Shand's methodology

The 2008 reports distinguished between coastal areas directly affected by stream and river discharge to the coast (inlets) and the rest (open coast).

Open coast erosion

The basic equation used is a version of the "standard" methodology used for Coastal Hazard Zonation, with no scaling factors evident in the relationship as expressed in Equation 1 (page 11 2008-2). This equation is

$$CEPD = LT + ST + SLR + DS + CU$$

where

$CEPD$ = Coastal erosion prediction distance (changed from CEHD = coastal erosion hazard distance terminology for 2012 report),

LT = Longer-term historic change based on 50 year time period from cadastral maps and aerial photographs.

ST = Shorter-term historic fluctuation. This was to be derived from statistical analysis of historical data, but it wasn't.

SLR = Shoreline retreat associated with sea-level rise induced by global warming.

DS = Dune stability. This accounts for the scarp retreat to a stable slope after an erosion event.

CU = Combined uncertainty. This is the error associated with the previous four terms in the equation, and any other precautionary measures that result from assumptions made in the analysis.

There are some issues with the approach to the uncertainty as expressed in the definition of Equation 1 in the original report:

- Some factors are time dependent (*LT* and *SLR*, which involve multiplying a factor by the time interval being considered) while others are not (*ST*, which is a fluctuation about zero, and *DS,* which is a one-off adjustment). Strictly the uncertainties of the time dependent factors will increase with time, and the others will not.
- It is not clear why there should be additional uncertainty factors beyond those that are already incorporated into the uncertainties of *LT*, *ST*, *SLR* and *DS*.

LT – long-term trend derivation and uncertainty

The long-term trends were derived from aerial photographs, and pre-digitised shorelines determined by NWASCO predominantly from aerial photographs and unspecified cadastral maps. It was noted that a systematic error resulting from using vegetation lines as shoreline indicators in aerial photographs, and reported high tide shoreline on the cadastral maps resulted in an over-estimate of shoreline erosion rates. These shoreline indicators may be several to tens of metres apart depending on beach state.

A landward reference point was used to define 68 locations (there are 59 C locations in the spreadsheet provided), and the distance between the shoreline and reference point measured in GIS (presumably but not stated?) from the geo-rectified aerial photographs and NWASCO plotted shorelines. It is assumed that the geo-rectification results in a location error of ±3 m, with a further error in estimating the shoreline position of ±3 m (for both aerial photos and NWASCO shoreline data?).

For each location about 9 measurements were made from aerial photographs, and 1-2 from cadastral map shorelines. These should have different uncertainties.

The long-term trend was determined by Ordinary Least Squares (OLS) regression analysis. Three different trends were determined:

Entire record – 1870s to 2007
Early period – 1870s to early 1950s
Late period – 1940s to 2007

These dates are not exact because the survey coverage varies along the coast. The early period was assumed to be unaffected by coastal management. This is not correct. The dunes were affected by grazing and burning resulting in extensive vegetation loss and destabilisation. Following the Sand Act (1908?) the dunes were planted in Marram Grass, which significantly altered their shape and behaviour. It is correct that coastal structures were employed after World War II in some areas. It can also be argued that land-use changes in the catchment have affected sediment yield over the entire record.

Although other NZ studies have identified long-term patterns of shoreline fluctuation, this study has decided to treat "non-linear" trends using break-point analysis without any constraints on the minimum trend duration (Figure 3). This approach has a significant effect on the long-term trend. In particular, it replaces a long-term (~100 y) trend with one based on a few decades. In figures 3A and 3C, it changes an accretionary trend into erosion, which is misleading. In Figures 3B and 3D, the magnitude of the trend is altered significantly.

It is claimed that apart from the sites in Figure 3, the late period trend was *qualitatively* similar to the trend over the entire record. No data are presented, and it is difficult to assess what is meant by qualitatively similar. I suppose I could waste time looking to see what the different trends were …

The report also compares the early period trend with the late period trend. This is important for assessing the impact of coastal structures, particularly since the analysis later considered scenarios where the structures are removed or fail. The difficulty is that the early period analysis typically compares 1-3 cadastral survey data points with 1-2 aerial points. Since there is a difference in the shoreline definition between the two types of data that biases the trend, the inferred trends are meaningless. This is acknowledged in the report as "Given that these rates may be exaggerated by the inclusion of tide-based shorelines from cadastral maps, and affected by lack of intermediate data-points, the pre-urban shoreline appears to have been relatively stable." (page 20 2008-2). Therefore, it seems to assume that in the critical area where structures now exist, the long-term rate prior to construction is "stable"?

