of various quality and resolution; therefore NEXIS derives building level information based on generic rules and assumptions which produce errors and uncertainties. Any estimates of damage based on this data therefore are compared on a relative scale, rather than in absolute figures.

Model Outputs

The information requirements of emergency managers and local land-use planners drove the scientific process and were identified during workshops across the State. Specific questions relating to impact included:

- what is the time between the earthquake event and arrival at the location?
- what is the extent of inundation from the tsunami impact?
- what damage is expected?
- what differences are expected if the tsunami arrives at the location at different tide levels?

Based on these questions, the model produced the following outputs:

- time of tsunami arrival;
- maximum inundation maps, and;
- estimates of number of inundated houses.

Maximum flow speed maps can assist in understanding the threat of tsunami in the offshore environment. These maps can be derived from the model and are now being recognised as important planning outputs.

To address the issue of tide, the model adopts a "bath tub approach", which means that the sea level is assumed to be at a range of different tide levels as the tsunami arrives in the area. That is, the tide is not dynamically modelled and as such, the assessments can be considered to overestimate the effect of the tide. For this project, the model is simulated at both Highest Astronomical Tide (HAT) and at Mean Sea Level (MSL) for each community (Australian Hydrographic Service, 2006).

Figures 3-6 show examples of the model outputs; travel time, maximum inundation at different tide levels, and maximum flow speed. The travel time map, Figure 3, provides a higher level of information for the State wide planning and response to events of this kind. For this hypothetical event, the travel time map indicates that once the tsunami arrives at Exmouth, it will impact Broome in less than an hour. This information would have consequences for emergency response in deploying resources over that distance. Figure 3 also shows how the travel time is affected by the shallow bathymetry on a regional scale. The maximum inundation maps, Figures 4 and 5, provide an estimate of the inundation extent thereby providing an indication of roads that could be cut and services potentially impacted. Figure 6 describes the maximum flow speed that could be used to assist the marine community in preparing for tsunami events.

Figure 3: Tsunami Model Output – Travel Time for a hypothetical event.

Figure 4: Maximum inundation map at Highest Astronomical Tide.

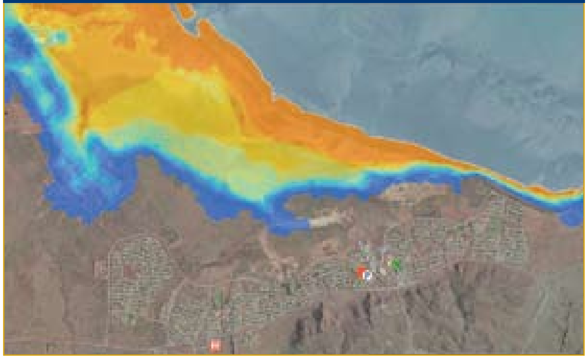
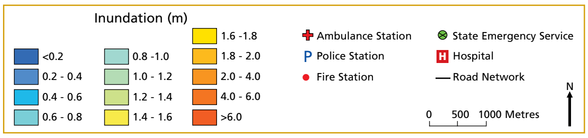
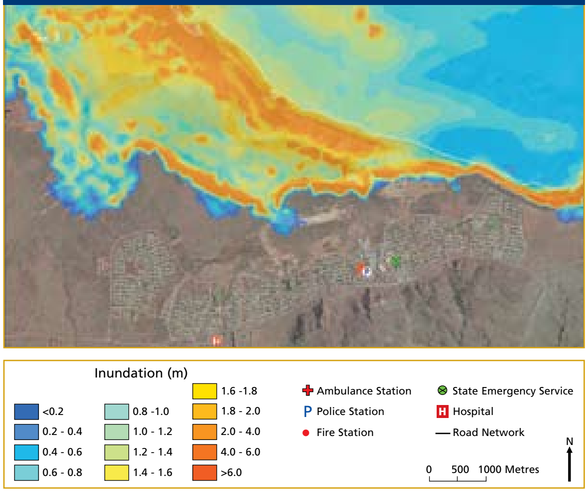


Figure 5: Maximum inundation map at Mean Sea Level.



Key is common for Figures 4 and 5.

Figure 6: Maximum flow speed map at Highest Astronomical Tide.



Scientific Findings

The key finding of this analysis is the important role the local topography and bathymetry play in protecting the six selected communities from onshore tsunami impact. In particular, the high beach dunes appear to have a significant role in the resultant inundation (both in a positive and negative sense) and the location at which the tsunami reached the highest elevation (i.e. run-up height), which typically occurred on the dunes themselves. It must be noted that the model does not take into account any changes to the topography as a result of the tsunami itself.

