# Risk Modelling of Cyclone Losses

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**Summary:** An overview and outline of the application of various analytical, numerical and statistical techniques is presented which address the problem of estimating structural damage and insurance losses due to the effects of tropical cyclones. The development of some of these techniques in the Australian context is presented, the maturity of the analyses in specific areas is demonstrated and areas for further research are highlighted.

## 1. INTRODUCTION

The global insurance industry has suffered considerable losses from a variety of natural and manmade disasters in the last decade. These include the loss of the Piper Alpha gas platform in the North Sea, large scale oil spills, Hurricanes Hugo and Andrew, as well as numerous severe earthquakes. The long term viability of a global insurance industry, which is essential to a modern society, demands increasing consideration of potential loss scenarios. Although these events can never be completely anticipated, statistical methods can be employed to gain a more complete understanding of each phenomenon and its likely probability of occurrence.

An appreciation and understanding of the effects of natural hazards has always been an essential part of professional engineering philosophy when applied to the safe design of human infrastructure needs. Inherent in any engineering design is therefore an implicit allowance for the probability of failure as a result of potentially extreme environmental loadings, be it in regard to isolated structural elements or total infrastructure systems such as water, wastewater, power and transportation. These extreme loadings might take the form of wind, rain, flood, drought, fire, surge, waves, earthquake or human and vehicular loads.

Typically the risks of such events have been classed in terms of average recurrence intervals (return periods) or perhaps serviceability, working stress or ultimate strength concepts. On a day-to-day basis extreme situations are then covered by Codes of Practice or Standards which, over time, the profession has developed to ensure (reasonable) upper envelopes of loadings are allowed for in the normal design process. These include the various Australian and International standards in respect to wind loadings, bridge and dam design codes and rainfall and runoff to name but a few.

However, when a problem is posed which is highly specific in terms of geographic location, with particular circumstances pertaining to the risk, complex causal mechanisms and where the consequences of failure (or loss) are very high, then much more sophisticated methodologies are needed. These techniques are outside the realm of conventional practice and are typically of the type required for estimating (say) potential lifetime loadings on particularly large or sensitive structures. It is also the case however that similarly sophisticated analyses are essential for estimating large scale insurance losses due to natural hazards. The objective of such analyses is illustrated schematically in Figure 1.

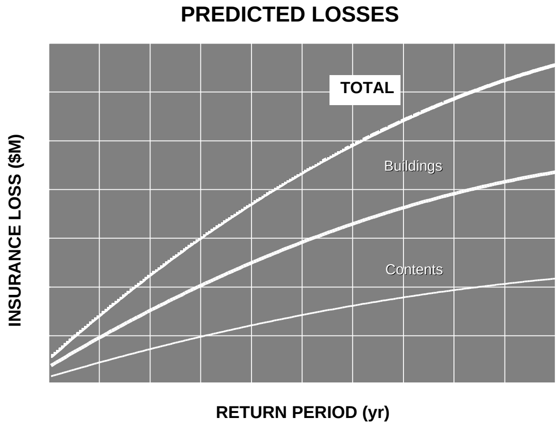


Figure 1: The Loss Prediction Objective

## 2. METHODOLOGIES

A variety of methodologies have been brought to bear to address these types of complex questions over the years. As techniques have developed and computer power has increased, there has been a gradual increase in the sophistication and mathematical robustness of such methods. All have typically involved the use of some statistical technique combined with mathematical modelling of environmental phenomena leading to an estimation of extremes. The “Design Storm” approach of the 1960’s considered a single event designed to produce an upper limit of damage. The return period attributed to the intensity of that single event was then normally (conservatively) associated with its staged outcome of damage. This is often the basis of a so-called *probable maximum* scenario. During the 1970’s, the “Hindcast” approach generally gained acceptance as a fundamentally more robust technique, whereby all available extreme events are individually modelled to determine their respective outcomes, followed by a statistical extrapolation of the extremes. This suits situations with extensive and reliable data sets but in other situations can be quite adversely data sensitive and breaks down when occurrences are very rare. By the 1980's "Simulation" methods had came to the fore, offering a much more comprehensive approach and offering the use of more sophisticated modelling. One of the pitfalls of simulation however has been its ease of application and in some cases the potential abuse of the technique. The power of simulation is that it combines a variety of tools and approaches in order to arrive at quantitative risk estimates whose sensitivity to assumptions can be readily tested.