Overall, the long-term trend is derived from the late period trend, except for those sites with seawalls or a "recent trend change" (Figure 4B). Those sites with a recent trend change use the short-term trend determined by the weighted linear model (strictly appears to be a truncated linear model using selected recent data points).

Sites with seawalls are assumed to have no long-term trend while seawalls are present. However, the report notes that there has been accretion at some seawall sites (in one case the seawall is completely buried now - site C12.50). What happens when seawalls are removed?

So for the calculated rates of shoreline movement there are:

Trends determined by OLS for the 1940s to 2007 (late period) – a trend over a maximum period of 67 years, which is barely long enough to span the 50-70 year fluctuations in NZ shorelines identified by other studies.

Trends determined by "weighted" OLS for the 1990s to 2007 (non-linear sites) – which is really a short-term trend.

"Stable" areas with no trend due to the presence of sea walls.

Then, if the trend is positive (coast is accreting) it is set to zero. Also, if the short-term weighted OLS trend is for faster erosion than the late period trend, it is used as a long-term trend.

Hence, a coast that the data shows to be predominantly accreting is transformed into either "stable" or eroding.

The uncertainty in the LT factor is determined as follows:

The assumed geo-rectification (±3 m) and shoreline detection errors (±3 m) are combined to give an assumed error of ±4.2 m.

The longshore variation of the "error" in the OLS regression for the late period data was assessed and an estimated 95% upper percentile was used to represent the entire coast. It is not clear exactly which error is referred to, but it appears to have been the Standard Error of Estimate, which is the standard deviation of the residuals.

Other factors that affect the uncertainty are discussed but then ignored.

The error that should be relevant to the LT factor is the uncertainty in the gradient of the OLS trend (ie. the uncertainty of b in Equation 2). This measures how much faster or slower the shoreline can be moving relative to the estimated rate. The report states that this was ignored because "the weighting procedure, together with the variance reduction measures of setting positive rates to zero and the selection of the maximum longshore rate, were found to be adequate" (page 26).

The report also states that the ±3 m shoreline detection error was found empirically to produce a ±3.7 m error in the "rates of change" over a 50-year prediction period. Apart from the inconsistent units, it is not evident how this was calculated and why? However, this number is taken to be the LT uncertainty for the entire coast. Further, it is assumed that the only uncertainty to take into consideration is -3.7 m.

Hence, setting all accreting coastal sites to zero, and then applying an LT uncertainty of -3.7 m transformed the entire Kapiti coastline transformed into an erosional zone (-0.074 m/y). Exceptional!

ST – Short-term shoreline fluctuation and uncertainty

The short-term shoreline fluctuation accounts for the cut and fill associated with storm events. Analysis of this fluctuation can be complicated for several reasons:

- The erosion phase (cut) is considerably faster than the recovery phase (fill); typically being hours compared to days to decades for the complete return of eroded sediment volume. Usually, up to 80% of the recover occurs within days to a few weeks if most of the eroded sediment is transported offshore into the offshore bar.
- If sediment is transported onshore by wave overwash, there may not be a significant recovery phase. This is particularly important for coarser sediments (mixed sand-gravel, and gravel beaches).
- Storms may occur in clusters, so that the beach may not fully recover before a subsequent erosive event occurs. Studies around the NZ coast have identified that there has been decadal-scale fluctuations in storm frequency and magnitude, which

means that a coast can show an erosive trend for several years to decades, followed by an accretionary phase.

Analysis of the short-term fluctuations requires a time-series data-set that captures the short duration erosion events, as well as the longer duration recovery phases and the decadal-scale effects of storm clustering. It is evident that the aerial photograph and cadastral survey records used for the 2008 study was not suitable for characterising the short-term trend. Some beach profile data were available, but were not utilised. However, from the description of the profile data sets (footnote page 27 2008-2), the time series data are not suitable for characterising the short-term fluctuation.

