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Modelling historical and future change of the Washdyke-Opihi shoreline

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Modelling Historical and Future Change of the Washdyke - Opihi Shoreline

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Summary

This report describes the simulation of the historical and near-future evolution of the Washdyke-Opihi shoreline north of Timaru using the numerical model GENESIS. The model was run with a spatial resolution of 500 m and with a time step of 1 day. Rollover of barrier material onto the backshore and abrasion were modelled as negative 'beach fills' that remained constant over the simulation periods. Rollover appears to have been the dominant process causing shoreline retreat over the past half century at least. The barrier from Washdyke to Seaforth appears to serve as a 'quarry' to supply a net northerly littoral drift of about 20,000 m^3/yr. A reasonably acceptable calibration and verification was achieved for the period 1965-87.

Running the model to the year 2040 A.D., with no change of controlling parameters from the present, suggested that a further 220 m of erosion could be expected at Washdyke, with the erosion rate decreasing alongshore to the north. These model predictions agreed well with the empirical predictions of Todd (1989).

By about 2040 A.D., it appears possible that gravel losses to northward littoral drift and abrasion will have exhausted the gravel currently stored in the Washdyke-Seadown barrier. Progressively more frequent barrier breaching, washover events, and hinterland flooding are foreseen up to that time.

Further documentation and research into the rollover process, abrasion, and river gravel supplies is recommended. This is required before the effects of changes in sea-level, wave climate, and river sediment supplies can be reliably investigated.

An increase in easterly wave energy and a decrease in southerly wave energy, in line with the future climate change scenarios adopted by the New Zealand Climate Change Programme, would diminish gravel losses and erosion due to littoral drift along the Washdyke barrier, but would not affect the retreat associated with abrasion and rollover unless there was also a net overall reduction in wave energy. Given the slow rate expected of any climate change, it is unlikely that favourable climate change effects would significantly delay the destruction of the Washdyke barrier much beyond the predicted 50 year time frame.

Contents

1. Introduction

1.1. Study Purpose

This report describes a study that attempts to model future shoreline positions along the Washdyke-Seadown-Opihi coast in South Canterbury (Fig. 1). The first consideration is the change that could be expected given a continuation of historical controls and conditions. The second consideration is after possible climate induced changes to sea level, wave climate, river sediment supply, and sediment transport rates. The study results should assist with coastal resource management planning decisions, particularly by identifying the width of backshore liable to be at hazard from coastal erosion.

The study involved five main tasks:

- formulating a model of the littoral sediment budget of the study shore and compiling data on its various components
- determining the nearshore wave climate using existing wave data and wave refraction
- incorporating the wave and sediment budget data into the GENESIS shoreline model
- calibrating and tuning the GENESIS model to historical shoreline changes
- running the calibrated model to predict the future change over the next 50 years, first assuming no change to the existing controls, then with various changes to these controls (i.e., higher sea-level, changed wave climate, changed supplies of river gravel)

1.2. Acknowledgments

The bathymetry and shoreline data were digitised by Wayne Stiven at the Canterbury Regional Council. Derek Todd, Canterbury Regional Council, provided reference material, beach profile data, and discussion. Graeme Horrell, Canterbury Regional Council, provided the deep water wave time series data.

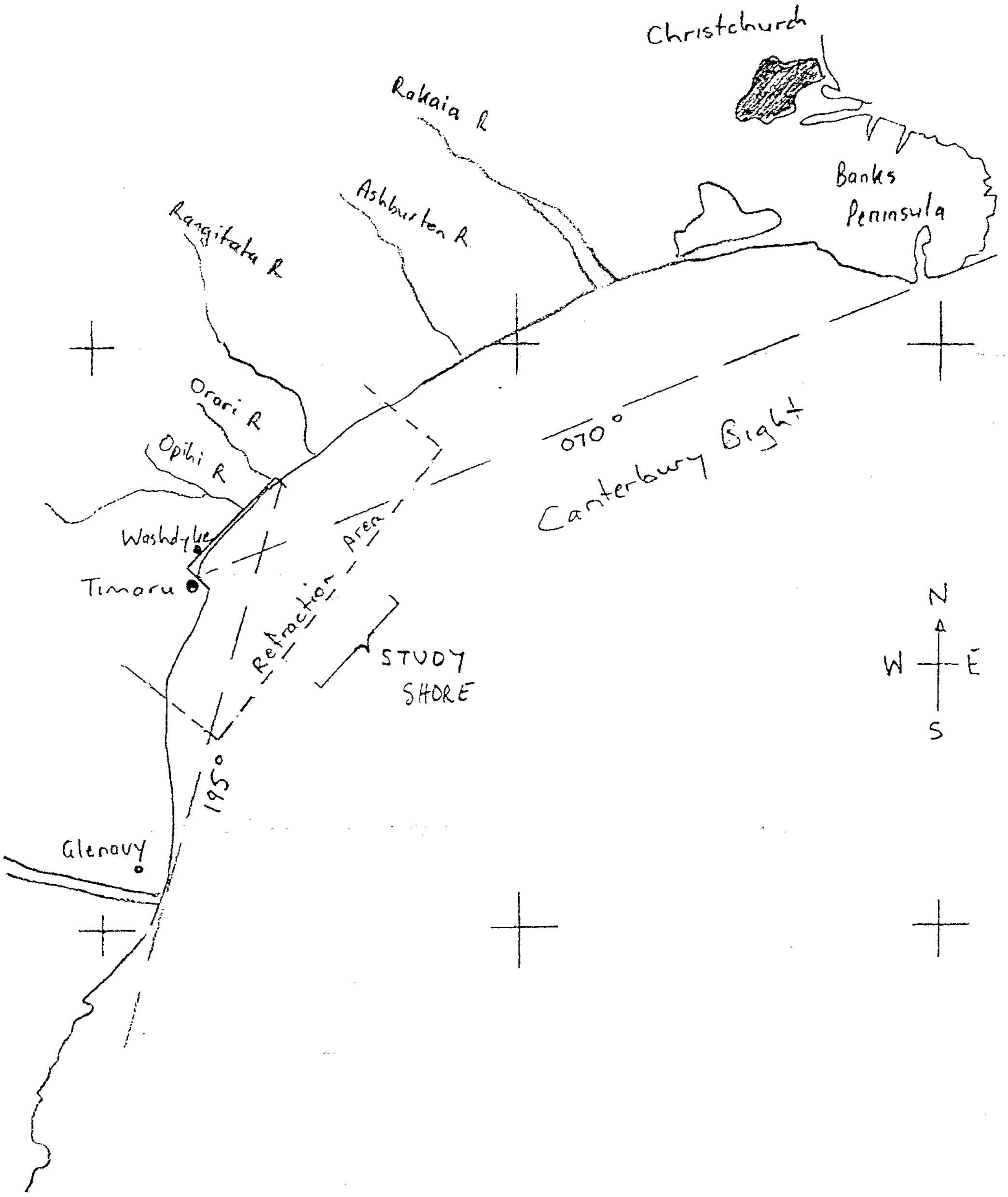


Fig. 1. The study shore, at the southern end of the Canterbury Bight. The shore is exposed to a deep-water wave window from 070° East of North to 195°. RCPWAVE refraction area spans 71 km alongshore.

2. Model formulation

2.1 Historical background on processes and conceptual model

The study coast, spanning approximately 21 km from Washdyke to Orari, is fronted by a sandy-gravel barrier beach. At present, apart from the material stored in the barrier itself, the only significant sources of sediment to this system are the Opihi and Orari Rivers.

