The contradictions of hazard lines; are they a risky business?

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Introduction

An essential precept for determining future shoreline behaviour is to first study the past and then examine what might be expected to, or could, change in the future. Responsible coastal zone management requires future projection to be a credible, risk-managed outcome as the social, economic and environmental impacts can be considerable thereby injecting political risk into any coastal zone management planning process.

All too often there is the tendency to present "hazard definition" lines, along with some management options as if they are a coastal zone management plan. This approach tends to lead to an outcome that fails to receive community, and hence political, support. Often the situation is further exacerbated if there has been no robust attempt to apply economic and financial disciplines to the selection of management options. Yet history dictates that without a sustainable, viable, funding plan the likelihood of coastal zone management plan being implemented is problematic at best.

Historical context

One hundred years after the first European settlement in NSW there were very few residential properties fronting the open coast and these were mainly in the Eastern Suburbs of Sydney, on the Northern Beaches at Manly, and at Newcastle. Much of this residential development was confined to the headland areas while the beach and back beach areas were given the traditional English treatment of seawalls, promenades and public parkland. By the early 1900s residential subdivisions with beachfront boundaries began to appear. The proliferation of coastal subdivisions enjoyed a "golden age", immediately after the First World War and during the 1920s, before the Great Depression. The first recorded damage to residential houses was at Collaroy in 1920, followed by further events in 1925 and 1928. The Depression, and then the Second World War, resulted in a hiatus in coastal development. Coastal development recommenced immediately following the War with increased intensity during the 1950s through to the 1970s. This tended to be centred in the Greater Metropolitan region but also spread to country areas. Not only did the numbers of dwellings rapidly increase but also the type of building changed from lightweight timber and fibro holiday cottages to masonry structures providing permanent residency. Hence the value of property potential in harms way has dramatically developed over the past 60 years and is therefore a relatively "recent" phenomenon.

Background

Up until the early 1970s it was generally believed that the threat to properties was associated with building on the foredunes, within the active erosion accretion cycle of beach movements, and that overall the net position of the coast was stable. Between the mid 1960s and mid 1970s a 10 year stormy period saw cyclones impacting on development on the north coast of NSW and East Coast lows affecting development in the remainder. These events resulted in damage to both public and private assets and infrastructure. This, along with the increase in the value of assets at threat, heralded a new awakening to the dynamic nature of the coast including a recognition of there being not only short-term shoreline fluctuations but also long term recessional trends due to sediment imbalances. By the late 1970s coastal “hazard” lines were coming into use as management tools. Initially these lines were based on a simple projection of historical trends. However, over the 35 years since these lines first appeared the methodology of calculating the location of the lines has become more complex with the addition of elements such as “storm cut”, escarpment slumping, reduced foundation effects, and additional recession due to projected climate change impacts.

Traditionally these elements have simply been directly added together to obtain the location of the hazard line(s) and thereby a prediction of the possible shoreline location, at nominated future dates. The credibility of these hazard lines has increasingly come under questioning. A more recent trend has been to replace the historical hazard lines by making reference to risk and hence the emergence of classifications such as “immediate impact zones”, “almost certain hazard zones”, “likely impact zones”, “unlikely impact zones” and “rare impact zones.

Historical shoreline ambulation

Typically “long-term” historical shoreline trends have been obtained using surveys and/or measurements from aerial photographs. There are two sources of survey data, onshore surveys and hydrographic surveys. Historical beach survey information is available in some locations over a period of 150 years however there are serious questions regarding the reliability of this data source. For much of this data, there is no information on the beach condition at the time: what part of the erosion/accretion cycle was being experienced; whether the identified “water marks” such as the commonly used high water mark was actually a tide line or whether it included wave run-up and wave set-up; the way any tide correction was applied, if at all; and generally the manner in which the bench marks were established and to what geosphere the surveys were related. Often the beach mapping was a secondary consideration to the main purpose of the survey and hence the “care” taken reflected the incidental nature of the beach information. Therefore land survey information must be used with caution and its likely inaccuracies recognised and taken into account.

