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Signed for Tonkin & Taylor Ltd:  

Tonkin & Taylor Ltd - Environmental & Engineering Consultants
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Executive summary

Tauranga City Council (TCC) commissioned Tonkin & Taylor Ltd (T&T) to review the coastal erosion hazard risk zones (CHZ’s) along the open coast between Mt Maunganui and the southern end of Papamoa. The review commissioned, required Tonkin & Taylor Ltd to take into account the additional coastal monitoring data, the feedback from the Environment Court Coastal Appeal (RMA 1666/98), more accurate ground contour data and the requirements set out nationally to consider more closely the effects of climate change.

The original coastal erosion hazard risk zones were produced by a GIS model that was developed in 1996 based on the available data at the time. T&T have reviewed this data and included additional data that has become available since the original study in 1996 was undertaken. This includes:

- additional beach profile data (in terms both of longer data sets and additional survey locations);
- LiDAR and ortho-rectified aerial photographs; and
- updated information on the rate of sea level rise to take into account future climate change risk and the need to consider a different time horizon that used in the 1996 study (i.e. 2060 and 2110 rather than 2050 and 2100).

The current coastal erosion hazard risk zones were produced by a GIS model that was originally developed in 1996. The original coastal erosion hazard risk zone methodology was developed to include the cumulative addition of episodic storm induced erosion, expected long term erosion rates and predicted climate change effects.

These components have been updated, based on a review of new information and improved data. The timeframes have also been extended to 2060 and 2110 to provide for 100 year planning horizon. The original GIS model was also reviewed and updated for this project as a set of GIS processes which create the coastal erosion hazard risk zones.

The reviewed and re-calculated CHZ’s are renamed as follows:

- CERZ: Current Erosion Risk Zone.
- 2060ERZ: The 2060 Erosion Risk Zone (which includes the CERZ and additional areas that are predicted to be subject to erosion due to long term erosion and sea level rise effects to 2060).
- 2110ERZ: The 2110 Erosion Risk Zone includes the CERZ and additional areas that are predicted to be subject to erosion due to long term erosion and sea level rise effects to 2110.

The 2060ERZ and 2110ERZ were formerly known as the 2050ERZ and the 2100ERZ respectively.

The results of this assessment shows a net overall reduction of private land both within the CERZ and within the 2060 ERZ, and a small increase in private land within the 2110 ERZ.

The total volume of reduced land area is of a similar order of magnitude as the additional land included in the 2110 ERZ. The increase of land area is due both to
the increase in sea level rise values and the modification to the original methodology of Gibb. The reduction in private land area within the CERZ and 2060ERZ has the effect of reducing the total number of properties situated within those areas, while a small increase in properties occurs within the 2110 ERZ.

The GIS model has been tested and validated during development in terms of ensuring the calculations are correct and the results verify what is occurring on the ground (i.e. based upon volume calculations and ground truthing). The model output (i.e. the three coastal erosion hazard risk zones) was validated at 4 locations where long term beach profile datasets exist (i.e. c34, c36, c38, c40) and the short term fluctuations compared with previous numerical model studies (T&T, 2001) and shown to be of a similar magnitude.

Tonkin & Taylor conclude that the hazard lines developed from this assessment can be used to replace the 1996 hazard lines shown in the Operative District Plan as part of the District Plan review process.
1 Introduction

1.1 Background

Tauranga City Council (TCC) commissioned Tonkin & Taylor Ltd (T&T) to review and update the coastal erosion hazard risk zones (CEHIZ’s) along the open coast between Mt Maunganui and the southern end of Papamoa.

The existing coastal hazard zone was established as a result of studies carried out in 1996 (Gibb, 1996) and modified as a result of outcomes from an Environment Court hearing (Skinner Reference RMA No. 1666/98). TCC has been committed to regular reviews of the hazard zones taking into account any new information, the ongoing profile monitoring, changes in direction from central government.

As TCC is currently reviewing its Operative District Plan, it is considered timely to undertake a review of the existing coastal hazard zone based upon the outcomes of this ongoing monitoring.

Over the last 10 years there has been additional beach profile monitoring at 18 open coast beach profile monitoring stations as well as new LiDAR survey and georeferenced aerial photographs, providing an extended data source to augment the original assessment. There have also been updates of climate change effects and new guidelines on managing coastal hazards from the Ministry for the Environment (MfE, 2008). This report sets out the outcomes of a review of the coastal erosion hazard risk zones.

1.2 Scope of works

This project involved the following scope of work:

- re-analyse the Tauranga open coast beach profile dataset and review the coastal erosion hazard components;
- review and update the GIS model using a methodology consistent with the previous model, however taking into account any new information or changes to variables;
- run the updated GIS model using the new coastal erosion hazard components and generate the updated coastal erosion risk zones;
- provide documentation on the GIS model process and the underlying coastal science; and
- outline the results of the above work and recommend results to be implemented.

1.3 Purpose

The purpose of this report is to:

- provide context and linkage between the current and previous coastal erosion studies and background reference to the coastal appeal of 1998 to 2004;
- outline the coastal hazard assessment parameters;
- clearly set out and explain the GIS model methodology and provide instructions to run the new GIS model to update the coastal erosion hazard risk zones along Tauranga’s open coast; and
- outline the results of the above work and recommend what results be implemented.
2 Context

This section sets out a summary of the previous hazard zones and the parameters used starting with the Dunewatch report (Gibb, 1996) and then the Environment Court proceedings.

2.1 Dunewatch report

The coastal erosion hazard zone (CEHZ) resulting from this report was based on the following equation:

\[ \text{CEHZ} = [(X + R) T + S + D] F \]  

(1)

Where:

- \( X \) was the horizontal rate of shore retreat as a result of future sea level rise based on the Bruun Rule. Sea level rise based on the IPCC (1995) sea level rise estimates of 0.2 m by 2050 and 0.49 m by 2100. The beach closure depth was taken as -8.5 m Moturiki Datum and the crest height of the dune was taken from TCC's (then Tauranga District Council) DTM.

- \( R \) was the long term rate of erosion or accretion which was calculated from the MWD survey plans measured at a scale of 1:2,000 and digitised at baselines of 1:10,000. Where the \( R \) was accretionary (i.e. historically the beach has been accreting) and the accretion rate exceeded the potential erosion effects of sea level rise effects (i.e. \( R \) greater than \( X \)), the \( X+R \) value was set to zero. If \( R \) was accretionary but did not exceed \( X \) there was a reduced set back due to climate change. This method created significant fluctuation along short stretches of coast where \( R \) values varied from negative (erosion) to positive over stretches of less than several kilometres. This has an effect of creating areas where there were no hazard lines landward of the CERZ.

- \( T \) was the time scale to 2050 (55 years) and 2100 (105 years).

- \( S \) was the maximum potential short-term dune line fluctuation based on field investigations and anecdotal observation. The observations were turned into volume changes, with 140 m³/m length at Papamoa Township, 150 m³/m length for Papamoa Domain, 175 m³/m length from Te Ara Place to just south of Mussell Rocks, 150 m³/m length from Mussell Rocks to the lee of Moturiki Island, grading to 100 m³/m length to 125 m³/m length north-westward along Main Mount Beach.

- \( D \) is the horizontal distance of retreat of the top seaward edge of the dune erosion scarp, which was based on half the height of the dune above MSL divided by the angle of repose of sand, which was taken to be 33 degrees.

- \( F \) is a factor of safety, taken to be 30% (i.e. 1.3).

The CEHZ was divided into following zones:

- Extreme Risk Erosion Zone (EREZ) based on the summation of \( S \) and \( D \);
- High Risk Erosion Zone (HREZ) based on the summation of the EREZ + (X+R) x 55 years;
- Moderate Risk Erosion Zone (MREZ) based on the summation of the EREZ +(X + R) x 105 years; and
- Safety Buffer Zone based on \( F \).
The hazard zone width was derived at regular (4 m) intervals along the coast and set back from the digitised dune toe line measured in 1994 based on field mapping.

2.2 Coastal Appeal to the Environment Court (RMA1666/98)

In 1998 the Beachfront Ratepayers Association (Incorporated) (BRA) lodged an appeal to the Environment Court.

The BRA disagreed with the extent of and science used to calculate the CEHZs. They proposed that the area adjoining Papamoa Township was not subject to coastal erosion.

As a result of the appeal, TCC undertook further and extensive studies to review the methodology used to calculate the CEHZs and to form a basis of a settlement with the BRA.

The additional studies largely confirmed the findings of the Dunewatch work (Gibb 1996) which was unacceptable to the BRA and a settlement was unable to be reached outside of the Environment Court hearings process.

These aforementioned additional studies included:

- numerical modelling of storm cut;
- reviews of aerial photograph assessment and statistical methods used to establish erosion events; and
- investigations on alternative methods to assess the effect of sea level rise on beach systems.

The appeal was heard before Judge Bolland during 2001 and 2002 with an interim and final decision provided in August of 2002 and November 2004 respectively.

The Environment Court decisions confirmed the basis and opinions of the work undertaken by TCC and confirmed the current coastal hazard District Plan provisions as being appropriate management rules.

The decisions also required the original safety buffer zone be discontinued and suggested that TCC consider the use of a singular erosion or accretion factor for any further coastal hazard zone calculations. The Environment Court also confirmed the need for consideration of climate change effects, as well as the adoption of a precautionary approach.
2.3 Coastal erosion hazard refinement process

Following the outcomes of the Environment Court hearing, TCC undertook a Plan Change to refine the operative rules of the District Plan in relation to Coastal. The Plan Change was required in response to the outcomes of the Environment Court decision.

The refinement process did not change the methodology of identifying the CEHZ’s, rather it related to the rules pertaining to activities within the Coastal Hazard Policy Area (CHEPA) that incorporated these zones.

