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Foxton Beach Erosion Hazard Assessment

A report prepared for Horizons Regional Council

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Client Report 2008-10a REP

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EXECUTIVE SUMMARY

In May 2008, Coastal Systems Ltd (CSL) was commissioned by Horizons Regional Council to undertake a coastal erosion hazard assessment at Foxton Beach. Two erosion hazard zones (EHZs) were to be prepared: firstly a current erosion risk zone (CERZ), and secondly a future scenario up until 2100 (2100ERZ). The terms of reference required the use of an empirical-based approach using the following erosion hazard components: long-term shoreline trend, short-term shoreline fluctuation, effect of sea-level rise, effect of dune stability processes and adequate allowance for uncertainty. This methodology is considered to be the industry best practice. In addition, the erosion assessment was to assume that the future rivermouth configuration will remain unchanged and the entrance will remain in its present location.

Historical shoreline locations and behaviour were derived from a comprehensive set of historical survey plans (1881 to 1926), aerial photographs (1937 to 2005), beach profiles (1985 to 2007) and LIDAR (high resolution, three-dimensional data) which was collected in 2005. Shorelines were abstracted using the most recent developments in image processing. Data analysis was carried out using digital terrain modelling and statistical analyses, thereby ensuring robust and defendable output.

Determining the nature of any underlying trend in shoreline behaviour was complicated by medium-term change caused by past rivermouth migration. The Manawatu Rivermouth area is particularly large and very dynamic. The entrance has migrated alongshore by up to three kilometers and the south spit configuration changed to a north spit configuration since the late nineteenth century. Indeed, the river flowed through part of the beach settlement before moving south throughout the twentieth century. While the entrance appears to have quasi-stabilized over the last decade, the adjacent shorelines are still adjusting to previous rivermouth change and this adjustment process appears likely to continue into the future. By defining and analyzing the historical rivermouth and shoreline change, it was possible to get broad estimates of the remaining shoreline response and also of the underlying shoreline trend.

The CERZ extends landward for approximately 35 m and this comprises the sum of the short-term shoreline fluctuation component, the dune stability component, and the uncertainty associated with these two components. By comparison, the 2100ERZ extends landward up to 100 m and this comprises the long-term component, the short-term fluctuation, the response to sea-level rise, dune stability and the combined uncertainty.

The final section of the report raises several related issues for council consideration:

- The effect of the existing seawalls have not been taken into account in the erosion assessment. However, if widespread and sustained shoreline erosion occurs, then the wall will require ongoing maintenance/strengthening and enhanced shoreline instability can be expected to occur adjacent to the wall (*end-effects*);

- Unless the shoreline within the centre of the study area begins to systematically prograde (migrate seaward), the foredune will continue to grow in height and become increasingly unstable, thereby requiring an ongoing sand stabilization programme to be operational;

- Riverbank meander development downstream of the Foxton Loop will increase pressure on the settlement training walls and it is conceivable, in the longer-term, that bank migration at the forest bend could result in an alternatively located entrance developing. River control measures should be considered.

- Further coastal investigation to quantify littoral drift direction and volume, and also periodic bathymentric surveys of the entrance should be considered with a view to helping predict future shoreline response to past rivermouth change.

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1 INTRODUCTION

1.1 Terms of reference

In May 2008, Coastal Systems Ltd (CSL) was commissioned by Horizons Regional Council to undertake a coastal erosion hazard at Foxton Beach. The Consultancy Brief required the following:
To carry out an erosion hazard assessment and recommend erosion hazard line locations for the 2 km reach of coastline immediately north of the Manawatu River mouth (from Grid References S24 976790 to S24 979810).

The EHZs are to be presented for two cases:

Current Erosion Risk Zone (CERZ): *This zone includes those areas that are subject to storm erosion (SE), short-term fluctuations (ST) and dune instability (DS). This area includes all the land* ***presently*** *at risk from erosion, with sufficient safety factors.*

2100 Risk Zone (2100ERZ): *This zone includes the CERZ and those areas that are predicted to be affected by shoreline movements due to projected sea level rise to the year 2100.*

A robust scientific approach is to be used which has regard to the following factors:

- *Shoreline response to storm erosion and flooding;*
- *Short-term fluctuations in shoreline position;*
- *The long-term trend in shoreline movements;*
- *Erosion impacts of sea level rise;*
- *A planning horizon to the year 2100;*
- *Dune stability factor;*
- *A sufficient factor of safety.*

In addition, Horizons staff subsequently instructed CSL *to assume that the river mouth will remain in its present location and configuration for the purpose of carrying out the hazard assessment.*

The 2 km stretch of coast for which the erosion hazard zones have been produced is depicted in Figure 1.

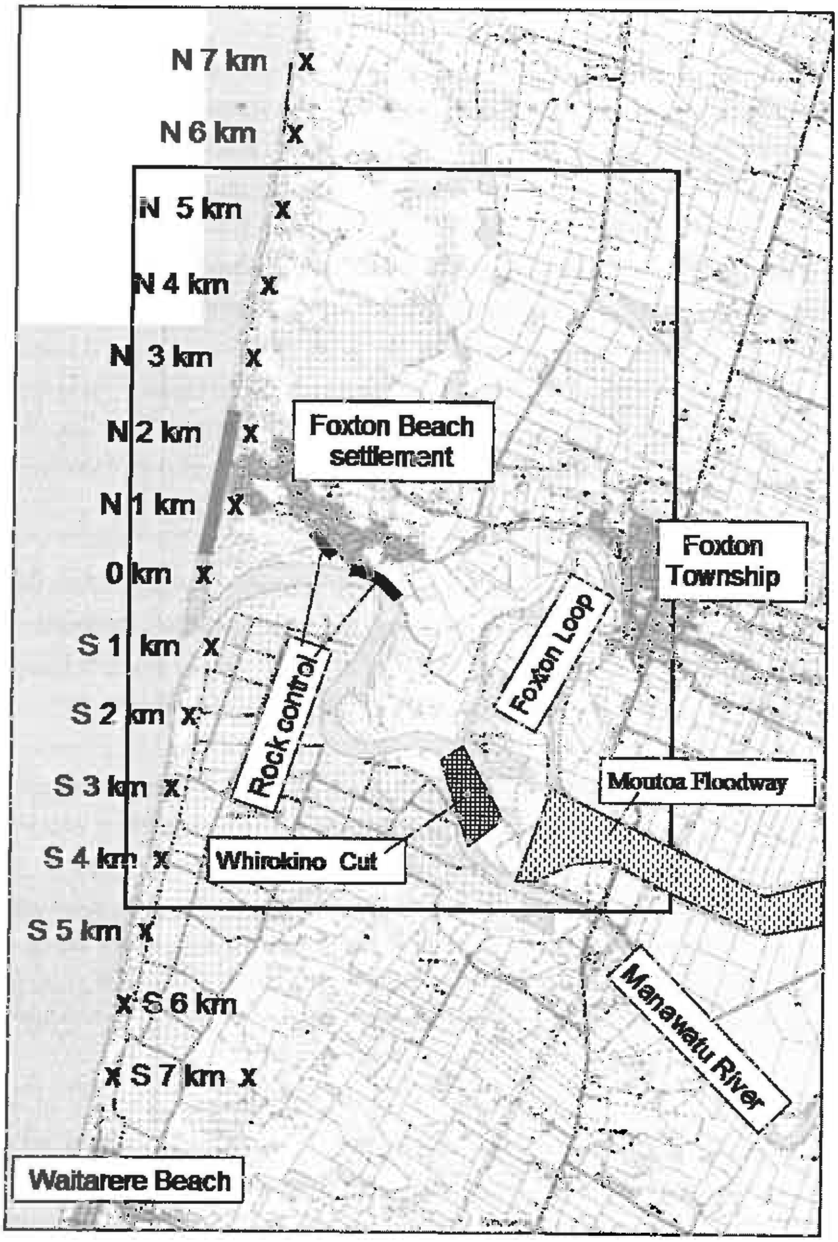

Figure 1 Location of Foxton Beach and environs. The 2 km stretch of coast for which this erosion hazard assessment is being carried out is depicted by the bold red line. The rectangle relates to the area covered by Figure 3. Longshore distances as used in the text are referenced to a datum on the northern side of the rivermouth with the prefix S being used for distances to the south and N for distances to the north.

