Selection of appropriate hazard levels for coastal hazards mapping of variable shoreline types

Richard A. Reinen-Hamill[1] and Tom D. Shand[1]
[1]Tonkin & Taylor Ltd, Auckland

Abstract

Many local authorities with a coastal edge as one of their administrative boundaries have the onerous task of managing appropriate development that both enables economic and social development while maintaining environmental values and avoiding hazards. There are a variety of shoreline types to manage, including both cliff and soft shores, as well as a plethora of hazards to plan for, such as structural erosion, storm effects, landslides, earthquake, weathering, storm surge and tsunami; all with a range of likelihoods and consequences. Coastal Hazard Mapping is a well used and familiar technique that assists in this process. However, interpretations on the level of risk with which to base the mapping on can be problematic with variable data sets and the consideration of joint probability of events as well as uncertain climate change effects. This paper identifies the various components typically used for coastal hazard mapping and presents suggested modifications to return periods for coastal hazards that could enable a more consistent and rigorous approach to both broad level hazard assessment and more detailed site specific assessment, considering risk, design life and consequence.

1 Introduction

The vexed issues of coastal hazards, climate change and increasing pressures for (re)development and intensification along the coastal margin is occupying significant time and energy for a plethora of private and state professionals. Even in existing developed areas, changes in development and use, as well as increasing land value, affects the public's expectation on the required amenity as well as the values of assets at risk.

The impacts of natural hazards have been increasing in almost every country, particularly in terms of economic and insured losses. Hydro-meteorological hazards have been increasing disproportionately with respect to other hazards and may be related to climate change effects (Tonkin & Taylor, 2005).

Determination of appropriate risks is hampered both by a lack of consistent guidelines and with varying levels of understanding of likelihood and probability from stakeholders involved in the process.

The task of the coastal manager is to determine reasonable buffers to reduce the risk of hazards, provide for public amenity and environmental enhancement, but not to the cost of unfair limitations of economic development on land fronted by the sea.

2 Coastal hazards

The impact of coastal hazards on society is substantial. Every year erosion, storms and tsunami inundation claim or injures thousands of lives, devastates homes and destroys livelihoods. Indeed, on a global stage the costliest natural catastrophe in recorded history in terms of human life was as a result of a significant tropical storm in Calcutta, India during 1937, where more than 300,000 lives were lost. This storm is closely followed by the 2004 Sumatra tsunami (> 290,000 lives lost) and a tropical storm affecting Mumbai, India in 1882 where 100,000 lives were lost. Coastal hazards, are also responsible for some of the largest economic losses, such as Hurricane Katrina in 2005 that had an estimated economic loss of more than US$100 billion (Munche Re, 2005).

In the Australian and New Zealand context, hazards typically include: cyclones, tropical storms, tsunami, structural (progressive) shoreline retreat and land slides. Recent flooding and debris flow events in New Zealand have challenged the effectiveness of existing protection infrastructure and heightened public awareness of the impact of natural hazards and the wisdom of allowing new development in areas of risk.

Since the Sumatra tsunami, increased investigation of tsunami risk has significantly reduced return period estimates of large tsunami (Berryman, 2006). Due to climate change effects, such as increased climate variability and accelerated sea level rise, there are areas where the effect of many of these hazards may increase.

Hazard assessment is a vital part in the whole risk assessment that involves:

- Identifying the hazard
- Identifying the risk
- Analyzing the hazard
- Analyzing the consequences
- Calculating the risk
- Evaluating the risk
- Treating the risk.

Risk assessment is carried out in a series of related activities that build up a picture of the hazards and vulnerabilities that explain disaster events:

Risk = [probability of hazard] x [consequence of social/economical loss]

A fundamental concept of risk management is that there is a degree of risk that is acceptable or tolerable. To enable decisions to be made, risks are typically banded into three distinct levels of 'broadly acceptable', 'tolerable' and 'unacceptable'. The upper and lower bounds of these bounds are typically defined in terms of loss of life of other form of probability. In the tolerable risk zone, risks should be *as low as reasonably practicable* (ALARP).