The Court in its decision required TCC to undertake this Plan Change so that there is a consistent approach to the sustainable management of use and development along the whole of the ocean coast from Mauao to the Kaituna River.

Following the Court’s decision TCC firstly declared the current Rules operative for the whole of the coastline so that administratively the whole of the coastline can be treated as one and the change to the relevant rules considered as a single Plan Change.

As part of this refinement process, TCC also undertook a refinement of the CHEZ’s based upon the additional monitoring undertaken since the notification of those lines in 1996.
3.1.1 Long term rates of shoreline movement (R)

It was considered that the original method used by Gibb (1996) to derive the long term rate of shoreline movement could be replaced by examination of beach profile data at the 18 sites now present along TCC’s open coast, combined with a review of these trends compared to more recent aerial photographs assessment. The use of beach profile surveys was seen as providing more accurate assessments of trends without the subjectivity of interpretation from aerial photographs.

T&T note that future shoreline movement may differ from historic trends due to climatic patterns associated with Interdecadal Pacific Oscillation (IPO) and global climate change. To provide an appropriate precautionary approach, areas of inferred long term accretion as well as areas showing dynamic stability had the long term erosion component set to zero. This means that historic accretion is not extrapolated into the future. Long term trends were analysed from Environment Bay of Plenty (EBOP) beach profile data sets at the dune toe (the results of this analysis are presented in Appendix A). The result of this analysis is that the open coast shoreline between Mt Maunganui and southern Papamoa is considered dynamically stable with no apparent long term trend of erosion. Therefore, the long term trend component (factor R) was set to zero.

The result of this change reduces the width of the CERZ where Dr Gibb identified historic erosion (e.g. the southern end of Papamoa Township).

3.1.2 Short term shoreline movement (S)

The short term erosion rate (factor S) takes account of both the storm induced erosion and the fluctuations around the observed long term trend of shoreline movement.

Short term erosion may occur in response to severe wave storms moving toward the coast from the north to northeast quadrant. However, there are also short term fluctuations in shoreline position over a longer period than an individual storm event. These fluctuations are in response to natural variations in climatic conditions and sediment supply. For example, there may be variations in the direction and magnitude of shoreline movements associated with El Nino and La Nina conditions, which typically occur within a three to seven year cycle.

The short term erosion rates were determined from a statistical analysis of beach profile data sets at the dune toe (the results of this analysis are also presented in Appendix A). The fluctuation defined by 3 standard deviations (SD) is the most appropriate order of magnitude to represent the maximum extent of shoreline movement that may occur due to significant storm events and cyclical shoreline movement for an event in the order of 1%AEP (i.e. has a probability of occurring on 4 days every year). The maximum 3SD value of 12 m was taken as the short term erosion component (factor S) for this Study and applied along the entire coast. The results compare well with the numerical model study results carried out by T&T in 2001. In the numerical model study a shoreline profile evolution model called SHEACH was used. Erosion set backs were examined at profile C34 and C36 for a 2%AEP, 1%AEP storm as well as a combined 2%AEP and 5%AEP storm in series. Setbacks of 11.7 m were recorded at the dune toe for the 2%AEP event and 13.2 m setback was recorded both for the 1%AEP storm as well as the 2%AEP and 5%AEP storm in series. This compares with a maximum observed movement of 9.3 m and three standard deviation assessment of 10.5 m. At C36 a setback of 9 m was measured for both the 1%and 2%AEP storms with 10.6 m setback occurring for a storm in series, which
compares with a maximum observed of 9.1 m and a three standard deviation assessment of 9.9 m.

This approach differs from the approach proposed by Gibb (1996) and used in the work which produced the CEHZ’s both in terms of applying a horizontal set back rather than a volume as well as applying a single figure to represent the entire shoreline. However, the approach proposed through this review is considered the most appropriate upon balance of the updated information and data sets.

### 3.1.3 Sea level rise effects (X)

The potential shoreline change due to accelerated Sea Level Rise (SLR) is assessed using the Bruun Rule. The Bruun Rule predicts the effect of SLR is a corresponding upward and landward movement of the shoreline (the components of the Bruun Rule are detailed in Appendix B).

Estimates of sea level rise were derived from the most recent climate change guidelines published from the Ministry for Environment (MfE).

The Ministry of Environment (2008) guideline recommends a base value sea level rise of 0.5 m relative to the 1980-1999 average be used along with an assessment of the potential consequences form a range of possible higher sea level rises, with, at the very least, consideration of the consequences of mean sea-level rise of at least 0.8 m relative to the 1980-1999 average and an additional sea level rise of 10 mm per year beyond 2100. Figure 3-1 shows the recommendations as set out by MfE.

Time lines of 2060 and 2110 have also been used (i.e. approximately 50 and 100 years from present). The resulting sea level rise components were 0.36 m and 0.9 m respectively from 1990 levels (taken as the mid range of 1980 to 1999). Therefore, the rate of sea level rise from 1990 to 2060 and 2110 is calculated as 0.00514 m/yr and 0.0075 m/yr respectively.

T&T note that no factor of safety will be used on sea level rise effects as the upper levels of estimates recommended by MfE have been used.

<table>
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<th>Timeframe</th>
<th>Base sea-level rise allowance (m relative to 1980-1999 average)</th>
<th>Also consider the consequences of sea-level rise of at least (m relative to 1980-1999 average)</th>
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</thead>
<tbody>
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<td>2030-2039</td>
<td>0.15</td>
<td>0.70</td>
</tr>
<tr>
<td>2040-2049</td>
<td>0.20</td>
<td>0.27</td>
</tr>
<tr>
<td>2050-2059</td>
<td>0.25</td>
<td>0.36</td>
</tr>
<tr>
<td>2060-2069</td>
<td>0.31</td>
<td>0.45</td>
</tr>
<tr>
<td>2070-2079</td>
<td>0.37</td>
<td>0.55</td>
</tr>
<tr>
<td>2080-2089</td>
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</tr>
<tr>
<td>2090-2099</td>
<td>0.50</td>
<td>0.80</td>
</tr>
<tr>
<td>Beyond 2100</td>
<td></td>
<td>10 mm/yr</td>
</tr>
</tbody>
</table>

*Figure 3-1 Extract from MfE 2008 showing baseline sea level rise recommendations for different future timeframes*
3.1.4 Dune stability (D)

The dune stability factor delineates the area of potential risk landward of the erosion scarp. This parameter is based on the angle of repose for loose dune sand (33°). The dune stability factor is applied as a horizontal distance from the resulting short term erosion dune toe position at Mean Sea Level (MSL). Following the original methodology of Gibb (1996), the horizontal distance is halved to provide a more representative distance as the recovered dune toe is unlikely to extend down to MSL. The dune stability components are detailed in Appendix C. This factor is the same as Gibb, although the LiDAR survey has improved the assessments of the dune crest elevation.

3.1.5 Planning time frame (T)

To provide a sufficient time scale for planning and accommodating development, both a 50 year and 100 year planning horizon were adopted for the purposes of this study:

- 51 years (2009 – 2060)

The long term planning time frames are considered to be consistent with the Operative Tauranga District Plan definitions of 50 year erosion risk and 100 year erosion risk (Chapter 6 – Hazards).

3.1.6 Factor of safety (F)

A safety factor of 1.25 was adopted to accommodate uncertainties in factor S. This is a slight reduction to the 1.3 safety factor derived by Gibb. However, this is justified due to the improved survey accuracy of the LiDAR survey and ortho-photographs as well as the increased duration of the beach profile data set.

3.2 Coastal erosion hazard risk zones

The areas at risk from coastal erosion hazard along the open coast are divided into three zones:

- **Current Erosion Risk Zone (CERZ):** The CERZ includes all land presently at risk from erosion due to storm erosion, short term fluctuations and dune instability with sufficient safety factors (i.e. CERZ = (S)F + D).
- **2060 Erosion Risk Zone (2060ERZ):** The 2060ERZ includes the CERZ and additional areas that are predicted to be subject to erosion due to long term erosion and sea level rise effects to 2060.
- **2110 Erosion Risk Zone (2110ERZ):** The 2110ERZ includes the CERZ and additional areas that are predicted to be subject to erosion due to long term erosion and sea level rise effects to 2110.

3.3 Start position for the erosion risk zones

Following the original methodology of Gibb (1996), the start point of the coastal erosion risk zones is the toe of dune. The same dune toe as that measured by Gibb was used. The coastal erosion hazard zone is measured horizontally inland from the dune toe at right angles from the general alignment of the shoreline.
3.4 Impact of stream mouths

The coastal erosion hazard zones are not applicable in close proximity to streams and river mouths. In these areas, flows from catchment can also have a significant effect the on local beach profile and fluctuation of the stream outlet position. In these areas a coastal erosion hazard zone should include the area buffered 50 m from the stream edge. Table 2.1 describes the streams located along Tauranga’s open coast.

Table 3-1 Streams exiting on the open coast

<table>
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<th>Name</th>
<th>Location</th>
<th>Easting (m)</th>
<th>Northing (m)</th>
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<td>Between Bermuda Drive and Santa Fe Key</td>
<td>2798800</td>
<td>6384870</td>
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</table>

Note: Coordinate system NZMG.

Storm water outlets discharge onto the beach face and the focused flow can also cause localised erosion. Storm water outlets are fixed points on the shoreline and are not prone to the same lateral movement as natural stream mouths. It is outside the scope of this study to identify all storm water outlets along the shoreline.
4 GIS model documentation

4.1 Model format

The original coastal erosion hazard zone GIS model was developed in Arc Macro Language (AML) and run in ArcInfo Workstation. Although AML was widely used during the original GIS model development (1996), it is not commonly used today. Because of this it was considered prudent to update the GIS model as part of the Operative District Plan review.

The GIS model was reviewed and updated for this project as a set of ArcGIS processes which create the CEHZ's. A flow chart for each GIS process is outlined in Appendix D.