1.2 Environmental setting

Foxton Beach settlement is situated on a sand plain which is some 4 km wide. This feature has formed during the past 6000 to 8000 yrs by the shoreline moving seaward (prograding) due to sediment supplied from the inner shelf, eroding cliffs of the Wanganui –Taranaki coast and also the major river systems, and transported to the Manawatu area under wind and wave induced currents from the west (Shepherd and Hesp, 2003). The changing shoreline orientation to the incident energy approach results in the transition from an erosional to a depositional coast. The sediment and wind regimes also favour the occurrence of sand dunes which develop along the coastline as foredunes. There have been several phases of widespread dune instability in which the dunes have migrated inland, reaching some 18 km from the present shoreline. Such dune migration affects the drainage pattern and this often caused ponding and the formation of lakes and swamps.

The lower Manawatu River meanders through this sand country which offers little resistance to bank-erosion and depositional processes. The meander pattern is continually changing as evidenced by truncated relict dunes on the Foxton Loop (Figure 1) and the extent of historical channel changes which will be described later.

Riverbank and flood control works characterize much of the lower Manawatu River (Wheeler, 1996). During the early 1940s the Whirokino Cut isolated the 8 km long Foxton Loop some 3 km upstream of the mouth. Further upstream, stopbanks were constructed and the 5 km long Moutoa Floodway and Sluice gates were established between 1958 and 1962. During this period rock walls were constructed along sections of riverbank at Foxton Beach settlement for erosion protection and to also act as a river guide wall to deflect the river seaward. These structures are depicted in Figure 1.

Rivers the size of the Manawatu flowing through soft sediment are capable of dramatic changes in the location and configuration of the mouth may typically affect several kilometers of coastal shoreline. Indeed, an initial inspection of historical survey plans and aerial photographs showed that this river flowed northwards to enter the sea in the late nineteenth century and that its path included much of the present settlement. By contrast, the river channel now has a southerly directed entry. While CSL have been directed to assume that the present rivermouth location and configuration will be maintained, such a large-scale system may take several decades for its shorelines to adjust to past changes. Such behaviour must be accounted for when predicting future shoreline location.

1.3 Approach

This erosion assessment uses the following formula to derive cross-shore erosion hazard distances (CEHD):

$$CEHD = LT + ST + SLR + DS + CU \qquad (1)$$

Where:

LT = *longer-term historic shoreline change.*
This component was derived up until 2100 by analyzing historical shorelines derived from cadastral maps and aerial photographs;

ST = *Shorter-term shoreline fluctuation.*
This component was to be derived by statistically analyzing historic shoreline data ;

SLR = *Shoreline retreat associated with sea-level rise (SLR) induced by global warming.*
This component was derived up until 2100 based on the latest guideline recently released by MfE/NIWA, and the most appropriate shoreline response model;

DS = *Dune stability.*
This component accounts for scarp retreat to achieve a stable slope following storm erosion of the foredune and was based on LIDAR data coupled with a slope stability model appropriate for this location;

CU = *Combined uncertainty*
This refers to the safety margin derived by combining the *measurement error,* which is the combined random error associated with the other four components, together with other quantifiable safety factors. Note that several non-quantified factors which further contribute to the precautionary nature of the hazard assessment, will also be described.

Such empirically-based methodology is widely used in New Zealand for coastal erosion hazard assessment and is considered to be industry best-practice (Auckland Regional Council, 2000; Dahm and Monro, 2002). In addition, the assessment utilized a comprehensive set of historical survey plans (1880 to 1926), aerial photographs (1937 to 2005), beach profiles (1985 to 2006) and LIDAR (2005). Information was derived using the most recent developments in image processing, data abstraction and statistical analysis. The approach ensures robust and defendable output.

1.4 Data-base

An erosion hazard data-base is included as Appendix A. This consists of the precise map co-ordinates (in NZMG) for all measurement reference points used in the study. In addition all shoreline distances measured seaward from each site are included, together with the location (NZMG co-ordinates) of the hazard lines. The information in the data-base will facilitate future update.

1.5 Review

The report was reviewed by Dr Mike Shepherd, a senior lecture in coastal processes at Massey University. Dr Shepherd's review is attached as Appendix B. Of particular significance were his comments relating to the ongoing effects of shoreline behaviour from past and future rivermouth change and this material has been incorporated/noted in the report.

1.6 Report outline

The report begins (Section 2) with an account of the area's historical rivermouth changes, how these have affected coastal shoreline behaviour and the extent to which ongoing shoreline adjustment may be expected. Once this has been established, meaningful longer and shorter-term shoreline data were obtained from several locations and then analysed (Section 3) to provide relevant parameter values for use in equation 1. Shoreline retreat associated with predicted acceleration in sea-level rise will be considered in Section 4 and the determination of dune scarp retreat necessary to derive a stable slope following storm wave cut of the foredune will be dealt with in Section 5. Note that uncertainty values for each hazard component are derived within each section. The erosion hazard component values are summed to produce hazard distances that are then used to locate erosion hazard zones (Section 6). Several *further considerations* are raised in Section 7.

2 PAST RIVERMOUTH CHANGE and SHORELINE RESPONSE

2.1 Shoreline data

Prior to the 1930s, shoreline data were derived from cadastral or public works survey plans. Several different types of shoreline and river/stream boundary indicators have been used by the early surveyors, e.g. previous high water mark, spring high water mark, mean high water mark, and care is required to ensure data points are comparable.

From the 1930s, vertical aerial photographs became available and either the vegetation front is used as an indicator for the foredune toe, or less frequently, the saturation boundary used as an indicator of MSL.

Because changes to the Manawatu Rivermouth have affected such a large area (about 4 km inland and several kilometres of coast), several plans and aerial photographs were often required to give comprehensive coverage for any particular period. Surveys plans for 1880, 1889, 1891, 1907,1926 were obtained from LINZ and Horizons Regional Council. Aerial photographs from 1937, 1942, 1949, 1953, 1958, 1964/5, 1971, 1974, 1979/80, 1985, 1990, 1995, 1998, 2000, 2005, 2006 were obtained from the Horizons archive, loaned from Lawrie Cairns Aerial Photography Ltd., or purchased from either GeoSmart Ltd, or New Zealand Aerial Mapping Ltd. Note that while all these data were used in the study, not all were included in the final report.

To compare shoreline/channel locations from different years, all plans and photos were scanned and geo-referenced thereby transforming them to a common spatial scale and standard map co-ordinate system to allow overlay comparison and analysis.

While the accuracy of coastal shorelines was 5.7 m (Section 3.2), riverbanks were located with a lower accuracy (10 to 20 m). This difference was acceptable as shorelines were required for statistical analysis while riverbanks were use used to identify a broader level of change.

2.2 Morphological change

While rivermouth morphology can vary widely, there are distinct components and these are illustrated along with the associated terminology in Figures 2A and 2B. A symmetrical configuration is shown in A and the skewed version typical of rivermouths along the Wanganui to Kapiti Coast is shown in B. Of particular note in Figure 2B, is the accentuated shoreline lobe on the offset side of the inlet and the oppositely directed