Up until the late 1800's when the Timaru Harbour breakwaters immediately to the south were constructed, the study coast was part of a long littoral cell that began at the Waitaki River mouth and extended as far north as Birdlings Flat at Banks Peninsula. Gravel, derived from the rivers and cliff erosion, was moved northwards along this coast by the prevailing southeast swells. However, the Timaru Harbour breakwaters have interrupted this system, trapping or diverting into the dredged entrance channel gravel that would naturally have passed Timaru.

The effect has been that, with no replacement material arriving from the south, the longshore transport capacity of the wave climate has exceeded the gravel supply. This has contributed to the chronic coastal erosion that the coast for some distance to the north of the port has experienced historically. This erosion has been most severe closest to Timaru, first with the disappearance of the Waimataitai Lagoon, then with the rapid retreat of the Washdyke Lagoon barrier, with gradually less erosion further to the north. The history of this erosion is well documented in several studies, for example Benn (1987) and Todd (1989).

As explained in greater detail in a later section, the erosion results from a net loss of beach material from the shoreline, and in this location is due to several processes. The losses include material that is transported out of the system alongshore by littoral drift, material that is lost by abrasion as it is scrubbed to and fro across the beach face by swash, and material that is washed or rolled over into the backshore by storm waves.

As the shore retreats with time, the absolute and relative intensities of these various losses can be expected to change, and they can be expected to interact. For example, the erosion due to littoral drift is expected to be self-limiting in the long term, since it induces a realignment of the shoreline more normal to the direction of wave approach. Also, as abrasion wears down the mean size of the beach material, beach height is expected to decrease and so higher rollover losses to the backshore might be expected, and littoral drift rates may increase, due to the reduced inertia of the finer beach material.

A further complication is that the beach barrier material sits atop a substrate of older fluvial gravels, lagoon, and swamp deposits. Once eroded, only a portion of this material is of barrier material size, and, being older and more weathered, may abrade much faster than the barrier sediment.

In order to model change in such a system, some simplifying assumptions are required. These are incorporated in the following conceptual model summarised in Fig. 2. In this, the change in volume of a unit-length segment of shore derives from losses due to littoral drift, rollover, and abrasion, and gains from rivers and artificially placed beach fill. In this model, while rollover contributes to a shoreline retreat, it also adds to the stock of beach material that can be consumed by the other erosion processes.

To date, studies of the sediment budget of the Washdyke-Seadown area (e.g., Benn, 1987; Todd, 1989) have not explicitly determined the influence of littoral drift on the erosion trend. An important product of this study will be establishing the relative importance of the various processes causing gravel loss to the study shore.

2.3. Applying the Genesis model

2.3.1 What GENESIS is

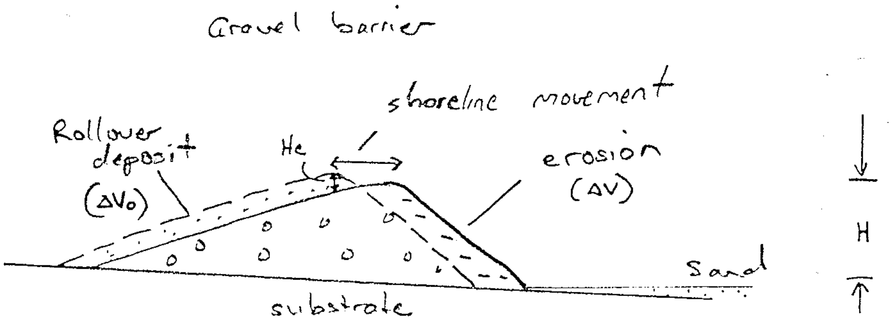
The GENESIS (GENEralised model for SImulating Shoreline change) model used in this study is a "1-line" model for shoreline change caused principally by longshore variations in littoral drift. It was developed by the U.S. Army Corps of Engineers' Coastal Engineering Research Center (CERC) at Vicksburg, Mississippi. A detailed description of GENESIS is given by Hansen and Kraus (1989).

Four basic assumptions underpin the application of such shoreline change models.

- The beach profile shape is constant in time and alongshore.
- The shoreward and seaward elevation limits of the profile are constant.
- The longshore transport is driven by breaking waves.
- The detailed structure of the nearshore circulation can be ignored.

The constant beach profile assumption can be justified by allowing that short-term changes in profile shape associated with storms and recovery periods average-out over time and by the common observation that the profile maintains an average shape that is characteristic for a particular coast (this is also reasonably true along the study shore). With this assumption, the beach profile simply translates, parallel to itself, seaward or landward as the shore accretes or erodes.

The second assumption requires that longshore sediment transport occurs only between the top of the beach and the seaward limit of the active profile - the so called "closure depth". These limits specify the cross-sectional area of beach involved in



$\Delta V_{cell} = G_{in} - G_{out}$: littoral drift

$- \Delta V_o$: rollover

$- \Delta V_a$: abrasion

$+ \Delta V_r$: river sediment

$+ \Delta V_f$: beach fill

Δy (for unit shore length) $= (G_{in} - G_{out}) \cdot H - \Delta V_o \cdot He - \Delta V_a \cdot He + \Delta V_r$

Fig. 2. Conceptual model of sediment budget for a unit length of shore.

the lateral translations. In this study, we will be considering only the nearshore wedge of gravel, not the sandy inner shelf seaward of this wedge.

The third and fourth assumptions require that the longshore sediment transport rate is related only to breaker height and approach angle, and that transport assisted by tide- or wind-driven currents is not included. This is a very reasonable assumption for this study since the longshore transport of gravel is predominantly driven by swash processes.

2.3.2. How it works

The equation governing shoreline change requires conservation of sediment volume, as illustrated in Fig. 3. In this figure, y denotes shoreline position relative to a baseline and x denotes distance alongshore. The shoreline of a unit cell of length Δx and height $D_c + D_b$ (both measured from a vertical datum such as mean sea level), equalling the elevation change from the closure point to the beach crest, translates seaward or landward a distance Δy when a net amount of sand enters or leaves the cell during time Δt. The cell volume change is defined by:

$$\Delta V = (D_b + D_c)\Delta x \Delta y \quad (1)$$

Sediment enters the cell by longshore transport at rate Qx and leaves at rate $(Qx + \partial Qx/\partial x)$.

Material can also enter (or leave) from line or point sources (or sinks) across the offshore and landward boundaries at lineal rates q_o and q_s, respectively. The total volume of sand contributed by these sources (sinks) in time Δt is

$$\Delta V = Qx\, \Delta t - (Qx + \delta Qx/\delta x)\, \Delta t + q_o\, \Delta x \Delta t + qs\, \Delta x \Delta t \quad (2)$$

Equating (1) and (2) and taking the limit as $\Delta t \rightarrow 0$ yields the governing equation for the rate of charge of shoreline position:

$$dy/dt = 1/(Db + Dc) * (qo + qs - \delta Qx/\delta x) \quad (3)$$

This equation is solved by specifying the original shoreline position over the full length of shore to be modelled, the boundary condition at each end, and appropriate values for D_b, D_c, q_o, q_s, and Q_x.

The longshore transport model used by GENESIS is

$$Q_x = (H^2 C_g)_b\, [a_1 \sin 2\, \alpha_b - a_2 \cos \alpha_b\, \delta H/\delta x]_b$$

where H is the wave height

C_g is the wave group speed, given by linear theory

b denotes the wave breaking condition

α_b is the angle of the breaking waves to the shoreline

a_1, a_2 are empirical coefficients that determine the transport efficiency, and are treated as calibration parameters to match the model runs with prototype test cases.

