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8A:
Before and
After the Storm:
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Friday 9th
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Erosive Capacity of Storms on a Typical Sandy Beach, Cross-Shore Sediment Transport Modelling

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Introduction

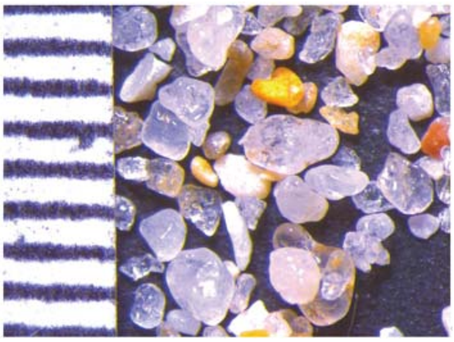
Schedule One of the Western Australia Planning Commission State Coastal Planning Policy (WAPC, 2003) provides guidelines for the determination of a setback that protects development from coastal processes. This includes an allowance for storm-induced acute erosion, historic change, and sea level rise. The guidelines consider ocean forces and coastal processes which have a statistical recurrence of once per one hundred years.

To quantify the potential storm-induced acute erosion cross-shore sediment transport modelling software, typically SBEACH, is used to model three successive runs of a severe storm event. Currently the Department of Transport (DoT) recommends using a recorded storm from 15th–19th July 1996. An upcoming revision of the Policy provides an opportunity to review which recorded storm is used. Three consecutive runs of the storm are expected to approximate an erosion event with a 100 year average return interval.

Conventionally the historical storm event with the largest wave height has been assumed to produce the most severe beach erosion. This may not be the case. Research by Callaghan *et al*. (2008), Dorsch *et al*., (2008) and Dolan and Davis (1992) has found that storm erosion processes involve several random or interconnected variables, which include wave height, wave period, wave direction, water level, and event spacing. The preceding beach profile may also play a role.

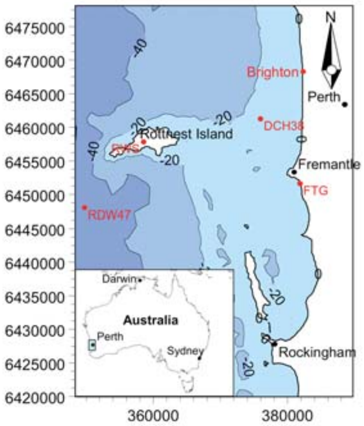
There is debate about the appropriateness of using SBEACH in Western Australia (WA) because of the differences in beach types between WA and where SBEACH was developed on the east coast of the USA. WA beaches often feature rock platforms underlying thin perched sandy beaches, and can be protected by significant near-shore, shore-parallel limestone reefs. In addition local sand often contains a high proportion of modern biogenic calcium-carbonate grains originating from skeletal remains of marine organisms (Figure 1). These grains vary in properties from the quartz sand.

Figure 1: Microscope photograph of beach sand collected from Brighton Beach. Calcium carbonate, quartz and other non-biogenic grains are present. The spatial markings are approximately 0.5mm apart.



This investigation only considers erosion on a typical, high-energy, sandy beach on the WA coast. Brighton Beach is located approximately 17kms north of the Swan River mouth (Figure 2), within the Perth suburbs. It is an exposed sandy beach and is considered to represent a typical sandy beach along the WA coast.

Figure 2: Perth coast (Western Australia) showing the locations of Brighton Beach, wave buoys, wind station, and tide gauge used in this study. Map projection: MGA-50, Datum: Australian Height Datum (+0.756m above Chart Datum), unit: metre, RDW47: Rottnest Directional Waverider, FTG: Fremantle Tide Gauge.



This paper investigates which storm events, measured in the 15 years from 1994 to 2008, have produced the biggest coastline recession. Li (2009) short lists the top ten extreme storm sequences from 15 years of wave and water level data by three methods:

1) Maximum storm peak wave height (WH);
2) Total wave power (TWP) of a storm, and;
3) Duration of non-tidal residual water levels (WL).

Available Data

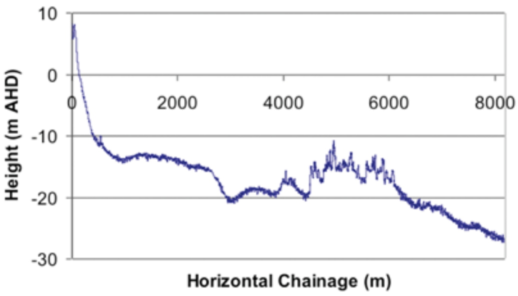
A waverider buoy (marked RDW47 in Figure 2) has been deployed since 1991, south-west off Rottnest Island in a water depth of 48 m. The early data were six-hourly with poor continuity and season losses. Hourly continuous data became available from February, 1994 onwards. The wave buoy recording includes significant wave height (Hs), total spectral peak period (Tp) and direction for sea, swell and total waves. Hourly total significant wave height and total peak wave period were used for this investigation.