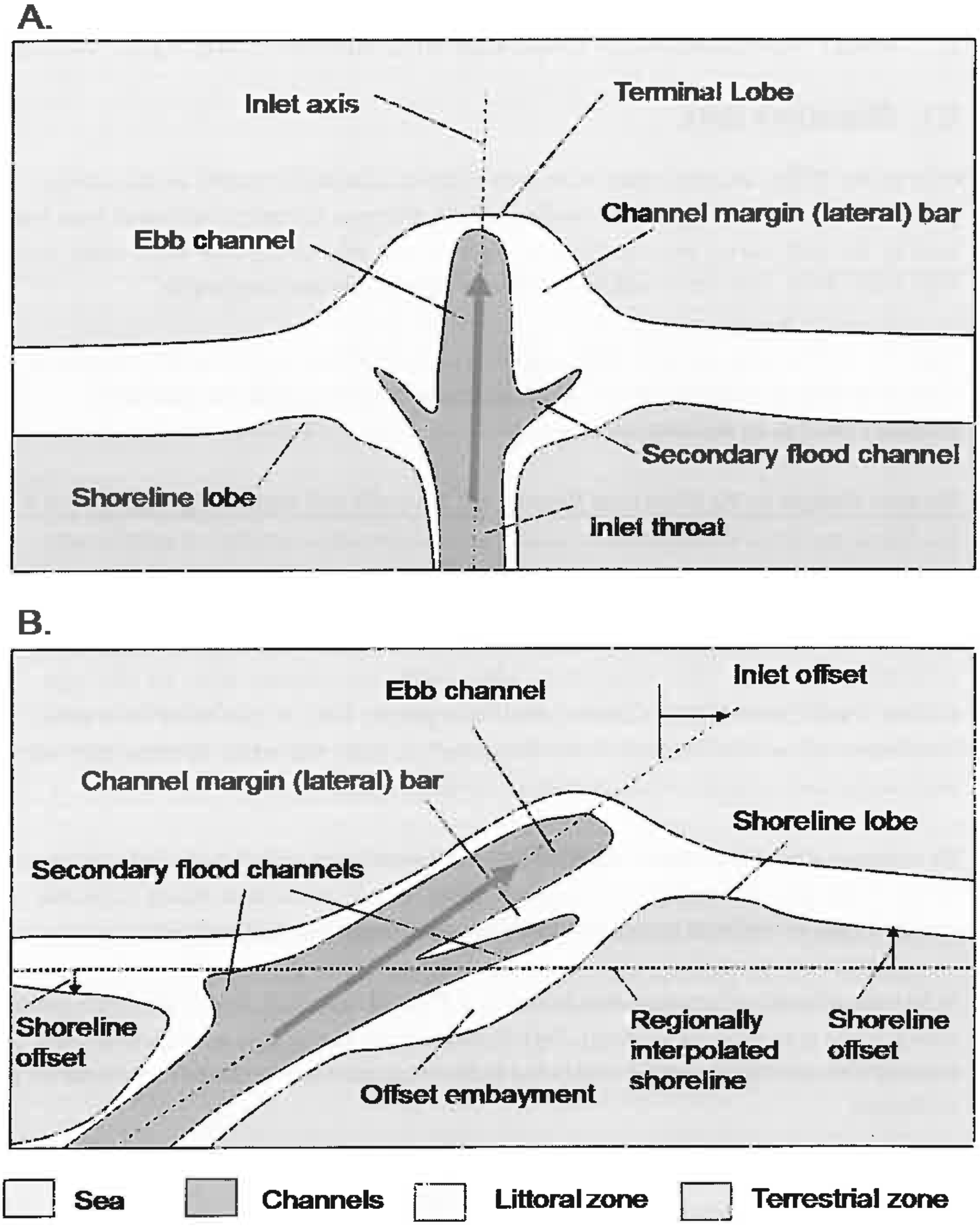

Figure 2 Schematic morphological diagram and associated notation used in the text for symmetric (A) and asymmetric (B) rivermouths with offset morphologies typical of those found on the southwest coast of the North Island. The *littoral zone* (yellow) broadly covers that area where breaking waves effect sediment transport. Terms are further described in the text.

shoreline offsets on each side of the inlet. The shoreline offsets are measured relative to the *regional shoreline* (dotted line) which is interpolated across the rivermouth and stretches some 15 km to detect large-scale shape. The shoreline depicted in Figure 2B, thus joins this dotted line further alongshore beyond the margins of the figure.

The differences in Figures 2A and B lie in the relativity of tide range, wave and wind regimes, river discharge, sediment availability and physical boundary conditions, e.g. the orientation of the coast and river channel.

Shorelines and river channels for three approximately equally spaced periods are depicted in Figure 3: in particular, the 1880s (1881-1892), 1942 and 2005. Note that inlet channel axes corresponding to several different rivermouth samples are also marked.

The shoreline offsets were measured on each side of the rivermouth, firstly at the maximum extent of the shoreline lobe, and secondly 1.5 km alongshore from the tip of the spit on the opposite side of the inlet. The selection of 1.5 km was to correspond with the centre of the hazard assessment area for the 2005 shoreline. Note that the *regional shoreline* from which the shoreline offsets were referenced was derived by cross-shore averaging the individual regional shorelines from the three samples. This averaging was carried out to improve the shape of the curve across the 3 to 4 km lengths of shoreline *contaminated* by inlet morphology in each sample. The resulting *average regional shoreline* thus defines a *representative shape* that was subsequently fitted to each shoreline to estimate the shoreline offsets. The results of this analysis are given in Table 1.

The 1880s shoreline and channel was offset to the north with the inlet axis (marked) being 52 degrees from shore-normal. A distinct shoreline lobe extends about 1.5 km to the north and an off-set embayment is evident between the lobe and the throat. The south spit had a relatively straight shoreline which extended across the present mouth to reach the southern part of the present settlement. The shoreline offsets (Table 1) were +180 m (seaward) at the northern lobe and -69 m (landward) at 1.5 km south of the then rivermouth. However, the shoreline indicator south of the mouth may have been the high water mark compare with the foredune toe that was definitely used in the survey of the northern coast. If this was the case then the southern offset for the 1880s shoreline would have been further landward and the recorded value will be a minimum.

The 1942 channel (Figure 3) shows an inlet-offset to the south with the throat axis being approximately 8 degrees from shore-normal. To the north, the nineteenth century lobe has reduced in size and the early riverbed has infilled. The shoreline offsets (Table 1) are +82 m (seaward) at what appears to be the new northern lobe adjacent to rivermouth, and

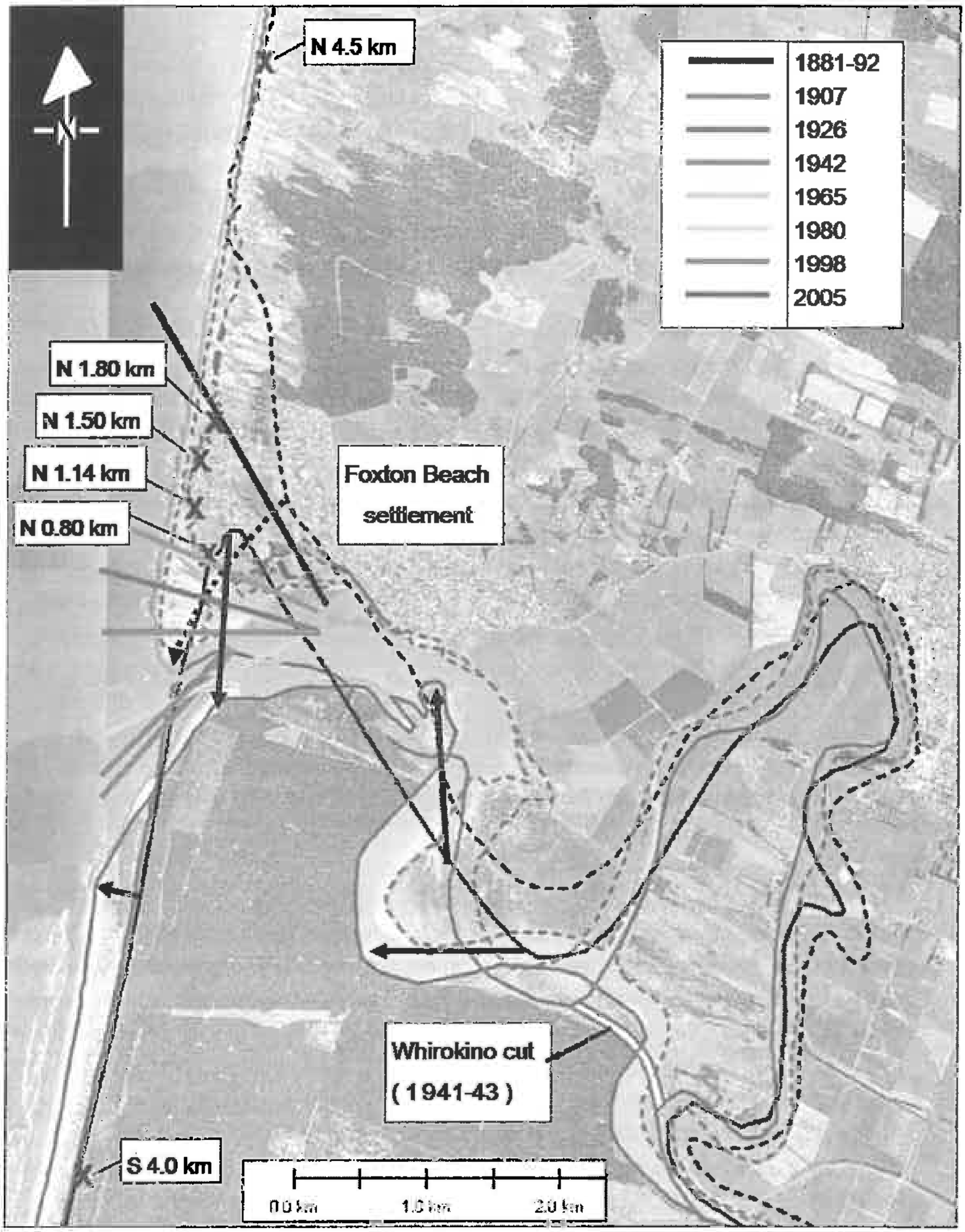

Figure 3 Large-scale shoreline and riverbank changes between the 1880s to 2005. Dashed curves represent right bank and northern shoreline, solid curves represent left bank and southern shoreline. Straight line segments depict inlet axes. Arrows indicate major channel and shoreline migrations with dashed arrow for northern bank/shoreline and solid arrows for southern bank/shoreline. Blue crosses locate reference measurement points for shoreline analysis with codes referring to distance from the end of the 2005 north spit, the distance datum used in the study.

