Assessment of the Past Extent of Cyclone Beach Erosion

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ABSTRACT


For the coastal manager to estimate future events, traditional coastal engineering methods are often inadequate. On the Gold Coast, supplementary local evidence of past events has been used to more accurately predict future events and trends. Methods used include analysis of recent cyclone storm events as related to erosion and storm bar generation, measurement of mineral sand tracer deposits showing historical erosion scarps, determination of podsolisation of existing dunes and evaluation of contour evidence of past dune breaches.

ADDITIONAL INDEX WORDS: Coastal manager, local evidence, past events, predictions, cyclones, storm bars, erosion scarp, tracers, podsolisation, dunes, contours.

INTRODUCTION

A crucial factor to the coastal manager, in planning new coastal developments and determining realistic policies for the protection of existing developments, is the ability to estimate and predict the likelihood and extent to which a beach might erode under storm wave attack. However, as is always the case with coastal processes, this endeavour is fraught with high levels of uncertainty but as the coastal zone becomes increasingly important, the level of risk involved in determining adequate protection needs to be reduced. For coastal management purposes, we need to consider perhaps, the 1 in 1000 year event and most certainly the 1 in 500 year event, but where can we ever find the weather and beach behaviour data that this needs?

Gold Coast City (Figure 1) like many other tourist resorts has developed along its 40 km of surfing beaches. However, whilst most of the beach system generally appears to be in long term equilibrium large magnitude temporary storm erosion occurs as a result of cyclonic waves of up to 11 m measured to date. As shown in Figure 2 the incidence of cyclones is extremely variable with the largest recorded number being experienced in 1967 when 7 cyclones caused the worst erosion in the 100 years of records.

In 1967 much of the developed public and private beachfront property was protected by boulder walls. Whilst these walls are now covered by either naturally accreted or nourished dunes, much of the extensive less developed beachfront parkland is still unprotected against extreme events by boulder walls. New developments are required to be protected by boulder walls designed for conditions experienced in 1967 and subsequent cyclones. However due to the uncertainty in predicting the probability of the number, persistance and intensity of future cyclones and thus the wave climate and cumulative erosion there can be no high degree of certainty that these “approved” boulder walls will not be grossly inadequate in the future. Even if adequate data was available the present dune erosion type models still do not cater adequately for extreme events.

Thus, to supplement the “conventional” quantitative coastal engineering methods and techniques other less precise methods and sources of data of past erosion events on the Gold Coast were investigated to give a better assessment of the possible extent of future events.
CONVENTIONAL DATA AVAILABLE

General

To make an erosion prediction, two separate steps are required. Firstly, one must attain some estimate of the frequencies of storm wave events (usually cyclonic on the Gold Coast) that could cause wave attack of the beach, together with their probable intensities and persistence. Secondly, one must then attempt to estimate what the beach erosion might be, for the various intensities of storms. Both these tasks however, remain extremely inaccurate.

When we search our local data bank on the Gold Coast we find that reasonable storm data is only available back some 90 years, but much of the early data is fragmented. Our accurate
data on beach erosion only goes back 20 years, giving a data base of only 20 years which is totally inadequate for any even reasonable extrapolation into the longer term. If we are not to fall back on pure guesswork, what might we do? Our first approach might be to attempt to construct graphical or mathematical models, of the storm wave/beach erosion response process, but for the Gold Coast, we have only 3 major storm data points within our 20 years of records, which is not nearly good enough to calibrate our models. We would need something like well over 25 to 30 points, before we could even start statistically to believe our efforts. Then when we look further, we find that we only have reliable storm wave data for two cyclones, and precise ambient seabed surveys, for one. We will not get very far this way.

However, we do have a great deal of local data on fine weather waves and resultant beach profiles. Perhaps we could construct a mathematical model, using this data and extrapolate it into great storm conditions. Our work on the prototype however, shows us that the "normal" beach state, is highly complex and much more variable, than a cyclone beach. In fine weather, the real beach is often controlled by memory (of past events) effects, time-lag and threshold behaviour, and only part of the seabed, may be in equilibrium at any one time. We can try and construct a fine weather beach/wave interaction model, using variable co-efficients to balance.
our mathematics, but until the actual mechanism that controls the wave/sediment interaction on the prototype, is known, we don't think that we will get very far this way either.