The GIS processes are broken down further into separate steps. The steps are provided as a set of instructions in MS Excel, which should be followed in order, to run the GIS model. Refer to Appendix E for the GIS model instructions. The instructions are split into pre-processing steps and processing steps. The pre-processing steps must be completed first.

Although there are no automated steps within the model, the GIS process steps have been formatted to aid future conversion to Model Builder. For example, the following components are identified for each process step:

- input required
- GIS extension required
- GIS tool required
- process detail (e.g. tolerances).

4.2 Software requirements

The GIS model has been designed to work in ArcMap (ArcView licence) with the 3D Analyst extension. The model also uses a number of external extensions where the required process is not available in ArcGIS (Table 4-1). The external extensions should be downloaded prior to running the GIS model.

Table 4-1 GIS extensions required

<table>
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</tr>
<tr>
<td>XTools Pro</td>
<td><a href="http://www.xtoolspro.com/">http://www.xtoolspro.com/</a></td>
</tr>
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</table>
4.3 Model input data

There are several key physical features along the open coast that are required as GIS model input data. These model data are constructed within the GIS model pre-processing steps (Appendix D).

4.3.1 Baseline

The latest digital LINZ coastline is required to construct a smoothed baseline parallel to the general shoreline alignment. The baseline is translated parallel beyond the closure depth (Section 4.3.4). The baseline is then used to construct a series of transects perpendicular to the shoreline.

4.3.2 Digital Terrain Model

The latest Digital Terrain Model (DTM) of the Tauranga open coast is required to extract elevation data and create contour features. The DTM used for this project was acquired from TCC. The DTM was created from LiDAR spot heights (relative to Moturiki Datum) collected on 13 and 14 January 2008. The DTM has a horizontal accuracy of 0.5 m and a vertical accuracy of 0.25 m elevation.

4.3.3 Dune toe and dune crest

The dune toe was based on a copy of the dune toe shape file used to create the existing CHZ lines (created in 2004). This dune toe file is spatially restricted to developed areas. The gaps in this dune toe file were digitised based on the seaward edge of dune vegetation in the 2007 aerial photograph.

The dune toe was then manually edited by a coastal expert where required, based on DTM and aerial photograph analysis.

The dune crest feature is relatively stable compared to the dune toe. A copy of the dune crest feature from the previous model was taken as the dune crest for this project. The dune crest was manually edited by a coastal expert where required, based on contours derived from the DTM.

The construction of both the dune toe and the dune crest should be supervised by a suitable coastal expert.

4.3.4 Closure depth

The closure depth is the estimated seaward limit of nearshore transport and is delineated as a depth or position offshore. A copy of the original closure depth was taken as the closure depth feature for this project. Gibb (1996) determined this closure depth (8.5m below MSL) from hydrographic survey work, which was validated against previous studies within the Bay of Plenty (Gibb & Abum, 1986; Harray & Healy, 1978; Hume & Hicks, 1993).

4.3.5 Long term shoreline movement

Long term trends were analysed from Environment Bay of Plenty (EBoP) beach profile data sets. The results of this analysis are presented in Appendix A.
4.3.6 Short term shoreline movement

The short term erosion rate takes account of both the storm induced erosion and the fluctuations in the long term trend of shoreline movement.

The short term erosion rates were determined from a statistical analysis of the EBoP beach profile data set using standard residuals. The results of this analysis are presented in Appendix A.

4.4 Model methodology

The foundation for the GIS model is a series of shore normal (perpendicular) transects, with equal spacing along the coast. The transects were constructed from the baseline which follows the general shape of the coast (Figure 4-1).

![Figure 4-1 Conceptual diagram of the shore normal transects (Adapted from Gibb, 1996).](image)

The GIS model builds up the attribute information for each transect from the model input data (refer Section 4.3). When all necessary attribute information is captured, the model calculates the coastal erosion hazard components (refer Section 0). As far as practicable, the GIS model is based on the same methodology as the original model description (Gibb, 1996). The main difference is the method used to determine the short term erosion component. The original model used a volume based calculation, whereas the new model uses a horizontal distance, based on profile analysis (refer Appendix A).

All calculations are performed in MS Excel spreadsheets. The purpose of using MS Excel is to provide for transparent analysis of calculations and to simplify edits where required.
The model then calculates the three coastal erosion hazard risk zone distances for each transect, based on Equation 1 (refer to Section 0). The horizontal distances are measured inland from the dune toe along each transect. The three distances are transformed into XY coordinate points for each transect. The positions are then joined to form three shore parallel polylines, which delineate the coastal erosion hazard risk zones (Figure 4-2).

![Diagram of coastal erosion hazard risk zone delineation](image)

*Figure 4-2 Conceptual diagram of the coastal erosion hazard risk zone delineation.*

Note there are several process steps that require expert supervision from an appropriately qualified and experienced coastal engineer or scientist. These steps are identified in the GIS model instructions (Appendix E).

A summary of the model methodology is provided in Table 4-2.

**Table 4-2 GIS model methodology summary**

| Pre-processing                  | - Prepare model input data  
|                                | - Create transects          |
| Processing                     | - Calculate coastal erosion hazard components based on model input data  
|                                | - Calculate the three coastal erosion hazard zones as a horizontal distance from the dune toe along each transect  
|                                | - Convert the horizontal distances into three XY points along each transect based on trigonometry  
|                                | - Map the following coastal erosion hazard zones from joining the XY points into polylines: CERZ, 2060ERZ and 2110ERZ. |
Table 4-3 List of processes that can be skipped in the next CHZ update

<table>
<thead>
<tr>
<th>Process</th>
<th>Output file</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>baseline.shp</td>
</tr>
<tr>
<td>G</td>
<td>transect_mask.shp</td>
</tr>
<tr>
<td>H</td>
<td>DSA5_shoreline.shp</td>
</tr>
<tr>
<td>I</td>
<td>transect_cast.shp</td>
</tr>
</tbody>
</table>

4.6 Model validation

The GIS model has been tested and validated during development in terms of ensuring the calculations are correct and the results verify what is occurring on the ground (i.e. based upon volume calculations and ground truthing).

The model output (i.e. the three coastal erosion hazard risk zones) was validated at 4 locations where long term beach profile datasets exist (i.e. c34, c36, c38, c40). The following validation checks were made at each of the four locations:

i. The three coastal erosion hazard risk zone distances are an accumulation of the correct coastal erosion hazard components (i.e. the correct equation has been applied).

ii. The three coastal erosion hazard risk zones are plotted at the correct distance from the dune toe feature (i.e. the correct transformation from horizontal distance to XY position has been applied).

All four locations passed the two validation checks listed above. The results of this validation are presented in Appendix F. Validation check i.) is shown in Appendix F as three separate cross sections for each locations. Validation check ii.) is presented in Appendix F, with the model output plotted on an aerial photograph at each location.

This process should be repeated after future model runs to validate the results. If results fail the validation checks, the internal calculations should be checked for consistency with the model instructions. We also recommend an independent review be undertaken to check model calculations where required. The independent calculation check was undertaken by TCC for this study.
5 Comparison of new and original lines

The hazard lines resulting from this assessment were overlain in GIS with the dune toe and original Gibb derived hazard lines which currently form the coastal hazard zones within the Operative District Plan. Table 5-1 provides a summary of the overall changes in terms of land area, the number of private properties and the horizontal movement of the lines. Appendix G includes three screen samples of locations of the foreshore where changes have occurred indicating the range of change in terms of horizontal movement.

Table 5-1 Summary statistics of land area, private property numbers and horizontal movement of the hazard lines

<table>
<thead>
<tr>
<th>Comparison</th>
<th>CERZ</th>
<th>2060 ERZ</th>
<th>2110 ERZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Land Area m² (existing)</td>
<td>36,529.76</td>
<td>50,863.07</td>
<td>72,365.05</td>
</tr>
<tr>
<td>Private Land Area m² (proposed)</td>
<td>15,271.35</td>
<td>41,121.16</td>
<td>103,921.86</td>
</tr>
<tr>
<td>Private Land Area m² (difference)</td>
<td>-21,258.40</td>
<td>-9,741.91</td>
<td>31,556.82</td>
</tr>
<tr>
<td>Property Number (existing)</td>
<td>176</td>
<td>194</td>
<td>199</td>
</tr>
<tr>
<td>Property Number (proposed)</td>
<td>116</td>
<td>161</td>
<td>210</td>
</tr>
<tr>
<td>Property Number (difference)</td>
<td>-60</td>
<td>-33</td>
<td>11</td>
</tr>
<tr>
<td>Horizontal Movement (max)</td>
<td>5.83m</td>
<td>15.16m</td>
<td>31.17 m</td>
</tr>
<tr>
<td>Horizontal Movement (min)</td>
<td>-31.5m</td>
<td>-24.87m</td>
<td>-23.05m</td>
</tr>
<tr>
<td>Horizontal Movement (avg)</td>
<td>-11.02m</td>
<td>-4.25m</td>
<td>8.24 m</td>
</tr>
</tbody>
</table>

Note: negative horizontal movement indicates seaward movement of the new lines compared to the old lines, positive indicates landward movement of the line.

The results of Table 5-1 clearly shows a net overall reduction of private land both within the CERZ and the 2060 ERZ and an increase in private land within the 2110 ERZ. The total volume of reduced land area (31,000 m²) is of a similar order of magnitude as the additional land included in the 2110 ERZ. The increase of land area in the 2110 ERZ is due both to the increase in sea level rise values and the modification to the original methodology of Gibb, where historic accretion rates were subtracted from the predicted sea level rise rates. The reduction in private land area within the CERZ and 2060ERZ has the effect of reducing the total number of properties situated within those areas, while a small increase in properties occurs within the 2110 ERZ.
Summary and Recommendation

Tauranga City Council (TCC) commissioned Tonkin & Taylor Ltd (T&T) to update the coastal erosion hazard risk zones along the open coast between Mt Maunganui and the southern end of Papamoa.