Table 1 Shoreline offsets (m) from average regional curve

	Maximum shoreline Lobe		Shoreline recession at 1.5 km	
	North	South	North	South
1880s	180			-69
1942	82			-64
2005		142	26	

Note that positive values infer seaward direction and negative landward direction

-64 m (landward) at 1.5 km south of the then rivermouth. These values are qualitatively similar to the nineteenth century shoreline thus demonstrating how shoreline adjustment lags behind the change in river channel location and configuration.

The question of how the rivermouth changed can be addressed by considering the 1907 and 1926 axes which have northern offsets of 16 and 7 degrees respectively and are located relatively close to the 1942 axis. This information suggests that the mouth changed rapidly during the particularly large floods of 1897 or 1902, rather than slowly re-orientating in response to change in the orientation of the landward channel or an influx of littoral sediment.

The 2005 shoreline (Figure 3) shows the channel with an extreme offset to the south; the axis angle of 58 degrees is 6 degrees higher than the 1880s offset and in the opposite direction. The set of inlet axes depicted in Figure 3 show a systematic progression occurred which reached a maximum of 66 degrees south in 1998. These data indicate the channel has now reached a state of *dynamic equilibrium.* The reason for the systematic southern progression of the inlet following the rapid change about the turn of the twentieth century, appears to be lie with meander development just east of the settlement which turned the channel/current toward the south. The Whirokino Cut (Figure 1) appears to have exacerbated meander development at its southern end and also at the state forest bend some 1.5 km downstream. This situation places additional stress on the settlement bend, with the rock wall playing an increasingly important protection-training role.

In direct contrast with the mouth in the late nineteenth century, the 2005 shoreline has a distinct lobe some 1.5 km to the south. The shoreline offset here is +142 m (Table 1). Although the associated embayment between the lobe and the mouth is not as developed as the nineteenth century version, it is systematically forming by erosion of the south spit. To the north of the present rivermouth the shoreline is notably straight and the offset at 1.5 km is +26 m.

The differences in shoreline offset between the nineteenth century and 2005 shorelines ha ve potential long-term significance in the present erosion hazard assessment. The lobe offset on the south spit is approaching the 1880's lobe offset (142 m c.f. 180 m), but the shoreline offsets on the opposite sides of the rivermouths differ considerably +26 m c.f. -62 m. The offset net difference for the 1880s data is 180 + 69 = 249 m while the net difference for 2005 is 142 – 26 = 118 m. These results indicate a future erosion potential along the assessment area of 133 m (249 – 116 m) if all the adjustment occurred on one side of the mouth, which is an unlikely scenario. However, if the adjustment occurred equally on each side, this being a more likely option, then up to 66.5 m of erosion could occur in the hazard assessment area.

While these results suggest the potential for future erosion along the hazard assessment section of coast, Dr Shepherd pointed out in his review that the minimal erosion observed to date (Section 3.3 Fig 6) may be associated with nourishment (redistribution) of sediment from the nineteenth century delta.

The accuracy of the calculated offset differences in Table 1 can be addressed in terms of the error associated with the calculated average regional shoreline curve. This curve was computed from the three separate curves by using measurements taken every 1 km along 15 km of coast; this produced an rms error of 20.2 m. While the magnitude of this error means the future shoreline erosion potential to past rivermouth change may be much less than estimated, it also means that it may equally likely be much greater.

While a more detailed investigation would be required to refine future shoreline adjustment to past rivermouth change, the present assessment raises the distinct possibility that the shoreline in this area may erode and adequate allowance must be made for this within the long-term shoreline change component in the hazard assessment. This matter is considered further in Section 3.2.

3 SHORELINE CHANGE ANALYSIS

3.1 Approach

In erosion hazard assessments, shoreline change is divided into shorter and longer time periods. The shorter-term period covers quasi-cyclic changes which range up to about 10 yrs and are associated with processes such as storm cut and recovery, seasonal and ENSO-scale change. Shorter-term change is often superimposed upon slower (longer-term) changes that are driven by climate or geological-based processes. Such longer-term change continues throughout the planning horizon used in an erosion hazard assessment. Complicating this framework are medium-term changes driven, for example, by rivermouth dynamics. Such events may influence shoreline behaviour for several decades and a hazard assessment must define and allow for such influences.

Shoreline change analysis at a particular site is determined by measuring the distance from a reference point to each shoreline, relating each measurement to the initial shoreline (making it the cross-shore reasurement datum) and then subjecting these data to *regression-based linear modelling.* Reference points are coded N (north) or south (S) of the distance datum (which is the tip of the 2005 north spit) followed by the distance in km. For example, *N 0.80 km* is the point 0.8 km north of the rivermouth. With the exception of the two most distant reference points (N 6.5 km and S 6.5 km) all others used in this report are depicted in Figure 3.

The linear regression technique fits a straight line using a *least squares* routine which incorporates the full set of data-points. The linear model is represented by equation 2 where Y is the dependent variable (cross-shore distance to the shoreline), X is the independent variable (time), a is the intercept on the Y-axis, b is the slope coefficient (rate of shoreline change) and e is the fitting error.

$$Y = a + bX + e \qquad (2)$$

The model outputs provide values for the rate of shoreline change in Section 3.2, and the fitting error (or residuals) are used to define the short-term change in Section 3.3. The linear regression concept and associated terms are illustrated in Figure 4.

Parameters are also available to describe the significance of the slope (F-ratio), the reliability of the slope (the standard error of b), the strength of the association (correlation coefficient), and the proportion of variance explained by the independent variable (coefficient of determination). These terms and concepts are described in statistical texts such as Shaw and Wheeler (1985). The correlation coefficient, together with the