Generally, any complex environmental risk assessment is a combination of climatological classification *("where and when")*, definition of the forcing mechanisms ("*how*"), and calculation of the forced outcomes ("*what*"). The outcomes must then be related to some natural time reference in order to develop the concept of probability or likelihood of occurrence within a particular time span. This can be effectively achieved through the application of Monte Carlo techniques whereby numerical randomising is introduced to mimic the natural variability of the hazards being considered. The accuracy of such techniques is directly dependent upon the sophistication and accuracy of the respective sub-components used. When a very high level of detail is addressed, the overall approach is best described as a joint deterministic and stochastic methodology (1) and the major steps of such a (JDS) analysis are briefly outlined in the sections which follow.

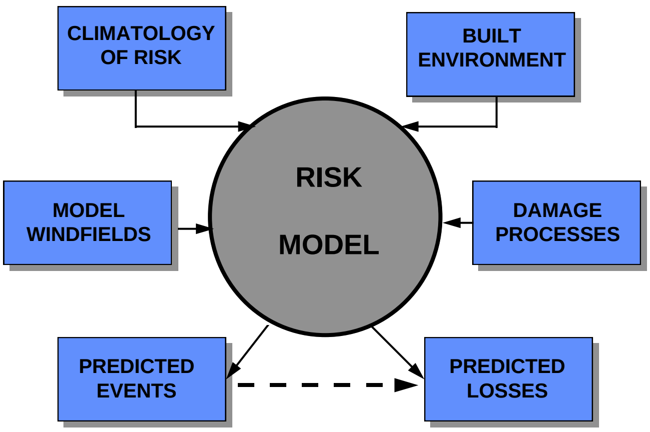


Figure 2: Schematic Loss Assessment Methodology

Figure 2 presents a schematic methodology as far as it might relate to the case of building damage caused by severe tropical cyclones.

## 3. TROPICAL CYCLONE STATISTICS

The Australian Bureau of Meteorology has international responsibility for the collation of data on tropical cyclones (hurricanes or typhoons) within the Western Pacific, Arafura and Timor Sea and Eastern Indian Ocean provinces. Bureau records within typically a 500 km radius of a target site need to be examined in order to determine a regional climatology. This data set then needs to be assessed in some detail to avoid poor quality data and is typically limited to the period post 1959/60 to ensure a stable and reliable statistical series is available (2). Other cyclone details such as intensity, track and forward speed must also be assembled to provide a detailed description of regional characteristics since these will impact subsequent analyses. However, some essential cyclone parameters such as radius and wind profile shape are not available from historic Bureau records and need to be separately estimated based on any specific wind, pressure or imagery data available. To facilitate the quantitative risk assessment, the historical storms can then be usefully grouped into common populations based essentially on track. At least three principal track populations would normally need to be identified, these being *offshore moving*, *parallel to coast* and *onshore* moving, each of which may relate differently in intensity and could also have distinct damage

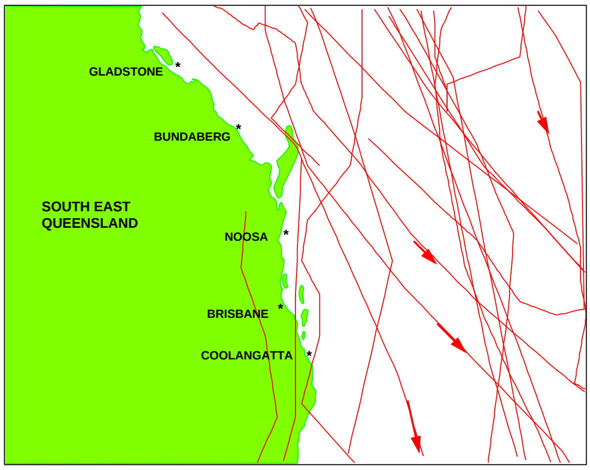


Figure 3: Example Historical Cyclone Tracks

outcomes as a result of the natural asymmetry of these storms. Statistical analyses of the various parameters can then be used to develop consistent models of occurrence, intensity and track which might be either long term or short term in variability. The influence of El Nino phenomena can therefore be implicitly included if necessary and global warming scenarios considered as a part of an investigation. Figure 3 illustrates an analysis of cyclone tracks parallel to the coast in the South East Queensland region recorded since the 1959/60 season.