Observed hourly water levels from Fishing Boat Harbour in Fremantle, approximately 25 kms from buoy RDW47 were used for this study. Water levels at Fremantle are considered representative of the Perth metropolitan coast.

A recently surveyed beach profile from Brighton Beach (24th April 2009) is considered to appropriately represent a 'pre-winter' profile likely to exist with the incidence of the first winter storms. Data were collected from the vegetated foredune to approximately 25 m water depth at a distance of approximately 8 kms from the shoreline. Subaerial beach profile data were collected at half metre intervals using differential Trimble

R8 GPS equipment. The subaerial data are considered to have a horizontal accuracy of 0.1m and vertical accuracy of 0.05 m. Submarine survey data were collected using differential Trimble R8 GPS equipment (for the nearshore environment) and PROXRS and OMNISTAR in combination with a Navisound 520 sounder aboard the DPI vessel SV Profiler. The hydrographic survey data are considered to have a horizontal accuracy of 1.0 m and vertical accuracy of 0.1m. Unfortunately due to weather conditions on the day there was a gap of 22 m in the wave breaking zone which could not be safely surveyed by differential GPS or by the SV Profiler. The data either side of the gap were approximately linear and hence the gap was filled by linear interpolation (Figure 3).

Figure 3: Surveyed Brighton beach profile (20th April 2009). The profile extends from behind vegetated dune to approximately 25m water depth at approximately 8kms from the shoreline.



Method

Storm Identification

Coastal storminess is a widely used indicator for coastal erosion and climate change. There is, however, no universally accepted definition. Coastal engineers commonly use numbers of hours, or number of storm events, when wave height is higher than a certain value (DPI, 2004, Lemm, 1999, Goda, 1988). Others use the number of hours, or number of events, when water level is higher than a certain level (Pattiaratchi and Eliot 2008, Zhang, 2000, Eliot and Clarke 1986).

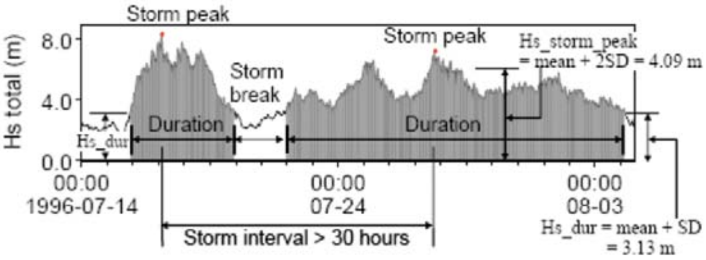
In the past, arbitrary criteria were commonly used as the threshold for storm identification. For example Hs > 4.0m (Lemm, 1999), Hs >1.5m (Dolan and Davis, 1992) wind speed >15.3 m/s (Lozano, *et al.*, 2004), wind speed >15 m/s (Travers, 2007). These threshold values generally corresponded to a low percentage of exceedance in their datasets. In this study the selection of thresholds for different datasets follows the statistical method used by Li (2009) after Zhang, *et al.*, (2000).

Three criteria have to be satisfied for a data sequence to be classified as a storm:

1) The event consists of at least one sample over its peak threshold value, $H_{s\_storm\_peak}$ (the dataset mean + two standard deviations); The storm continues while the total H_s remain above H_{s_dur} (dataset mean + standard deviation);
2) The interval between two consecutive storms (storm peak to storm peak) is not less than 30 hours. Otherwise they are regarded as the continuation of a single storm;
3) The storm break, the end of previous storm to the beginning of current storm, is not shorter than three hours; otherwise they are regarded as the continuation of one storm.

Figure 4 uses the Rottnest wave record as an example to graphically illustrate the definition of a storm, storm duration, and the terminology used in this study.

Figure 4: Storms are defined as events during which the significant wave height exceeds 4.09m and duration is calculated for when Hs exceeds 3.13m.



The total wave power (TWP) for each storm sequence is defined as:

$$P = \sum \left(Hs_{Rottnest}^{2} * \Delta t \right) \quad (1)$$

where HsRottnest is the hourly significant wave height in metres, Δt is the wave data interval in days, for hourly dataset, Δt =1/24 day. This index was first introduced by Dolan and Davis (1992) and more recently used by Li (2009) to define the top ten storms ranked by TWP for Rottnest Island from 1994 to 2008, listed in Table 1. The top ten storms by WH and WL are not included.