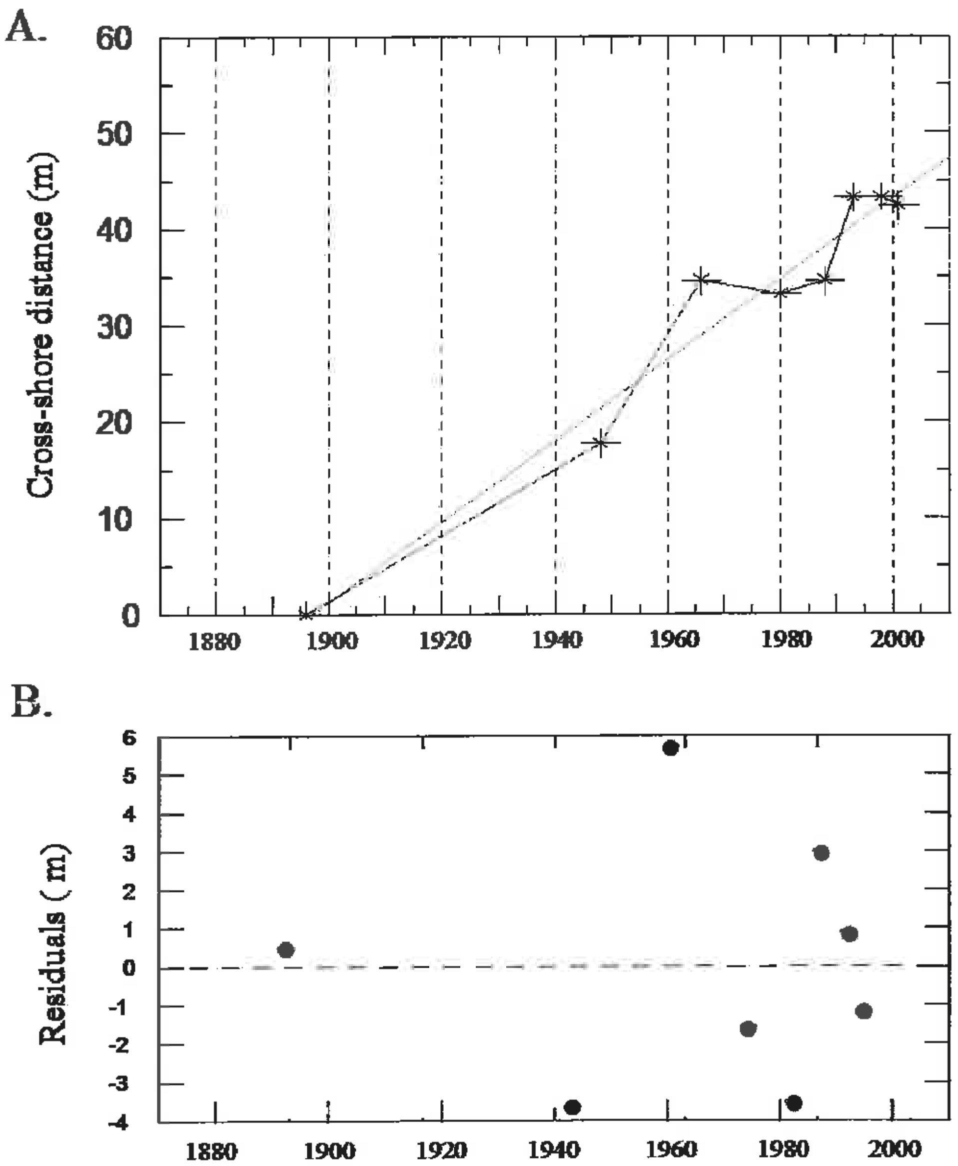

Figure 4 Example of a linear regression model (straight red line) fitted to a shorelinetime-series (A) to define a longer-term trend of progradation (seaward advance). Differences between the modelled (straight line) and observed values (crosses) in A, are plotted in B. These differences (called *residuals*) are used to determine the shorter-term shoreline fluctuation.

magnitude of the fitting error, indicate a changing trend, and non-linear regression procedures may be considered. However, while non-linear models provide a better fit for such data, they may also lead to increased trend inaccuracy when used for predictive purposes. In the present study, data displaying non-linear behaviour due to rivermouth influence) were excluded from analysis.

Regarding short-term shoreline change, the *standard error of estimate (SEE)* is the statistic representing the residuals that is used to estimate population variability. In particular, the SEE equals the square root of the residual mean square as determined by an *analysis of variance* routine. Note that the *population* refers to all shoreline locations rather than the sample of shorelines used for analysis. It can be shown that 2 x SEE on each side of the regression (average) line will encompasses 95% of population values. In other words, we can be 95% certain that this interval will encompass the range of possible shorelines. Alternatively, 3 x SEE will encompass 99% of population values. As the shorter-term fluctuation is a particularly significant component in erosion hazard analysis, and as the number of sites and data points per site used for the short-term analysis (Section 3.3) are somewhat limited, the 3 x SEE option will be adopted in this study to minimize uncertainty.

3.2 Longer-term shoreline change

3.2.1 Shoreline measurement analysis

To identify any underlying trend in shoreline behaviour, time-series were constructed for several sites located to each side of the rivermouth. In addition, sites were selected some distance alongshore where the dramatic changes associated with past rivermouth behaviour would be more easily defined. Southern sites were selected at S4.0 km and S6.5 km and their time-series (Fig 5A and B) show a marked increase in seaward migration from the mid 1960's which appears to reflect river influence. Prior to this occurrence the shoreline was migrating seaward at rates of 0.4 and 0.5 m/yr respectively.

Northern sites were selected at N4.5 km which is about 1 km north of the 1880s shoreline lobe, and N6.5 km. The time-series (Figure 5C and D) show both sites behaved similarly up until 1942 with progradational rates of 0.85 and 0.80 m/yr. However, subsequent samples show that site N4.5 km (Fig 5C) began to erode and then recover back to its 1942 location. Such behaviour is consistent with sediment infilling the old rivermouth. By contrast, shorelines at site N6.5 km continued to prograde, apparently unaffected by the rivermouth change. The overall rate of change for N6.5 km is 0.89 m/yr. These results show that Manawatu Rivermouth processes are able to influence shoreline behavour at considerable distances from the entrance. By selecting sites distant from

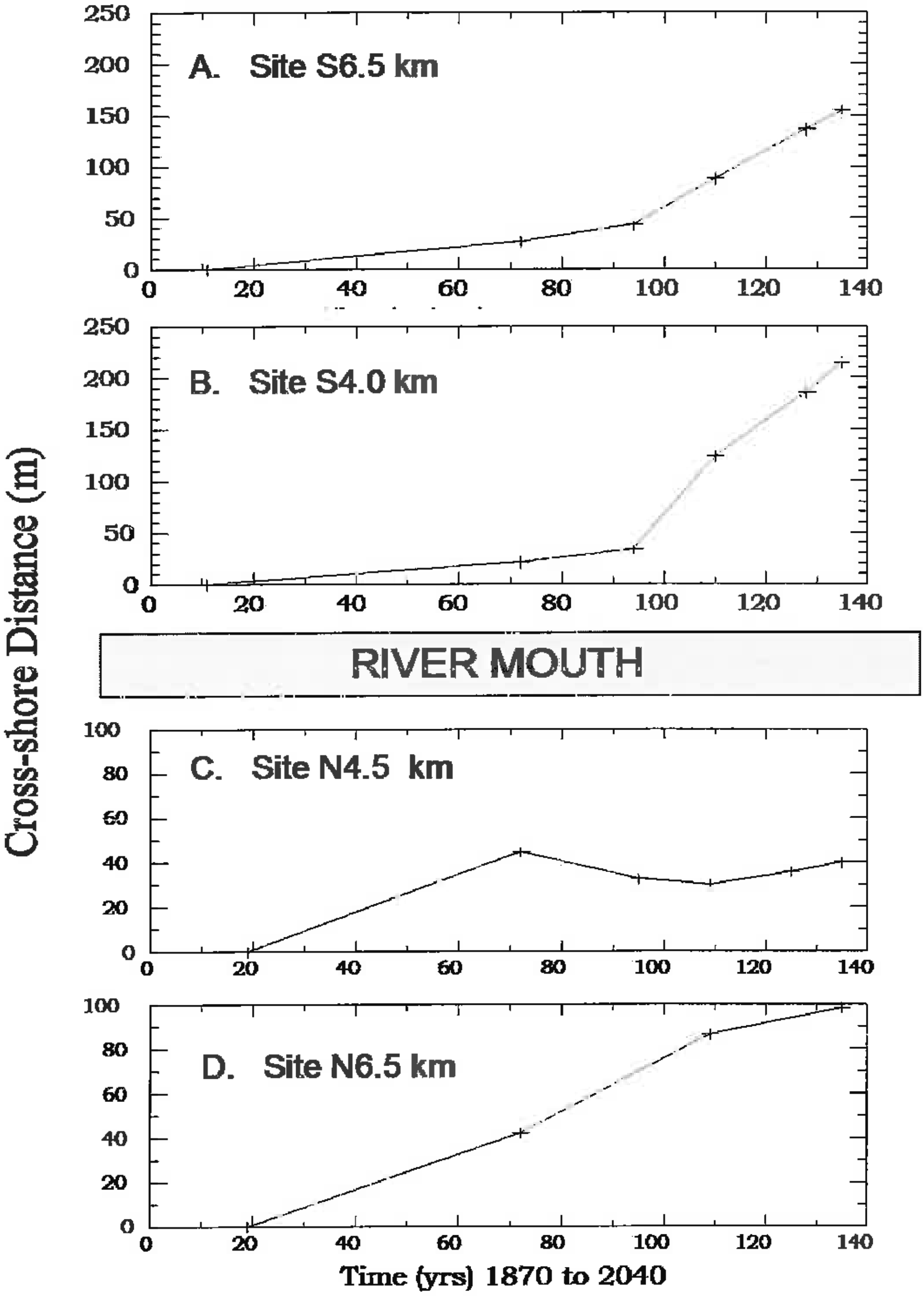

Figure 5 Shoreline time-series used to determine longer-term change. These sites were located 4.5 and 6 km north and 4.5 and 6 km south of the present mouth to minimise rivermouth influence.

rivermouth influence, and excluding contaminated parts of such data, representative long-term rates ranging between 0.4 and 0.9 m/yr were obtained.

The measurement error (95% confidence interval) associated with the calculated long-term rate of shoreline change consists firstly of combining the geo-referencing error term (±4 m) and shoreline detection term (±4 m) which gives ±5.7 m. Note that these terms are independent so they were combined using the *root sum of squares (RSS)* method defined by equation 3.

$$CE = \sqrt{(E_1^2 + \dots\dots\dots + En^2)} \qquad (3)$$

where CE = combined error (shoreward directed), E_1 = first error term, and En = n^{th} error term.