## 4. WIND AND PRESSURE FIELD MODELLING

There is a variety of techniques for the estimation of wind and pressure fields caused by tropical cyclones but the vast majority share a common technical development. Whilst some complex 3D boundary layer models exist, experience shows that relatively more simple analytical models perform equally well in the majority of cases. One of the most highly respected and widely used models of this type throughout the world is based on research undertaken by Dr Greg Holland, Principal Research Scientist with the Bureau of Meteorology Research Centre (BMRC) in Melbourne (3). The model was subsequently jointly enhanced (Harper/Holland) and has, for example, been used extensively for risk assessment studies in the West Australian region for Woodside Offshore Petroleum (1,4). These studies included comprehensive wind and pressure calibrations for over 30 severe cyclones, including the 905 hPa cyclone *Orson* in 1989 - Australia's most intense on record and amongst the most intense world-wide. Figure 4a (5) illustrates the typical accuracy of this wind model when applied to extreme cyclones such as *Orson*. More recently, as part of specific insurance industry investigations (6), further calibration checks have been undertaken against other notable storms of record such as cyclone *Tracy* (Darwin, 1974), *Althea* (Townsville, 1971), and *Winifred* (Innisfail, 1986). Figure 5 presents an example of the pattern of wind speeds about cyclone *Dinah* near Brisbane in 1967 as predicted by the Holland analytical model (6).

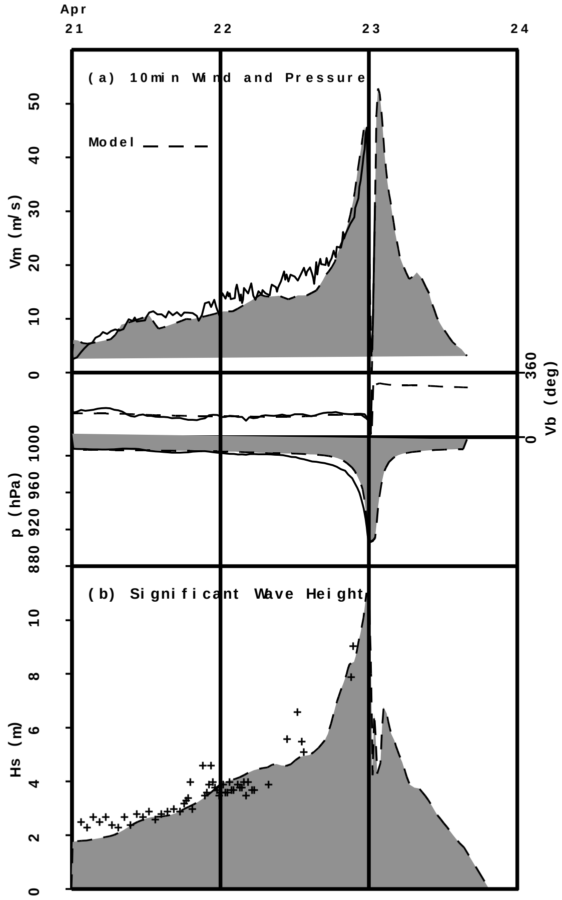


Figure 4: Cyclone *Orson* Verification

## 5. REGIONAL AND LOCAL WIND SPEEDS

Land based studies should also consider the degree to which wind speeds would vary across a given suburban region as a function of the local surface roughness and topography. These variations would ideally be consistent with the guidelines in the Australian Standard Wind Loading Code AS 1170.2 (7) whereby "terrain categories" are defined ranging from "2", representing flat open land such as airfields, through "3" for residential areas and finally "4" for high-rise CBD areas.

In general terms, local wind speeds will decrease with increasing terrain category for a given structure height but are also affected by the presence of hills where acceleration can occur which is a function of the slope of the hill or may even be reduced due to shielding effects. It might also be appropriate in some cases to make some statistical allowance for small scale micro-burst or severe local vorticity which

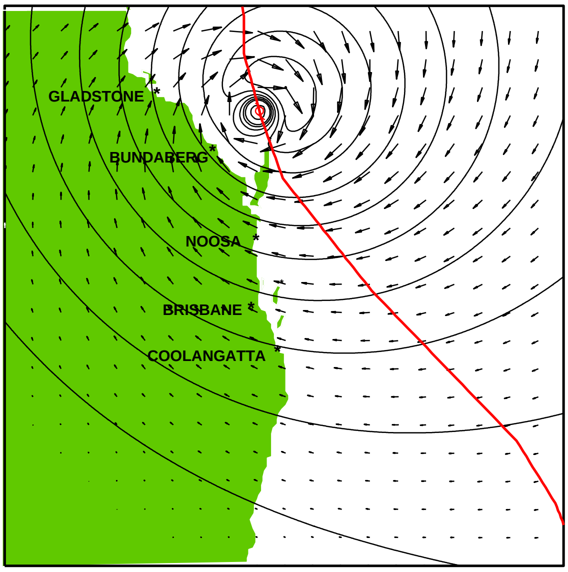


Figure 5: Example Model Cyclone Windfield

has been observed in several situations. The ultimate aim of this type of analysis, as shown in Figure 6, is to develop regional extreme wind predictions at a finer scale than available, say, from (6).