Table 1: Top ten storms ranked by total storm wave power (TPW) for Rottnest Island total Hs wave record from 1994 to 2008.

Ranking	TWP (m^2 day)	Storm started at	Storm ended at
1st	293.9	21/07/1996 23:00	4/08/1996 3:00
2nd	195.9	10/07/2000 7:00	19/07/2000 16:00
3rd	144.2	15/07/1996 22:00	19/07/1996 22:00
4th	137.8	22/08/2004 14:00	27/08/2004 8:00
5th	137.5	27/07/2007 18:00	2/08/2007 10:00
6th	124.7	4/09/2005 9:00	10/09/2005 2:00
7th	123.6	14/09/1996 1:00	19/09/1996 16:00
8th	109.0	17/06/1996 14:00	22/06/1996 11:00
9th	108.8	20/09/2003 1:00	24/09/2003 22:00
10th	105.48	13/08/2005 6:00	18/08/2005 21:00

Cross-shore sediment transport modelling

The numerical model, SBEACH was used to estimate and compare the cross-shore erosion the ten identified storms could theoretically cause at Brighton beach. SBEACH (Storm-induced BEach CHange) is a numerical simulation model developed by the U.S. Army Core of Engineers (Sommerfeld, Kraus and Larson 1996). It is a relatively simple program which applies input metocean conditions onto an input cross-shore beach profile. It is widely used for beach erosion prediction.

Model inputs

All 'storm' information for this study were real data measured in the Perth metropolitan area. Variable, hourly wave height, period, and water level data were input into the 'storm' data section of SBEACH. The storm was configured with irregular waves and a 10 minute calculation time step. The input wave depth was 48m and wave height was randomized with a seed value of 4567 and 20% variability. For simplification, waves were considered to have arrived with crests parallel to the coast. Similarly, wind has been ignored in this investigation for simplification.

Pilot investigations suggested the full length of the profile (~8 kms) did not produce different results from using only part of the profile extending approximately 3 kms offshore to a depth of approximately 20m. Therefore the shortened profile (~3kms) was used for the majority of analysis.

Sensitivity analysis

Where local data were unavailable, default values defined in the SBEACH user manual have been used. Due to concerns regarding the application of SBEACH on WA beaches a sensitivity analysis was conducted to assist in estimating a standard error for the results. Table 2 defines available field data, estimates from previous work and default values for input into SBEACH.

Table 2: Available field data and initial estimates of inputs, and/or default values for SBEACH configuration.

Variable	Value	Comment
Water Temp.	17 °C	Field data from Perth coast
Sand remains on grid	No	Previous work by DPI
Wind	Neglected	Simplification
Grain size—initial	0.51 mm	Literature (Stul 2005)
Cell sizes—initial	500 @ 1 m; 300 @ 5 m; 94 @10 m	Previous work by DPI
Avalanching angle – initial	30°	Previous work by DPI

Variable	Value	Comment
Surf zone depth—initial	0.3 m	Previous work by DPI
Transport rate coefficient—initial	1.75 *10^{-6} m^{4}/N	Default
Slope dependant coefficient—initial	0.002 m2/s	Default
Transport coefficient multiplier—initial	0.5	Previous work by DPI

The sensitivity of input parameters was investigated by adjusting +/- 10%. The transport rate coefficient multiplier was adjusted by -10% and -20% as the upper bound was used as the default value. Unfortunately calibration of the inputs into SBEACH was not possible as pre and post storm profiles have not yet been obtained at Brighton Beach for any significant storm events.

Estimation of standard error

With difficulty in verifying the accuracy of the outputs of SBEACH, an approximate standard error was calculated. This error was calculated by summing the component error for each input parameter.

Comparison of erosion from TWP storms

Following quantification of an approximate total standard error associated with the unknown input parameters the top ten storms defined by TWP were applied to the beach profile using values from Table 2. The only change was a different cell size combination of 1 m, 2 m, 5 m and 10 m cells. Modelling of the application of each storm on the profile was observed live in SBEACH to ensure there was no unusual/anomalous behaviour. Unusual spikes can occur in the beach profile during modelling—which are not realistic.

Comparison of erosion from storms ranked by peak Hs and non-tidal residual

The top ten storms calculated by both maximum storm peak wave height and the duration of non-tidal residual water levels by Li (2009) were also applied to the beach profile. Only one application of each storm on the profile was carried out, using the input parameters defined in Table 2.