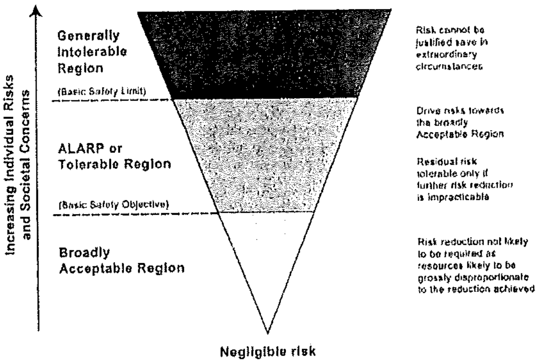

Figure 1 ALARP principle (Source: AS/NZS, 2004)

From our experience, the definition of what is tolerable varies significantly from stake-holder group to stake-holder group. In terms of coastal hazard for the beach front property owner whose land is at stake from erosion trends, erosion is typically unacceptable, even if there is no significant risk of loss life. However, from the community point of view, in terms of potential cost to the wider community for coastal protection and/or environmental or amenity matters, it is more likely the beach front property owner, rather than nature, who is seen as the villain.

3 Evaluation process

Hazard identification and quantification requires information of the particular hazard being assessed and understanding of the triggering agent and response.

There are a number of ways hazards can be estimated. It some circumstances it may be possible to calculate hazard and express it quantitatively. In other cases, qualitative estimation may be the best that can be achieved based on the information available. Often qualitative assessments rank the likelihood of occurrence into classes using various sources of quantitative evidence, such as:

- Extreme
- Very likely
- Likely
- Possible
- Unlikely
- Very unlikely
- Rare

In our experience, qualitative assessments have been carried out for district and regional level hazard assessments, while quantitative assessments are more typically seen for site specific assessments covering a smaller area or, more recently, single hazards, such as tsunami.

Ultimately, quantitative estimation provides an objective, reproducible measure of hazard that can be compared and evaluated along with other similarly estimated hazards.

4 Return period requirements

New Zealand case law points to a 100-year planning horizon, particularly for coastal hazard planning. Consideration also needs to be given to events of low frequency that have the potential to cause catastrophic effects (Tonkin & Taylor, 2005), although the probability of these events are not clearly identified.

In New Zealand, residential design is controlled by the Building Act, which defines a permanent building as having a design life of 50 years, with a requirement of flooding of a 2%AEP rainfall event not entering the building. However, there has been a recent move by some council's in New Zealand to increase the flood level requirement to 1%AEP rainfall.

New subdivision is controlled by the Resource Management Act and under S106 of this Act requires authorities to decline subdivision consent, or to grant consent subject to conditions, if there is or is likely to be material damage to land or structures.

The term "likely" is undefined and is the subject of much debate during these consent hearings. In the case of *Kotuku Parks Ltd v Kapiti Coast DC* EnvC A73/2000 noted [2000] BRM Gazette 89 the Court decided that because it is not standard practice to design for catastrophic events with long return periods (events that occur every 250 to 400 years were discussed in the case), s106 would not apply to damage from such events. The implication of this decision together with the one above, is that the low probability events required to be considered in terms of subdivision therefore have return periods of less than 250 years.

Table 1 shows alternative definitions of return period events associated with the qualitative rankings of likely to rare as included in an example in the AS/NZS standard, landslide risk and general geotechnical hazards. It is noted that the AS/NZS definitions do not appear consistent with the other definitions for natural hazards. Table 2 shows AEP for normal structures (such as residential housing) and community structures for wind and earthquake loading based on the loading code for structural design (AS/NZS 1170.0:2002). Table 3 shows indicative standards of flood/erosion protection used in recent flood publication in the UK (FCDPAG3, Defra, 1999). This publication separates coastal flooding from catchment induced (fluvial) flooding.

