VULNERABILITY ASSESSMENT AS A TOOL FOR HAZARD MITIGATION

ALLAN T. WILLIAMS [1,2] & RICARDO A. ALVAREZ[2]
[1] *Applied Science Department, University of Glamorgan, Pontypridd, Wales, UK.*
[2]*International Hurricane Centre, Centre for Engineering and Applied Sciences*
Florida International University, 10555 West Flagler Street, Miami, 33174, USA

Abstract

In emergency management, hazards are considered as sources of damage and damage reduction is the core of *hazard mitigation,* defined as the cost-effective measures taken to reduce the potential for damage on a community from the hazard impact. The equation seems simple: *HAZARD (SOURCE OF DAMAGE) +DAMAGE REDUCTION ALTERNATIVES = MITIGATION.* However, important questions arise when this definition occurs within the context of annual or historical damage from hazard impact. If the relationship is simple, why are damages, often repetitive, mounting as hazards strike vulnerable communities/specific facilities? *Knowledge gaps* exist regarding the causal relationship between hazards and the damage that results from their impact on the realm of human activity. These gaps reflect a general lack of understanding about the sequence of events that lead to actual damage. In the simplest terms, humanity is generally ignorant about its *vulnerability* to the adverse effects of hazards. Consequently, vast segments of human society continue to engage in building structures and facilities, in developing infrastructure, and in all the wide range of human activity seemingly without utilizing the assessment of its vulnerability as a tool to reduce the potential for damage from the impact of hazards. Truly effective mitigation – *hazard damage reduction* - must be based on a clear understanding of the causes of damage. This knowledge is gained by applying the methodology of *vulnerability assessment.* The methodology is applicable regardless of the specific types of hazards that may strike a community or facility. Assessment takes place at three levels: *Hazard identification* defines the magnitudes and probabilities of the hazard that threatens anthropogenic interests; *vulnerability assessment* characterises the population exposed to the hazard and the damage/injuries resulting; *risk analyses* incorporates the probability of damage/injury. As an emergency management tool, vulnerability assessment is a sound foundation for hazard mitigation. Vulnerability assessment and hazard mitigation must be essential components in the practice of any anthropogenic activity in a hazardous area.

A. C. Yalçıner, E. Pelinovsky, E. Okal, C. E. Synolakis (eds.)
Submarine Landslides and Tsunamis 303-313.

1. Preamble

Most weeks, the media brings news of disasters and catastrophes, causing death, injury, immeasurable human suffering and considerable damage to the built and natural environments. Poverty, war, and a coastal migration of people, together with poor infrastructures, make many world areas unprepared for these catastrophes. With each new disaster the cycle of blame allocation, finger pointing, calls for action and analysis of causes of damage, of lessons learned, not learned, begins again. A common thread in all this is the endless capacity of humankind to be surprised by the power inherent in nature, or its ability to render the best emergency plans quite ineffective in reducing potential damages.

The United Nations declared the period 1990-2000 as the International Decade for Natural Disaster Reduction (IDNDR), stressing that solutions should be supported at national level, but the fulcrum for all consequent mitigation measures should be implemented at the local level. In this decade, 82 tsunamis were reported, eleven causing >4,600 deaths and more than $1 billion damages [1]. Technology alone will not protect inhabitants in any potential tsunami risk area; awareness and the reading of nature's signals must be drilled into inhabitants in order to create a cultural mitigation.