Results

Sensitivity analysis results

Table 3 defines upper and lower values of various inputs and the resultant maximum % recession change compared to the initial inputs from Table 2. The recession from the approximate vegetation line elevation (2m AHD) has been used.

Table 3: Sensitivity analysis for adjustments to input data. Recession is the maximum difference between the initial configuration's recession defined in Table 2 and the configuration being tested, in both metres and as a percentage of the recession in the initial run.

Variable	Value	Recession Change (m and %)
Grain size—High	0.561	5.34 m; 24%
Grain size—Low	0.459	4.89 m; 21%
Water Temp.—High	19°C	1.37 m; 6%
Water Temp.—Low	15°C	2.23 m; 10%
Avalanching angle—High	33°	2.27 m; 10%
Avalanching angle—Low	27°	2.96 m; 14%
Surf zone depth—High	0.33m	2.54 m; 12%
Surf zone depth—Low	0.27m	2.26 m;10%
Transport rate coefficient—High	1.925 *10^{-6} m^{4}/N	1.64 m; 8%
Transport rate coefficient—Low	1.575 *10^{-6} m^{4}/N	3.26 m; 15%
Slope dependent coefficient—High	0.0022 m^{2}/s	2.14 m;10%
Slope dependent coefficient—Low	0.0018 m^{2}/s	3.02 m;14%
Transport coefficient multiplier—Interim	0.45	2.46 m; 11%
Transport coefficient multiplier—Low	0.4	2.41 m; 11%

Standard error

The standard error components calculated from the sensitivity analysis for each of the input parameters are listed in Table 4.

Table 4: SBEACH input parameters and their estimated standard errors, with summed total.

Variable:	Standard Error (m):
Grain size	5.50
Water Temperature	2.25
Avalanching angle	3.00
Surf Zone Depth	2.50
Transport Rate Coeff.	3.25
Slope Dependent Coeff.	3.00
Transport Coeff. multiplier	2.50
Total	**22.00 m**

Capacity of erosion from TWP storms

Despite fluctuations in the maximum recession values with changes to the input parameters (Table 5), the ranking of erosion relatively between the top ten storms by TWP storms is consistent (Figure 5).

Figure 5: Maximum recession of the 2mAHD elevation caused by the top ten storms ranked by TWP when applied to configurations with different input parameter values.

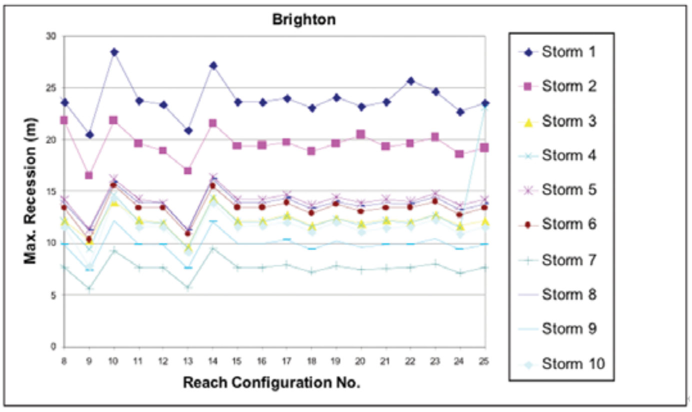


Table 5: Adjustments to input parameters for each configuration in Figure 5.

Reach Configuration	Input Parameter Adjustment
8	Table 2 values; cell sizes: 1 m,2 m,5 m,10 m
9	Grain size +10%; cell sizes: 1 m,5 m,10 m
10	Grain size -10%
11	Avalanching +10%; cell sizes:1 m,2 m,5 m,10 m
12	Avalanching -10%
13	Slope dependent coefficient -50%
14	Slope dependent coefficient +50%
15	Transport rate decay coeff. multiplier -10%
16	Transport rate decay coeff. multiplier -20%
17	Slope dependent coefficient +10%
18	Slope dependent coefficient -10%
19	Water temperature -10% (approx.)
20	Water temperature +10% (approx.)
21	Surf zone depth +10%
22	Surf zone depth -10%
23	Transport rate coefficient -25% (approx.)
24	Transport rate coefficient -10%
25	Long profile (48m depth); Cell sizes (m): 1,2,5,10,20, 50,100,500

There are some small changes to the ranking with Configurations 9, 10 and 11 (Figure 5). These configurations were those for which the grain size sensitivity was investigated. The most significant anomaly, however, is the magnitude of change for Storm 4 for Configuration 25. This configuration re-tested the extended beach profile which reached 48m water depth. Incorporating the results of the sensitivity analysis, and the calculation of standard error with available data for the input parameters defined in Table 2 allows the estimation of erosion for each of the ten TWP storms,

In Table 6 the ten TWP storms have also been ranked from most erosive to least erosive based on the modelled recession.