In 2008-2, it is assumed that the short-term fluctuations are represented by the residuals between the measured shoreline location and the trend line. This is not a reasonable interpretation for several reasons:

- The shoreline position was recorded using two different approaches: cadastral survey of high water mark or toe of the foredune; and vegetation line determined from aerial photographs. These would correspond to different shoreline positions, even if taken at the same time, and would appear as residuals from the trend. However, late period trends should involve only one type of measurement;
- The vegetation lines are not likely to represent the average shoreline position (assumed by this approach). As noted in the report, the vegetation line retreats during erosion, and takes time to return to the original position after shoreline recovery. Therefore, the vegetation line is biased towards an eroded shoreline.
- The residual approach assumes that the rate of erosion/accretion is constant over time (linear trend). It is likely that this is not the case, as the sediment supply and driving processes are not constant.
- The errors in geo-rectification and shoreline position determination appear to be of a similar magnitude to the calculated standard error of estimates. Therefore, a component of the residual is likely to represent the measurement errors.

Therefore, the variations represented by the residuals probably do not represent the short-term cut and fill fluctuations. It is also of concern that the residuals appear to be the error term considered for the uncertainty of the *LT* factor, and therefore have been incorporated in the summation more than once?

Interestingly, the estimated *ST* does not appear to correlate well with measured short-term fluctuations along the Kapiti coast, and Appendix C discusses this. In my opinion, the discrepancy arises because the methodology used (3xSEE) does not reflect the true short-term fluctuations of the shoreline.

The uncertainty was derived from the measurement errors using an undefined empirical method that gave an uncertainty of ±2.6 m.

For the CEPD summation, only negative values for *ST* and the uncertainty were considered. Again, for an accreting coast experiencing cut and fill, this approach will generate an erosional hazard.

There was also an assumption of a 5 m erosional uncertainty if the existing seawalls are maintained, due to vertical scour in front of the structure. It is not clear how the vertical scour translates into horizontal erosion in the presence of a stabilised shoreline?

SLR – Impact of sea level rise determination and uncertainty

This factor is included to account for sea level rise anticipated as a consequence of global warming. Since the *LT* factor already includes the effects of historic relative sea level changes and is extrapolated into the future, the *SLR* factor should strictly be based on the changed rates of sea level rise or fall over the period of interest. This was not done, so the *SLR* factors calculated will be biased too high.

Appendix D of the report assessed shoreline response models to sea level rise. It confuses the Bruun Rule with later variations of it, such as the Dubois model (presented as Equation D1) and mostly discusses estimates of the closure depth. This is largely irrelevant as most studies have found that the most effective estimate of nearshore slope is based on the surf zone, or the steepest parts of the submarine nearshore zone. Equation D1 attempts to approximate this by including the height of the sub-aerial berm or foredune.

Overall, Bruun type approaches have been found to be unsuitable for predicting shoreline response to sea level rise. In particular, using the approach to hindcast the effect of historic sea level rise has been found to normally overpredict erosion (Note the method will only predict erosion, and clearly does not work for an accreting coast).

It is suggested that the Komar et al equation is a better alternative. This was intended to predict the extent of storm cut during a single event, and the methodology developed by Paul Komar and his students differs from Equation D2 presented in the report. Equation D2 is the original formulation of the Bruun Rule (1963).

Insert existing discussion of this cock up

The method used depends on the nearshore slope, which was taken to be the inter-tidal beach slope, and the predicted change in sea level. For the Kapiti coast, nearshore slope was estimated for 22 sites that do not seem to coincide with the 68 coastal hazard calculation sites (details hidden in the database?).

The nearshore slopes estimated varied between 0.8° and 6°, although most were around 1-2°. Using Equation 3, the predicted sea level rise is multiplied by 9.5 to 71.6, with most locations having a multiplier of 28.6-57.2. These relatively high multipliers reflect the generally dissipative to intermediate beach state along the Kapiti coast. Note that based on the measured shoreline response to the historic sea level rise of order 17 cm/century assumed in the report, the multipliers should be predominantly negative (-247 for the average accretion rate of 0.42 m/y).

The other component is the predicted sea level change. Both the 2008 and 2012 reports are based on various projections of future sea level derived from economic scenarios used to estimate future radiative forcing, and hence future temperatures. The projections then assume that sea level responds in a predictable manner to global temperatures. So far this has not been the case, and more than 40 years of sea level projections have not successfully the actual global sea level response.