2. Introduction

All tsunamis are potentially dangerous; although damaging ones are rare the potential for death and property destruction is huge. Tsunami hazards occur as a major event *circa* once every 100 years in the Atlantic. The 1755 Lisbon earthquake spawned in the Azores-Gibraltar fracture zone, generated waves that reached a height > 6m., off the southwest UK coastline, and *circa* 4m. for the USA east coast (Maul, *pers. comm*). In 1867, the Virgin Islands tsunami generated by an earthquake in the Anegada Trough caused huge damages in Puerto Rico and the Virgin Islands. In the Pacific 'Ring of Fire', some five tsunami events take place annually, but only one is large enough to be observed [2]. The 7.3 Richter scale earthquake in the Aleutian Islands in 1946 generated a 17m. tsunami wave height in Hawaii and $26 million in damages. The great Alaskan earthquake at Prince William Sound in 1964 measured 9.2 on the Richter scale and caused > $84 million damages in Alaska and 123 deaths. At Crescent City, Ca, the wave reached 6.3m. in height resulting in > $7 million damages [2]. The Krakatoa tsunami (1883) caused > 36,000 casualties, the Chilean tsunami (1868), >25,000. Since 1946, six tsunamis have caused $0.5 billion damages and killed 350 people in Hawaii, Alaska and the west coast of the USA [3]. Drowning is the main cause of death, however flooding; polluted water supplies and damaged gas lines all make a contribution. Turkey experienced a minor tsunami on the 17th August 1999 due to the Kocaeli earthquake in Izmit Bay. Minor damage and a few deaths occurred but these paled into insignificance when compared to the utter devastation caused by the earthquake to people (>15,000 deaths), homes (>60,000 made homeless) and the destruction of large-scale industries in a major economic region of Turkey [4].

Currently, a controversy exists re the possibility of the lateral collapse of the Cumbre Vieja Volcano in the Canary islands which would create the sub-aqueous 'La Palma slide' involving >500cubic km. of material. It has been postulated that this would produce a tsunami wave of some 50m. in height, that would cross the Atlantic and shoal at the eastern seaboard of the USA. A tsunami is *circa* a 100km wave and this tsunami would generate some 306,250,000,000 J/m energy per unit metre of wave front, or a force of 306,250,000,000 Newtons. If this scenario ever takes place, and it is very questionable, current mitigation measures would be miniscule and ineffective.

3. Hazard and risk

Assessments of hazard and risk are essential pre-requisites, indeed a required foundation for effective hazard mitigation, to the formulation of policies for the reduction of potential damage and managing risks for all situations. Both draw upon experience, the application of common sense, as well as data interpretation. Additionally, they are concerned with the future i.e. what has not happened, and always involve decision-making. Isolated measurements of risk are not very helpful when decisions are made for managing or developing policies for controlling hazards. Generally, these terms are interchangeable, although specifically a *hazard* is defined as a set of circumstances that could lead to harm i.e. death, injury or an illness of a person. The *risk* of such an event happening can be considered as the probability that it will occur as a result of exposure to a defined amount of hazard. Therefore, risk analysis is concerned with chance, consequences and context [5], whereas risk management is undertaken in order to reduce the adverse events identified by risk analysis. The *rate of incidence* (frequency of recurrence) can be viewed as the expected number of events that occur for this defined hazard amount. Probabilities and rates obey different mathematical laws, but if the events are independent and probabilities small, the two values are basically the same. Risks can vary from negligible - an adverse event occurring at a frequency of one per million plus e.g. an asteroid hitting the earth, to high - fairly regular events occurring at a rate of greater than one in a hundred, e.g. hurricanes, tsunamis. For example, with respect to the former, the chances of a category 1 hurricane striking a site specific spot in Florida is *circa* 3 per annum; a category 5, once in 5,000 years. For tsunamis, a damaging one can be expected in Hawaii/Alaska, once every seven years.

Risk reduction emphasises the vulnerability aspect of natural disasters and the differing perceptions associated with risk, as within social systems different cultural values exist. Currently, an intellectual vacuum seems to exist with respect to a theoretical framework between risk and disaster management. Perhaps in the 21st Century, the concept of impact thresholds should be stressed [6]. This would examine links between critical biophysical change (e.g. as a result of flooding associated with a tsunami, hurricane), and socio-economic (behavioral) impact. This would involve management, geography and risk, at a local or regional scale. In this instance, critical would refer to a local/regional scale.