Cyclone Impact Data

On the other hand, our field studies suggested that we might make some progress, if we consider very simple graphical models of storms. Tropical cyclones in Queensland are major events and fortunately for us our Bureau of Meterology records of past cyclone parameters are good. The cyclone records only run from 1909 to the present, but when we plot-up the cyclone return periods against central pressure, we find a good fit to the Gumbel distribution, as shown in Figure 3, very much as we might anticipate. The frequencies shown are for any cyclone existing within a 300 nautical miles square of ocean, with one side centered on the Gold Coast. We pick this parameter, rather than the distance from the eye of the cyclone, as a matter of observation. Cyclone swell wave trains, can run for very long distances with very little decay, but for the four local cyclones of 1972 and 1974, it was noted in the field, that once cyclones moved away about this distance, their wave trains began to wane. The general impression also has been that most local cyclones, either make landfall if they are moving westwards, or otherwise translate away to the southeast. The cyclone wave trains that affect the Gold Coast from the latter, are thus escaping from behind the cyclone, not being pushed ahead of it. The difference in wave power, appears to be quite significant. Our statistics indicate that twice as many local cyclones veer east or southeast, as either cyclones that turn westwards or keep running south offshore.

Classifying cyclones by their central pressure alone, is a very crude measure, but we are doing very crude work, and one has to start somewhere. There are then two features of great storm wave attacks, that are of real help to the graphical modeller. The first is that during a great storm, its powerful wave trains, will acti-

![Gumbel Plot](Figure 3. Cyclone frequency Vs intensity.)
vate the seabed nearly out to the continental shelf. During the storm then, there will be little or no relict seabed zone and very little seabed memory effects. It is true that the more offshore seabed active zone is controlled rather by the swell period than the wave height, but the change in the far seabed shape, is not grossly important. The second important feature is the development of storm bars. Prototype evidence suggests that the local beaches will accept a deepwater swell wave with a height of just over two metres, before a storm bar develops at all. From then onwards however, the swells will manufacture a series of storm bars, such that the incident deepwater wave, will break on a bar in approximately its own depth of water and it will then reform at nearly half its original height. The incoming swell, will thus form 1, 2, 3 or perhaps more storm bars, until the final breaking wave on the visible beach, is about two metres or less.

In this, the behaviour of storms bars is dominated by the wave height, for this sets the storm bar depth. The wave period may determine the length and depth of the trough between the bars, but as a first approximation, it might be ignored. The graphical modeller, then by trial and error, can very rapidly draw a series of storm bars, on a given beach mean profile, assuming that during the storm, the total beach cross section, will be nearly constant (i.e. there is no longshore transport differential). The only other assumption required is that of a given swell wave height, H sig., for any postulated return period cyclone, together with the estimated sea level surge.

At this point, we move away from simple graphics and back into the area of total uncertainty. We have no hard field data on either parameter, but from the graphs of the Shore Protection Manual (1984) and with a great deal of intuition, we postulate the relationships, shown in Figure 4. This graph holds a very high quotient of interpretation, but when we use it for our graphical storm bar cross sectional diagrams, our storm erosion penetrations, are as shown in Figure 5. To our astonishment, our points very closely indeed, meet a straight line Log-Gumbel plot; just as we might again expect from the most extreme of events. Perhaps it is all pure chance (or luck) but it is strange that the results are so simple and direct. But where then has this got us? The diagram is useless, unless we can calibrate it in other ways. To calibrate our results we need evidence of past erosion penetrations, and very fortunately for us on the Gold Coast, we have been able to detect and recognize this evidence.