In more recent years specific beach survey data has been relatively accurately collected at many NSW beaches. At Collaroy/Narrabeen and at Moruya, approximately 40 years of detailed data has been amassed due to the work of Andy Short, Bruce Thom, their teams and subsequent investigators. In the 1970s the NSW PWD started a program of detailed ground surveys at numerous NSW beaches however this was superseded by the use of photogrammetry for obtaining beach profiles.

Historical hydrographic surveys have a number of limitations. It is important to recognise that the purpose of these surveys was not to accurately map the seabed but rather to provide “clearance depths” for assisting in the safe navigation of vessels. It is also important to recognise the inaccuracy of position fixing in many of the early surveys. Differential GPS combined with wave correction devices and real time digital tide gauges have significantly improved seabed-mapping accuracy in recent times. Like land surveys, hydrographic surveys require specialist interpretation and must be used with caution when investigating historical trends.

The 1970s first saw the use of current and historical large format aerial photographs to obtain information on coastal change. In some coastal locations the aerial photography goes back to the 1930s although much of the early imagery is of questionable quality and information is not necessarily available on the distortion characteristics of the camera lenses, the tilt of the aircraft or on ground control reference points. Initially shoreline locations were simply scaled off the photos with no attempt to apply corrections however by the late 1970s sophisticated, computerised, photogrammetric machines came into use which allowed for all corrections to be included and relatively accurate beach profiles to be reconstructed at any location along the photographed shoreline. However the frequency of photography determines the reliability of the calculated net shoreline trends and beach fluctuations.

Factors such as the El Nino/la Nina and the Interdecadal Pacific Oscillation cycles complicate the interpretation of historical data. Gordon (1988) demonstrated an interesting potential link between historical recession trends and historical sea level rise at over 30 locations on the NSW coast. However typically investigators continue to include recession due to future projected sea level rise but fail to adjust calculated historical recessional trends for the associated sea level rise induced recession, using those trends in their forward projections hence effectively “double counting” the sea level rise component of the historical data.

A factor also often overlooked is that historical shoreline trends are based on time averaged results from analysis of the available data and do not represent the actual year-to-year expectations. Hence when using these trends to predict shoreline positions at specific future dates, such as 2050 or 2100, the assessed probability of the predicted outcome also needs to be provided by analysing the spread of the data either side of the net trend.

In summary historical average shoreline trends are often considered to be the most reliable component in establishing hazard lines however they may not be and so must be used with caution, by experienced operators, if credible outcome are to be achieved.

Storm cut (also known as storm demand)

Storm cut (demand) is defined as being the quantity of sand removed from the sub-aerial beach/dune zone (above M.S.L.) during a single storm or a closely linked series of storms. Gordon (1987) analysed the response of 32 NSW beaches to severe storm conditions, and in particular the impact of the 1974 storms on the beaches of the Greater Metropolitan area. The May 1974 storm feature high water levels, and the overall erosion was the result of these and a combination of both the May and a closely following June event. From analysis of the data Gordon concluded that it is the combination of wave height, storm surge, and high tides that are the determinants of severe erosion events. The data also showed that simplistic traditional method often adopted, of just using wave data to determine recurrence of erosion events, was flawed as the intensity of the storm, its direction of travel and distance offshore, along with the duration of the storm and the co-incidence of high water levels on the beach, during the storm, all contribute to the severity, or otherwise, of the resulting erosion.

As a result Gordon (1987) chose to develop an empirical representation of storm cut recurrence based on the “naturally integrated” observed erosion data. An example of Gordon’s results for the 1% ARI storm demand gives a range from 140 m^3/m for a “low demand” section of an open coast beach to 220 m^3/m of beach for a “high demand” section of ocean beach, at the rip heads. However, in determining the appropriate values for storm cut it is important to also account for the additional losses due to longshore sediment losses in “open” compartments. This was highlighted by Nielsen et al (1992) who reported higher figures for open compartments with longshore drift losses.