4. Damage

The components of damage resulting from a hazard occurrence (tsunami, hurricane, typhoon etc.) can be sub-divided into direct, indirect and consequential, and the types classified as physical, structural, environmental, political, socio-economic. Direct damage can be quantified in a relatively easy manner, e.g. the replacement cost of houses, businesses demolished. The indirect and especially the consequential damages are much harder to assess. In the wake of many natural disasters, drunkenness, suicides, bankruptcy, psychological traumas - often with a variable time lag, occur which add to the indirect costs that wipe out the coherent social fabric of a community and seem incalculable on any monetary basis.No current mechanism is able to systematically identify and evaluate these latter factors.

5. Vulnerability

The etymology of the word, from the Latin noun *vulnus* = wound or the verb *vulnerare* = to wound, certainly evokes an image of pain, of suffering, i.e. of damage. Vulnerability *has* many meanings and is a dynamic natural process involving change. In order to be vulnerable, there must be a source of the damage i.e. a hazard and also a damage receptor, e.g. a community, environment. It can be defined as: the capacity loss of a system after a disturbance to return to its former dynamic equilibrium; the interaction of human activity with a hazard; interference of human activity with natural processes; incapacity of human activity to confront the consequences of impact from a hazard. There always has to be a two-way exchange because local factors including some under anthropogenic control, affect an area's vulnerability and it is a dynamic process as it continuously changes in response to population and urban development [7].

There are two types of vulnerability [8]:

• *Absolute*, which is a function of location, global processes and is beyond human control e.g. the siting of Japan, Hawaii in relation to tsunamis; tropical cyclones in Florida or the Caribbean; or earthquakes in California or Turkey.

• *Relative*, which results from specific factors present in any given location/site that may affect or modify how the hazard impacts the area. Some degree of control together with modifiers exists, and local factors would include, population density, culture, demographics, infrastructure (housing, communication), tourism, as well as geomorphological, ecological and other physical features.

The recognition that a region, community, facility, or site-specific factors exist, that can to some degree modify the impact of a hazard on the receptor community is of importance. It provides an opportunity for human society to exercise some control over the actual impact of a hazard to the extent that such local factors or modifiers can be analysed and understood. Relative vulnerability allows for the use of vulnerability assessment as a method leading to the identification of mitigation alternatives through an understanding of the causes of damage, the components of a hazard, and of the sequence of events that lead from impact to resulting damage. The assessment of relative vulnerability supports the practice of hazard mitigation.

6. Vulnerability assessment

The considerations examined above help establish that vulnerability assessment is a source of knowledge, a tool and a method to acquire additional knowledge about the causal relationship between a hazard and damage as well as about the mode of damage. To be useful as a tool for knowledge acquisition, the methodology itself needs to be logical, comprehensive and, above all, understood by those who can use it in the practice of the professions or duties on a daily basis.

A sound vulnerability assessment starts by charting the value at risk, meaning the actual monetary cost of replacing or repairing that, which may be damaged by the impact of a hazard. This includes the value of the human function not limited only to the economic losses associated with damage caused by a hazard, but also to the cost of interruption of any element of human function including that of governance. The methodology then assesses the hazard impact in terms of:

- Space, i.e. the geographic area that may suffer the direct strike from a hazard.
- Time, referring to the direct duration of a hazard. This could be seconds, as in the case of earthquakes, to hours as with tropical cyclones, to days and even years for drought and other extreme natural events.
- Intensity, meaning the actual category or magnitude of each hazard event as measured by pertinent ad-hoc scales, such as the Saffir-Simpson scale for hurricanes, or the Modified Mercalli scale for earthquakes.
- Frequency, which goes to the issue of what is the annual probability that a specific hazard may impact a given community.