While this transport model is largely used on sand beach systems, it is quite applicable to gravel beaches. This is because the coefficients a_1 and a_2 determine the transport efficiency, and they can simply be tuned down for gravel systems. a_1 determines how effective the obliquely-incident wave thrust is at driving longshore transport. a_2 determines the effectiveness of longshore currents driven by longshore gradients in wave height. Since the sediment transport on the study beach is driven mainly by swash action, not by a longshore current, a_2 was set to zero.

Input data on waves for GENESIS requires a time-series of wave heights, periods and directions. The time series can be of any length; the program reads one series value at each time step and, if necessary, loops back to the start - thus a short representative period of wave data, even a single value, can be used repeatedly for a much longer simulation period. In this study, a 10-year record of daily values was used.

GENESIS has an internal wave transformation sub-model that handles shoaling, refraction and diffraction. This is used where the nearshore bathymetry is simple, with nearly straight shore-parallel contours. Where the bathymetry is irregular (which is the case with the Timaru headland), the wave data must first be transformed from deep water starting points to a nearshore reference line using an external refraction model (for this we use RCPWAVE). From this line, the GENESIS's internal model brings the waves to breaking.

2.3.3. Boundary Conditions

The boundary conditions that must be specified include those at either end of the modelled reach of shoreline, external losses or gains of beach material within the modelled reach, and any fixed,

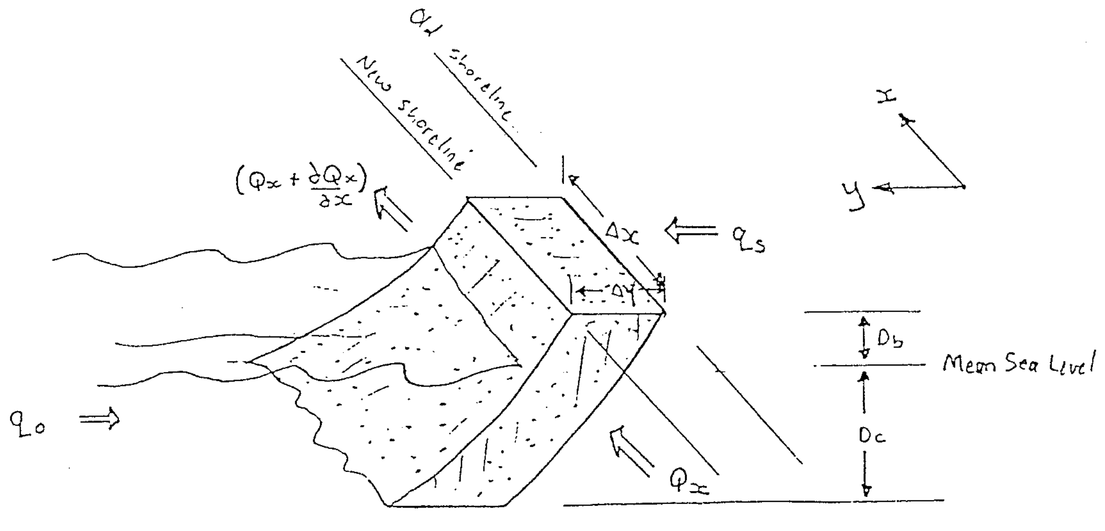


Fig. 3: Definition diagram for a 1-line shoreline evolution model such as GENESIS.

hard structures, such as seawalls and groynes.

The ends of the modelled shoreline can either be "pinned", where there is no advance or retreat of the model end-cells, or "gated", where transport into and out of the modelled reach is constrained by a structure such as a long jetty. In GENESIS, all external losses or gains of material across the shoreline must be treated as beach fills. Thus we treat regular injections of river gravel as ongoing beach fills located about the river mouths, and beach material losses associated with "rollover" and abrasion are simulated as "negative" beach fills. A limitation of GENESIS is that these external sediment sources and sinks must be specified in the model's setup file, and can only be applied uniformly over spans of cells and for given periods of time. Thus the facility to have them vary alongshore and with time is limited and empirical.

This limitation becomes important where these sediment sources/sinks are significant components of the littoral sediment budget and they respond dynamically to variables that may or may not be incorporated in the model. For example, the rollover process appears to be related to the size of the beach material, the nature of the backshore, and the wave energy, yet there is no representation of these relationships in the model. As discussed in section 4.3, this simple treatment of the rollover and abrasion processes does impose a significant limitation on the GENESIS model results when it is used to predict the future changes along the Washdyke shore.