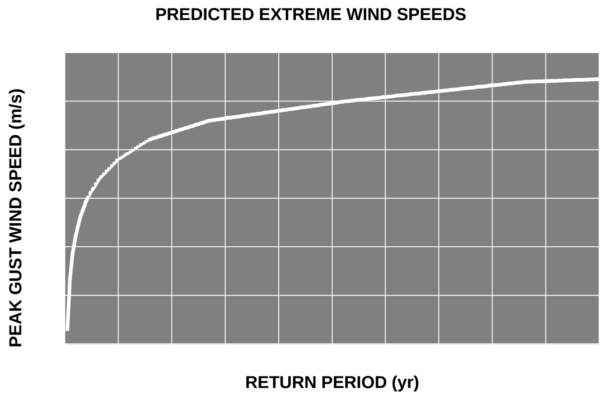


Figure 6: Regional Extreme Wind Speeds

The regional variability in terrain and topography influences is conveniently assessed using a Geographic Information System (GIS) using satellite imagery combined with a digital elevation model to map the suburban areas according to their relative wind exposure. Wind speeds derived from an analytical wind model can then converted to local winds on this basis, retaining a wide range of terrain and topography classes.

Figure 7 presents a LANDSAT image of the Brisbane region in South East Queensland which has been used (6) to delineate differing infrastructure components (built/nonbuilt) and surface roughness (grass, forest, housing) so as to form a basis for classifying the area into various wind speed zones. Topography is assessed separately but in a similar manner via a digital terrain model which covers the same area. This technique importantly delineates potential high wind regions from potential high exposure regions at a scale commensurate with the wind field itself.

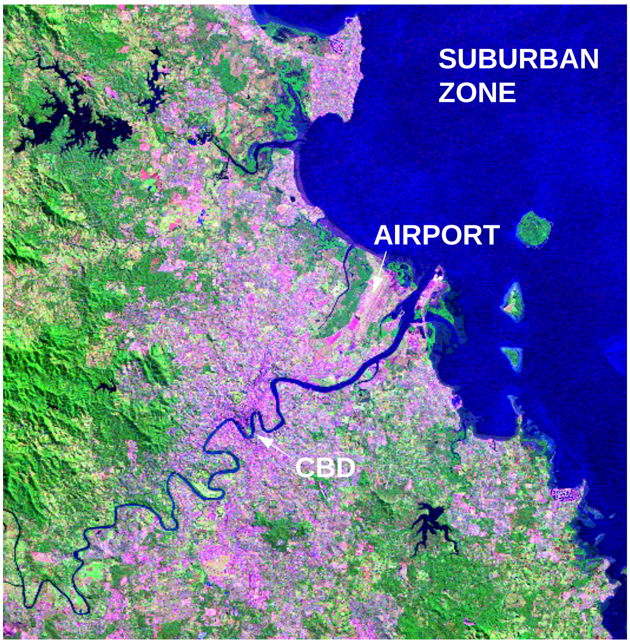


Figure 7: LANDSAT Image of Brisbane

## 6. BUILDING DAMAGE ASSESSMENT DUE TO WINDS

Prior to cyclone *Althea* in Townsville in 1971, it would seem there was little or no quantitative information on the performance of many types of domestic and residential class structures to wind damage, not just in Australia but apparently world-wide. The assessments undertaken then at James Cook University (8) formed the cornerstone for what continues to be a most valuable research program into domestic building strength under wind loadings and one which has undeniably contributed to the significantly increased strength standards in this country. Cyclone *Tracy* three years later caused an even more urgent reassessment of building strengths and wind risks - much of the work being undertaken by or for the Commonwealth Department of Works and involving the CSIRO Division of Building Construction and Engineering and James Cook University (9).