The original coastal erosion hazard risk zones were produced by a GIS model that was developed in 1996 based on the available data at the time. T&T have reviewed this data and included additional data that has become available since the original Study was undertaken. This includes:

- additional beach profile data in terms both of longer data sets and additional survey locations;
- LiDAR and ortho-rectified aerial photographs; and
- updated information on the rate of sea level rise to take into account future climate change risk and the need to consider a different time horizon (i.e. 2060 and 2110 rather than 2050 and 2100).

The original coastal erosion hazard risk zone methodology was reviewed and revised to include the cumulative addition of episodic storm induced erosion, dune slope stability, and predicted climate change effects. The effect of historic long term trends has been removed as the beach profile data show the general state of the beach to be of dynamic stability. T&T have also removed the process of reducing climate change effects by subtracting historic accretion as this created significant short term variation in the profile and anomalies such as areas of beach with no identified hazard risk for climate change effects.

The GIS model was re-built for this project as a set of GIS processes which create the coastal erosion hazard risk zones. A set of instructions to run the GIS model are provided in MS Excel format. Although there are no automated steps within the model, the GIS process steps have been formatted to aid future conversion to ArcGIS Model Builder.

The results of this assessment shows a net overall reduction of private land both within the CERZ and the 2060 ERZ and an increase in private land within the 2110 ERZ. The total volume of reduced land area is of a similar order of magnitude as the additional land included in the 2110 ERZ. The increase of land area is due both to the increase in sea level rise values and the modification to the original methodology of Gibb. The reduction in private land area within the CERZ and 2060ERZ has the effect of reducing the total number of properties situated within those areas, while a small increase in properties occurs within the 2110 ERZ.

The GIS model has been tested during development in terms of ensuring the calculations are correct and the results are sensible. The model output (i.e. the three coastal erosion hazard risk zones) was validated at 4 locations where long term beach profile datasets exist (i.e. c34, c36, c38, c40) and the short term fluctuations compared with previous numerical model studies (T&T, 2001) and shown to be of a similar magnitude.

T&T conclude that the coastal erosion hazard lines developed from this assessment can be used to replace the original hazard lines shown in the Operative District Plan.
7 Applicability

This report has been prepared for the benefit of Tauranga City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

TONKIN & TAYLOR LTD
Environmental and Engineering Consultants

Report prepared by:                           Authorised for Tonkin & Taylor by:

Mark Ivamy                                 Richard Reinen-Hamill
Coastal Scientist                          Senior Coastal Engineer
8 References


Appendix A: Beach profile analysis
REPORT
TAURANGA CITY COUNCIL

Beach Profile Analysis
Appendix A

Report prepared for:
TAURANGA CITY COUNCIL

Report prepared by:
TONKIN & TAYLOR LTD

July 2009

T&T Ref: 25836
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2. Beach profile locations 1
3. Beach profile data 1
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Attachment A: Profile location plan
Attachment B: Linear Regression plots
Attachment C: Residual plots
1 Introduction

This report presents an analysis of beach profile data obtained from Environment Bay of Plenty. It includes a review of both the beach profile short term changes and long term trends.

2 Beach profile locations

Environment Bay of Plenty (EBOP) monitors 18 beach profiles at selected locations along Tauranga's open coast (refer to Attachment A for beach profile location plan). The profiles start from the fore dune system and extend across the backshore onto the fore shore. The vertical position of the dune toe was determined to be the 3 m contour, based on analysis of the profile dataset, a 2008 Digital Terrain Model (DTM) and a 2007 aerial photograph.

3 Beach profile data

The beach profile data was imported into BMAP (version 2.0) software. BMAP was used to evaluate horizontal excursions of the beach profiles and analyse shoreline movement trends. Table 1 includes a summary of the beach profile survey information.

Table 1 Summary of beach profile data

<table>
<thead>
<tr>
<th>Profile</th>
<th>Start Date</th>
<th>End Date</th>
<th>No. Years</th>
<th>No. Surveys</th>
</tr>
</thead>
<tbody>
<tr>
<td>c34</td>
<td>5/02/1978</td>
<td>27/08/2008</td>
<td>29</td>
<td>76</td>
</tr>
<tr>
<td>c35a</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>37</td>
</tr>
<tr>
<td>c35b</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>37</td>
</tr>
<tr>
<td>c36</td>
<td>1/06/1977</td>
<td>7/08/2008</td>
<td>31</td>
<td>79</td>
</tr>
<tr>
<td>c37</td>
<td>10/12/1996</td>
<td>27/08/2008</td>
<td>12</td>
<td>50</td>
</tr>
<tr>
<td>c37a</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>38</td>
</tr>
<tr>
<td>c37b</td>
<td>20/10/1999</td>
<td>28/11/2008</td>
<td>9</td>
<td>35</td>
</tr>
<tr>
<td>c38</td>
<td>5/02/1978</td>
<td>28/11/2008</td>
<td>29</td>
<td>101</td>
</tr>
<tr>
<td>c38a</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>c38b</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>c38c</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>37</td>
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<tr>
<td>c38d</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>c38e</td>
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<td>27/08/2008</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>c38f</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>37</td>
</tr>
<tr>
<td>c38g</td>
<td>20/10/1999</td>
<td>27/08/2008</td>
<td>9</td>
<td>33</td>
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<tr>
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<td>27/08/2008</td>
<td>30</td>
<td>96</td>
</tr>
<tr>
<td>c39a</td>
<td>20/10/1999</td>
<td>7/08/2008</td>
<td>9</td>
<td>37</td>
</tr>
<tr>
<td>c40</td>
<td>6/02/1978</td>
<td>27/08/2008</td>
<td>31</td>
<td>93</td>
</tr>
</tbody>
</table>
Detailed checks on reference levels and datums have not been carried out as part of this study. The origin and benchmarks of each profile is assumed to be correct.

## 4 Long term trends

Shoreline movement was measured as the horizontal excursion distance between the horizontal datum (benchmark) and the dune toe contour (3m above MSL). Long term trends were calculated by undertaking linear regression analysis of shoreline movement over time. The results of the linear regression analysis are presented in Table 2, where the long term trends for each profile are listed under the Rate column.

<table>
<thead>
<tr>
<th>Profile</th>
<th>No. Years</th>
<th>No. Surveys</th>
<th>Rate (m/yr)</th>
<th>SD (m)</th>
<th>r²</th>
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<tbody>
<tr>
<td>c34</td>
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<td>76</td>
<td>0.06</td>
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<tr>
<td>c35a</td>
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<td>0.41</td>
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<td>0.14</td>
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<tr>
<td>c37a</td>
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<td>38</td>
<td>0.66</td>
<td>2.1</td>
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<td>c37b</td>
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<td>1.5</td>
<td>0.45</td>
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<td>c38e</td>
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<td>36</td>
<td>1.02</td>
<td>1.5</td>
<td>0.77</td>
</tr>
<tr>
<td>c38f</td>
<td>9</td>
<td>37</td>
<td>0.64</td>
<td>1.5</td>
<td>0.57</td>
</tr>
<tr>
<td>c38g</td>
<td>9</td>
<td>33</td>
<td>1.43</td>
<td>1.5</td>
<td>0.88</td>
</tr>
<tr>
<td>c39</td>
<td>30</td>
<td>96</td>
<td>0.23</td>
<td>3.9</td>
<td>0.14</td>
</tr>
<tr>
<td>c39a</td>
<td>9</td>
<td>37</td>
<td>2.28</td>
<td>1.2</td>
<td>0.96</td>
</tr>
<tr>
<td>c40</td>
<td>31</td>
<td>93</td>
<td>0.24</td>
<td>1.9</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Based on linear regression of the EBoP profile dataset, the average rate of long term shoreline change for the Tauranga coast is 0.52 m/year of accretion.

Some profile locations have longer data sets than others. The profile locations that have a dataset longer than 29 years include c34, c36, c38, c39 and c40 (bold values in Table 2). This study focused on these datasets to represent long term shoreline movements. The average rate of long term shoreline change for these profiles only, is 0.11 m/year of accretion. The linear regression plots for these profile locations are presented in Attachment B. The majority of the profiles record a long term rate of accretion and one profile records a long term rate of erosion (i.e. c38).
The fore dune system adjacent profile c38 has a different land use history than the other profile locations. The fore dune system adjacent profile c38 was lowered to provide for vehicle beach access (Figure 1). The fore dune system in this location has a reduced volume relative to the naturally accreting shoreline. Therefore, horizontal shoreline fluctuations extend further inland and the fore dune system takes longer to build out under accretionary conditions.

The majority of the fore dune system adjacent profile c38 is now vegetated and the area is no longer used for vehicle beach access. Based on analysis of aerial photographs, the 2007 seaward edge of vegetation is further seaward than in 1977 (Figure 1). Therefore, although the profile results suggest the shoreline is eroding, in our opinion the shoreline adjacent profile c38 is dynamically stable.

Figure 1 Aerial photograph of profile location c38 in 1977, showing a lowered dune system for vehicle access. The green line represents the 1977 seaward edge of vegetation and the blue line represents the 2007 seaward edge of vegetation. The red line represents the c38 profile location.

In our opinion, the Tauranga open coast shoreline between Mt Maunganui and southern Papamoa is dynamically stable with no apparent long term trend of erosion. However, future shoreline movement may differ from historic trends due to climatic patterns associated with Interdecadal Pacific Oscillation (IPO) and global climate change. Therefore, the long term trend component was set to zero.