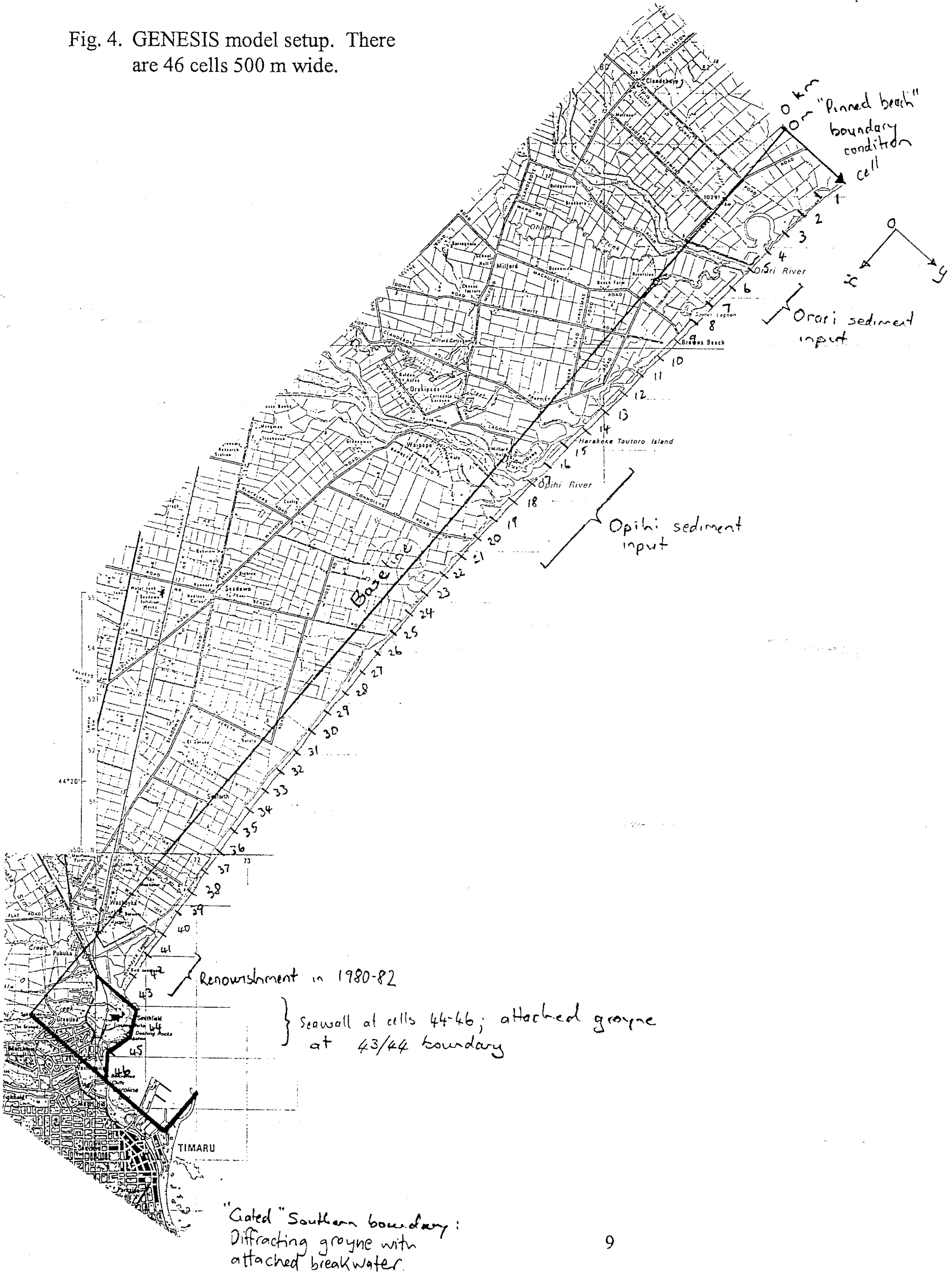
2.3.4 Model setup for study shore

The modelled reach of shoreline extends 23 km from Caroline Bay to 2.5 km north of the Orari River mouth. There is a closed "gate" at the southern boundary (i.e. no gravel bypassing Timaru Harbour), and a "pinned" boundary at the northern end, at the beginning of the cliffed portion of coast north of the Orari River mouth. Although repeated historical shoreline fixes were only available for the shore between Smithfield Head and the Opihi River mouth, it was considered necessary to extend the model past the Orari mouth in order to achieve a "far-field" pinned boundary. Thus while the predictions of the model north from the Opihi mouth are un-calibrated and should not be used for planning purposes, they are there to improve the predictions south of the mouth.

This shore span was represented by 46 cells at 500 m spacings along a baseline that followed the average shoreline trend of 40 degrees east of north (Fig. 4). The model was run with a time step of 24 hours. The calibration runs, from historical shoreline fixes, ranged from 10 to 53 years. The future simulations were for 53 years, from 1987 to 2040.

Some simplifications were required to model the hard shore and port structures at the south end of the model reach (Fig. 4). The rocky shore between Smithfield and Bienvenue Cliffs was represented by a "crinkly" seawall. The port was represented by

Fig. 4. GENESIS model setup. There are 46 cells 500 m wide.



a combination of a diffracting jetty and an offshore breakwater at the southern boundary of the modelled reach. This combination essentially formed an inverted "L" breakwater which prevented any littoral drift from the south from entering the modelled reach.

On initial calibration runs, the Opihi River sediment input was represented by a "beach fill" distributed evenly over 5 model cells, centred about the river mouth, while the Orari input was distributed over 3 cells. As explained further in the calibration section, uncertainties with the river sediment inputs led to them being ignored during later runs. An actual beach fill of 29,000 m^3 was added to cells 41 and 42 (along the Washdyke segment) between 1980 and 1982. This fill material was gravel extracted from the Opihi River bed (Kirk and Weaver, 1985; Benn, 1987).

Abrasion was modelled as a negative beach fill that was uniform alongshore and continuous in time. Rollover was also modelled as a negative beach fill continuous in time, but was varied alongshore. For this, the study shore was divided into 5 sub-reaches, each with a constant rollover rate. This pattern resulted in no rollover at the hard shore south of Smithfield, then decreasing rollover rates from the Washdyke shore north. The rollover rates used are detailed in section 3.6. As discussed in the previous section, this approach is a simplification over the real situation where the rollover rate does not vary alongshore in such discrete jumps and probably also varies with time. The alongshore variation is not considered too important since the model tends to smooth out discontinuities between cells. However, variation in rollover rates with time, particularly into the future, does appear to be an important factor that cannot be accomodated by the model. The implications of this are discussed in section 4.6.

3. Input data

The GENESIS model requires input data on the wave climate, beach profile characteristics, beach material size, historical shoreline positions, and beach sediment budgets (including gravel gains from rivers and renourishment and losses to abrasion and barrier rollover).

3.1 Waves

Much of the time and effort required to run a model such as GENESIS is consumed in providing information on nearshore waves along the length of the study reach. This requires a number of steps, beginning with defining a "deep water" wave climate, processing bathymetric data for refracting this climate towards the shore, performing the refraction analysis itself, then interfacing the results from the refraction analysis with GENESIS.

3.1.1 Deep Water Wave Climate

The deep water wave climate used in this study was derived from Horrell's (1992) compilation of ship observation data over the period 1970-1991. This was drawn on a preferential basis, first from observations made in the Canterbury region, then, if no observations were made in the Canterbury region, from observations in the Dunedin or Wellington regions. Horrell's dataset provides noon values of the significant height, period, and direction of the dominant wave condition on each day.

Inspection of the frequency-of-occurrence of waves by direction, period, and height bands for the 1970's and 1980's showed quite similar patterns for these two decades. Based on this, the 10 years of data through the 1970's was assumed to be representative of the deep water wave climate for the study area, and was cycled through the GENESIS model.

The study shore is exposed to deep water waves through a window spanned by 070 degrees east of north to 195 degrees east of north (Fig. 1). To speed computations, deep water waves from outside this window were removed from the wave data series. This reduced dataset was then grouped into 31 individual period-direction cases, with each case then being refracted shoreward.

3.1.2. Bathymetry

Data on the bathymetry of the Canterbury Bight, from opposite the Rakaia mouth in the north to opposite Glenavy in the south and offshore to the 100 m depth contour, were digitised from the Ellesmere and Approaches to Timaru bathymetry charts. The data were captured into the ARCINFO Geographic Information System both from spot soundings and from bathymetric contours on these charts by Canterbury Regional Council staff. "Mirror image" on-land topography was added to the dataset to ensure that the digital terrain model correctly reproduced the nearshore bathymetry. The bathymetry data were first exported from ARCINFO as ASCII files, converted to easting-northing-elevation files (the eastings and northings being in terms of the New Zealand Map Grid projection), then transformed to a local coordinate system aligned with the regional trend of the study shoreline (40 degrees east of north).

The digital terrain modelling software package SURFER for WINDOWS was used to create the uniformly spaced grid of sea-bed elevation values required by the wave refraction program RCPWAVE. The grid created by SURFER included 56 cells at 500 m spacings in the offshore direction and 71 cells at 1000 m spacings in the longshore direction. The area covered by this grid is shown in Fig. 1. Its offshore boundary approximately coincides with the 40 m bathymetry contour, which is the depth at which significant refraction effects commence for 10 second waves (equal to 0.25 of the deep-water wavelength). The 23 km long GENESIS modelling shoreline is centrally located within the wave refraction area. There was one wave refraction cell for every two GENESIS cells.

3.1.3. Wave Refraction

Three stages of wave refraction were involved before the deep water wave data could be used in the shoreline model. The first stage involved using a relatively simple "Snell's law type" model to transform the 31 wave cases from deep water into a depth of 40m (coinciding with the seaward margin of the RCPWAVE grid discussed above). This type of model was acceptable given that the bathymetry seaward of 40 m is relatively gently sloping and with reasonably parallel contours.

The next stage was using the RCPWAVE program to refract the 31 wave cases from the 40 m line shoreward to the "nearshore reference line", which, for this study, ran parallel to the study shore at a depth of 10 m (this is the approximate depth at the tip of the southern breakwater at Timaru Harbour). RCPWAVE employs linear wave theory in a numerical model that covers both refraction and bottom-induced diffraction. It solves the wave field over a rectangular grid area using a finite-difference approach rather than by tracking individual wave rays (Ebersole, et al., 1986).

The third stage of wave refraction is performed by the GENESIS program itself. For each cell of the model shoreline, GENESIS first scales the wave heights at the nearshore reference line according to the deep water height, then refracts (and diffracts) the waves from the nearshore reference line shoreward until they break.