This assessment methodology also identifies specific local factors, both natural and anthropogenic, that may either contribute to an exacerbation of damage or modify the actual impact on a location specific basis. The objective of this methodology is to provide analytical criteria, which may be used to obtain a realistic evaluation of the type and cost of damage that could result from the impact of a hazard on a location specific basis. Application of this method should provide a foundation for effective mitigation. From emergency management viewpoints, an understanding of the relative vulnerability of a region is absolutely essential in order to refine the response mechanisms to be implemented. Proper hazard mitigation can only be analysed and implemented if based upon a fundament of vulnerability analyses at various (local, regional, country) levels. Analysis must be based on a methodology that includes hazard assessment from a catholic spectrum of impacts (e.g. physical, structural, ecological, socio-economic). The level of understanding, or lack thereof, can directly affect preparedness, mitigation and response, as emergency plan components, especially with regard to location specific factors that can affect the relative vulnerability. This is a function of the level of resolution of the analysis. Methodological updating is another core essential.

Therefore, vulnerability assessment is an attempt to predict how different property types and populations will be affected by the hazard in question. As such, it comprises a fundamental data source inventory upon which to base any emergency response actions. A standard application is that of damage loss and these are termed deterministic as distinct from probabilistic assessments where probabilities are assigned to a complete scenario of possible events. Deterministic assessments can predict the demand upon emergency services, insurance loss, assistance etc. for any large-scale disaster. Housing areas, schools, hospitals, population, age ethnicity, income, health etc. all should be included in relevant databases and much of this information can come from census returns, tax assessments etc.

Many workers have developed methodologies of estimating the societal impacts of natural hazards, e.g. Perkins [9]. Building inventories should include type (wood, steel, reinforced concrete, etc.), location, age, are all-important facets of the inventory. A region's infrastructure takes into consideration roads, sewerage, water supplies, gas and electric supplies, bridges, and details are vitally important for any mitigation. Details of the economic vulnerability of the infrastructure are very important to any successful mitigation measures.

Mintzberg & Waters [10] have described four strategic management planning types: i) *Deliberate,* ii) *Imposed* iii*) Umbrella* and iv) *Emergent.* Of these, the latter two appear to be applicable to tsunami mitigation research, i.e.

iii).'*Umbrella type'*: applicable where elements of the environment are uncontrollable and unpredictable. Only general guidelines for behaviour can be set in such context i.e. overall boundaries are defined within which some parameters can be manoeuvred. This strategy requires the maintenance of a delicate balance between pro-action and reaction.

iv). '*Emergent type'*: this is appropriate where the environment is even more unstable or complex to comprehend. Such a system requires open flexible and responsive management styles.

7. Management and Mitigation

Tsunamis cannot be prevented or predicted and warnings seem unable to prevent destruction of boats, housing, or anything that lies in the path of the runup, but areas at risk can be identified and stringent controls put into place. For example, avoidance of potential runup areas for buildings, placing of potential inundation areas under a floodplain zoning, constructing breakwaters or wave-energy attenuating structures at harbour entrances, planting tree belts between shorelines and areas needing protection, having adequate warning systems (real time) in place, setting in place sound construction and building elevation standards and have streets/homes aligned perpendicular to the wave advance, public education campaigns, etc.

For all the above, when a tsunami or any other natural hazard breaks on a densely populated area, emergency plans are often inadequate and inhabitants frequently seem surprised at the results. *Reduction of the potential for damage is the key objective of mitigation*. Mitigation is those actions taken singly or in combination, which attempt to rectify impacts, associated with a particular activity i.e. a natural hazard. The goal '*should be to substantially increase public awareness of natural hazard risk so that the public demands safer communities in which to live and work'* (Jamieson and Drury; [p257; 11]).