During the period from approximately 1973 – 1999, predominant El Nino conditions have contributed to accretion through a local relative fall in sea level and a lack of severe onshore wave storms (i.e. positive IPO phase).
Over the last 10 years (1999 – 2009), La Nina conditions have dominated in the negative IPO phase. The negative IPO phase is expected to last for the next two decades. During these conditions the local relative sea level is expected to rise and there is likely to be an increase in severe onshore wave storms. More frequent episodes of shoreline erosion are expected during these conditions. This trend is evident in the residual plots presented in Attachment C. A higher percentage of negative residuals (i.e. shoreline movements lower than predicted) occur after the year 1999.

5 Short term trends

The short term erosion rate takes account of both the storm induced erosion and the short term fluctuations in the long term trend of shoreline movement. This study focused on the longer period datasets to analyse short term shoreline movements (i.e. c34, c36, c38, c39 and c40).

The standard deviation of the mean method was used to measure short term erosion trends from the profile dataset. This method assumes that the magnitude of shoreline movements is normally distributed. The observed frequency of shoreline movement is compared to the expected normal distribution frequency in Figure 2.

![Observed shoreline movement against normal distribution](image)

**Figure 2** Observed frequency of shoreline movement compared to the expected normal distribution frequency (black line).

Figure 2 indicates that the distribution of shoreline movement can generally be considered to be normal. Having largely satisfied the normality of the data, we can then use the standard deviations (SD) from the mean as our measure of short term fluctuation. From normal probability theory, we know that an observation value at 1SD, 2SD, and 3SD from the mean will have corresponding probabilities of occurrence of 16%, 2.5% and 0.5% respectively. Since the dataset is shoreline movement over time, these probabilities can be
considered to be equivalent to Annual Exceedance Probabilities (AEP). Therefore, a shoreline retreat greater than 2SD is the same as a 40 year return period event, and greater than 3SD is the same as a 200 year return period event.

Table 3 shows the short term erosion results for the long period datasets. Both the 1SD and 3SD results are presented for each long period dataset. The maximum negative residual is the largest difference between the surveyed shoreline position (in an erosion phase) and the predicted shoreline position based on regression analysis. Refer to Attachment C for residual plots. The maximum shoreline movement in an erosion phase is the largest distance of continuous erosion over several survey intervals.

Table 3  Short term erosion results

<table>
<thead>
<tr>
<th>Profile</th>
<th>No. Years</th>
<th>1SD (m)</th>
<th>3SD (m)</th>
<th>Maximum negative residual (m)</th>
<th>Maximum shoreline movement - erosion phase (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>c34</td>
<td>29</td>
<td>3.5</td>
<td>10.5</td>
<td>-7.6</td>
<td>-9.3</td>
</tr>
<tr>
<td>c36</td>
<td>31</td>
<td>3.3</td>
<td>9.9</td>
<td>-6.3</td>
<td>-9.1</td>
</tr>
<tr>
<td>c38</td>
<td>29</td>
<td>2.1</td>
<td>6.3</td>
<td>-5.8</td>
<td>-7.2</td>
</tr>
<tr>
<td>c39</td>
<td>30</td>
<td>3.9</td>
<td>11.7</td>
<td>-9.8</td>
<td>-8.6</td>
</tr>
<tr>
<td>c40</td>
<td>31</td>
<td>1.9</td>
<td>5.7</td>
<td>-7.1</td>
<td>-5.7</td>
</tr>
</tbody>
</table>

The maximum shoreline movement recorded in an erosion phase was 9.3 m at profile c34 (Table 3). The maximum negative residual was 9.8 m recorded at profile c39. The full magnitude of the shoreline change may not have been recorded due to the intervals between surveys.

In our opinion, the fluctuation defined by 3SD appears in the right order to represent the maximum extent of shoreline movement that could occur due to significant storm events and cyclical shoreline movement (Table 3). Therefore, the maximum 3SD value of 12 m was taken as the short term erosion component for this study.

6  Summary

Shoreline movement was measured as the horizontal excursion distance between the dune toe contour (3m above MSL) and a horizontal datum (benchmark). Long term trends were calculated by undertaking linear regression analysis of shoreline movement over time. In our opinion, the Tauranga shoreline is dynamically stable with no apparent long term trend of erosion. However, future shoreline movement may differ from historic trends due to climatic patterns associated with Interdecadal Pacific Oscillation (IPO) and global climate change. Therefore, the long term trend component was set to zero.

The standard deviation of the mean method was used to measure short term erosion trends from the profile dataset. In our opinion, the fluctuation defined by 3SD appears in the right order to represent the maximum extent of shoreline movement that could occur due to significant storm events and cyclical shoreline movement. Therefore, the maximum 3SD value of 12 m was taken as the short term erosion component for this study.
Attachment A: Profile location plan
Attachment B: Linear Regression plots
c34 Linear Regression

\[ y = 0.0002x + 10.565 \]

\[ R^2 = 0.0158 \]
c38 Linear Regression

\[ y = -0.001x + 84.52 \]
\[ R^2 = 0.4959 \]
c39 Linear Regression

$y = 0.0006x + 23.924$

$R^2 = 0.1401$
c40 Linear Regression

\[ y = 0.0007x + 4.457 \]

\[ R^2 = 0.442 \]
Attachment C:  Residual plots
c39 Residual Plot

Y-axis: Residuals
X-axis: Dates


Data points are scattered across the plot, indicating variability in residuals over time.
Appendix B: Bruun Rule components
**Bruun Rule Component**

Sea level rise will permit waves to attack the backshore and fore dunes more frequently. Sandy open coasts that have been relatively stable over time are likely to show a bias towards erosion with rising sea levels, unless the supply of sand to the beaches can keep pace with erosion.

The potential shoreline change due to accelerated Sea Level Rise (SLR) is assessed using the Bruun Rule. The Bruun Rule predicts the effect of a rise in sea level as a corresponding upward and landward movement of the shoreline (Figure 1).

![Diagram of shoreline retreat](image)

*Figure 1 Components of the Bruun Rule, adapted from Komar (1976).*

The rate of shoreline retreat from the effects of sea level rise is obtained from the Bruun Rule shown in Equation 2 below:

\[
X = \frac{L \times a}{(h + d)}
\]

(2)

Where:

- \(X\) is the rate of shoreline retreat from the effects of sea level rise (m/yr).
- \(L\) = distance from fore dune crest to the contour representing the closure depth.
- The model takes this component as the transect length, because each transect is clipped between the closure depth contour and the fore dune crest polyline.
- \(a\) = rate of sea level rise (SLR).
- The Ministry for Environment (2008) guidelines recommend a base value sea level rise of 0.5 m relative to the 1980-1999 average be used along with an assessment of the potential consequences form a range of possible higher sea level rises, with, at the very least, consideration of the consequences of mean sea-level rise of at least 0.8 m relative to the 1980-1999 average and an additional sea level rise of 10 mm per year beyond 2100.
Table 2.3: Baseline sea-level rise recommendations for different future timeframes

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>Base sea-level rise allowance (m relative to 1980–1999 average)</th>
<th>Also consider the consequences of sea-level rise of at least (m relative to 1980–1999 average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030–2039</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>2040–2049</td>
<td>0.20</td>
<td>0.27</td>
</tr>
<tr>
<td>2050–2059</td>
<td>0.25</td>
<td>0.35</td>
</tr>
<tr>
<td>2060–2069</td>
<td>0.31</td>
<td>0.45</td>
</tr>
<tr>
<td>2070–2079</td>
<td>0.37</td>
<td>0.55</td>
</tr>
<tr>
<td>2080–2089</td>
<td>0.44</td>
<td>0.66</td>
</tr>
<tr>
<td>2090–2099</td>
<td>0.50</td>
<td>0.80</td>
</tr>
<tr>
<td>Beyond 2100</td>
<td>10 mm/year</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Extract from MFE 2008 showing baseline sea level rise recommendations for different future timeframes

With time lines of 2060 and 2110 (i.e. approximately 100 years from present), the resulting sea level rise components were 0.36 m and 0.9 m respectively. Therefore, the rate of sea level rise from 1990 to 2060 and 2110 is calculated as 0.00514 m/yr and 0.0075 m/yr respectively. We note that no factor of safety will be used on sea level rise effects as the upper levels of estimates recommended by MFE have been used.

$h =$ height of fore dune crest above MSL. The height of the fore dune crest above MSL is captured at each transect from the DTM.

$d =$ closure depth is the seaward limit of nearshore transport and is delineated as a depth or position offshore. Gibb (1996) determined the average closure depth (8.5 m below MSL) from hydrographic survey work, which was validated against previous studies within the Bay of Plenty. A copy of the original closure depth component was taken as the closure depth feature for this project.

The GIS model names all Brunn Rule components with a X_prefix (i.e. X_l, X_a50, X_a100, X_h, and X_d). The Brunn Rule components are calculated for each transect, and the resulting shoreline retreat due to sea level rise is calculated separately for both the 2060 and 2100 planning time frames (i.e. X50 and X100).

References


Appendix C: Dune stability components
Dune stability

The dune stability factor delineates the area of potential risk landward of the erosion scarp. This parameter is based on the angle of repose for loose dune sand (33°). The dune stability factor is applied as a horizontal distance from the resulting short term erosion dune toe position.

The original methodology calculated the dune stability parameter based on the fore dune crest height (h) using Equation 3 (Figure 1A). This is a standard method to calculate land stability where no detailed DTM of the dune exists.

\[ D = \left[ \frac{h}{\tan(33°)} \right] 0.5 \]  \hspace{1cm} (3)

Equation 3 includes a scale factor of 0.5. This scale factor is based on the assumption that approximately half of the upper erosion scarp cut during storms would collapse onto the beach causing a localised advance of the dune line.

![Diagram showing dune stability parameters](image)

Figure 1 Components of the dune stability parameter (D), showing the interim risk zone for the CERZ. Note the diagram is not to scale.