3.2. Shorelines

Historical "fixes" of the study shoreline between Smithfield and the Opihi Mouth are available for 1881, 1934, 1956, 1965, 1977, and 1987. These were supplied in digital form in terms of the NZ Metric Coordinate System by Canterbury Regional Council. The 1881 fix was based on cadastral surveys, while the later fixes were from aerial photography. Greater detail on these surveys is given in Todd (1989). Repeat surveys of the shores between the Port of Timaru and Smithfield and from north of the Opihi mouth were not available. In order to place the GENESIS model's northern boundary in the "far field", the historical positions of the shoreline from the Opihi mouth north as far as the onset of the cliffed portion of the coast were estimated from the 1987 shoreline and the average historical erosion rates reported by Benn (1987b) for the 1866-1985 period. It was assumed that the historical erosion rate was steady at the average rate. Linear interpolation was used to fix the shoreline positions between Benn's measurement points. Benn's historical erosion data is given in the table below.

Point	**Period**	**Erosion rate (m/year)**
Prattley Road	1866-1985	1.70
Whites Road	1866-1985	1.20
Ohopi Creek	1866-1985	0.73
Canal Road	1866-1985	1.25
Parkes Frontage	1866-1985	0.49
Rangitata Huts Rd	1866-1985	0.25

The shorelines were transformed to the local, shore-parallel coordinate system required by GENESIS and the wave refraction analysis, then the shoreline positions at the centres of each 500-m long GENESIS grid cell were interpolated. Finally, a 5-point running-mean function was used to smooth the beach portions of the shorelines. These historical shorelines are shown in Fig. 5.

3.3. River sediment supplies

The only significant sources of fresh beach material to the study shore are the gravel-bedded Opihi and Orari Rivers. The impact of these rivers on the study shoreline is apparent in a distorted scale map, which shows delta features at each river mouth (Fig. 6). The larger Opihi delta appears to be skewed to the north, suggesting mainly northward dispersion of the Opihi sediment by longshore transport.

No direct measurements of the bed material yields of these two rivers to the coast are available, nor does there appear to be adequate hydraulic and flow data available to calculate this.

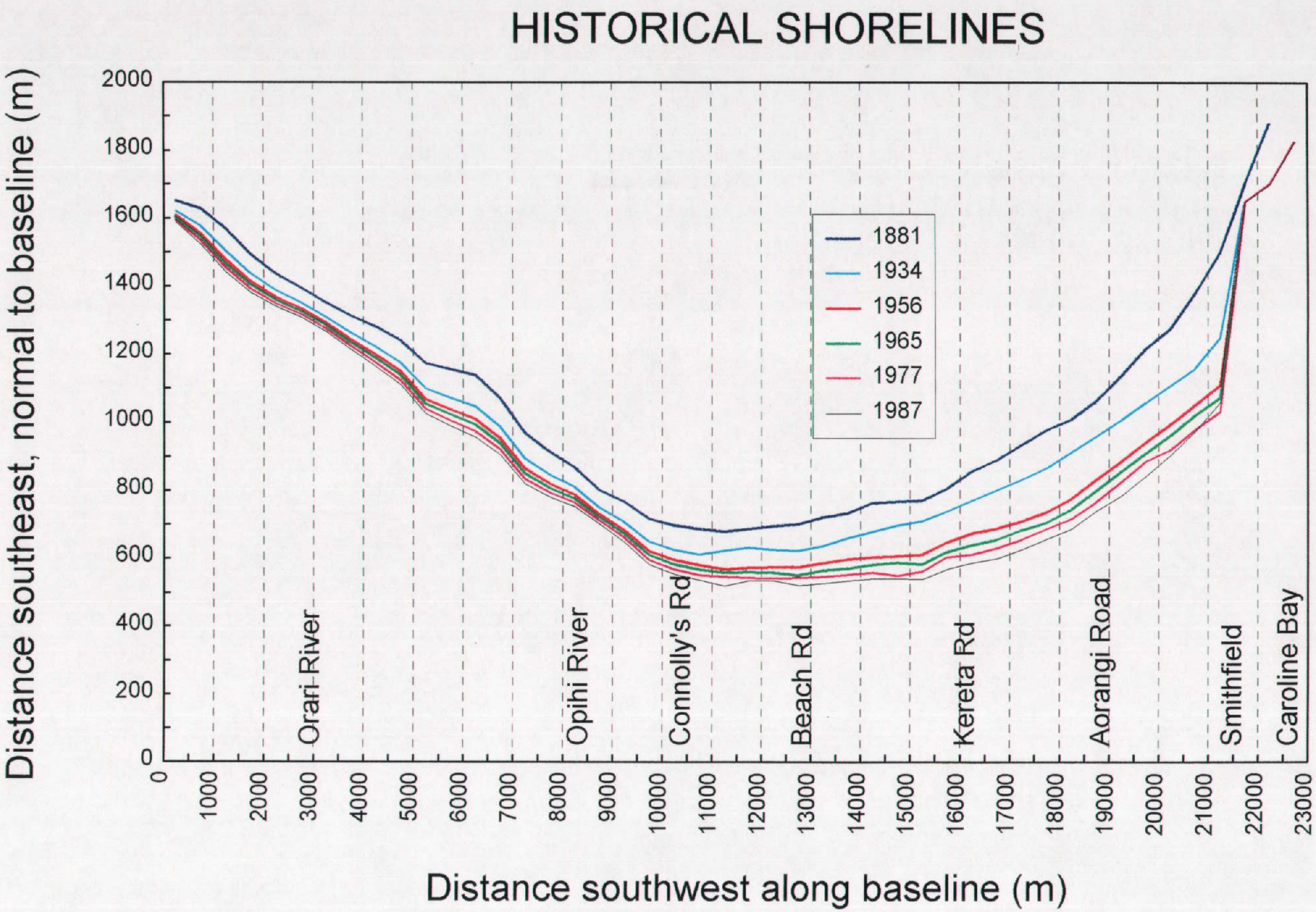


Fig. 5. Historical positions of the study shoreline. Positions from 0 to 9500 m along the baseline prior to 1987 are estimated only. Note the exaggerated scale.