A number of 2-D deterministic models are available to calculate storm cut for particular wave conditions. For example S BEACH (Larson and Kraus, 1989) and X Beach (Roelvink et al, 2010), which seek to predict erosion at a specific profile location, as a result of wave conditions. Time variability of water levels can be considered but this adds complexity. Theoretically these models could be applied to any location along a beach if the specific inshore wave conditions, time history of water level and wave height variations at that location, beach profile and antecedent conditions were all known. Unfortunately, the simplicity of these models as compared with the complex nature of the reality of the time dependency of how the variables combine and the local modifications of all of these factors as a result of the presence of rip cells means that the existing deterministic models become clumsy and do not generally provide realistic results, except in very simple situations. Woodroffe et al (2012) developed a statistical methodology to examine beach response over time as a result of wave action and water level variation. However the statistical nature of the approach means that it requires a considerable amount of site-specific data to achieve meaningful results. Further, the method involves the synthesis of integrated wave and water level conditions, and hence shoreline location, rather than simply the values of storm cut for design/planning purposes.

The traditional approach has been to simply add the selected storm cut to the historical long-term erosion trend. This generates a result that is only valid if, at the selected future date, the actual shoreline recession was that predicted by the average trend and the selected storm erosion occurred at the selected date. Given the tendency to select the 1% ARI storm erosion event, the probability of the shoreline actually being where it is predicted to be must arguably be less than 1%. Haskoning (2014) has recognised this problem and has sought to develop a methodology that involves a rational structure of subjective judgement for the selection of an appropriate storm cut value to add to projected shoreline locations determined from historical trends and future projections of recession. The Haskoning approach generates a table of 95%, 50% and 5% exceedance values of storm demand for likely, possible, unlikely and rare outcomes.

Escarpment slumping and foundation conditions

Clark and Small (1982) developed a simple approach for escarpment slumping and hence the calculation of the distance of retreat of escarpment crests. The methodology was based on the assumption that the top half of the escarpment would collapse to infill the bottom half until the front face was at the natural angle of repose of the resident material; a simple geometric model of material displacement.

Nielsen et al (1992) sought to consider the issue from a different view; that of the stability of buildings. They incorporated the basic concepts of Clark and Small along with the storm demand and the geotechnical competency of the region landward of the escarpment to sustain building loads. Four zones were delineated: the zone of wave impact - the storm cut; the zone of slope adjustment – effectively the Clark and Small adjustment; the zone of reduced foundation capacity – determined by geotechnical considerations of the resident material; and the zone of stable foundations – the area landward of the zone of reduced foundation capacity. Nielsen et al (1992) indicated the limitations in direct application of their approach to specific sites such as the water table in the escarpment/dune, the homogeneity of the dune material and its consolidation but they also recognised that in most cases the lack of data dictated a conservative approach. Other factors can also influence escarpment behaviour such as if the escarpment is well vegetated by deep routed plants the slumping of the crest may be somewhat delayed thereby allowing the re-building of the foredunes at the base of the escarpment and hence a reduction in the slumping. Also, the presence of indurated sand, consolidated layers of material, pebbles or calcified layers may reduce the net angle of repose of the slope.

This again introduces the problem of what are the appropriate values to be used to meaningfully determine the likely location of a shoreline at a future date. For example if the 1% storm cut is used and added onto the mean historical recessional trend, and the Nielsen et al calculation is fully included the implication is that, say for the 100 year line, the 1% event also occurs at the 100 year mark but at a specific time sufficiently distant from the end of the year that the escarpment slumping adjustment is fully achieved; clearly a near virtual impossibility.