Secondly, averaging within the regression procedure reduces the shoreline location error. Using an empirical approach, it was found that 5.7 m reduced to 5.0 m. Note that regression-based error reduction also applies to the variance and hence to the shorter-term shoreline change error in Section 3.3.

3.2.2 Incorporating past rivermouth change

Results in Section 2.2 suggest that 66.5 m of shoreline erosion may yet occur along the hazard assessment area in response to past rivermouth change (PRC). This is be balanced against an underlying progradational trend ranging between 0.4 m/yr (37 m by 2100) and 0.9 m/yr (83 m by 2100). As these values are broadly compensatory. i.e. LT = -PRC, it can be argued that there is no need for direct inclusion of a rivermouth response term within the hazard assessment. However, considerable uncertainty is associated with the lagged shoreline response, and in situations where significant consequence may follow from uncertainty, the RMA (via the NZCPS) requires the *precautionarity principle* be invoked, i.e. to err on the side of caution. Consequently, a 50% factor of safety will be applied to RPRC = 66.5 m, and the resulting 33.3 m will be included with the combined uncertainty component as a systematic term, i.e. combined by addition rather than by the root sum of squares approcach. Note that based on Dr Shepherds review comments the value of 50% replaced the 20% factor of safety used in the draft report

In future reviews, should a clear erosional trend be demonstrated that is significantly different from the shoreline behaviour along the adjacent coast, i.e. it is independent of other erosion hazard drivers such as rising sea-level, then the possibility that such erosion being a response to past rivermouth behavour will need to be considered in greater detail.

3.3 Shorter-term shoreline change

The minimal number of data points available at the long-term sites (Figure 5), prevents the derivation of reliable SEE values. The situation is further compounded by shorelines within the erosion hazard assessment area being influenced by conservation works and engineering structures in addition to rivermouth changes. However, shorelines from a shortened time-span (late 1970s to the present) were usable as these influences were minimal during this period and several samples were available for analysis.

Shoreline data from four sites approximately 250 m apart (N0.8 km, N1.15 km, N1.5 km and N1.8 km) were used to represent the study area. These locations are depicted in Figure 3. These sites bracket the landward residential area and avoid seawall locations.

The shoreline time-series for the four sites are depicted in Figures 6A-D and the standard error of estimate values * 3 are listed in Table 2. These values range between 5.2 m and 24.4 m. The maximum value (24.4 m) was selected to represent the entire hazard assessment area.

It is also noted that the shape of the central graphs (B and C) differ considerably from the end graphs (A and D). This is because the center of the study area corresponded to the shallower tip of the original south spit, so less time was required for infill before dune development could proceed.

The shorter-term measurement error was determined empirically by assessing the effect the shoreline location error (geo-referencing and shoreline detection errors = ±5.7 m (see Section 3.2) had on 3 x SEE. This was empirically found to equal ±3.5 m. As noted earlier, the averaging process within regression procedures reduces the error to below that of the location error. NB, additional safety margin for the shore-term parameter was attained by applying the maximum SEE value from the four measurement sites to the entire erosion hazard study area, and by using 3 times this SEE value rather than a lesser value.

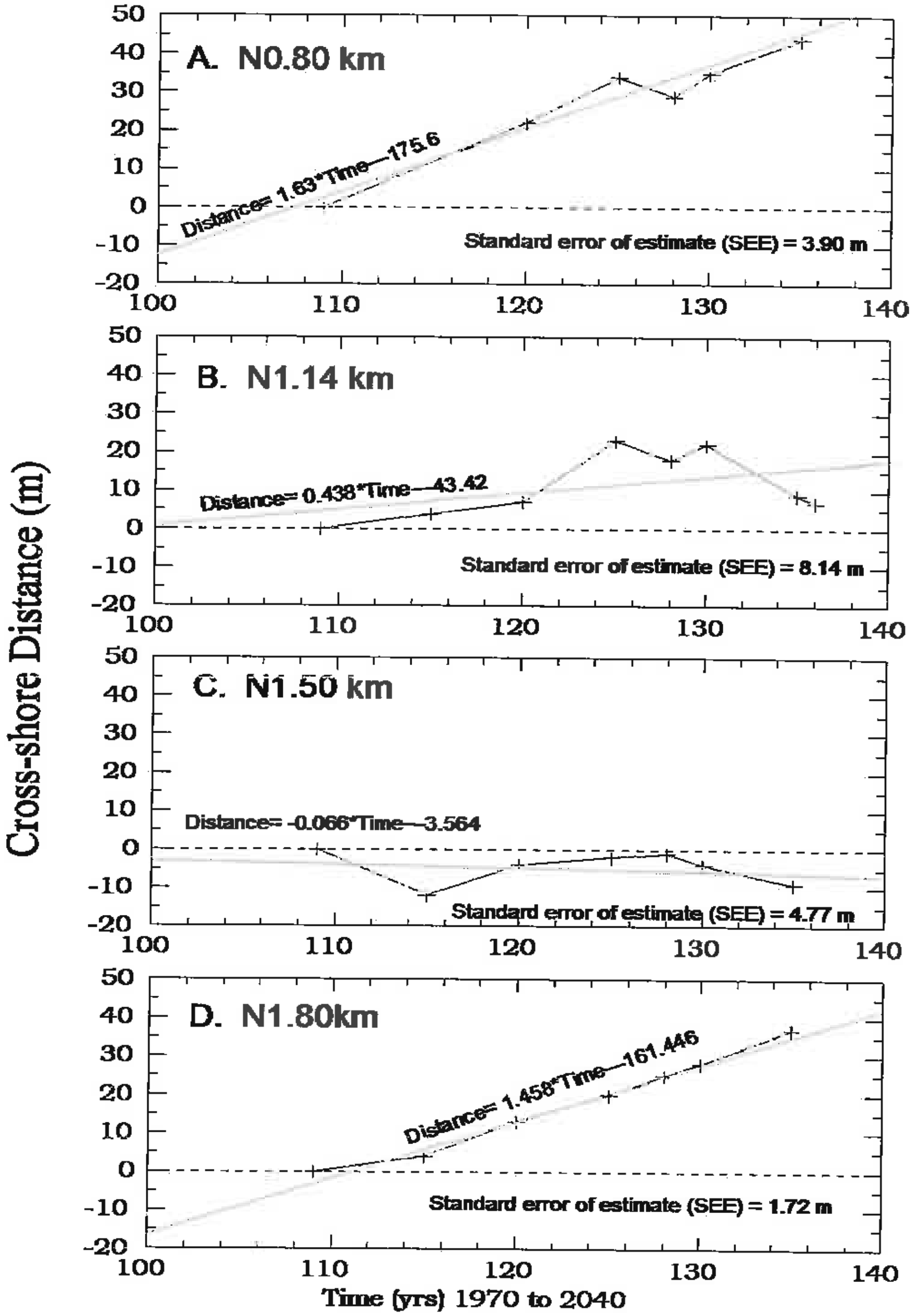

Figure 6 Shoreline time-series for sites within the erosion hazard assessment study area. Only data covering the period 1979 to the present have been used to avoid past rivermouth and anthropogenic influences. The standard error of estimate (SEE) values were used to calculate short-term fluctuation. The regression models (red lines and equations) are used to locate the 2008 average shoreline from which the hazard distances are measured.

Table 2 Erosion hazard component values and cross-shore erosion hazard distances (CEHDs) for the current risk scenario and the 2100 risk scenario

A. Current scenario

Site	N 0-80 km	N 1-14 km	N 1-50 km	N 1-80 km
Long-term (LT)	NA	NA	NA	NA
Short-term (LT)	-24.4	-24.4	-24.4	-24.4
Sea-level rise (SLR)	NA	NA	NA	NA
Dune stability (DS)	-5.9	-7.6	-8.2	-5.3
Combined uncertainty (CU)	-4.2	-4.2	-4.2	-4.2
Total cross-shore erosion hazard dist	-34.5	-36.2	-36.8	-33.9

B. 2100 (92 yr) scenario

Site	N 0-80 km	N 1-14 km	N 1-50 km	N 1-80 km
Long-term (LT)[1]	0	0	0	0
Short-term (LT)	-24.4	-24.4	-24.4	-24.4
Sea-level rise (SLR)	-27.8	-27.8	-27.8	-27.8
Dune stability (DS)	-5.9	-9.6	-8.4	-6.7
Combined uncertainty (CU)	-37.8	-37.8	-37.8	-37.8
Total cross-shore erosion hazard dist	-95.9	-99.6	-98.4	-96.7

1. Assumes the regression-based long-term shoreline progradation compensates for a possible erosional shoreline response to past rivermouth change. But a 50% safety factor for predicted rivermouth response is included within the CU component.
2. Positive values represent seaward direction, negative represent landward direction

4 SEA-LEVEL RISE

4.1 Introduction

Sea-level rise associated with global warming is expected to result in additional shoreline recession for coasts comprising weakly consolidated sediment such as the sandy, dune-backed beach at Foxton. This section will consider official sea-level rise estimates and then input these data into the most appropriate shoreline response model.