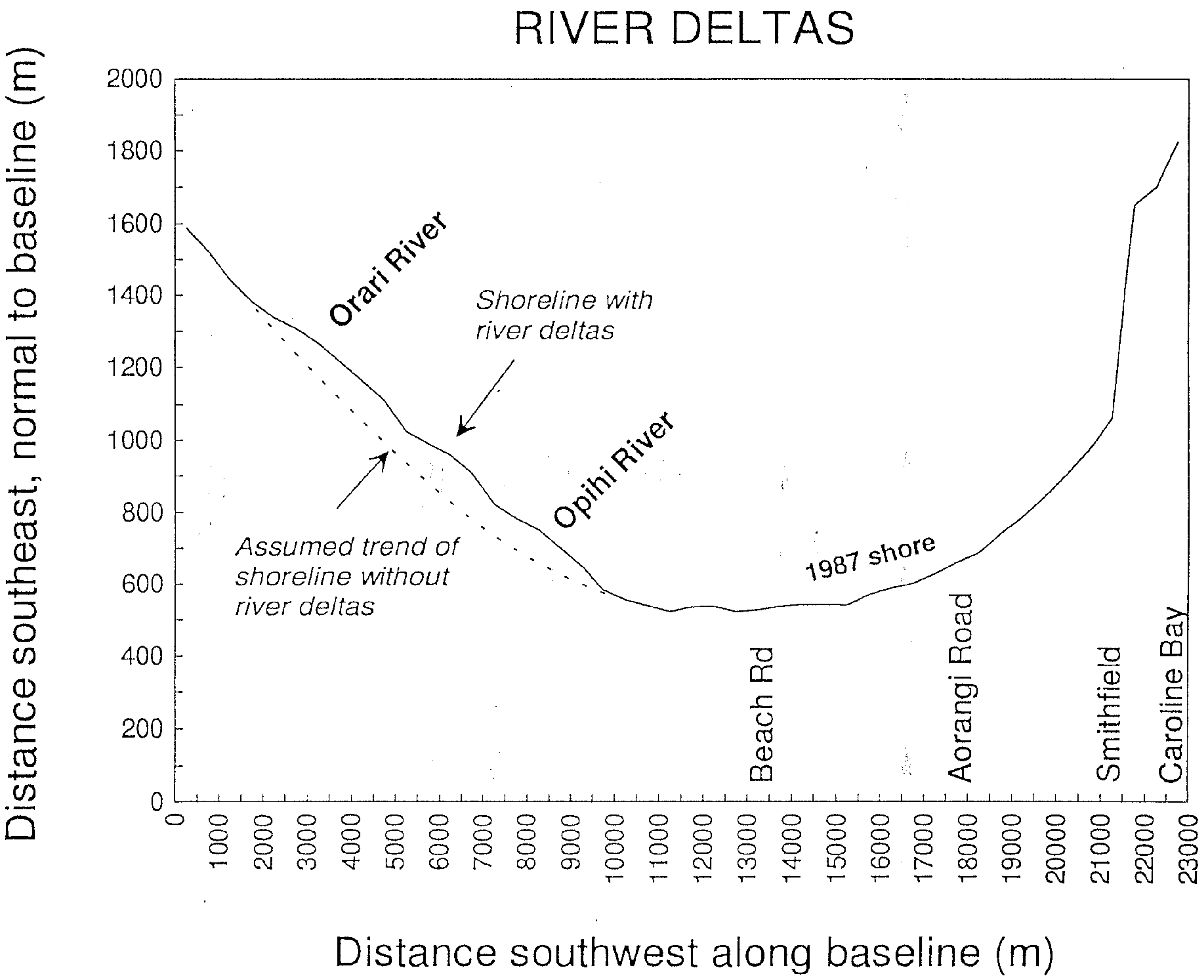


Fig. 6. Signature of Opihi and Orari River deltas on shoreline. Norhward skew of Opihi delta suggests predominantly northward drift of Opihi sediment.

Gibb and Adams (1982) crudely estimated bedload yields of 37,000 m^3/year from the Opihi and 15,000 m^3/year from the Orari, based on Adams' use of the Einstein-Brown bedload formula with mean flow rates. Griffiths and Glasby (1985) arrived at similar estimates (40,000 m^3/year from the Opihi and 11,000 m^3/year from the Orari) by assuming the bedload yields as being 3% of the suspended loads which they estimated from an empirical regional suspended sediment yield equation.

The Gibb and Adams estimates were used initially in this study. The annual yields of river sediment (Q_{rs} in m^3/yr) were converted into equivalent widths of "beach fill" (Δy in m/yr) using the formula:

$$\Delta y = Q_{rs} / (\Delta x * n * H) \qquad (6)$$

where Δx is the length of a GENESIS cell (500 m)

n is the number of GENESIS cells over which the river gravel was assumed to be dispersed

H is the height of the beach profile (this was assumed equal to 6.5 m - see the following section for further details).

As discussed in section 4, during the model calibration runs excessive accretion occurred around the river mouths. This suggested that the above river yield figures are too high, since the littoral drift potential could not cope with the supply of material. Possibly only a portion of the river bedload is of beach material size. However, there is also considerable uncertainty regarding the processes by which river bedload is introduced to and dispersed into the beach system. These processes may well be oversimplified by the GENESIS model.

In the end, given the uncertainties in the river yields and river-beach mixing processes, there being no data on historical shorelines north of the Opihi mouth, and the predominance of northerly littoral transport, river sediment inputs were ignored in the model.

3.4 Beach material and profile

GENESIS requires a beach profile height in order to convert volume changes into shoreline shifts. A height of 6.5 m between the beach crest and the toe of the wedge of gravelly barrier material was assumed, based on beach profiles from the Washdyke-Seadown shore plotted by Benn (1987). This height was assumed to be uniform along the study shore. Although this is not strictly so, the assumption is reasonable.

Benn's (1987) study showed that, apart from the south end of the Washdyke segment, the beach barrier is not uniformly composed of modern beach material. Instead, it comprises a relatively thin wedge of sandy gravel overlying an older substrate of peaty-gravelly sediments of fluvial-swamp-lagoonal origin. Benn's measurements showed that the profile-averaged thickness of the modern beach material varied from about 1.8 m at Washdyke to 1.2 m at Seadown. An overall average thickness of 1.6 m was assumed for this study.

There is uncertainty over the amount of beach material that should be 'released' as the study shore retreats. Benn's map of the hinterland substrate material shows that it is composed predominantly of gravel for approximately 500 m inland from the present coastline, but the abrasion resistance of this weathered material is thought to be significantly less than that of the modern beach material. For this study, the conservative assumption was made that no beach material is yielded from the substrate during shoreline retreat.

An average grainsize of the beach material was taken to be 5 mm (2.33 phi). This figure was derived by Benn (1987) from samples collected in 1986 from the Washdyke-Seadown barrier. Benn suggests that the mean grainsize had decreased since 1978, but there is debate as to how much. Certainly, some fining should be expected as abrasion wears down the stock of gravel with little replenishment. Given the uncertainty, a constant grainsize with time was assumed for all model runs.

3.5 Abrasion

The loss rate of beach material due to abrasion is not known with any great confidence. Gibb and Adams (1982) fitted Sternberg's empirical abrasion model

$$\text{Final weight/ initial weight} = \exp(-3\alpha_0 * x)$$

where α_0 is the abrasion coefficient (units 1/km) and x is the distance travelled alongshore (km), to beach material size data along the Canterbury Bight. From this they derived an α_0 value of 0.024/km. Adams' earlier tumbler tests with greywacke cobbles had produced an α_0 value of 0.0009/km. Adams and Gibb argued that the larger field value was due to the gravel travelling much greater distances up and down the beach face with swash in the course of its net drift alongshore.

For this study, the question is: what proportion of the active layer of beach material is lost to abrasion each year? This can be estimated from the Sternberg equation using Gibb and Adams' α_0 value of 0.024/km, assuming that the gravel travels alongshore 1.4 km/year, and that the active volume of gravel is approximately 8.4 m^3 per m length of beach. The 1.4 km/yr travel distance is based on Neale's (1987) observations of gravel slugs moving along the coast south of Timaru. The active volume of gravel was averaged from Kirk's (1987) observations of the range of short-term beach profile changes at Washdyke and Seadown. These figures suggest a volume loss rate of approximately 10% of the active beach material per year, which equates to approximately 0.84 m^3/m of beach per year[1].

This volumetric loss rate was converted to an equivalent retreat rate by dividing by the average depth of the beach gravel layer (1.6 m, as discussed above).

3.6 Rollover

Beach profile surveys show clearly that the retreat of the Washdyke-Seadown barrier is partly due to beach material being washed over into the backshore by storm waves (termed 'rollover'). Backshore accretion volumes were determined from profiles surveyed in 1977 and again in 1994 at 21 sites between Smithfield and the Opihi mouth. The average volumetric rollover rates indicated by these figures are plotted in Fig. 7. This shows a trend for rollover rates to increase south towards Smithfield, but with considerable local scatter. The regression equation for the trend is

$$V_0 = 1.5 + 0.18\ x$$

where V_0 is the rollover rate in $m^3/m/yr$ and x is the distance south from the Opihi River in km. $R^2 = 0.21$ for this regression model, which is significant at the 5% level.