Climate change

The most controversial and complex matter to take into account, not only from a scientific but also from social, economic and political view points is that of the potential impact of climate change in attempting to determine future shoreline locations for the purpose of planning and asset management. Climate change can have two drivers, long-term natural variability and anthropogenic causes. Both provide for an uncertain future climate (Gordon, 2013). It is important to recognise that the models used for determining anthropogenic impacts provide projections, not predictions. Also, they include a range of results based on future emission scenarios yet often only the upper level projections are used for coastal hazard assessments. Also investigators tend to only consider global sea level projections rather than determining the local relative sea levels movements, corrected to take into account landform movements such as natural tectonic trends or the man induced impacts from, for example, mine subsidence.

An even greater source of uncertainty is introduced by the currently available theories to convert sea level rise into coastal recession. The most commonly used “Bruun Rule” (Bruun and Schwartz, 1985) has significant limitations in both its general applicability and particularly in its usefulness on a littoral drift coast. Woodroffe et al (2012) present a comprehensive criticism of the use of the Bruun Rule and conclude, “The reality that the Bruun Rule has been widely applied probably reflects its simplicity rather than its appropriateness”. However, without a practical alternative, given the paucity of data, the Bruun Rule continues to be used. Interestingly, the two beaches on the NSW coast with the longest detailed records of beach profile movement, Moruya and Collaroy-Narrabeen show no net landward translation of their shorelines over the 40 years of data, despite the recorded sea level rise that has occurred over this period raising possible questions about the application of the Bruun Rule on the NSW coast. Gordon (1988) on the other hand argued a possible link between sea level rise and long-term shoreline recession at 32 beaches on the NSW coast by applying the Bruun Rule to historical data sets. The dilemma produced by these apparently opposing positions is yet to be resolved.

Factors yet to be included in most coastal hazard studies are: the potential rotation of embayments due changes in net wave energy flux as weather patterns shift latitudes; the possible changes to storm frequency and intensity as a result of climate change; and other potential climate induced changes in wind and rainfall patterns. In recognition of uncertainties, including the limits to the historical data, but including the then very preliminary knowledge of the potential for climate change, the first major coastal management study in NSW applied a “factor of safety” of 2 to the historical time averaged recession trend in constructing the “hazard lines” (Gordon et al, 1978); an approach not followed by later investigators. The climate change challenges for coastal management are not new, they have been recognised for more than 35 years.

Uncertainty

The scientific approach to uncertainty in coastal studies has generally been the application of the precautionary principle. This principle states “where there is a threat of serious or irreversible environmental damage, and scientific uncertainty as to the nature and scope of the threat, the decision maker must assume the threat is a reality and take appropriate measures to avoid or mitigate the potential harm”. There has however been an inclination to apply the principal to each individual element of hazard assessment resulting in an often ill-defined, potentially overly conservative, compounding of uncertainty “adjustments”. Interestingly coastal management is usually about the impact of natural hazards on the built environment; arguably the reverse of the precautionary principle which aims at avoiding environmental harm due to impacts from development, so it is questionable as to whether the precautionary principal is applicable. However, If the precautionary principal is to be used a carefully considered “uncertainty allowance” should be added at the end of the analysis with all components being “best estimates” rather than “precautionary” values.

The use of the precautionary principle to justify the selection of the high range sea level rise projections and their application to define the threat to all built assets, infrastructure and landuse planning is clearly inappropriate and illogical.

Further, the application of the precautionary approach to coastal management generally focuses only on the environmental hazard and takes no account of social and/or economic hazards. This lack of precaution for the totality of the overall societal and environmental risk would seem inconsistent with a balanced approach to risk management and is a demonstration of the contradictions generated by the simplistic use of only environmental hazards and not including socio-economic hazard; a very risky business if effective outcomes are to be achieved in a political environment.

Risk and risk management

There are many layers of risk involved in selecting a coastal zone management strategy. They include, the risks generated by natural phenomenon, typically shoreline recession and storm erosion, the risks to local, State and Federal economies and the risks to the well being of individuals and societies, all of which introduce political risk as politicians respond to community concerns. It is important to note that the economic impacts are not only associated with damage to assets, infrastructure and businesses associated with the coast but also the costs, funding and financing of either protection works, including nourishment, or the losses and relocation costs suffered by individuals forced to relocate, as well as the cost of funding an on-going beach amenity.