The Puerto Rico Tsunami Warning and Mitigation programme can be taken as an exemplar of the above [12]. It emphasises the preparation and supply of tsunami flooding and evacuation maps together with awareness raising of the potentially affected populations. The latter will:

- Hold regional conferences (with representatives from state/regional/local emergency managers, schools, hospitals, hotels, and industries) for potentially tsunami hazard areas.
- Place tsunami hazard signs in exposed coastal locations urging people to seek higher ground if shaking ground can be felt.
- Carry out evacuation exercises.
- Utilise the WEB to give tsunami information, flood maps, information.
- Produce a tsunami video from the Caribbean viewpoint.

In addition, a network of seismic networks termed the Puerto Rican Seismic Network, (PRSN) will be centred on the University of Puerto Rico and part funded by the US Federal Emergency Management Agency (FEMA). Partnership in the National Tsunami Hazard Mitigation Programme (with the states of Alaska, Washington, Oregon and Hawaii), is envisaged. The Caribbean is unique in that as well as having tsunami potential via earthquakes, slumping and volcanic activity it may also have seismic induced waves as a result of hurricanes or low pressures.

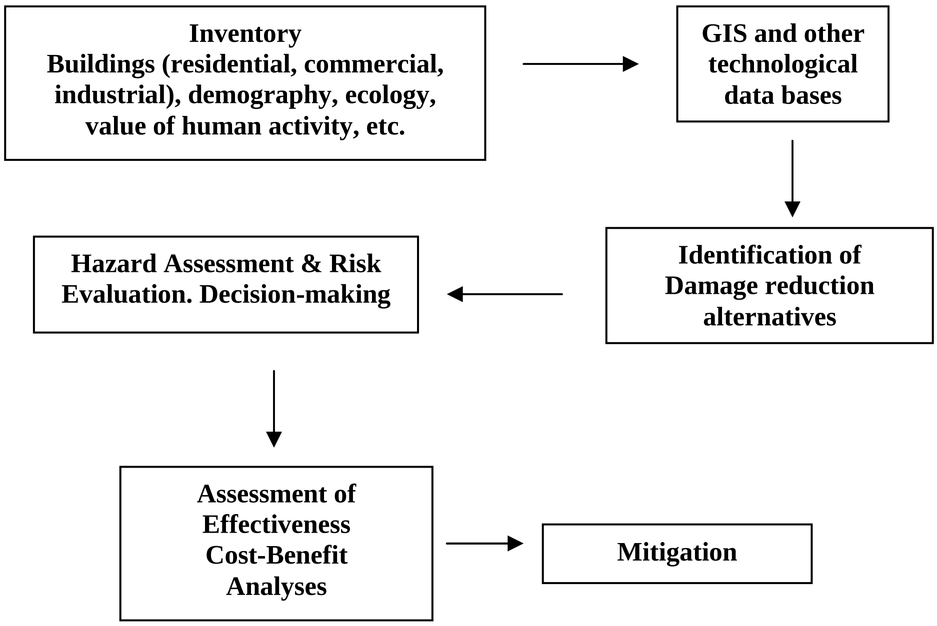

Figure 1. Mitigation flow chart.

Change in coastal systems generates through interaction between the objective and subjective variables that constitute the environment. Huge changes in coastal systems, occur as a result of large-scale natural disasters, such as tsunamis, hurricanes. This change occurs via interaction between objective variables (quantifiable measurements i.e. the scale of the tsunami, hurricane, volcanic eruption etc.), and subjective variables (set within the complex of socio-economic and cultural factors). The latter are much more difficult to quantify. Effective mitigation strategy depends upon a detailed management planning procedure concerning structured data collection pre a natural disaster plus the availability of correct quality information during the event, so that clear guidelines are set (Figure 1). Emphasis should be placed on the gathering of reliable, sufficient, impartial, consistent, comprehensive information that can be of predictive value. Data must be organised into a logical format particularly where problems are complex, as in natural disaster areas [13]. It is an axiom that management of nature/anthropogenic interactions is always concerned with, *'mutual interactions and feedback based on power differentials, conflicting values and competing interests and expectations'* (Boehmer-Christiansen, p84; [14]).