A linked outcome from these many studies has been a standardised Building Code consistent with AS1170.2 which was introduced and adopted variously throughout Australia around 1980. With significant changes in design, construction practice and inspection, it is generally acknowledged that post-1980 construction is much more wind resistant. Leicester et al (10) were amongst the first to propose analytical methods relating wind speed to structural damage and presented potential loss figures at the time for many regions. Those techniques, whilst still conceptually sound, can now be updated with more recent experiences here (11) and overseas (12) provided that the essential differences in architecture, materials and building culture are accounted for between the various sites and that reliable wind and loss damage information is available. Hurricane *Andrew* in 1992, with its US$20B damage bill, has provided a most critical data set in this regard.

In essence, building damage as a function of incident wind speed can be postulated in a form illustrated by Figure 8 (11), showing a typical threshold of damage onset (around 30 m/s) and a damage index which may then rise sharply beyond there, dependent perhaps in the Australian context, on year of construction. Contents damage might be separately estimated as a function of building damage. Other delineations of structure performance might also be postulated based on wall or roof material and commercial or industrial building types

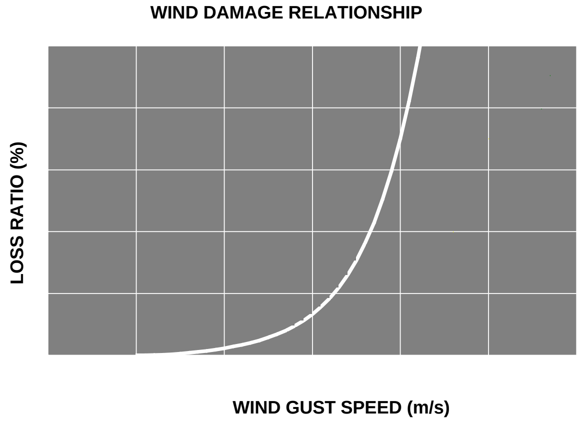


Figure 8: Postulated Wind Damage Relationship

but unfortunately there is much less historical data in these categories than for domestic construction. In this regard, a too fine postulation of the damage mechanisms without accurate data, may lead to severe misrepresentation of losses where the actual proportions of building type and/or strength remain essentially unknown at many locations. In this case integrated “total loss” damage curves will remain the more reliable and robust until much more essential research on failure mechanisms is undertaken. In the insurance context, post-disaster construction inflation allowance may also be a necessary consideration for certain remote locations.

## 7. COASTAL SURGE AND WAVE PATTERNS

Where the study area is located in the coastal zone, which is common for major population areas throughout Australia, the possibility of flooding of low lying land from the sea must be considered. All severe weather systems are capable of generating a so-called storm surge which can result in water levels being raised well above normal tide levels for a period of several hours. The increase in water level is due to the combined effects of surface wind shear driving the sea forward in shallow continental shelf regions and also the low atmospheric pressure generally associated with such events which allows the sea to rise. Figure 9 schematically illustrates the build-up of storm surge at a coastline combined with wave and tide effects.

The accurate estimation of storm surge levels requires the use of sophisticated numerical hydrodynamic models of the sea combined with the type of analytical wind and pressure field model described earlier. Again, Cyclone *Althea* provided the impetus for the development of state-of-the-art models for storm surge calculation at James Cook University

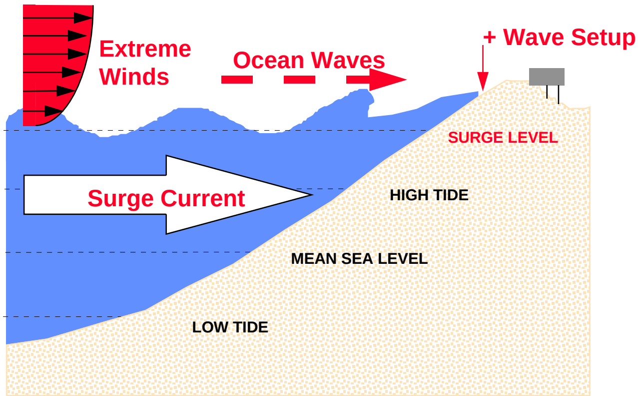


Figure 9: Components of Storm Surge

in the mid-1970's (13) which continues to this day.

Following this development, one of the earliest applications of statistical simulation techniques for assessing natural hazards in Australia was undertaken in 1977 (14) when the results of deterministic storm surge modelling were considered in a statistical framework combining with the normal astronomical tide. Since that time these techniques have also advanced appreciably (15,16) to include local wave setup and wave runup, and give not only the return period of a particular depth of total surge plus tide but also indicate the expected persistence at that level, i.e. the time that the water level is likely to continue to exceed that level during a particular cyclone. This has important implications for the structural resistance of infrastructure, buildings and also civil defence requirements.