The GIS model developed for this project calculates the dune stability parameter using the DTM, which provides a more accurate representation of the dune topography. The GIS model constructs a dune stability plane (i.e. essentially a DTM) that starts from the vertical erosion scarp at MSL and extends inland at the angle of repose for dune sand (shown as the blue line in Figure 1). The dune stability component is calculated as the horizontal distance between the intersect point of the two DTMs and the position of the erosion scarp (Figure 1B). The model then applies a scale factor of 0.5 to remain consistent with the original methodology.

The new GIS model calculates a separate dune stability component for each of the three coastal erosion hazard risk zones. This is required because the vertical erosion scarp will most likely occur in different positions through the dune profile over time. The GIS model calculates three vertical erosion scarp positions based on the coastal erosion hazard components (Section 2.1), which are termed interim risk zones. The interim risk zone is measured landward from the dune toe.

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For the CERZ, the interim risk zone is simply the distance of the short term fluctuation component (Figure 1). For both the 2060ERZ and the 2110ERZ, the interim risk zone includes short term erosion, long term erosion and erosion due to the effects of sea level rise (Figure 2).

![Diagram showing dune stability parameter (D), showing the interim risk zone for the 2060ERZ and the 2110ERZ.](image)

Figure 2 Dune stability parameter (D), showing the interim risk zone for the 2060ERZ and the 2110ERZ.

The GIS model creates another two dune stability DTM's for the 2060ERZ and the 2110ERZ. The DTM's start from the landward position of the interim risk zone and extend inland at the angle of repose for dune sand (33°). Both the 2060ERZ and the 2110ERZ dune stability DTMs include a vertical datum shift to reflect a predicted change in MSL over the planning time frame (MSL + offset). The offsets applied for 2060ERZ and 2110ERZ are 0.36 m and 0.9 m for respectively. The dune stability component is then calculated as the horizontal distance between the intersect point of the two DTMs and the landward position of the interim risk zone (Figure 2).
Appendix D: GIS model process flow
GIS model process flow

KEY
A = Process ID

1. PRE-PROCESSING

1.1 Model data inputs
Features that are a copy of the previous model run (i.e. need to be reviewed, but should not change):
A

closure_depth

Features that require geoprocessing:
Create TIN mask
B

Existing Dune toe → Buffer 150m → TIN_mask

Create baseline feature class for transects:
C

LINZ coastline → Select feature representing study area and export as baseline → Generalize → Copy parallel 800m → Add fields, delete fields and select seaward feature and export → baseline

Create TIN of dune:
D

0.5m_DTM → Clip DTM to a mask → Convert DTM to TIN → TIN_dune

TIN_mask

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Create dune toe feature class:

E

TIN_dune → Create 3m contour → Generalise → Check for double-backs and move vertices where required → dune_toe

Create dune crest feature class:

F

TIN_dune → Copy existing dune crest → Move vertices where required → dune_crest

Create transect mask:

G

dune_crest → Merge into one shape file → Join features at each end → Convert polyline to polygon → transect_mask

closure_depth

Create DSAS shoreline feature class:

H

dune_toe → Copy features with new DSAS prefix → Add fields → Merge features → DSAS_shoreline

dune_crest → Copy features with new DSAS prefix → Add fields
Create transect feature class:
1

Create point file of transect intersect with both dune toe and dune crest:
J
Create point file of dune crest with elevation:

K

1.2 Model parameters

Create short term erosion parameter:
L

Create long term erosion parameter:
M
2. PROCESSING

2.1 Model development

2.1.1 Populate transect attribute fields

Capture parameters for each transect from the intersection with shore parallel parameter layers and point layers (S, R, X_h and dune toe intersect):

N

\[ \text{dune_crest_elev,} \]
\[ \text{dune_toe_intersect,} \]
\[ \text{short_erosion,} \]
\[ \text{long_erosion} \]

\[ \text{Join parameter by location (spatial join)} \]

\[ \text{Delete unnecessary fields} \]

\[ \text{transect_model} \]

\[ \text{transect} \]

Note: This step is rerun for each of the four parameters

Populate constant model parameters (T, F, X_d, X_a50 and X_a100):

O

\[ \text{transect_model} \]

\[ \text{Calculate field} \]

\[ \text{transect_model (updated version2)} \]

Calculate components (X50, X100, interim ERZ, interim MRZ, interim LRZ) from other parameters within the attribute table:

P

\[ \text{transect_model} \]

\[ \text{Export attributes to MS Excel} \]

\[ \text{Add fields} \]

\[ \text{Populate fields} \]

\[ \text{Calculate X2060, X2100 and interim RZ's based on populated cells} \]

\[ \text{IMERZ_D} \]

\[ \text{Import as shape files} \]

\[ \text{Save as XYZ files} \]

\[ \text{Convert dist from interim RZ's to the inland_dist into XY, based on the azimuth of the transect} \]

\[ \text{ILRZ_D} \]

\[ \text{Convert dist from dune toe to the interim RZ's into XY, based on the azimuth of the transect} \]

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Capture dune stability distance from TIN analysis (D):

Q

IRZ_XYZ → Convert 3D points to TIN → TIN_IRZD → Create polygon at the intersection of the 2 TINs

TIN_dune → IRZ_intersect

Several steps required here to convert polygon of dune stability to a polyline (saved as IRZ_intersect_line)

IRZ_intersect_line → Create points at intersection of IRZ_intersect_line and transect_cast

Several Arcview and MS Excel steps are required here to combine the coordinates of the interim risk zone and the dune stability intersect. A MS Excel formula then calculates the horizontal distance between the two points along the transect (D)

IRZ_intersect_points → Calculate the horizontal distance from IRZ_start to IRZ_intersect point (dune stability). Populate the D field in transect_model with this value.

transect_model (updated version3)

Note: Repeat process for each IRZ (i.e. IERZ, IMRZ and ILRZ).

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2.1.2 Create CEHPA zones
Calculate from CEHPA zones within MS Excel and convert distances to XY points. Export points to shape file and join points to from polylines (CERZ, ERZ50 and ERZ100):