Global warming may also alter the wind, wave and current regimes along the Manawatu Coast. However, at the present time the nature of such change, and hence the shoreline response, is not quantifiable. While the effect of such additional climatic influence cannot be directly included within the present erosion hazard assessment, some allowance has been made by way of safety margins.

4.2 Shoreline response modelling

Sea-level rise predictions by the International Panel on Climate Change (IPCC) have been published on four occasions: 1990, 1995, 2001 and 2007. The 2008 draft NIWA/MFE recommendations relating to the most recent IPCC predictions are for an 0.5 m rise by 2100. However, the NIWA/MFE recommended values do not directly compensate for New Zealand's historical SLR of 1.7 mm/yr. As this amount is already incorporated within the long-term shoreline change component, the use of 0.5 m would lead to *double dipping*. Nonetheless, the value of 0.5 m will be used as this creates a safety margin to compensate for the other non-quantified effects of global warming.

Shoreline response to a change in sea-level is often based on the Bruun Model (Bruun, 1983) which states that *an elevated sea-level enables wave action to erode the upper beach while maintaining the form of the profile, and that this eroded sediment is transported offshore and deposited such that the quantity of eroded material balances the quantity of deposited material.* The application of this model (the Bruun Rule) requires the identification of a depth below the initial MSL beyond which significant sediment exchange is not considered to occur, the so-called *closure depth.* The depth of closure can be estimated using several methods including wave statistics, change in profile slope, onset of constant variance in the nearshore-offshore profile bundle, and changes in sediment characteristics. However, application of the Bruun Rule to the Foxton Coast is thwart by lack of relevant information to estimate closure depth. In his review, Dr Shepherd also notes that the Bruun Rule's underlying assumption of continuity of longshore sediment flow may not be met on the Manawatu coast.

An alternative approach is the so called Komar Model (Komar et al., 1999). The Komar Model is based on the same concept of conservation of form as the Bruun Model but is applied to the inter-tidal beach, for which Foxton data does exist. Calculation of the shoreward retreat in the profile due to sea-level rise using the Komar model is defined by equation 4:

$$R_{SLR} = S/\tan\beta \qquad (4)$$

where R_{SLR} is the retreat distance (SLR in equation 1), S is the predicted rise in sea-level and tan β is the average inter-tidal slope. Note that the *average* inter-tidal slope is used as it is the predominant slope that will control the profile response in the longer-term.

An estimate of the average inter-tidal slope was derived from profiles contained in the Horizons Regional Council and Horowhenua District Council data-bases. An inter-tidal range of 2 m was used and this resulted in five independent samples being suitable for analysis: October 1986, February 1999, March 2005, October 2006 and July 2007. The mean slope was 0.018 (0.016 to 0.02) and applying this value in equation 4 gave a shoreline retreat of 27.8 m. Note that there appears to be minimal longshore variation in slope based on Horowhenua District Council sampling which covers six sites along 750 m of beach.

Uncertainty of shoreline retreat associated with sea-level rise depends on the errors associated with inter-tidal slope measurements which were derived from high resolution beach profiles. The slope error is estimated to be within $\tan\beta = \pm 0.001$ (i.e. ±0.05 degrees) which produced additional shoreline retreat of 1.6 m. And as noted earlier, component uncertainty is also addressed by using the global estimate of SLR and not removing the New Zealand average historical regional contribution.

5.0 DUNE STABILITY

5.1 Introduction

Episodes of shoreline erosion occur when storm waves are able to reach the upper beach. Such erosion can extend back into the foredune and leave a near vertical *scarp or cliff-like* feature. The scarp-top subsequently retreats landward as a stable slope evolves and this retreat is accounted for in erosion hazard assessments by the *dune stability* component.

The dune stability process involves the top of the escarpment retreating and the base of the scarp moving seaward as a debris slope develops. This process continues until the stable slope-angle for dry dune sand (~34 deg) is attained. However, it is noted that while remnant vegetation (roots), and subsequent regrowth, allows for a higher stability angle, the more conservative angle of repose is used in erosion hazard assessments.

5.2 Dune response modelling

The model used to determine retreat of the scarp top (equation 5) is based on the *slope replacement theory* for cohesiveless materials (Clark and Small, 1982).

$$R_{ST} = h/2(\tan \propto) \qquad (5)$$

Where R_{ST} is the landward distance the scarp-top must retreat to achieve dune stability (DS in equation 1), h is the height of the escarpment and $\propto$ is stable slope angle (34 degrees).

To determine h at each of the four measurement sites in the study area, retreat distances were determined based on the sum of the other relevant hazard components for the current and 2100 erosion hazard scenarios. The corresponding maximum (upper 95%) dune height in the vicinity of each site was then identified from Horizon's LIDAR database and these heights converted to scarp-top retreat values via equation 5.

For the current risk scenario the only relevant component was the short-term parameter plus its measurement error which gave a value of 24.4 + 3.5 = 27.9 m. Corresponding dune heights were 8.0 m at N0.80, 10.2 m at N1.14, 11.0 m at N1.50 and 7.2 m at N1.80, and these heights gave scarp-top retreat values of 5.9 m for N0.80, 7.6 m for N1.14 km, 8.2 m at N1.50 and 5.3 m at N1.80.

For the 2100 risk scenario all erosion hazard components apply plus their measurement errors. The component values and measurement errors totaled 83.5 m (ST = 24.4 m + 3.5 m; SLR = 27.8 m plus 1.6 m, and the rivermouth adjustment safety factor = 26.2 m). Corresponding dune heights for these distances were 8.0 m at N0.80, 13.0 m at N1.14, 11.3 m at N1.50 and 9.0 m at N1.80, and these heights gave scarp-top retreat values of 5.9 m for N0.80, 9.6 m for N1.14, 8.4 m at N1.50 and 6.7 m at N1.80.

Measurement errors for the dune stability component consisted of the LIDAR accuracy (±0.55 m), cross-shore location of the dune-toe (± 2 m) determined by draping the 2005 aerial photo over a DTM of the LIDAR data, and cross-shore location of the maximum dune height per sector (±1 m). The combined RSS value for these terms is ±2.3 m. Note that the selection of the maximum dune height per sector, together with the minimum stability angle provides additional margin of error for this component.

6.0 EROSION HAZARD ZONES

6.1 Erosion hazard distance

The *cross-shore erosion hazard distances* (CEHD) for the four sites within the study area are derived by adding the relevant component values (equation 1). For the *current scenario,* the relevant components consist of ST, DS plus their associated uncertainty values. Note that all measurement error terms are independent so combined using the RSS method (equation 3, Section 3.2). The resulting distances range between 33.9 and 36.8 m (Table 2).

For the *2100 scenario,* the components consist of ST, SLR, DS plus their associated uncertainty values, along with the safety factor of 33.3 m for shoreline response to past rivermouth change. It will be recalled from Section 3.2.2 that the long-term shoreline progradation is assumed to compensate for any further shoreline adjustment to past rivermouth change less a 50% factor of safety applied to the potential response of 66.5 m. The 50% factor of safety is a systematic term rather than a random uncertainty term so is combined by addition within the CU component. The resulting distances range between 96.9 and 99.6 m (Table 2).

6.2 Erosion hazard zones

The landward margin of the erosion hazard zones are identified by applying the cross-shore erosion hazard distances (CEHDs) to the modelled 2008 (reference) shoreline. It is necessary to use the modelled shoreline as it is an *average shoreline* and it will be recalled from Section 3.1 that the SEE term, from which the shoreline fluctuation (ST) hazard component is derived, relates to the average (regressed) shoreline. The 2008 modelled shoreline locations are derived by applying t = 138 to the regression models given in Figure 6 (NB the temporal datum was 1870). The resulting erosion hazard zones are shown in Figure 7, and NZMG co-ordinates for precisely locating the landward boundary are given in Appendix A.