In addition to the phenomenon of storm surge, severe weather systems will also generate extreme waves (i.e. swell) which when combined with surge can penetrate above highest tide levels. Riding on the surge they can then attack structures such as domestic housing which have clearly not been designed for such loadings. Wave generation in the presence of complex moving windfields and complex coastal landforms (such as the Great Barrier Reef) demands quite sophisticated numerical modelling. Use of a spectral wave model is indicated, of the type also initially developed at James Cook University (17). Figure 4b for cyclone *Orson* illustrates the type of accuracy attainable in wave hindcasting with such a model.

In an analogous manner to determining local wind speed patterns, GIS techniques can also be used to map low lying coastal lands, mangrove sheltering effects and also to construct data bases of dwelling floor levels.

## 8. BUILDING DAMAGE ASSESSMENT DUE TO SURGE AND WAVES

The degree to which coastal flooding due to surge might affect buildings is firstly a function of elevation but also one of exposure to the even more damaging effects of waves. One of the first studies of structural adequacy of domestic housing against surge was undertaken as part of the Greater Darwin Storm Surge Study (18). This considered typical surge and wave loadings combined with a structural strength check on various housing types. The US experience is also most relevant because of the greater frequency of surge damage along the Gulf of Mexico and Florida coasts leading to valuable data sets of losses becoming available (19). Care is needed however in terms of making reasonable estimates of wave penetration consistent with known coastal wave mechanics.

Where inundation alone is the most likely impact of surge effects, insurance loss estimates can be based on data available for the more frequent cases of terrestrial flooding.


Figure 10:Townsville Inundation Map

## 9. TYPICAL LOSS MODEL OPERATION

The foregoing elements representing the regional risks of damage due to natural hazards such as wind, wave and surge can be combined into a mathematical computer model which, based on Monte Carlo techniques, can examine many thousands of possible environmental scenarios in a region. Generally only a very small proportion of such events come close to severely influencing a particular site and so a very long period of time must often be simulated, extending out to 50,000 years or more of possible occurrences. This ensures that the final probability distribution is adequately sampled and stable at very low probabilities of occurrence.

As model weather systems are allowed to develop, based on the environmental risks for the region, the local estimated windspeeds, surge heights, flooding and estimated cumulative insured loss are calculated and then stored to assemble the long term quantitative risk for the region. The most intense cyclone possible in any region can often be limited based on climatology arguments and, for example, cyclones which cross the coast may be subjected to attenuation. In the case of wind damage, coastal regions will likely experience the more severe wind speeds, followed by hilly areas which could be further from the coast. Winds also vary with respect to the location of the cyclone track. In respect of surge and coastal flooding, low lying coastal areas will be most affected.

The model available to Rust PPK is known as MIRAM - Monte Carlo Insurance Risk Assessment Model - and has been based on developments in such models over the past two decades. Once the results of a particular risk assessment are known, it is possible to then assemble a number of disaster scenarios each with the same predicted probability of occurrence.

Results of risk analyses are often presented in terms of the so-called return period (or average recurrence interval). The return period is the average number of years between successive events of the same or greater magnitude, noting that there is a 67% chance of exceeding the "N" year event in any "N" year period. Whilst the insurance industry traditionally follows the concept of a Probable Maximum Loss (PML) as a single figure estimate or loss, there is of course a continuous variation in risk. A more consistent way of considering the above is to include the concepts of "design life" and "encounter probability" which, when linked to the return period, provide better insight into the problem. This describes the complete continuum of risk when considering the prospect of at least one event of interest occurring in a given period. In many situations there is unlikely to be a levelling out of the predicted loss at levels which significantly affect business decisions. The only alternative is to adopt a comfortable level of risk.

## 10. CONCLUSIONS

The assessment of insurance losses due to natural hazards such as tropical cyclones requires experience and expertise in a number of diverse fields such as mathematics, numerical modelling, statistics, engineering and meteorology.

The accuracy of present day deterministic modelling of tropical cyclone winds, waves and storm surge is very good. These elements have benefited from a long development cycle and the increasing availability of more and better data. This does not mean that further research is not needed in specific areas but that the marginal benefit of research has somewhat diminished relative to the other unknowns. By comparison, knowledge of damage processes is incomplete and requires more fundamental research and continued detailed analysis of even the limited data sets available. It will be important to be prepared for the next major disaster to ensure that the right type of data can be collected quickly and accurately to add to the existing knowledge base.

## 11. ACKNOWLEDGEMENT

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