Long-term behavioural characteristics to natural disasters may be identified/responded to via a strategic management approach, as policy making has an inexact and non-scientific nature that is characterised by considerable uncertainty and ambiguity [15, 16]. This is evidenced by the 'surprise factor' that occurs in virtually all such natural disasters, epitomised by the, '*it will not happen to me'* attitude, or the cognitive dissonance factor of people blocking out unwelcome reality and believing only what they want to believe. Therefore, management mitigation decisions should be based on models that have:

- Evidence obtained from environmental monitoring
- A set of clear objectives
- Evaluation of strategic options.

The ultimate tsunami mitigation strategy is to keep people and critical facilities away from areas prone to flood. Bernard [1], postulated three effective paradigms that would save lives:

1.Develop high-resolution tsunami inundation hazard maps to identify areas liable to flood. Numerical models now exist that can simulate tsunami behaviour and estimate the extent of potential flooded areas. These should be locally based and mapped ((hardcopy and electronic format) on scales of 1:2000 or less. GIS systems now make this task routine, but greater precision means greater costs. Building foundations should be deep enough to reduce erosion and scour, and buildings should be elevated above the flood levels

2.Implement/maintain a community wide awareness/educational programme on tsunami dangers to provide community understanding and commitment. Education, is frequently commented upon as a panacea for virtually all matters, but it is crucial in hazard mitigation strategies and stakeholder participation is a mandatory aim. It would include evacuation procedures, practice drills, video presentations etc. as disaster mitigation should be the responsibility of all citizens. This should be carried out in the communities. To date, it appears that people still need to increase awareness, preparation and response to warnings, but awareness is *'the most cost effective way to create a tsunami-resistant community'* (Bernard, p60; [1]). A lack of impact expectation, minimal preparation, and confusion still appears to be the norm in many areas – see below.

3.Have an *efficient* early warning system in place to alert coastal inhabitants about the potential forth-coming danger. Many false alarms have been triggered off by regional systems as currently many do lack precise accuracy. A May 1986, a false alarm in Hawaii cost an estimated $30-60 million in lost business revenue and it also undermined credibility

The above points are exemplified in the following two case studies. On 12 July 1993, a tsunami struck the village of Aonae, Japan. Eighty five percent of a population of *circa* 1,400 people were saved simply by moving to high ground at the onset of the earthquake [17]. The 17th July 1998 tsunami at Papua New Guinea (PNG) generated from an earthquake epicentre 12km. offshore (magnitude of 7.1), had a wave of *circa* 10m in height, which affected an area some 30km wide along the northern coast of PNG where the highest land elevation was some 3m. Three villages arranged alongside the Sissano lagoon were devastated and out of a total population of some 10,000, over 3,000 died [18]. Dengler and Preuss [19], concluded that more than half the population of 2,730 people inhabiting the village of Warupu survived as a result of knowledge about tsunami behaviour. Awareness saved many, but many died due to no vertical elevation structures.

Demonstration micro-projects, as carried out by the European Community Humanitarian Office (ECHO), have stressed preparedness via the Disaster Preparedness ECHO (DIPECHO) programme. To be effective this needs to have up to date accurate information and the means of disseminating that information quickly through the media.