Of concern is the lack of probability associated with the sea level projections. Although terminology such as *most likely value* is often applied to sea level projections, this is a qualitative judgement and not a statistical interpretation. The 2008 report is based on a value of 0.6 m/Century, while the 2012 report used 0.6 m/Century for the 50-year projection (0.3 m total) and 0.9 m/Century for the 100+ year projection. In my opinion, these values are excessive and improbable, and I note that the 2008 report considered the assumed sea level rise or 0.6 m/Century to be "conservative" (page 34, 2008-2), which in context reflected an expectation that it would result in an overestimate of shoreline response.

For stabilised coasts (with seawalls), it is assumed that sea level rise will not cause erosion.

The *SLR* uncertainty is based solely on the estimated error in the measurement of the nearshore slope, and was determined to be ±1.6 m. I am uncertain as to why the slope measurement was converted to an angle for this determination. The slope error was originally ±0.001 grad, and, since this the calculation effectively takes the reciprocal of the slope, the error analysis should have been based on percentage error. The *SLR* uncertainty should consider the uncertainty of the sea level projections.

DS – Dune stability factor determination and uncertainty

The *DS* factor takes into account the slope adjustments that occur after an erosion event, particularly the scarp retreat that results in an additional landward migration of the upper dune face, assuming that the erosion has scarped the frontal dunes. In relation to the Kapiti coast assessment, this scarp adjust has already been accounted for because the shoreline is based on the vegetation line (ie. landward of any scarp, after a period of time during which it is likely that the face has adjusted to a stable angle). As discussed above, the *LT* and *ST* factors are both based on the vegetation line and will already include any *DS* adjustment. Therefore, for the CEPD the *DS* term is double-dipping.

The methodology used to assess *DS* is standard, and assumes that the material falling from the top of the slope accumulates at the toe until a stable slope is achieved. The result depends on the assumed stable slope angle (34° for this analysis) and the height of the scarp. It was assumed that the future scarp height equated to the maximum dune height near the profile for sites south of Otaki, and equal to the maximum for the entire Kapiti coast for sites north of Otaki. This is only valid if the final future erosion event terminates coincident with the maximum dune height. Overall, the approach used will over-estimate *DS*, as noted in the report (page 36, 2008-2).

The uncertainty is based on the RSS measurement error for the estimated maximum dune height, and was calculated as ±2.3 m. It does not include any consideration of the uncertainty in the assumed stable slope angle.

CU – Combined uncertainty determination

The uncertainties derived for the LT, ST, SLR and DS factor were combined using the Root Sum Squares (RSS) approach. The report states that the *CU* factor was also included in the RSS summation, but this appears to be incorrect (it shouldn't be included). It was also stated that the 4 factors are independent. However, the LT and ST factors are highly correlated and their uncertainties were derived from the same measurement errors by unspecified empirical methods. Hence, I would not consider them to be independent.

The calculated CU factor was ±5.3 m, which was rounded up to ±6 m.

Inlet methodology

Where a stream or river discharges at the coast a tidal inlet typically forms. Different types of inlets can form depending on the balance between freshwater discharge, tidal flows and longshore sediment transport. The type of inlet is not too important for a hazard zone assessment, but the amount of inlet migration is a factor. Over time the inlet position can move along the coast, generally in the direction of longshore sediment transport, with erosion on the downdrift side and accretion on the updrift side of the inlet forming a longshore spit and tidal lagoon. There tends to be a maximum amount of lateral movement, as flood events tend to breach the longshore spit and effectively straighten the inlet. The spit may also be artificially breached to achieve the same effect.

It is argued that for the Kapiti coast, the hazards associated with tidal inlets are significantly different to those experienced on the intervening open coasts. To account for this, the open coast CEPD equation was modified by replacing the short-term fluctuation with an inlet migration factor (*IM*).

$$\begin{aligned} IEPD &= LT + IM + SLR + DS + CU \\ &= IM - (LT + SLR + DS + CU) \end{aligned}$$

The *IM* factor is not clearly defined in the report.

Discussion

At each step of the determination of the CEPD, the analysis maximises the estimated future shoreline erosion. This is described as "conservative" and "precautionary". Of particular concern is that this approach ignores any mitigating factors, except for the presence of seawalls. Overall, it has the effect of exaggerating the future hazard and almost certainly has identified areas that are unlikely to experience any coastal erosion as being hazardous.