**Evidence of Previous Erosion**

A feature of the Gold Coast beach sand sediments, is that they contain a significant volume of black heavy spherical mineral sands, intermixed with the silica sands and shell fragments. During fine weather mild wave conditions, the heavy mineral grains remain mixed and distributed throughout the beach sand. During very heavy wave attack, however, nature winnows this spherical material from within the high energy wave breaking zones, and moves the black particles offshore of the most offshore bar seawards, and landwards onto the top of the swash zone. Particularly near high tide during a cyclone, one can stand on the beach and watch the heavy mineral concentrate as a black layer on the visible beach. The effect is striking indeed (Figure 6), and the larger and longer lasting the storm wave train, then the thicker and more “pure” is the layer. As the storm subsides, the mineral layer is then left as an upper beach relic deposit that remains as a black seam until the post-storm waves and wind rebuild the visible beach and bury the erosion scarps.

The Gold Coast beachfront is now becoming highly developed and every so often excavations within the post dune area for building foundation, an underground carpark or even to recover the minerals expose evidence of past storm erosion profiles. It is then only reasonable to apply the principles of geological stratigraphy, and deduce that the deeper the mineral seam, the greater its age. Also, it seems reasonable to assume, that the thicker and darker the mineral seam, the longer was the storm erosion event. An example of such evidence, is shown in Figure 7. The darker seams are very obvious, but unfortunately the seams were not detected until dusk, and the excavation that was then clean, could not be photographed until 0800 h the next day. In the night, it rained very heavily and as can be seen from the cap and parka of the engineer, it was still pouring when the photograph was taken. The clean excavation scarp shown, is thus contaminated with slumps
Figure 4. Central pressure Vs wave height.

Figure 5. Return period Vs total sediment volume.
that have obscured much of the continuity. The site however, was carefully surveyed and the total erosion scarp seam geometry is shown in Figure 8.

The next step then, is to attempt to "date" some or all, of the seams. The three uppermost seams can be dated precisely. After the 1967 erosion, a boulder revetment was constructed on the original property beach boundary. The two seams dated as 1974 and 1972, were the results of wall overtopping, and Sam Smith actually stood near this wall and watched the seams form. The seam marked as 1967, was not observed in real time, but it was inspected immediately after the cyclone, and also captured on film from the air, during the event. The dating of all the deeper seams from then on, however, is a matter of interpretation.

For this, we have reanalyzed the Bureau of Meterology records, of major cyclone and wave events, back to the commencement of their records. We then compared these records with historical photographs that demonstrate that the Gold Coast erosion of 1935, was worse than in 1967, and that 1923 was even worse than that. This then gives us our next two postulated "dates." There are no photographs of beach erosion locally, earlier than 1923, but the Bureau of Meteorology records indicate that the next greatest previous cyclone (and flooding) coastal events in southern Queensland, occurred in 1894 and 1893. The records suggest that both these storms were fierce and prolonged, so we use these two dates for the next two deeper seams, because they are the thickest and most concentrated (81%) of all in our available record. Of the three seams beneath the 1893 layer, we know nothing, and we can deduce precious little. The meterology records suggest that the greatest flood ever to affect Brisbane, occurred in 1841, and if this was the result of a close cyclone, then the next seam, may date from this event, but we cannot now tell. All that we might deduce, is that the final two deepest seams, could date from the 1400 to perhaps 1700 epoch when the global weather changed.
for the worse. These were the times of the European mini-ice ages, and the Southern hemisphere probably followed suit, even if a few sun-spot cycles later.

Now if we are to attempt to use our storm erosion seam data, to quantify beach erosion, then we have to try and set up some datum for the mean beach location. This of course is not as simple as it might appear. The world is full of people who equate the width of the visible beach, as a measure of beach accretion or secular erosion. Sometimes they also use the location of an erosion scarp, and sometimes the degree of frontal dune vegetation. Unfortunately all these things are highly variable and unreliable, in addressing overall beach behaviour. The visible beach and the ambient swash zone, are Nature's only buffer zone between the offshore seabed work prism, and the dunes and land behind them. The width of the visible beach at any point in time, is controlled by the incoming wave energy and the volume of the active seabed work prism, that is required to absorb that energy. The visible beach, since it only contributes a swash zone to the incoming waves, locally represents only about 5% to the overall work capacity of the total beach system. When the climate is mild, the visible beach is wide, but during stormy weather, it becomes quite narrow. Gold Coast geological historical evidence, strongly suggests we believe that there has been no longterm losses and the gross cross section of the active seabed sediment volume has been nearly constant, at least during the Holocene. We cannot prove this of course, our precise survey data is all only recent, but the general visual trend is unmistakable.