In recent times a number of investigators have sought to address the uncertainties of coastal hazard definition using a risk based approach. The methodologies of this approach have become increasingly sophisticated. This shift focuses on risk management whereas the traditional approach was centred on risk avoidance. However there is still insufficient recognition of the need to fully address the other risks; while community “consultation” is part of the overall process, a detailed assessment of the socio-economic impacts of management impacts generally is not.

Interestingly the concepts of vulnerability to natural hazards, risk, and risk management versus risk avoidance are often poorly understood. Risk is the product of likelihood and consequence.

In 2007 the Australian Geomechanics Society published a watershed document (AGS 2007). This document lead the way in providing a methodology for a rational approach to assigning risk by competent practitioners based on assessments of likelihood and consequence. The outcome was a 2-D risk matrix linking the likelihood of an event to the assessed consequences for life and property. Haskoning (2014) have adapted the AGS methodology to coastal hazard risk assessment. In doing so they have produced what could be conveniently referred to as a vulnerability matrix linking the likelihoods of the possible range of shoreline location outcomes, at a given future date, with the consequential potential damage. The approach allows for combinations of scenarios of probabilities of recessional trends and storm cut likelihoods in order to determine a statistical assessment of the likely shoreline location at nominated future dates. The matrix provides a rational, and structured methodology to achieving a more realistic assessment of potential vulnerability, albeit the methodology requires a level of subjective judgement and statistical interpretation which is only as good as competence and experience of the practitioner involved. However the matrix provides the likelihoods that an natural coastline, subjected to net recession and storm erosion, will be in a particular location at the nominated future date; typically 50 or 100 years hence. And, the likely damage built assets and infrastructure would suffer as a result of the coastal movement. Therefore the vulnerability matrix provides an indication of the probabilities of the outcomes of potential shoreline movements and exposure of assets. In its basic form the matrix only defines the potential vulnerability and hence the outcome if a “do nothing” option is adopted.

In managing coastal risk both the likelihood of adverse impacts and the consequences can be altered through intervention. The likelihood of a coastline receding to a specific location and/or storm damage occurring at some time in the future can be modified by, for example, construction, maintaining and upgrading over time, a competently designed and constructed sea wall, and/or implementing an on-going beach nourishment program. Similarly, consequences can be altered by, for example, not developing in vulnerable areas, developing but using a disposable infrastructure and relocatable buildings philosophy (Gordon, 2013) or, in areas potentially subject to inundation, raising the buildings. Hence, there should be multi tiered management matrix of which the basic vulnerability matrix is only one layer. The other tiers include the various management options and their social, environmental, economic and political risk factors that make up the overall decision-making process. It is only by testing a range of paths through this 3-D compendium of risk layers that a workable, and implementable solution can be achieved. If not approached in this manner there can be unwelcome or unintended consequence. For example, the construction of a sea wall to protect properties but which results in the loss of the beach and hence an economic downturn, not only in property prices, including those of the protected properties, but also in the local businesses that depend on trade associated with the beach, such as the hospitality industry. Another example could be the development of coastal zone management plans that are can not be implemented because there has been no consideration given to viable funding strategies, or plans that divide the community and hence become hopelessly stalled in the political arena (political risk).

The multilayered matrix approach demonstrates the complex reality of the methodologies and decision-making process involved in a generic approach to coastal zone management.

Way forward

Rather than undertaking detailed generic coastal zone studies for the entire NSW coast a more pragmatic approach consists of recognising that there are four basic coastal landuse regimes involved: parkland (National Parks, State Parks and council parkland);

as yet undeveloped non-urban land, land subdivided for development an/or subdivided land that has infill/redevelopment potential; and intensely developed coastal land.