Table 1 Alternative definition of return period assigned to qualitative assessments

Term	AS/NZS 4360 (2004)	Landslide (Moon & Wilson, 2004)	Australian Geomechanics Society, 2000
Extreme	1	<5	10
Very likely		5-10	
Likely	3	50-500	100
Possible	10	500 - 5,000	1,000
Unlikely	30	> 5,000	10,000
Very unlikely	100	>>>5,000	100,000

Table 2 AEP for normal structures and community structures (AS/NZS 1170.0:2002)

Ultimate limit states				Serviceability limit states
Design working life	Type	Wind	Earthquake	
50 years	Normal	1/500	1/500	1/25
	Community	1/1000	1/1000	1/25
100 years	Normal	1/1000	1/1000	1/25
	Community	1/2500	1/2500	1/25

Table 3 Indicative standards of flood/erosion protection (Defra, 1999)

Land use	Definition	Fluvial		Coastal	
		RP	AEP	RP	AEP
A	Intensive urban development	50-200	0.005-0.02	100-300	0.003-0.01
B	Moderate urban, high value agricultural land and/or environmental asset	25-100	0.01-0.04	50-200	0.005-0.02
C	Camp grounds, high value agricultural land, environmental assets	5-50	0.02-0.20	10-100	0.01-0.10
D	Mixed agricultural land, including flood prone	1.25-10	0.10-0.80	2.5-20	0.05-0.40
E	Low grade/grassed area	<2.5	>0.4	<5	>0.2

Table 4 Design risk for a range of ARI/AEP for 50 and 100 year design life

	ARI	10 years	20 years	50 years	100 years	500 years	1,000 years	2,500 years
	AEP							
Design life		P= 0.1	P=0.05	P=0.02	P=0.01	P= 0 .002	P=0.001	P=0.0004
50		99.5%	92.3%	63.6%	39.5%	9.5%	4.9%	2.0%
100		100.0%	99.4%	86.7%	63.4%	18.1%	9.5%	3.9%

It can be seen from the tables that there is some anomaly between likelihoods for structural design consideration and the requirements within the key legislation for assessment of effects. Typically the tabulated likelihoods are an order of magnitude higher than the policy documents.

It is evident that design risk is used to determine return period events for structural design shown in Table 2. The *design risk* is related to the annual exceedence probability according to the statistical relationship:

$$\text{Risk} = 1 - (1 - Q(Z))^{T}{}_{L}$$

Where T_L is the design lifetime and Q(Z) is the probability of an erosion setback being exceeded in a single year. The relationship between the risk of encountering an extreme erosion event with approximate annual probabilities of 1/10, 1/20, 1/50, 1/100, 1/500, 1/1000 and 1/2,500 over a planning period of 100 years is shown in Figure 2 and Table 4.

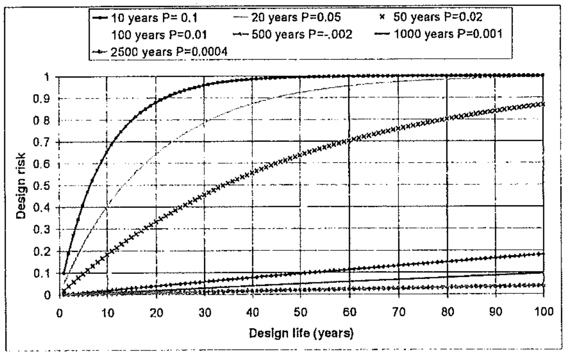

Figure 2 Illustration of design risk over 100 year design life

This data shows that there is around a 63% chance of a 1/50 annual probability event (P=0.02) occurring over a 50 year design life, or of a 1/100 annual probability event (P=0.01) event occurring over a 100 year design life. In our experience, this reality is not well understood, particularly within the general community and those within the industry with a less robust knowledge of statistics. As an example, the following is an extract from an email discussion from one of our clients, who shall remain anonymous:

> *"..But even working with the 100yrs/1%AEP surely we are comfortable, because a 1%AEP equates to a 100% chance of an event occurring in a 100yr period."*

Clearly this demonstrates a misunderstanding on the actual likelihoods, as a 1/100 annual probability event is more than likely to occur within a 100 year period, but even a 1/10,000 annual probability has a 1% chance of occurring.