While the 2100EHZ is appropriate for new development, consideration could be given to creating an additional EHZ for *minor modifications to existing buildings or mobile structures.* The boundaries of such a zone are commonly defined by eliminating the combined uncertainty term within the assessment. This would result in a boundary some 37.8 m seaward of the 2100EHZ boundary depicted in Fig 7.

Figure 7 Erosion hazard zones for the *current* risk scenario and for the *2100* risk scenario.

7.0 FURTHER CONSIDERATIONS

7.1 Seawall effect

This assessment has not taken into account the effects that the 120 m long seawall fronting the beach car park will have on shoreline erosion. The wall will prevent landward erosion along its length as long as it is maintained. However, if the coast is affected by systematic erosion, then the beach profile in front of the wall will lower and the upper beach will be lost by a process known as *coastal squeeze*. Under this scenario, the wall will eventually need to be strengthened.

In addition, if the coast is affected by systematic erosion, then the adjacent shoreline may well undergo localized (end effect) erosion. This could affect over 50 m of shoreline which will retreat for several metres.

7.2 Dune management

The foredune on the relatively stable shoreline fronting the central section of the hazard assessment area, will continue to grow in height and become increasingly prone to blowouts and landward wind-drifting sand. Dune erosion will become even more extreme if the coast undergoes long-term erosion. A beach management strategy should pay particular attention to dune change and implementation of a stabilization programme.

7.3 River control

Ongoing riverbank migration (meander development) downstream of the Foxton Loop will increase pressure on the settlement training walls. Furthermore, long-term migration of the *forestry bend* (between 1942 and 2005, on average, this feature migrates seaward 12 m/yr) could eventually result in an alternatively located entrance developing. Modelling and river control measures should be considered. Dr Shepherd was particularly concerned (Appendix B) with the council's assumption that the mouth location would remain fixed without detailed morphodynamic investigation, control work design and allocation of future resources for such river control works.

7.4 Information

This erosion hazard assessment has been frustrated by the difficulty in predicting future shoreline response to past rivermouth change. Future research that would help resolve this matter including the determination of littoral drift direction and volume (past studies are conflicting), and Dr Mike Shepherd's suggestion of periodic bathymetric surveys in the vicinity of the entrance (Appendix B).

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APPENDIX A

Erosion hazard data-base

This Appendix gives location details (NZMG co-ordinates) for the 8 measurement sites reported in this hazard study, i.e. S6.5 km, S4.0 km, N0.80 km, N1.14 km, N1.50 km, N1.80 km, N4.5 km and N6.5 km. In addition, all shoreline measurements are included, together with the location (NZMG co-ordinates) of the hazard zone landward boundaries.

The information in the data-base is designed to facilitate future update and reassessment.

Reference Sites	S6.5 km	S4.0 km	N0.80 km	N1.14 km	N1.50 km	N1.80 km	N4.50 km	N6.5 km
Co-ords (NZMG)	6072759.36 N 2696557.42 E	6075144.01 N 2697106.75 E	6079837.60 N 2698015.01 E	6080174.64 N 2697906.89 E	6080527.37 N 2697956.58 E	6080814.63 N 2698071.25 E	6083525.46 N 2698437.80 E	6085441.20 N 2698791.93 E

Year	Chronology[1]	Distance (m) from site to shoreline[2]							
1889	19	32.3	46.5	These values were excluded due to the influence of rivermouth dynamics, sand stabilizing conservation works and seawalls.				25.9	39.5
1942	72	58.9	67.8						81.7
1953	83	-	-						-
1958	85	-	-						-
1964	94	43.0	80.4						-
1965	95	-	-					58.4	-
1971	101	-	-					-	-
1979	109	-	-	238.0	103.0	112.0	126.0	55.8	126.0
1980	110	120.0	170.0	-	-	-	-	-	-
1985	115	-	-	-	107.0	100.0	130.0	-	-
1990	120	-	-	260.0	110.0	108.0	139.0	-	-
1995	125	-	-	272.0	126.0	110.0	146.0	-	-
1998	128	168.0	232.0	267.0	121.0	111.0	151.0	61.5	-
2000	130	-	-	273.0	125.0	108.0	154.0	-	-
2005	135	186.0	261.0	282.0	112.0	103.0	163.0	65.8	138.0

EHZ[3] co-ords (NZMG)								
Current scenario	NA NA	NA NA	6079881.61 N 2697770.01 E	6080189.48 N 2697823.84 E	6080540.00 N 2697887.29 E	6080838.16 N 2697944.99 E	NA NA	NA NA
2100 scenario	NA NA	NA NA	6079869.35 N 2697832.85 E	6080177.96 N 2697888.77 E	6080528.08 N 2697950.35 E	6080825.98 N 2698009.12 E	NA NA	NA NA

1. Time datum is 1870.
2. Distances referenced to 1889 (first) shoreline to facilitate use in the regression analysis.
3. Cross-shore hazard distances (CEHDs) are measured landward from the modelled 2008 shoreline which was derived from the regression equations given in Figure 6.

APPENDIX B

Peer Review by Dr Mike Shepherd

I have been asked to review the Foxton Beach Erosion Hazard Assessment Report prepared by Dr. Roger Shand (Coastal Systems Ltd.). I have over 30 years of research and lecturing experience in coastal geomorphology at Massey University and the University of Sydney and am very familiar with the Manawatu Coast and its river mouths. My work also involves lecturing about a variety of coastal hazards.

An erosion hazard assessment was required for Foxton Beach for the present time together with a prediction for 2100. The terms of reference required the standard component-based approach and an assumption that the river mouth would remain unchanged until 2100.

Dr. Shand acquired data to map an appropriate range of historical shorelines that demonstrate how, since the 1880's, the outlet of the Manawatu River migrated southwards from near the Surf Club, when the spit extended northward, to its present southern location with a southward-extending spit. Much of Foxton Beach settlement is located within this dynamic area and the erosion hazard assessment takes this into account.

Dr. Shand applied a geometric method to indicate how the shoreline may continue to respond to the historical river-mouth change and concluded that there could still be over 60 m of further erosional adjustment to come. I concur with his approach and conclusion and make the following comment that could explain the lag in shoreline response to past river-mouth change.

River mouth changes can result in the river-mouth delta/sand bars becoming relict features containing large volumes of sediment. Such bars dissipate wave energy, thereby protecting the shoreline. As they degenerate they also supplement the beach sediment volume thereby prograding the shore. Such nourishment may continue for some time after the river-mouth changes which could explain the relative stability within the assessment area. However, when the nearshore zone returns to equilibrium, shore erosion could occur as Dr. Shand's analysis suggests.

In his draft report, Dr. Shand assumed that any coastal erosion would be offset by long-term progradation, and included a 20% factor of safety. However, given the extent of the uncertainty regarding future shoreline response to past rivermouth change and the consequence of underestimating such erosion, I consider a higher safety factor should be used in the case of new subdivision.

Given the lack of knowledge about the size and volume of the present river-mouth bars/delta, the presence or absence of relict features, and the effects these factors may have on future shoreline change, it would seem prudent that periodic (say 5-10 yearly) bathymetric surveys should be carried out to define these features and their behaviour.

Dr Shand's methods of deriving the component values for long-term change, short-term change, response to sea-level rise, dune stability and combined uncertainty are adequate. However, I would note that while the Bruun Rule was not used in the assessment for practical reasons (the necessary data being unavailable), I am not certain that its use would actually have been appropriate on this coast as the underlying assumption of insignificant (or balanced) longshore sediment flow may not be satisfied.

I am concerned that the council appears to assume that the "river mouth would remain unchanged until 2100" because river mouths are inherently unstable in the absence of major engineering work to stabilize their entrance and seawardmost estuarine meanders. This study demonstrates that dramatic change in river-mouth location has occurred over the past 100 years or so. Such behaviour is characteristic of river mouths along this coast and it should be recognized that it would be normal for the river to resume a more direct route to the coast either through sudden breaching of the spit during a major flood event, or by slower erosion of the outer bank of the seawardmost estuarine meander. There is ongoing river-bank meander migration upstream from the beach settlement which may well cause a change in river-mouth location, as noted in the report. At present the only protection work is the rock wall at the settlement. This may need to be extended seaward and southward to maintain flow southwards towards the present entrance, while stabilization of the mouth itself may also be required. If the council is not prepared to commit future major resources to engineering works, then any new building within the envelope of historical estuarine and river-mouth migration could be considered imprudent.

The report itself was written clearly enough; however, I do suggest that dates are added to the time scale used with Figs 5 and 6, as the chronology on its own is a little confusing.

31.7.2008

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