The greatest offshore flow speeds at HAT are up to 10 m/s (20 knots/36 km/hr) in some locations, which may pose an equivalent or even greater threat to the marine environment than the onshore impact. The flow speeds are slightly reduced at MSL, but may still be significant, especially close to, and on the beach. All of the model-based risk analyses to date have concluded that significant dangerous currents and rips are generated near-shore. This phenomenon has now been recognised by the local emergency management communities and incorporated into local emergency management plans. In particular, implications for recreational activity and commercial operations (offshore, on the beach and dunes) are being considered.

Travel time is dictated by a combination of distance from the source and the bathymetry to the coastal community. Importantly, once a tsunami is detected at the western end of the North West Shelf, it will be then impact the length of the shelf in under an hour. For each of the tsunami modelled, the first communities to be impacted are Exmouth and Onslow which are closest to the edge of the Continental Shelf. The last community to be impacted (out of the six considered) is Karratha which may be a result of the shallow water and the complex island chains in the region.

The Need for Elevation Datasets

This leading edge research would not have been possible without various organisations sharing geospatial information both in the marine environment and onshore areas of impact. The datasets underpinning the risk assessments were considered to be the best available at the time of modelling and have been sourced from Landgate and the Department of Planning and Infrastructure (DPI) within the State Government of Western Australia. These datasets have been supplemented with offshore data from the Australian Hydrographic Office (AHO) and Geoscience Australia (GA).

Some of the data is incomplete in coverage and verification of data quality has not always been easy or even possible.

The predicted tsunami impacts are sensitive to variations in elevation data and the tsunami source, and should be used with caution. This is an open area of research and the required resolution is not yet fully understood. Data coverage has not been consistent across the identified communities, which has been acknowledged when making comparative assessments. Western Australian agencies are now working more closely with other jurisdictions to develop and employ strategies for a nationally available and consistent data set. For example, the WA Land Information System (WALIS) marine group is working with the Department of Defence and other States to address these issues.

Validation and sensitivity analysis is currently being conducted in order to improve the accuracy and reliability of tsunami risk estimates in Australia. Importantly, while many of these improvements will come from national scale research, there is a crucial need to incorporate all available State datasets that could support this work. This includes up to date bathymetry and topography, which is invaluable for refining models as well as high resolution exposure data, which ultimately describes the tsunami impact to identified communities.

Tsunami Preparation and Response

In the preparation of the project plan, FESA community engagement included consultation with local government, remote indigenous communities, Emergency Management Committees, industry, tourist bodies and other community groups.

The approach used in this project was based principally on the input and guidance of local communities, FESA's experienced emergency service personnel, and through the scientific research gained from collaborative agreements with GA and the Bureau of Meteorology.

The project outcomes are:

- the community, industry, volunteer and career response groups, media, and local government will know the threat, risks and action to take for tsunami in at risk areas;
- emergency Managers are aware of the science, risks and threats of tsunami;
- emergency Managers will positively reflect their partnership responsibilities with the community, industry, volunteer response groups, media, and local government for the emergency management of a tsunami event;
- effective local, district and state emergency management arrangements are established and emergency management committees, the community, industry, volunteer and career response groups, media, and local government have embraced the preparedness requirements for tsunami;
- standard coordination and response protocols in an ‘all hazards’ context established;
- tsunami planning is embedded in local emergency planning by mid 2009; and
- where there is a risk of tsunami inundation, local government review land use planning.

Regional milestones were established to achieve staff and community awareness, development of local and regional emergency plans and an exercise and review phase was included to evaluate the response plans.

Figure 7: Community engagement at Broome.

Western Australia Project Implementation

The immediate priority for FESA was to design a secure and robust process to disseminate a tsunami warning or alert from the Joint Australian Tsunami Warning Centre (JATWC) in a timely manner to emergency managers, responders, community, and other stakeholders so local plans can be enacted.

The first phase of the project involved an Introduction to Tsunami Workshop (ITEM - designed by the Australian Tsunami Working Group and supported by Emergency Management Australia) for local emergency managers who have a key role in the preparation and response functions for a tsunami event in their area. In excess of 25 workshops were conducted across the State involving over 500 participants.

The second phase involved conducting special awareness sessions for the coastal and indigenous communities at risk. Attendees at these sessions included emergency managers and responders, emergency management committees, indigenous leaders, local government and industry. The purpose of these sessions was to bring the groups together and give them an understanding of the threat and actions they need to consider in the event of a tsunami warning or alert. The workshops were characterised by a high level of collaboration between all participants with a wide range of issues identified.