Therefore an alternative datum is desirable. Our recent Gold Coast research into natural dune behaviour, implies that our local back beach parallel dunes are a very long term phenomenon of extremely low mobility, in their pristine state. The leading dune(s), may be seriously eroded during a storm, but given suitable fine weather, then they will rebuild slowly to their original static stable shape. Then if the ambient visible beach is narrow, they cannot grow, but if the beach is currently very wide, they will not grow either. The wider beach, merely forms a lower ephemeral sub-dune, in front of them. Our observations therefore, lead us to consider (in the lack of very long term profile data) that the location of the toe of the pristine frontal dune, is the best indicator available of the mean location of a sandy beach system in plan, over the very long term. There may be many who might take issue with this concept, but we can only invite them to find something better as a long term physical indicator. It is certainly the feature of a dynamic ocean beach, that can and does exist for centuries, on a "stable" beach.

We therefore apply this criterion as our datum for beach erosion and repair. When we do, we take our Figure 8 erosion scarp data and plot the 1935, 1923 and 1893 storm recessions on Figure 3, as a new Figure 9. When we look at Figure 9, we might note that the return frequencies that they plot upon, are quite reasonable. The 1935 erosion plots as about a 1 in 40 years event, the 1923 at about 1 in 60 years, and the 1893 at about 1 in 90 years event. In terms of their deduced dates before the present, these values are not at all repugnant. Subsequently we checked a major excavation more landwards and found another storm mineral seam, vanishing at a scarp 180 metres from the dune line. We plot this then, as what we call the X band on Figure 9, and find that it plots near to a 1 in 800 year event. In fact, the excavation on this site, went to a depth of three metres below mean ground level, but the seam remained on its own—there were no more mineral storm scarp seams, below it. We then checked a similar excavation that was 500 metres shorewards of the dune line, but there were no mineral seams in the deep cut faces. Extrapolating an erosion distance landwards of the dune line, to 500 metres on Figure 9, we found that it should have a return period of 25,000 years, but the local Holocene stable sea level, has only existed here for probably only 6000 years. Perhaps our inadequate fragmentary evidence, is telling us more than we appreciate.

More recently another two suitable deep building excavations were located. In both of them at a level of nearly R.L. + 3.0 m, were found mineral seams that tailed out at a distance of 310 metres, from the original dune line. There were no other higher mineral bands. From this, we deduced that this seam, that we now call our V Band, could be approximately 4,000 years old and we have added this point subsequently to Figure 9. The "front" or beach parallel "length" of seam, as exposed, was over 60 metres of continuous mineral material. The
probability that a 1 in 4,000 year event, has occurred in the Holocene, is not unreasonable. It should be noted that the older records may have been influenced by previous locations of the migrating river and creek entrances but the lack of anomalies in the records would indicate that this has not been a problem with the data collected.

**Dune Records**

There is other geological evidence, that we might apply to our study. It is very diffused and uncertain, but it must be able to be interpreted. It concerns the degree to which the dune sand has been podzolized by mature terrestrial vegetation. From storm erosion scarps, we know that the pioneer dune vegetation species, i.e. Spinifex grass and Casuarina trees, induce practically no podzolization into the parent dune sands. We also observe from sands on the Southport Spit, that have only been in place for 100 years or so, that secondary coastal dune growth, requires a much longer time than that, to induce any obvious podzolization at all. GRIMSTONE (1974) offered that it could require up to 4,000 years, for a new dune sand to be podzolized down to a depth of a metre, but his figure seems exceedingly conservative. Locally, it would certainly require nearly 200 years for a leading dune to become stable, with a covering of Casuarina and Banksia, before more terrestrial podzolizing trees and shrubs, could prosper behind their wind and saltbreak shrouding. But after that, we might expect a reasonably rapid terrestrial vegetation podzolization process, to become initiated. Our site 500 m from the dune line, was podzolized to a depth of 2.4 m and our 180 m and 310 m sites to a depth of 1.0 m, 2.1 m respectively. If we assume that the 500 m site sands were about 4,000 years old (they were originally a secondary barrier spit) then following a square law, our 180 m site sands should be a little more than 1,000 years old or close to 1,400 years. Our estimates based on Figure 9 seem to be approaching the same ballpark, but the correlation remains extremely vague. As always, we simply never have enough hard prototype data to calibrate our efforts.