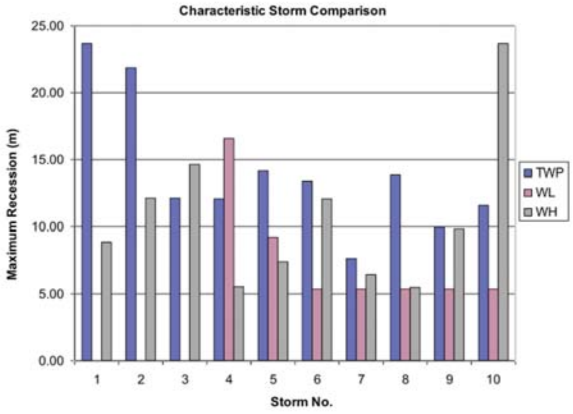
Table 6: Maximum recession of 2m AHD elevation by top ten storms ranked by TWP and erosion capacity ranking based on recession values.

TWP Storm #	Maximum Recession (m)	Error (m)	Erosion Ranking
1	23.6	+/- 22	1
2	21.9	+/- 22	2
3	12.1	+/- 22	6
4	12.1	+/- 22	6
5	14.2	+/- 22	3
6	13.4	+/- 22	5
7	7.6	+/- 22	9
8	13.8	+/- 22	4
9	9.9	+/- 22	8
10	11.6	+/- 22	7

Comparison of erosion from storms ranked by peak Hs and non-tidal residual

The top ten storms defined by both maximum storm wave height (WH) and the duration of non-tidal residual water levels (WL), were not as erosive as the TWP storms when applied to the Brighton Beach profile, Figure 6. For a majority of cases the TWP storms were noticeably more erosive than the WH and WL storms.

Figure 6: Brighton Beach Maximum recession of the 2mAHD elevation caused by the top ten storms ranked by total wave power (TWP), maximum storm wave height (WH) and duration of non-tidal residual water levels (WL). NB: WL Storms 1, 2 and 3 recorded no recession, and hence are not shown.



Discussion

The sensitivity analysis, and subsequent calculation of standard error, clearly demonstrates how important it is to have accurate input parameter values or be able to calibrate the model for a specific location. As this was not possible for Brighton Beach the standard error (+/- 22m) is generally greater than the modelled erosion distances. Therefore predictions of erosion using SBEACH along the WA coast must be appropriately scrutinised and the inherent error investigated.

The anomalies in relevant erosion ranking between the ten TWP storms are not considered significant. It is clear that grain size is a very sensitive input parameter and should be known accurately. Consideration must be given to the grain type as WA beaches often contain significant portions of biogenic calcium carbonate material as compared to the quartz/silicate beaches of the USA's east coast. The anomalous jump by Storm

4 on Configuration 25 does not have a clear cause, but is considered insignificant when compared to the wider results. Analysis of the ten TWP storms indicates that the four most erosive storms are Storms 1, 2, 5 and 8. Storm 3, the storm currently used for the State coastal Planning Policy only ranked as equal 6th in erosion capacity (Table 6). It is pertinent to consider choosing TWP Storm 1 or 2 as the storm to be used under the Policy in the future as the results indicate they are much more erosive events.

Comparison of the erosion from the top ten storms by TWP, WH and WL revealed that the top TWP storms has the greatest erosive capacity. Storms ranked by WL were least erosive. This suggests that long-duration wave height events are the most erosive for typical sandy beaches along the WA coast. Significant water level events, by themselves, do not have the ability to greatly erode the coast. Maximum peak wave height is not as important as storm duration for beach erosion.

It is pertinent to note that three storms from the TWP set are also in the WH set. Hence only 27 separate storms were analysed during this study.

Conclusion

It was found that for Brighton Beach the most severe storm erosion was produced by the storm from 21st July to 4th August 1996, according to analysis with SBEACH. The TWP index is a better indicator than the maximum storm wave height, and duration of elevated non-tidal residuals for the purpose of calculating beach erosion. The main reason for this result is likely to be the inclusion of storm duration in the TWP index. The main drivers for beach erosion are wave height and duration. Further research is required for the effects of other beach erosion variants such as the joint probability of high WL and powerful waves, and storm event spacing and wave direction.

Acknowledgements

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