TABLE 1. A Hazard Mitigation Summary

HAZARD	A source of danger that may cause damage.
MITIGATION	To soften, mollify, make less harsh.
HAZARD MITIGATION	Cost-effective measures to reduce the potential for damage from hazards.
H AZARD MITIGATION ACTIONS	a) Acts upon the hazard – e.g. fire fighting. b) Keeps the hazard away – e.g. flood control. c) May interact with a hazard – e.g. hurricane shutters. d) Keeps people away i.e. relocate – e.g. relocation. With respect to tsunamis, b) and d) are the main actions.
LONG TERM HAZARD MITIGATION	a) Strengthening building codes. b) Strict zoning regulations. c) Responsive development. d) Education/Awareness.
WHEN TO MITIGATE	a) During the design phase of new buildings. b) During the restoration effort post a disaster. c) At any time as a retrofit. d) During the daily practice of a profession/job. e) When planning for development or re-development of a community.
VULNERABILITY ANALYSIS	a) Sets the foundation for effective mitigation. b) Commences with hazard assessment. c) Documents time, space and frequency components of the hazard. d) Reviews the physical, social and economic aspects.
ACTIONS	a) Macro (Regional) mitigation b) Micro (Site specific) mitigation. c) Damage function (benchmark) d) Cost-benefit analysis. e) Environmental issues.

When a natural hazard strikes, the ‘well oiled machinery’, rarely functions smoothly with the best-laid plans all tending to stutter along, but summary checklists, as depicted in Table 1, can help the process. Better interdisciplinary, inter-agency and sectoral co-operation should be the norm, but frequently a lack of co-ordination and leadership prevails. Governmental support via legislation if necessary should be a common denominator for natural disaster prone areas. For example, in Turkey, there exists no national co-ordinating agency for disaster management. The nearest that currently exists is termed ‘The National Preparedness Plan; law number 7269.’ Additionally, the development of regional, national and international incentives should be enhanced in order to encourage localities, regions, and countries to practice mitigation in order to reduce the adverse consequences of any disaster. The creation of natural disaster research, education centres and/or schools would be an extremely advantageous measure for any state or country. The syllabus should concentrate on remote sensing, GIS, sound data acquisition/transfer especially for low lying, high risk, flood prone areas, geomorphology, erosion trends, socio-economic characteristics, including valuations, i.e. Willingness to Pay and Contingency Evaluation, sea level changes, ecological, hydrological, meteorological, studies etc.

8. Conclusions

The continued development of coastal areas plus population growth ensures a higher vulnerability and loss probability in the event of an impact from a natural hazard. Real time warning, mapping of inundation and wave run up limits and public education/awareness campaigns are the main key tsunami hazard mitigation concerns. It is of paramount importance that people understand the vulnerability of the natural and human systems, together with the measures that must be taken to reduce the potential for damage. Public Disaster plans have to be developed which must have the support of all stakeholders. Hazard mitigation relates to any cost-effective measure undertaken to reduce the potential for damage from a hazard, but the limits of cost/benefit analyses are well known. The hazard can be a hurricane, tsunami, earthquake, etc., but mitigation matters remain fairly constant irrespective of the natural disaster. Hazard identification is the fundament re disaster mitigation measures. The base line for these studies should be the local area and integration of mitigation planning into local decision process is imperative, but many communities rarely use formal risk analyses. The growth of GIS, and usage of other technologies such as LIDAR (LIght Detection And Ranging) and computer-based simulation and visualization, now enables planners and scientists to utilise probabilistic risk analyses to predict impacts and assess cost-benefits of various management strategies. However, there is limited knowledge of the probabilities/magnitudes of many events. This is often coupled with poor regional building codes along with scant Legislature and/or Institutional implementation of mitigation measures; the existence of communication gaps between local vested interests and pure science based researchers who couch hazard assessments in a highly technical language. The preservation of wetlands, currently under threat in most areas of the world, should be done, as these act as buffers to flood waters. This infers that there is a long pathway to travel before reaching the optimum mitigation strategy for any potential natural hazard. Goethe commented that, '*nature understands no jesting. She is always right, and the errors and faults are always those of man.*' This is extremely applicable to tsunami mitigation.

Acknowledgements

We wish to thank Prof. George Maul, Florida Institute of Technology, Miami, USA and Prof. Aurelio Mercado-Irizarry, Dept of Marine Sciences, University of Puerto Rico, Mayaguez, PR, for their detailed advice and insight regarding tsunamis in general. Many meaningful discussions were held with Mr. Scott Caput, International Hurricane Centre, Florida International University, Miami, USA, and we thank him. However, the views expressed are the authors and do not necessarily reflect official university policy. ATW wishes to acknowledge financial help from the Andrew W. Mellon Foundation.