Now, in all our estimates, we have assumed a nearly constant beach volume cross-section and a nearly constant littoral drift. Suppose that either one, or both of these parameters has been a variable over time. We might first postulate, as it is believed by some sources that the Gold Coast beach system is progressively receding. If it was, however, the overall beach system would have been migrating shorewards, and this migration should have consumed and erased
most or all our previous storm scarp heavy mineral seams—but they are still there. We know how the beach has behaved since 1967, and the erosion seams have not been consumed so it appears that the progressive secular erosion concept based upon very recent photographic evidence of the width of only the visible beach is probably false. On the other hand, our precise beach profile sections, demonstrate that the local beach system is not obviously prograding either, so apart from local littoral drift starvation shadow zones, we again seem to see a nearly constant volumetric active zone across section.

Localised Erosion Effects

A strange feature of peak storm erosion on the Gold Coast, is that it is markedly uneven. Before the storm, the beach is an even Zeta curve in plan, but when the erosion scarp develops, it develops significant departures locally from a smooth curve. The peak erosion penetration concentrates in some areas and is lesser in others, often over longshore distances, as short as 300 to 400 metres. The reason for this phenomenon is not at all clear, but it adds much uncertainty to all storm erosion estimates. If you find a sequence of mineral erosion scarps, you cannot tell whether these scarps were in a maximum or minimum erosion zone, but the penetration difference has been 10 metres or more in storms observed in recent times.

There are some local beach zones on the Gold Coast, where the local storm erosion is nearly always greater than the average, but the reason behind this, is often readily deduced. Zones of "regular" accentuation are found landward of offshore seabed reefs which have been charted with side-scan sonar and seismic profiling. During fine weather, the reef surface is usually covered with a thin layer of sand, that holds a thickness that is compatible with the smaller mild weather wave trains. When the great storm arrives, this sand is swept offshore, and the larger waves that roll over the reef, are impinging on an impervious surface. They therefore lose less energy than the waves either side, that are shoaling over a thick pervious sandy seabed, so the reef crossing waves carry much more power onto the final swash zone. With more power than the average, they simply erode the beach a little more in the lee of the reef.

The mechanism that makes other parts of the local beaches that are not landwards of reef structures or at a rip cell, erode more than the mean, remains very much an enigma. Real storm wave trains, are very much irregular and highly three dimensional, but their very variability should ensure that given time, their natural overlapping behaviour, should average-out the wave peaks, carried by an individual or "set" of large waves. A peak storm erosion, lasting 3 hours of near high tide water levels, with a 10 sec. wave period, lands over 1,000 waves on the beach. The most likely contender for an explanation, is swash beat. In our graphical erosion models, we used the wave height alone, to estimate the offshore bar locations, and ignored the effects of storm surge, on mean sea level. The reason for this, was a pure matter of long term field observation. During most coastal storms, the barometric induced rise in sea level is small, unless an intense cyclone approaches within 50 to 100 nautical miles. While this is a comparatively rare occurrence it may be a factor in extreme events. The Bureau of Meteorology has predicted a 1 in 500 year storm surge of approximately 1 m which coupled with high tide component of + 1.5 m the relic storm scarps at + 3 m are reasonable. However, most storms also manufacture a surge due to wind setup and wave setup. It has been readily seen from the beach, that this component of storm surge, forms under the outer wave breaking zones, where it can escape back into the ocean, more readily than it can flow ashore. The still water level on the visible beach, for most of the time, is much lower than out under the breaking waves, often startlingly so.

What seems to hold the surge water back from the beach, is the reformed waves and bores, that are manufactured by the wave breaking process. These reformed waves slow down as they shoal onto the swash zone, but their major feature is that they almost never catch up with each other, until they reach their final swash zone bore geometry. In this location, they often ride over each other, particularly where the undertow is momentarily strong. The result is a swash beat. For perhaps 30 to 40 waves, the final swash bores will remain separate, but slowly the undertow holds them back until the water depth is enough to let the next wave ride.