The New Zealand regulators appear to feel uncomfortable with the 1/50 and 1/100 annual exceedance probability (2%AEP and 1%AEP) definition as there are significant freeboards of up to 1 m and other factors added to flood levels based on these exceedance rainfall events.

For the coastal protection of the Netherlands a 1% design risk (i.e. 0.01% AEP, or 1/10,000 annual probability of exceedance) is used for a 100 year design life and for many British coastal protection schemes a design risk of 10% (i.e. 0.1% AEP or 1/1,000 annual exceedance year return period event) is typically applied for the same design life (Pugh, 2004).

Examining Table 2, it can be seen that a 10% design risk has been used to determine the return period for design with consideration of a 1/500 annual probability of exceedance with a 50 year design life for normal structures and a 1/1,000 year annual probability of exceedance for a 100 year design life. Less frequent events are required to be considered for community structures. These return periods equate to "likely" or "possible" risk scenarios in Table 1 based on Landslide or Australian Geomechanics Society criteria.

Table 5 shows a suggested delineation of appropriate probabilities for the likelihood of natural coastal hazards in terms of design risk and design life based on my judgement. Table 6 shows a simplification of return periods for likelihood assessments.

Table 5 Possible annual probabilities for selected design life design

		Annual probability for design life of:	
Term	Design risk (%)	50 years	100 years
Extreme	98	1/13	1/26
Very likely	85	1/27	1/53
Likely	40	1/98	1/196
Possible	10	1/475	1/950
Unlikely	5	1/975	1/1,950
Very unlikely	1	1/4,975	1/9,950

Table 6 Simplification of annual probabilities for likelihood assessments of coastal hazard

	Annual probability for design life of:	
Term	50 years	100 years
Extreme	1/10	1/25
Very likely	1/25	1/50
Likely	1/100	1/200
Possible	1/500	1/1,000
Unlikely	1/1,000	1/2,000
Very unlikely	1/5,000	1/10,000

It is suggested that these annual probabilities should be used to determine the particular event, and where there are a number of factors, the cumulative assessment of these factors should be determined to reach the annual probability of exceedance.

A joint exceedence approach could be used to determine the combination of events. This is a simplified approach that involves the derivation of joint probability contours (lines having equal joint occurrence probability, constructed by considering the probability of exceeding a specified level in Variable 1, whilst at the same time exceeding a specified level in Variable 2). Dependence is assessed empirically and is used to calculate the joint occurrence probability.

For example, when considering the sea inundation likelihood for a building, the coincidence of a 1/50 year annual exceedance probability storm surge (AEP=0.02) with a 1/10 (AEP = 0.1) predicted tide level has a combined annual exceedance probability of 500 years (AEP= 0.02 x 0.10). This could be one condition used to assess possible effects for a 50 year design life structure for a 10% design risk, although other combinations of events should be considered. For a subdivision with a longer intended design life a 0.01 AEP storm surge event with a 0.10 AEP water level would be one combination of events that would produce a 1/1,000 year annual exceedance probability (also a 10% design risk over a 100 year period).

5 Temporal changes

In addition to probabilistic events, there are temporal changes that need to be taken into account in hazard assessments. These can include temporal factors such long term rates of shoreline change or the increase in sea level. The effect of these temporal changes can increase the design risk over the design life.

Figure 3 shows a comparison of a standard design risk with one that takes into account a uniform annual change, progressively increasing the design risk over time.