References

1. Barnard, E. (1999). Tsunami. In, Jon Ingleton, (ed.), *Natural Disaster Management*, Tudor Rose Ltd. Leicester, UK, 58-60.
2. Lander, J.F., Lockeridge, P.A and M.J. Kozuch (1993). *Tsunamis Affecting the West Coast of the United States, 1006-1992, Key to Geophysical Records*, Documentation, N0 29. NOAA, National Geophysical Data Centre, Boulder, Colorado, USA.
3. www.redcross.org/services/disaster/keepsafe/tsunami/html
4. Yalciner, A.C., Synolakis, C.E., Borrero, J., Altinok, Y., Watts, P., Imamura, F., Kuran, U., Ersoy, S., Kanoglu, U., and S. Tinti, 1999. Tsunami Generation in Izmit Bay by the 1999 Izmit Earthquake. *Proceedings of ITU-IAHS International Conference on the Kocaeli Earthquake*, Istanbul Technical University, Turkey, December 1999, 217-220.
5. Elms, D.G. (1992). Risk Assessment. In, D Blockley, (ed.), *Engineering Safety*, MacGraw-Hill International Series in Civil Engineering, London, 28-46.
6. Jones, R.N. 2001. An Environmental Risk Assessment/Management Framework for Climate Change Impact Assessments. *Natural Hazards.* 23 (2-3), 197-230.
7. Mitchell, James K., (ed; 1999) *Crucibles of Hazard: Mega-Cities and Disasters in Transition,* United Nations University Press, Tokyo, New York, Paris.
8. Alvarez, Ricardo. A (1999). Tropical Cyclone. In, Jon Ingleton, (ed.), *Natural Disaster Management,* Tudor Rose Ltd. Leicester, UK, 34-36.
9. Perkins. J.B. (1992). *Estimates of Uninhabitable Dwelling Units in Future Earthquakes Affecting the San Francisco Bay Region*. Oakland, California: Association of Bay Area Governments, San Francisco, Ca, USA
10. Mintzberg, H. & Waters, J.A. (1989). Of Strategies, Deliberate and Emergent. In, D, Asch and C. Bowman, (eds.), *Readings in Strategic Management,* Macmillan, London, in association with the Open University, 37-56.
11. Jamieson, G. and Drury, C. (1997). Hurricane Mitigation Efforts at the US Federal Emergency Management Agency. In, H.F. Diaz and R.S. Pulwarty, (eds.), *Hurricanes: climate and socio-economic impacts*, Springer-Verlag, Berlin.
12. www.poseidon.uprm.edu/welcome.html
13. Taylor, J.W. (1961). *How to Create Ideas*. Prentice Hall, Inglewood Cliffs, New Jersey, USA.
14. Boehmer-Christiansen, S. (1994). Politics and Environmental Management. *Journal of Environmental Planning and Management,* **37 (1)**, 69-85.
15. Donaldson, G. and Lorsch, J.W. (1983). *Decision Making at the Top*. Basic Books, New York, USA.
16. Lentz, R.T. and Lyles, M.A. (1989). Paralysis by Analysis: is your Planning System Becoming too Rational? In, D. Asch and C. Bowman, (eds.), *Readings in Strategic Management*, Macmillan, London, in association with the Open University, 57-70.
17. Barnard, E. (1998). Program Aims to Reduce Impact of Tsunamis on Pacific States. *Eos, AGU*, 70(22), 258-263.
18. www.geocities.com/CapeCanaveral/Station/Lab/1029TsunamiPNG.html
19. Dengler, L. and Preuss, J. (1999). Reconnaissance Report on the Papua New Guinea Tsunami of 17July, 1998, in, *EERI Special Earthquake Report* January 1-8.