R

[Diagram showing the process with nodes for transect_model, Export attributes to MS Excel, Add fields and calculate values, Convert dist from dune toe to the RZ's into XY, based on the azimuth of the transect, Import shape files, Delete unnecessary fields, CERZ, ERZ50, ERZ100, Convert point to polygon feature class]
Appendix E: GIS model instructions
<table>
<thead>
<tr>
<th>ID</th>
<th>Required No.</th>
<th>Process</th>
<th>Extension</th>
<th>GIS PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Copy existing closure depth file to working folder</td>
<td>GIS MANAGEMENT TOOLS</td>
<td>Copy</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>Buffer dune toe by 150m</td>
<td>Analysis Tools</td>
<td>Buffer</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>Select feature representing study site</td>
<td>ArcMap</td>
<td>Select feature</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>Export selected feature as coastline</td>
<td>ArcMap</td>
<td>Export Data</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>Generalize coastline polygon</td>
<td>PT_Overlays</td>
<td>Generalize</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>Copy coastline_gen100 parallel 800m</td>
<td>Editor</td>
<td>Copy parallel</td>
</tr>
<tr>
<td>G</td>
<td>7</td>
<td>Add required fields</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Add Fields</td>
</tr>
<tr>
<td>H</td>
<td>8</td>
<td>Populate ID field of coastline_gen100 with 1</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Calculate Field</td>
</tr>
<tr>
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<td>9</td>
<td>Delete unnecessary fields</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Delete Fields</td>
</tr>
<tr>
<td>J</td>
<td>10</td>
<td>Select seasonal feature</td>
<td>ArcMap</td>
<td>Select Feature</td>
</tr>
<tr>
<td>K</td>
<td>11</td>
<td>Export selected feature as baseline</td>
<td>ArcMap</td>
<td>Export Data</td>
</tr>
<tr>
<td>L</td>
<td>12</td>
<td>Editor</td>
<td>Modify Feature</td>
<td>baseline</td>
</tr>
<tr>
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<td>13</td>
<td>Convert mask to graphics</td>
<td>ArcMap</td>
<td>Convert to Graphics</td>
</tr>
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<td>Clip 5km ETM to TRIM_mask</td>
<td>ET Analyst Tools</td>
<td>Raster to TIN</td>
</tr>
<tr>
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<td>15</td>
<td>Convert DTM to TIN</td>
<td>ET Analyst Tools</td>
<td>TIN contour</td>
</tr>
<tr>
<td>P</td>
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<td>Create 3D contour</td>
<td>ET Analyst Tools</td>
<td>3D_contour</td>
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<td>17</td>
<td>Generalize</td>
<td>ET Generalize</td>
<td>Polygon 3 Generalize</td>
</tr>
<tr>
<td>R</td>
<td>18</td>
<td>Check for double backs</td>
<td>Editor</td>
<td>Modify Feature</td>
</tr>
<tr>
<td>S</td>
<td>19</td>
<td>Copy existing dune crest to working folder and rename dune_crest</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Copy Feature</td>
</tr>
<tr>
<td>T</td>
<td>20</td>
<td>Move verticals where required</td>
<td>Editor</td>
<td>Modify Feature</td>
</tr>
<tr>
<td>U</td>
<td>21</td>
<td>Merge closure_depth and dune_crest into one shape file</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Merge</td>
</tr>
<tr>
<td>V</td>
<td>22</td>
<td>Join two ends of curves merge with two extra stopped polygons</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Create new feature</td>
</tr>
<tr>
<td>W</td>
<td>23</td>
<td>Convert mask, merge to polygon feature class</td>
<td>ET Generalize</td>
<td>Polygon to Polygon</td>
</tr>
<tr>
<td>X</td>
<td>24</td>
<td>Create GIS (input features and give them a new file name (dune_crest GIS and dune_tie GIS))</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Copy Feature</td>
</tr>
<tr>
<td>Y</td>
<td>25</td>
<td>Add required fields for GIS</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Add Fields</td>
</tr>
<tr>
<td>Z</td>
<td>26</td>
<td>Regularize DUSE Fields of DUSE_dune_crest and DUSE_dune_tie</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Calculate Field</td>
</tr>
<tr>
<td>A</td>
<td>27</td>
<td>Append dune_crest GIS and dune_tie GIS</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Append</td>
</tr>
<tr>
<td>B</td>
<td>28</td>
<td>Rename DUSE_shoreline</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Rename</td>
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<td>C</td>
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<td>Create RGB for DUSE</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Create Personal ODB</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>Import baseline into FGDB</td>
<td>ArcCatalog</td>
<td>Import Feature Class</td>
</tr>
<tr>
<td>E</td>
<td>31</td>
<td>Import DUSE_shoreline into FGDB</td>
<td>ArcCatalog</td>
<td>Import Feature Class</td>
</tr>
<tr>
<td>F</td>
<td>32</td>
<td>Run DUSE - run VBA script (refer to DUSE user guide for more information - <a href="http://woodside.et.usgs.gov/project_pages/DUSE/">http://woodside.et.usgs.gov/project_pages/DUSE/</a></td>
<td>ArcMap/DUS</td>
<td>DUS.VBA</td>
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<td>Delete Fields</td>
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<td>Data MANAGEMENT TOOLS</td>
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<td>Check for transit overlap</td>
<td>Editor</td>
<td>Modify Feature</td>
</tr>
<tr>
<td>J</td>
<td>36</td>
<td>Clip to mask between dune_crest and closure_depth</td>
<td>Analysis Tools</td>
<td>Clip</td>
</tr>
<tr>
<td>K</td>
<td>37</td>
<td>Add length of transits</td>
<td>ArcMap</td>
<td>Calculate Geometry</td>
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<tr>
<td>L</td>
<td>38</td>
<td>Create points where transit intersects with dune_tie</td>
<td>Analysis Tools</td>
<td>Intersect</td>
</tr>
<tr>
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<td>Kmlxfo</td>
<td>Table Operations, Add XY</td>
</tr>
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<td>41</td>
<td>Create points where transit intersects with dune_crest</td>
<td>Analysis Tools</td>
<td>Intersect</td>
</tr>
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<td>Buffer dune toe 25m</td>
<td>Analysis Tools</td>
<td>Buffer</td>
</tr>
<tr>
<td>U</td>
<td>47</td>
<td>Add field named D</td>
<td>Data MANAGEMENT TOOLS</td>
<td>Add Fields</td>
</tr>
<tr>
<td>V</td>
<td>48</td>
<td>Cut polygon at distinct erosion lengths based on profile work and assign erosion values</td>
<td>Editor</td>
<td>Cut Polygon Features</td>
</tr>
<tr>
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<td>Analysis Tools</td>
<td>Buffer</td>
</tr>
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<td>Data MANAGEMENT TOOLS</td>
<td>Add Fields</td>
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<td>Cut polygon at distinct erosion lengths based on profile work and assign erosion values</td>
<td>Editor</td>
<td>Cut Polygon Features</td>
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<td>Name</td>
<td>Format</td>
<td>Shape</td>
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<td>polyline</td>
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<td>Shp file</td>
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<td>Tin_mask</td>
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</tr>
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<td>Generalised UNZ coastline</td>
<td>Shp file</td>
<td>polyline</td>
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<td>Digital Terrain Model of dune system</td>
<td>DTM</td>
<td>TIN</td>
<td>TIN_dune</td>
</tr>
<tr>
<td></td>
<td>Clipped DTM raster to dune system</td>
<td>DTM</td>
<td>Raster</td>
<td>9_10TM_chip</td>
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<td>tin_3m_contour</td>
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<td>polyline</td>
<td>dune_crest</td>
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<td>Shp file</td>
<td>polygon</td>
<td>transect_mask</td>
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<td>Merged closure depth and dune crest</td>
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<td>polygon</td>
<td>mask_merge</td>
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<td>DSAS shoreline</td>
<td>Shp file</td>
<td>polyline</td>
<td>DSAS_shoreline</td>
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<td>Copy of dune crest for DSAS input</td>
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<tr>
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<td>Shp file</td>
<td>polyline</td>
<td>transect</td>
</tr>
<tr>
<td></td>
<td>Intersection points with transects</td>
<td>dbf file</td>
<td>data</td>
<td>transect_cast_intersect</td>
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<tr>
<td></td>
<td>Transects perpendicular to dune toe spaced at 4m, pre-clipped</td>
<td>Shp file</td>
<td>polyline</td>
<td>transect_cast</td>
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<tr>
<td></td>
<td>Personal Geodatabase with all feature classes required for DSAS</td>
<td>FGDB</td>
<td>feature</td>
<td>OSAS</td>
</tr>
<tr>
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<td>Intersection point of dune toe with transects</td>
<td>Shp file</td>
<td>point</td>
<td>dune_toe_intersect</td>
</tr>
<tr>
<td></td>
<td>Intersection point of dune crest with transects</td>
<td>Shp file</td>
<td>point</td>
<td>dune_crest_intersect</td>
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<td>short_erosion</td>
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<td>M</td>
<td>Long term erosion parameter</td>
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<td>long_erosion</td>
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<td>Id</td>
<td>Step No.</td>
<td>Process</td>
<td>Extension</td>
<td>GIS TOOLS</td>
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<td>-----------</td>
<td>-----------</td>
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<td>52</td>
<td>Join dune_angle attributes to transect feature class by location (closest with each transect)</td>
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<td>Spatial Join</td>
</tr>
<tr>
<td>N</td>
<td>53</td>
<td>Join short_erosion attributes to transect feature class by location (closest with each transect)</td>
<td>Analysis Tools</td>
<td>Spatial Join</td>
</tr>
<tr>
<td>N</td>
<td>54</td>
<td>Join long_erosion attributes to transect feature class by location (closest with each transect)</td>
<td>Analysis Tools</td>
<td>Spatial Join</td>
</tr>
<tr>
<td>N</td>
<td>55</td>
<td>Join dune_top_intersect attributes to transect feature class by location (closest with each transect)</td>
<td>Analysis Tools</td>
<td>Spatial Join</td>
</tr>
<tr>
<td>Q</td>
<td>56</td>
<td>Calculate fields with constant model parameters</td>
<td>Data Management Tools</td>
<td>Calculate Fields</td>
</tr>
<tr>
<td>P</td>
<td>57</td>
<td>Export transect_model attributes to MS Excel</td>
<td>KToolsPro</td>
<td>Table Operations, Export Data to MS Excel</td>
</tr>
<tr>
<td>P</td>
<td>58</td>
<td>Add required fields</td>
<td>MS Excel</td>
<td>Add Fields</td>
</tr>
<tr>
<td>P</td>
<td>59</td>
<td>Calculate F adjusted to deal with - and + values (i.e. erosion and accretion)</td>
<td>MS Excel</td>
<td>Insert Formula</td>
</tr>
<tr>
<td>P</td>
<td>60</td>
<td>Calculate X,0,10,0 and then IRZ (IRZ, MRZ, and LRZ) based on populated cells</td>
<td>MS Excel</td>
<td>Insert Formula</td>
</tr>
<tr>
<td>P</td>
<td>61</td>
<td>Save the updated transect spreadsheet 1 times as IRZ-D.shx, MRZ_D.shx and LRZ_D.shx</td>
<td>MS Excel</td>
<td>Insert Formula</td>
</tr>
<tr>
<td>P</td>
<td>62</td>
<td>Populate fields with constant parameters (Irzval_d, Irzval_l, Irzval_z, Irz_val_r)</td>
<td>MS Excel</td>
<td>Insert Formula</td>
</tr>
<tr>
<td>P</td>
<td>63</td>
<td>Convert distance from dune toe to the IRZ into XY based on azimuth of the transect</td>
<td>MS Excel</td>
<td>Insert Formula</td>
</tr>
<tr>
<td>P</td>
<td>64</td>
<td>Convert distance from IRZ to the barrier into XY based on azimuth of the transect</td>
<td>MS Excel</td>
<td>Insert Formula</td>
</tr>
<tr>
<td>P</td>
<td>65</td>
<td>Copy both the inland X, Y, Z fields and IRZ X, Y, Z fields into one spreadsheet under 3 fields (X, Y and Z)</td>
<td>MS Excel</td>
<td>Copy, Paste Values, Move Cells and Save</td>
</tr>
<tr>
<td>P</td>
<td>66</td>
<td>Import IRZ_XYZ into ArcMap</td>
<td>ArcMap</td>
<td>Tools/Add XY data</td>
</tr>
<tr>
<td>P</td>
<td>67</td>
<td>Export each IRZ event table to shape file</td>
<td>ArcMap</td>
<td>Export Data</td>
</tr>
<tr>
<td>NOTE</td>
<td>E</td>
<td>Add the following layers to ArcMap:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SELECT THIS PROCESS FOR EACH RISK ZONE (Substitute ERZ with either IMRZ or IZD and substitute ERZD with either IMRZD or IZD):