The third phase involved returning to the communities and assisting them with their local tsunami emergency management plans.. This included delivery of the set of tools that were designed from the scientific research conducted by GA to assist emergency responders in the event of a tsunami alert.

The final phase was conducting exercises at the State, regional and local levels. A total of four exercises were conducted over a one week period, and involved the Bureau of Meteorology notifying FESA of a tsunami warning or alert and this information being disseminated to the local emergency managers to implement local emergency tsunami plans. This dissemination occurred in a timely and effective manner.

Further Tsunami Research in WA

FESA and GA are currently undertaking tsunami impact modelling in the localities of Carnarvon, Geraldton, sections of the coastline of the Perth metropolitan area and Busselton. This risk modelling is scheduled for completion by December 2008 and is embracing the same community planning focus used for the north-west communities.

It also provides a model that other jurisdictions can adopt in understanding tsunami risk to their coastline.

National and International Awards

An Asia-Pacific Spatial Excellence Award – 2007 (in the category of Spatially Enabled Government) was jointly awarded to GA and FESA for their work on Tsunami Risk Modelling for Emergency Management. This award recognises projects that use spatial information and technology to improve government productivity, efficiency, service delivery, and help agencies integrate ‘customer-centric’ service delivery models.

The Australian Safer Communities Award - 2007 (sponsored by Emergency Management Australia), category of Pre-Disaster – Projects of National Significance, was jointly awarded to GA and FESA for their development and application of applying state of the art science to model tsunami risk, and the effective communication of this science to inform and underpin local emergency management plans and response arrangements in Western Australia.

Figure 8: Some of the FESA and Geoscience Australia team members.

Conclusion

The FESA – GA tsunami modelling has improved community safety in WA, by raising community awareness and providing a solid platform of knowledge on which emergency management planners can now base plans. It allows emergency managers to prioritise planning and mitigation activities for communities that are identified at greater risk and provides initial estimates of tsunami impact based on a selection of representative "worst-case" scenarios. FESA can now gain a picture of how a tsunami could affect the length of the WA coastline and also identify potential implications that may compromise emergency response infrastructure.

Emergency management planning is now based on a realistic understanding of the likely consequences of a tsunami in WA. This project has served to emphasise and highlight phenomena associated with tsunami that must be managed for an effective response.

Acknowledgements

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References

Burbidge, D., Cummins, P. and Mleczko, R, (2007) A Probabilistic Tsunami Hazard Assessment for Western Australia, Report to the Fire and Emergency Services Authority of Western Australia.

Wang, R., Martin, F. L., and Roth, F., (2006) Computation of deformation induced by earthquakes in a multi-layered crust – FORTRAN programs EDGRN EDCMP, Comp. & Geosc., 29, 195-207 (inc. erratum).

Satake K. Yoshida Y. Abe K., (1992) Tsunami from the Mariana earthquake of April 5, 1990: its abnormal propagation and implications to tsunami potential from outer-rise earthquakes. Geophys Res Lett 19:301–304.

Nielsen, O., Roberts, S., Gray, D., McPherson, A. and Hitchman, A. (2005) Hydrodynamic modelling of coastal inundation, MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australian and New Zealand, 518-523, URL: http://www.mssanz.org.au/modsim05/papers/nielsen.pdf.

Papathoma, M. and Dominey-Howes, D. (2003) Tsunami vulnerability assessment and its implications for coastal hazard analysis and disaster management planning, Gulf of Corinth, Greece, Natural Hazards and Earth System Sciences, 3, 733-747.

Nadimpalli, K. and Dhu, T. (2007) National Exposure Information System (NEXIS) for risk assessment, Proceedings of Spatial Sciences Conference, Hobart, May 2007.

Australian Hydrographic Service, (2006), Australian National Tide Tables 2006: Australia, Papua New Guinea, Solomon Islands and Antarctica and East Timor. Australian Hydrographic Publication 11.

About the authors

Russell Stevens is the Director of Research and Liaison at the Fire and Emergency Services Authority (FESA WA) and oversees FESA's tsunami research activities. Prior to taking up this role Russell was involved in emergency response and planning for 25 years.

Gordon Hall is currently the Director for Corporate Governance and Strategic Projects for the Fire and Emergency Services Authority (FESA) in Western Australia. Prior to this, he was the Project Director for the tsunami warning system for Western Australia following being a Regional Director for the State Emergency Service and FESA.

Dr Jane Sexton is currently leading the tsunami risk modelling activity at Geoscience Australia. Prior to this, Jane worked on applied mathematical aspects of defence acquisition and operational projects at DSTO following combustion projects at the University of Sydney.