The trend for increasing rollover to the south appears to be related to an overall decrease in grainsize and barrier height in that direction (Kirk, 1987, has shown that barrier height decreases as grainsize decreases) and the nature of the backshore. The Washdyke barrier is backed by lagoon and low-lying land, whereas the Seadown barrier is backed by a hinterland that gradually rises to the north.

A series of discontinuous, offset floodbanks in the backshore appears to contribute to the longshore variation in the rollover rates. The shoreline retreat appears to locally and temporarily stall when these are encountered: the barrier material tends to pile up and steepen against these, the retreat stalls while the toe is gradually undermined, then, after the stopbank has failed, the retreat progresses again (D. Todd, pers. comm.). As far as these stopbanks affect the model, it has been assumed that their effects are local and temporary - over the order of a few to 10 years - and they can be ignored for longer term changes.

The volumetric loss rate due to rollover was converted to an equivalent retreat rate by dividing by the 1.6 m average depth of

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[1] For the 12.5 km of barrier north from Smithfield, this equates to a total loss of approximately 10,000 m^3/yr of active beach gravels. This is an order of magnitude less than the abrasion loss determined by Benn (1987) for this shore - Benn appears to have assumed that all of the gravel on the barrier was subject to abrasion processes each year, not just that in the active zone.

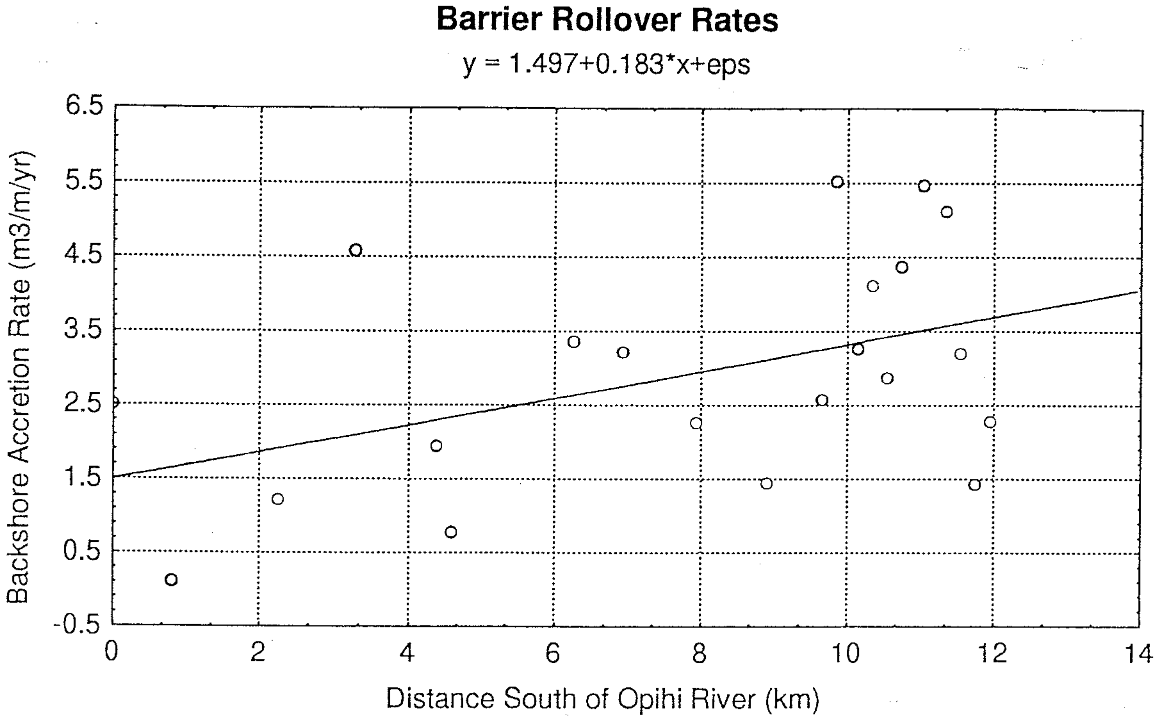
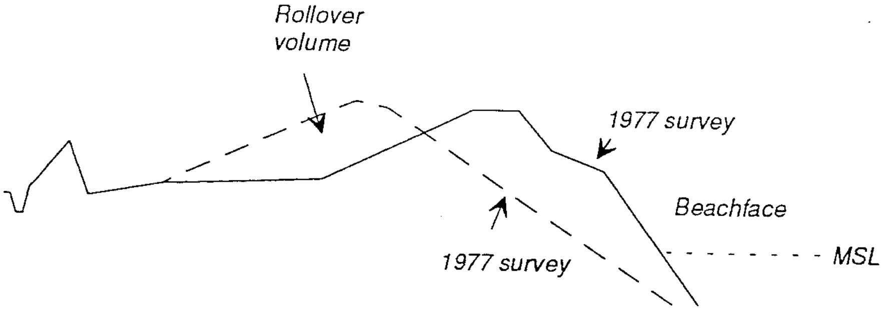


Fig. 7. Longshore variation in rate of backshore accretion due to rollover of barrier material by storm waves: Opihi River mouth to Smithfield. Sketch below shows how rollover volumes were determined from beach-backshore profiles.



the beach gravel layer. For practical incorporation in the GENESIS model, rollover rates were assumed uniform along six segments of the study shore:

Segment	Rollover m^3/m/yr	rates m/yr
Cells 1-8 (North end - Spider Lagoon)	0.6	0.4
Cells 9-19 (Spider Lagoon - Opihi mouth)	1.3	0.8
Cells 20-31 (Opihi mouth - Kerata Rd)	1.8	1.1
Cells 32-38 (Kerata Rd - Aorangi Rd)	2.6	1.6
Cells 39-43 (Aorangi Rd - Smithfield)	3.6	2.2
Cells 44-46 (Smithfield - South end)	0.0	0.0.

The actual rollover data were used for the shore south of the Opihi mouth. To the north, the rollover rates were estimated by subtracting a loss to abrasion of 0.84 m^3/m/yr (equivalent to 0.52 m/yr retreat) from Benn's (1987b) historical erosion rate data. This approach assumes that the historical retreat on this reach of shore was due only to abrasion and rollover.

The total rate of rollover to the backshore, accumulated along the 12.5 km reach of Washdyke-Seadown shore, was 29,500 m^3/yr.

3.7 Longshore transport coefficient and rates

An initial value of 0.0084 was assumed for the longshore transport efficiency factor K_1 in the GENESIS model (K_1 is directly proportional to the a_1 coefficient described in section 2.3.2). This was based on Neale's (1987) value of the transport efficiency factor (after unit conversion) which he derived from measurements of wave conditions and foreshore accretion at South Beach, immediately south of the Port of Timaru, over a 4-month period. When used in the GENESIS model with the refracted wave data, this indicated a net northwards littoral drift potential of about 20,000 m^3/yr for the study shore. This net drift was the balance of 22,000 m^3/yr to the north and a lesser counterdrift to the south of 2,500 m^3/yr. Although this net drift value is less than the approximately 50-60,000 m^3/yr estimated at South Beach (e.g. Kirk, 1987; Neale, 1987), the study shore is somewhat more sheltered from southerly weather.