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onto them. Then the hydraulic "damming" or "hold" capacity of the multiple bores, is overwhelmed, and a surge of water sometimes up to nearly 1.5 m thick, rushes up the beach, penetrating far inland. It is these waves that cause rapid dune erosion. It is just one kind of the classical "doubled" wave break behaviour. The great uprush, then returns as a strong backwash and the bore containment process, commences again. For some reason quite unknown, this "super" swash bore behaviour, is quite localised and highly variable, since presumably, it is controlled by only the peaks of the very largest waves in the total train. As a generator of local enhanced erosion however, it can be highly potent. This may also explain why different cyclones cause accentuated erosion, in different parts of the beach—they each must simply manufacture different peak wave patterns. It would be only reasonable if they did, the escape wave direction for each cyclone, should be different as well.

Contour Plans—Evidence of Past Erosion

Our final site evidence of extreme storm erosion penetration, is also of geological origin, although this evidence is apparently much more diffused and uncertain, than our other evidence above. The evidence is derived from studies of the early contour plans, of the pre-1960 Gold Coast natural dunes. However, this evidence must still hold some meaning. From the general alignment of the local dunes, and the degree of podzolization that we see, we deduce that the dunes are quite ancient, particularly the secondary dune. Our estimates must remain extremely crude, but we might at least expect that the rear slope of the primary dune, is generally 1,000-2,000 years old, and the rear of the secondary dune 4,000-5,000 years old maximum. These estimates nevertheless might give us some starting point.

At least over recent times, we observe that when the natural dunes are at their maximum new wind-blow growth stages, that the final dune is usually continuous and of near constant cross-section and height. From the contour plans however, we see that there are breaks or gaps, in the crest contours that suggest previous breaches by waves. The breaches vary from about 100 to 500 m in length and we deduce that they are not wind blow-outs, simply from the lack of a barchan-like sand tail, landwards of the "gaps." We also note that there are twice as many breaches in the primary dune, as there are in the secondary, much as we might expect, if wave attack has been the eroding agency. The primary dune is closer to the ocean, so it will be prone to wave attack, much more often.

The more southern Gold Coast beaches, i.e. from Tugun to Burleigh, tend to demonstrate somewhat confused dune geometries, but all these beaches have, until recent times, been affected by wandering creek and stormwater outflows, and are intercepted by marked "hardpoint" headlands. The main smooth beach compartment that appears reasonably "pure," is then the beach from Burleigh to Main Beach. This is a length of some 14 km of sand, and from the contour maps, we detect 3 breaches of the secondary dune and 17 breaches of the primary dune, over this length. We first consider whether local wave attack is our culprit, or could the breaches be the results of local dunal vegetation, or of flood escape from the estuary behind the dunes. Our first conclusion is that in the short term, mature trees could certainly inhibit some dune building more landwards, but mature trees are easily buried and die-back from sand blast. Also our local Casuarina and Banksia trees, hold a much shorter life span than a thousand years or so.

We next consider inland flood overtopping, as a cause. If it was high flood levels that breached the dunes, our first expectation might be that there should be more breaches in the secondary dune than in the primary. Then the width of the breaches, does not seem nearly wide enough, to carry a typical sediment-rich barrier island river outflow crossing, particularly a migrating one; but all our local creeks and rivers, have migrated in the past, with the littoral drift. Since most severe Gold Coast erosion occurs during cyclones, we would expect that extreme wave attack, should be associated with concurrent or sequential flooding. Our usual problem is that we have totally inadequate data available, that could allow us to even explore the probable association. The floods may have accentuated the breaches, but wave attack still seems to remain the most convincing "cause."

At least our research into localised accentuated erosion, as discussed above, can explain why the "breaches" as we see them, are also local-
ised and of finite “size.” If the breaches are induced by extreme wave attack, then they only mirror, in an exaggerated scale, what we have already seen on the beaches, under lesser extreme events. We also observe that during cyclones, the wave attack readily shoals a river outlet crossing, and sometimes the littoral drift becomes so high, that it can completely block the flood outfall, except perhaps for at periods of very low tide, when the wave energy onto the beach is much reduced.