68. Open tool and save output as TIN/DEND, Import the coordinate system from TIN done.
69. Open tool and save output to TIN/ERZ as input TIN and ERZ_K as the input feature class. Change the tolerances to 0.1m under Environmental Settings/General Settings.
70. Load TIN/ERZ input command onto ArcMap, Open both the TIN done and TIN/ERZ in ArcMap to make sure both TINs have the same coordinate system i.e. Rectified coordinate system for TIN/ERZ done from TIN done under the first step of this process. Open TIN intersect command and select TIN done as the first input TIN and TIN/ERZ done as the second input TIN. Leave the tolerance on default value of 0.0. Save output TIN and TIN/ERZ done as output feature class as ERZ intersect.
71. Open ERZ intersect_line_in ArcMap edit mode. Select the input feature from the edit task bar and select the polygon features that represent the dune stability interface (COASTAL EXPERT MAY BE REQUIRED). Open the attribute table for ERZ_intersect_line, and switch selection under options and then hit the delete key. Stop and save edits.
72. Open ERZ intersect_line_2 in ArcMap edit mode. Select the split triple adjacent the edit task box and split the polygonal features that represent the dune stability interface. Open the attribute table, switch selection under options and hit the delete key. Open edit mode. Stop and save edits.
73. Open ERZ intersect_line_3 in ArcMap edit mode. Open transact_icon in ArcMap for reference. Select modify feature under the edit task bar and select the ERZ/intersect_line feature class. Select and delete nodules that double back across the same transect. Stop and save edits.
74. Open tool and browse to ERZ, line and transect line canvas for the transect input features. Output type is POINTS. Save the output feature class as ERZ_trncnt_points.
75. Open tool and browse to ERZ_intersect_points as input file and add X and Y coordinates. Name the new fields intersect_x and intersect_y respectively.
76. Open tool and browse to ERZ_intersect_points as input file and as the intersect input features. Output type is POINTS. Save the output feature class as ERZ_intersect_points.
77. Add ERZ/D shapefile to ArcMap. Open command from tool bar and select ERZ/D as the layer file. Select features where Z = 0 (50m or 60 m for the MRZD and IZD respectively), right click on ERZ/D in TOC and hit Data, Export Data. Export all features and use the same coordinate system as the layers source data. Save the output as ERZ/D_points (repeat for IMRZD and IZD shape file).
78. Open tool and select ERZ points as the target feature. Select transact as the feature using a one to one join (CLOSEST). Join only the TransOrder field from transient join. Delete all other fields from transient join. Save output file as ERZ_intersects. Repeat process for IMRZD and IZD.
79. Open tool and browse to ERZ_intersects as the input file and as the output file field (name). Select the receive fields (ERZ_K, ERZ_Y, intersect_x, intersect_y, TransOrder, Azimuth) to export and save output as ERZD_distance.xls. Repeat for IMRZD_intersects and IZD_intersects points.
80. Open ERZD_distancex.xlS in MS Excel and create new field called ERZ/2D. Insert formula to calculate ERZ/2D and copy down all rows (refer to Formulas tab for formula). Make sure the TransOrder field name does not have any suffix (i.e. If it does change it back to TransOrder). Repeat for IMRZD_distance.xls and IZD_distance.xls, note the name of the new fields will be MRZD and IZD respectively.
81. Open tool and browse to ERZD_model attributes.xlx. Add the following fields: K_adjusted, ERZ/2D, ERZ/2Y, MRZ/2D, MRZ/2Y, IZD/2D and IZD/2Y. Insert formula to calculate K/adjusted, ERZ/2D, ERZ/2Y, MRZ/2D, MRZ/2Y, IZD/2D and IZD/2Y fields and save (refer to Formulas tab for formula).
82. Insert formula into the three ERZ_X and ERZ_Y fields to convert the ERZ/ERZD and ERZ/2D fields (distance in X and Y coordinates and save (refer to Formulas tab for formula).
83. Open tool and browse to ERZ_model attributes.xlx. Add the following fields: ERZ/2D and ERZ/2Y fields to coordinates and name the event layer ERZ/2D. Repeat process using IZD/2D and IZD/2Y as coordinates and name the event layer IZD/2D.
84. Open tool and browse to ERZD_model attributes.xlx. Add the following fields: ERZ/2D and ERZ/2Y fields to coordinates and name the event layer ERZ/2D. Repeat process using IZD/2D and IZD/2Y as coordinates and name the event layer IZD/2D.
85. Right click on the ERZ_distancex.xlS in TOC and hit Data, Export Data. Export all features and use the same coordinate system as the layers source data. Save the output as ERZD_model join.
86. Open tool and browse to ERZD_model attributes.xlx. Add the following fields: ERZ/2D and ERZ/2Y fields to coordinates and name the event layer ERZ/2D. Repeat process using IZD/2D and IZD/2Y as coordinates and name the event layer IZD/2D.
87. Right click on the ERZ/2D_model event layer in TOC and hit Data, Export Data. Export all features and use the same coordinate system as the layers source data. Save the output as ERZ/2D_model join.
88. Open tool and browse to ERZD_model attributes.xlx. Add the following fields: ERZ/2D and ERZ/2Y fields to coordinates and name the event layer ERZ/2D. Repeat process using IZD/2D and IZD/2Y as coordinates and name the event layer IZD/2D.
<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Format</th>
<th>Shape</th>
<th>File name</th>
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<td>0</td>
<td>Transect joined with dune crest elev (X, Y) field</td>
<td>shp file</td>
<td>polyline</td>
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<td>transect_join2</td>
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<td>transect_join3</td>
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<td>Transect joined with X &lt; 5, S, and dune toe intersect fields</td>
<td>shp file</td>
<td>polyline</td>
<td>transect_model</td>
</tr>
<tr>
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<td>Transect update version 3</td>
<td>shp file</td>
<td>polyline</td>
<td>transect_model</td>
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<td>Dune stability XYZ files required to calculate D</td>
<td>shp file</td>
<td>point</td>
<td>IMR_D</td>
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<td>Dune stability XYZ files required to calculate D</td>
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<td>Dune stability XYZ files required to calculate D</td>
<td>shp file</td>
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<td>IRZ_D</td>
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<td>Transect attributes as MS Excel file</td>
<td>xls</td>
<td>Spreadsheet</td>
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<td>IMRZ attributes</td>
<td>xls</td>
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<td>IRZ attributes</td>
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<td>IRZ stability plane in XYZ format</td>
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<td>IRZ2_KZ</td>
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<td>xls</td>
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<td>IRZ stability plane in XYZ format</td>
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<td>Spreadsheet</td>
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<td>DTM</td>
<td>TIN</td>
<td>TIN_IKZ_D</td>
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<td>TIN of dune stability slope (for the MKZ)</td>
<td>DTM</td>
<td>TIN</td>
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<td>TIN</td>
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<td>Point file of the three risk zone distances from the dune toe</td>
<td>shp file</td>
<td>point</td>
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<td>Polyline of intersect between two TINs</td>
<td>shp file</td>
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<td>IRZ_intersect</td>
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<td>Polyline of intersect between TIN, IRZ and TIN_dune</td>
<td>shp file</td>
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<td>Point file of intersect between TIN, IRZ and TIN_dune</td>
<td>shp file</td>
<td>point</td>
<td>IRZ_intersect_points</td>
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<td>NOTE in this section, all file names with IRZ_prefix will actually have three files (i.e. IRZ2_IKZ_D and IRZ2)</td>
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<td>Point file of the intense risk zone from the dune toe</td>
<td>shp file</td>
<td>point</td>
<td>IRZ_points</td>
</tr>
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<td>24</td>
<td>Point file IRZ_points with OBJECTID attribute joined from transect_3D</td>
<td>shp file</td>
<td>point</td>
<td>IRZ_points</td>
</tr>
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<td>25</td>
<td>Combined MS Excel file of IRZ attributes and IRZ_intersect_attributes</td>
<td>xls</td>
<td>Spreadsheet</td>
<td>TIN_distance</td>
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<td>26</td>
<td>transect update version 4</td>
<td>shp file</td>
<td>polyline</td>
<td>transect_model_join</td>
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<td>NOTE in this section, all file names with IRZ2_prefix will actually have three files (i.e. IRZ2_IKZ_D and IRZ2)</td>
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<td>28</td>
<td>Final ERZ</td>
<td>shp file</td>
<td>polyline</td>
<td>CERZ</td>
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<tr>
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<td>Final MKZ</td>
<td>shp file</td>
<td>polyline</td>
<td>ERZ201600</td>
</tr>
<tr>
<td>30</td>
<td>Final LKZ</td>
<td>shp file</td>
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<td>transect_model_join export</td>
<td>dbf</td>
<td>database file</td>
<td>transect_model_attributes</td>
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</tbody>
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Appendix F: Model validation
Notes: Aerial photograph taken in 2003 and provided by TCC.

The graph X axis represents horizontal distance from EBOP benchmark (m). The graph Y axis represents vertical height in metres above Mean Sea Level (MLLW) based on UGMN provided by TCC.

Coastal Erosion Hazard Components:
- S - short term erosion, including safety factor (F)
- R - long term erosion
- D - dune stability
- X50 - erosion due to SLR to 2060
- X100 - erosion due to SLR to 2110

Coastal Erosion Hazard Risk Equations:
- CERZ = (S) F + D
- 2060ERZ = (S) F + X50 + R + D
- 2110ERZ = (S) F + X100 + R + D
MAP LEGEND

- Dune Toe
- EBOP Profile
- Current Erosion Risk Zone
- 2060 Erosion Risk Zone
- 2110 Erosion Risk Zone

Coastal Erosion Hazard Components:

S - short term erosion, including safety factor (F)
R - long term erosion
D - dune stability
X50 - erosion due to SLR to 2060
X100 - erosion due to SLR to 2110

Coastal Erosion Hazard Risk Equations:

CERZ = (S) F + D
2060ERZ = (S) F + X50 + R + D
2110ERZ = (S) F + X100 + R + D

Notes: Aerial photograph taken in 2003 and provided by TCC.
The graph X axis represents horizontal distance from EBOP benchmark (m).
The graph Y axis represents vertical height in metres above MSL (MSL) based on LIDAR provided by TCC.
Coastal Erosion Hazard Components:

- S - short term erosion, including safety factor (F)
- R - long term erosion
- D - dune stability
- X50 - erosion due to SLR to 2060
- X100 - erosion due to SLR to 2110

Coastal Erosion Hazard Risk Equations:

- CERZ = (S) F + D
- 2060ERZ = (S) F + X50 + R + D
- 2110ERZ = (S) F + X100 + R + D
Appendix G

Comparison of hazard line changes at selected locations along the open coast