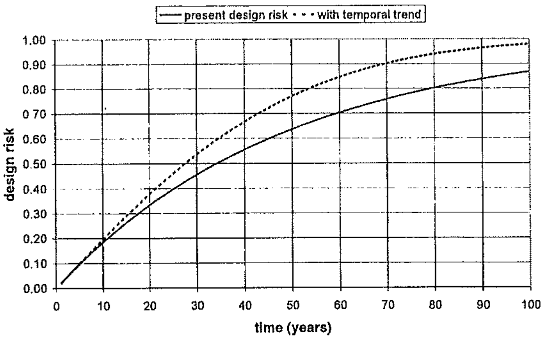

Figure 3 Comparison of standard design risk and that incorporating negative temporal change

These results show the ongoing effect of temporal change increases the design risk, with the potential for likelihood levels to change to more critical conditions.

6 Conclusions

Selecting appropriate hazard levels for coastal hazard assessments is essential in providing a rational basis for assessing risk.

Historic values typically applied to coastal hazards appear no longer acceptable to communities, possibly due to the increasing cost of these hazards on communities and their insurers. More consideration is now being given to land use, with different probabilities attributed to different uses. There is also a trend observed from UK studies to consider risk differently for coastal flooding compared to fluvial flooding, with lower probability events considered for coastal flooding.

When comparing AS/NZ building code requirements with those typically applied for coastal hazards by regulators in New Zealand and Australia, there is an apparent inconsistency in the selection of appropriate return period or annual exceedance probabilities, with the building code required to consider lower probability events. We have also found there to be different interpretations on return period, exceedance probabilities and tolerable risk depending upon the stakeholder group concerned.

A design risk approach provides a likelihood of exceedance over the life of the development or structure and could provide a more consistent and easily understood method of presenting potential risk and the joint probability consideration that is required for coastal hazard assessment. Similar consideration of extreme events is applied for landslide and geotechnical risks. We suggest a similar approach be considered for coastal hazards and include suggested annual probabilities and their associated definition in Table 6. Consideration of design risk over the assigned design life of a development or structure should enable a more meaningful consideration of joint probability events that typically characterise coastal hazards.

A further complication is the inclusion of temporal changes with other hazards that are probabilistic in nature, such as sea level rise or long term shoreline change. These temporal factors is can be addressed by taking into account by factoring in these temporal changes over the design life under consideration to modify the design risk.

7 References

AS/NZS 1170.0 (2002). Structural design actions. *Standards New Zealand*

Australian Geomechanics Society (2000). Landslide risk management concepts and guidelines. *Australian Geomechanics*, Vol 35, No 1, March 2000. pp49-92

Berryman, K. (2006). Review of tsunami hazard and risk in New Zealand. Unpublished report prepared for

Ministry of Civil Defense and Emergency management by IGNS, January 2006.

Defra (1999) Flood and Coastal Defense Project Appraisal Guidance. A procedural Guide for Operating Authorities. *Ministry of Agriculture, Fisheries and Flood*, December 1999.

Moon, A.T. and Wilson, R.A. (2004) Will it happen? Quantative judgments of landslide likelihood. *Proceedings, 9th Australia New Zealand Conference of Geomechanics, Auckland*, NZ Geotechnical Society.

Munche Re (2004). Topics Geo: Annual Review, Natural Catastrophes 2005. *Knowledge series, Munche Re*, Munich, 2005.

Pugh, D.T. 2004. Changing sea levels. Effects of tides, weather and climate. Cambridge University Press, 280pp.

SAA/SNZ HB 436 (2004). Risk Management Guidelines Companion. *Standards New Zealand*

Smith, B. and Jones, V. (1999) Recent advances in report writing, *Macmillan Publishing*, New York.

Smith, C.; Jones, A. and Howard, J. (1984) Australian history. *Journal of Science*, Vol. 99, 45–90.

Tonkin & Taylor(2005). Natural Hazard Management. *Research report for Ministry for the Environment*, Wellington, NZ