Much of the NSW coast is currently undeveloped and a significant portion falls into the first category of parkland. This can readily be managed to ensure assets and infrastructure that might potentially be in harms way are "disposable" or relocatable. Of the second category, the remainder of the undeveloped coast, it is possible to initially apply conservative coastal buffer zone and hence a impose setback distances that can be refined over time as more information becomes available.

It is the third regime that is the most challenging. These are the so-called "legacy" areas where, at the time of their initial development the fact that they were potentially in harms way was not recognised. There is a basic management decision to be made: whether to "defend" or "withdraw" from an already developed area that is identified by the vulnerability matrix as potentially being in harms way within a selected planning time scale. Adaption is not a third option but rather sub options of either "defend" or "withdraw". The decision to defend or withdraw from a section of coast should primarily be a strategic planning decision dependent on the State Governments long-term aspirations for the area. The mistake often made is to attempt to make the decision, based on the local issues of the day, without taking into account the longer-term contingent liabilities, for both the area and the State.

Some of the shortcomings currently associated with withdrawal strategies include their difficulties in implementation and the fact that little or no thought is given to any funding that may be required, nor are the likely adverse impacts to the local economy, including the losses for individual property owners, taken into account. Another problem is caused by the open-ended nature of standard development consents. Hence coastal managers tend to seek to limit future council liability by the use of "trigger" conditions, such as "time limited consents" or consents that use the distance of a structure to the receding escarpment as the trigger which terminate the consent and hence initiates the "withdrawal" action. Experience dictates that these triggers are likely to be difficult to enforce and/or are impractical. The alternative is simply to provide a condition that states the approval is valid up until the building is no longer considered safe and that the intervention of protective actions is not permitted. Councils in NSW already have the legal ability to order that structures be demolished if and when they are deemed to be no longer safe.

Finally, for "legacy" areas that are already intensively developed either due to density or value of the public or private assets and/or infrastructure, there is seldom any other practical option other than to "defend". Whether this is an iconic beach such as Bondi or Manly, a coal loader at Port Kembla or densely populated, high value beach front residences. All too often considerable time and money is consumed investigating politically unrealistic options in areas of intense development. Rather than wast resources on such exercises it is more productive to recognise the defence option will prevail and focus on how to fund and maintain a well-planned defence strategy over time. Any defence strategy should however include offsets for any adverse impacts to the public beach amenity and the environment occasioned by the strategy. This is likely to involve long-term, on-going beach nourishment programs, but at least if there is intensive and valuable development and/or commercial activities, there is the potential for an on-going funding base.

Conclusions

Coastal shorelines are naturally ambulatory; an uncertain future climate only adds complexity. Development involving public and private assets and infrastructure should be risk managed to accommodate the ambulatory nature of the coast yet balance it against the communities desire to “enjoy” usage and beneficial occupation of areas of the coast that may be under present and/or future threats.

Historically the approach taken to obtain “coastal hazard lines” has been scientifically conservative, arguably too conservative because of the tendency for direct addition of individual components which, in themselves, have each been conservatively assessed using the more extreme values of threat. This has been driven by the traditionally approach to coastal zone management that has tended to focus mainly on risk avoidance of natural processes and their associated threats.

However the coastal region involves complex interactions, leading to contradictions regarding outcome objectives for natural systems and processes, communities' desires, economic drivers and State strategic planning. Hence the traditional approach has tended to generate outcomes that are not economically palatable nor socially or politically acceptable. This has frustrated many attempts to develop and implement coastal zone management plans. A more sophisticated approach of a layered risk management matrix is required in order to allow all the elements of the decision making process to be expressed and considered in a structured manner.

What is required is a pragmatic approach to planning and management of coastal regions that balances the potential vulnerability of an area against socio-economic and environmental outcome objectives and recognises that “legacy” areas need to be treated differently from “green field” sites. To be workable the outcome also must be a product that is useful and meaningful to planners, regulators and the community and is in keeping with the long-term strategic objectives of the State.

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