In addressing our deduced breach “counts” through the dunes, we now have to consider the natural dune rebuilding and “repair” capacity upon the evidence. Since we regard the secondary dune to be ancient and highly moribund, we would expect that the “breach” evidence is probably quite explicit and reliable. For the frontal dune however, this may not be the case. Here, over the last 500 to 2,000 years, there could have been a great deal more dune breaching, but the breaches have been subsequently erased by later beach sand, blowing into the gaps and filling them. We next have to consider whether each breach is a record of a single storm event, or whether one single storm might have manufactured more than one breach, during the event. In this, we are back in the realms of conjecture, but we may still try to evaluate this evidence against our storm scarps and sand podzolization evidence. What then, might we think?

Suppose we first take the evidence at its face value, and assume that each extreme erosion penetration, is the result of only a single event. If we say that the secondary dune is between 4,000 and 5,000 years old, or say 4,500 years as a mean, then three separate breaches will have a return period of about 1,500 years. To breach the secondary dune, from the leading edge dune line, we require a storm penetration erosion of about 220 metres, so we then plot this as what we call the Y Band on Figure 9. To our surprise, it is not a bad fit, but then as always, this may be quite accidental. We next consider the seven breaches to the primary dune, again say, for a mean dune life of 1,500 years. This gives a return period of about 215 years, and our erosion penetration required to erode the primary dune, is now 120 metres. We plot this on Figure 9 as the Z Band, and again the fit is not too bad. At least, based upon our very simple logic, all our evidence can be made to look reasonable, but what good that may be, is a very different matter. However, if we do accept our very simple logic, and accept that each breach is the result of a single event, then somehow or other, we have attained a single unified pattern. It is of course, only human nature, for any investigator, to reconcile his results with what he expects to happen, and perhaps we have committed the same error. Yet the matter that we are addressing, is of vital import to our local coastal community, and we have to start somewhere. At least for our local Gold Coast, our calculated regime storm beach shapes, our mineral seam erosion scarps, our podzolization evidence and our dune breach contours, can be made to look compatible.

CONCLUSIONS

This past erosion evidence, tenuous and very clouded as it may be, must very certainly be better than nothing at all. It represents at least, a serious start to better understanding the long term dynamics and short term instability of a beach system.

But where then has this all really taken us? What we now need to decide is how reasonable and rational, are all our evidence interpretations. For this, we should zero-in on our evidence, as displayed by our erosion seams. This is the most positive evidence that we have ever found to date and the V band represents the most landwards erosion scarp evidence, that has been found, without an earlier record beneath it. Now we do not know whether this mineral seam, represents the “average” beach scarp of the time, or if it could have been a localised “peak” erosion. However, in terms of overall probabilities and the small number of peak recessions, we found on the dune contour maps, it would be highly unlikely that this particular spot would have been a peak area. Our graphical erosion plots were drawn for the maximum erosion, so we might put the X Band event peak erosion, at nearer 210 metres or so—which would give us a return period of nearer 1250 years, on Figure 9. We might at this stage therefore, take it as approximately the 1 in 1,000 year event. Similarly using the V band recession of 350 m could be approximated to the 1 in 5,000 year event.
SUMMARY

This is about as far as we can go with this method at present. How good is it all? We are dealing with highly uncertain and variable events, and whilst we have tried to sift every shred of past evidence recognised and available to us, it is highly likely that our estimates are still significantly inaccurate. On the other hand, we have applied data from several very different sources, all of which provide a reasonable fit to our predictions. The Figure 9 plot, at least "feels" reasonable, so we thus might consider that our predictions are of "ball-park" acceptability and that they provide perhaps some guidance as to what we might expect in the long term. Further local evidence will come to light as time goes by, and clearly the search for additional data should be ongoing and premeditated. The risks are still there and the next eroding cyclone is inevitably "on its way." It is just a matter of when. However this research has provided a better appreciation of the potential impact and reduces the risks involved with future predictions.

LITERATURE CITED