Fig. 8 shows a typical time-averaged pattern of net littoral drift rates along the study shore, as computed by GENESIS. The main divergence in the littoral drift rate occurs between Smithfield and Seaforth Road (GENESIS cells 43 - 35). This length of beach is essentially the "quarry" from where littoral drift is mined by the mainly southerly waves until the 20,000 m^3/yr potential is met. The relative decrease in the northerly

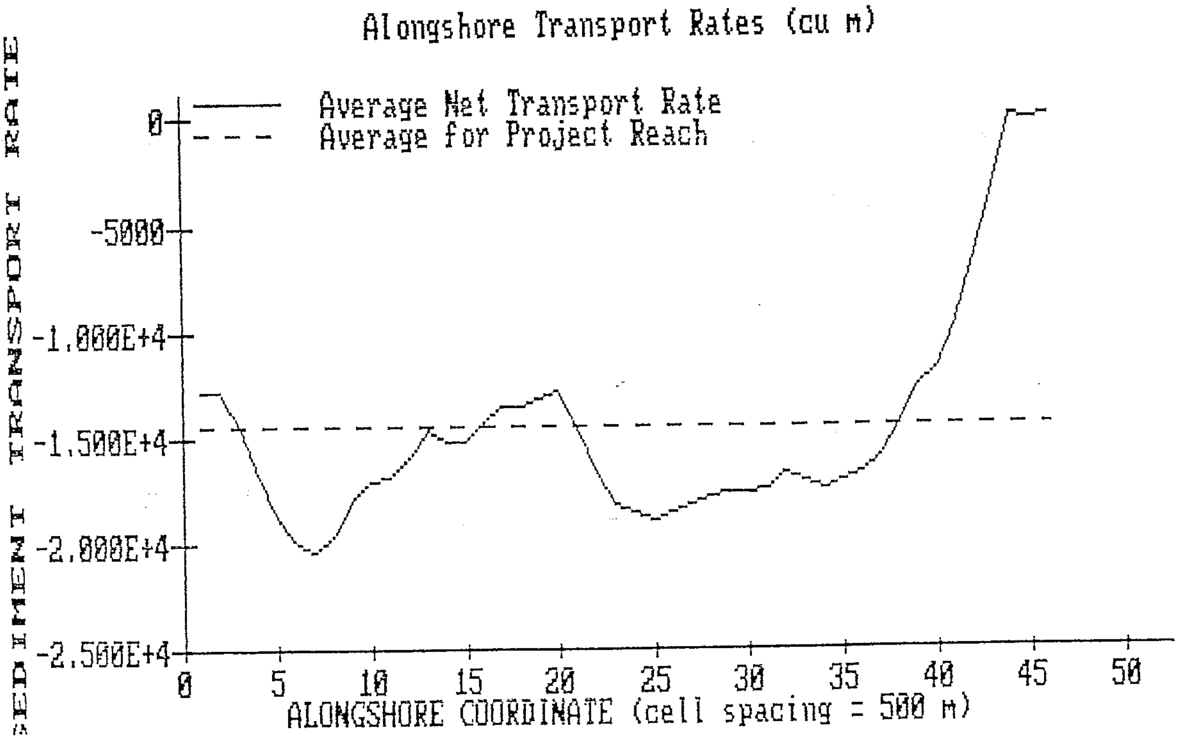


Fig. 8. Average nett littoral drift rates along the study shore during the 1965-77 calibration run. The alongshore coordinate is in terms of the model cell number. The model cells are located on Fig. 4. Northwards drift is negative.

drift rate on the south side of the Opihi mouth, and the relative increase on its north side, reflect the subtle, delta-like changes in shore alignment about the Opihi mouth (as shown in Fig. 6).

3.8 Sediment budget

A gravel budget was estimated in order to check the reliability of the above figures. A budget was possible for the shore between Smithfield and the Opihi mouth (i.e, where there is reasonably good data on beach profile and gravel storage changes.

For this 12.5 km reach, the gravel losses are:

Abrasion	10,000 m^3/yr
Net longshore transport to north	20,000 m^3/yr
Total	30,000 m^3/yr

Assuming zero gains for this shore from the Opihi River and ignoring relatively small injections of beach fill, the net change in gravel storage for this control cell is approximately 30,000 m^3/yr.

This figure compares very closely with the gravel loss rate of 31,000 m^3/yr estimated for this shore for the period 1977-87 by Benn (1987) using an independent method. Benn directly measured a 284,000 m^3 net decrease in gravel storage from profile data. Allowing for an injection of 29,000 m^3 of beach fill during the early 1980's, the total gravel loss over 1977-87 was 313,000 m^3/yr.

Gravel rollover to the backshore is not included as a loss in this budget since the material is still available for littoral drift. That the rollover rates match the loss rates suggests that, overall for this shore reach, the rollover process will ensure an ongoing supply of backshore material to be fed to littoral drift and abrasion. This is so even along the shore between Smithfield and Seaforth Road, which is the main "quarry" for the littoral drift (see previous section). The rollover rate along this 3.5 km length of shore is 15,000 m^3/yr, which is very close to the modelled littoral drift potential at Seaforth Road.

The above budget differs from one calculated by Benn (1987) for the same length of shore. The differences lie substantially in the losses due to abrasion and littoral drift. Benn estimated much higher abrasion losses (25,000 m^3/yr) and a very small net northerly littoral drift (6,000 m^3/yr). Benn's littoral drift value was not estimated directly but was determined from the residual of the other budget components; consequently, it accumulated any errors in the other terms.

4. Calibration and verification

4.1 Approach

The general approach adopted in the calibration runs was to test the model with the initial calibration values described above, then to tune these values as necessary to obtain the best match of modelled to measured shoreline changes. With 6 repeat shoreline fixes, there was an abundance of choice over which period would serve best for calibrating. In the end, it was decided that the 1965-77 period would be used to establish the calibration, the 1977-87 period would provide the principal verification, while the earlier periods would check the verification.

The 1965-87 period was favoured because it was the most recent, the shoreline fixes were more likely to be reliable, the wave data covered much of this period, and the beach morphology and rollover data pertained to this period. As the modelling proceeded, it became clear that the rollover process was a major factor in determining the shoreline shifts. Since the rollover intensity may very well be following a time trend, this provided another reason for using the more recent shorelines for calibration and verification.

4.2 Runs

1965-77

The most satisfactory modelling of the shoreline changes for the period 1965-77 resulted from use of the initial input data detailed in the previous section, except for the river sediment inputs. With river inputs, the model predicted significant shoreline accretion (up to about 40 m) near the river mouths, which has not been historically observed. Without any river inputs, the model performed much better overall.

There are several factors that justify ignoring the river yields: the model probably does not do a good job of modelling the dispersion of river material, which is not well understood in the first place; the river yields have a large uncertainty and are input as long-term average values only, not as real time values; the net drift is to the north and so the river sediment will tend to be dispersed in that direction - where the shoreline changes were estimated anyway.

For these reasons, in all subsequent model runs river sediment inputs were assumed to be nil.

Fig 9 shows the performance of the calibration run (W26), comparing the modelled shoreline changes with the measured changes. Note that the shoreline positions are with respect to the regional baseline and are grossly magnified. The success of the model fit is gauged between cells 19 and 43 (Opihi mouth to

Smithfield), which covers the span of the measured historical shoreline fixes. The local errors, everywhere less than ± 6 m, are acceptable given the extent of shoreline movement.

1977-87

The verification run (W27), for the period 1977-87, is shown in Fig. 10. The model performance is reasonable except for immediately south of Smithfield where the modelled erosion is excessive. The extreme south end of Washdyke beach actually accreted by some 20 m over this period, against the long-term trend. This discrepancy appears to indicate an episode of reversed, southerly drift that was not contained in the 'representative' ten-year input wave time series.

1881-34

Two model runs for the period 1881-1934 are shown in Fig. 11. The first run (W40) used the model exactly as calibrated. This tended to over-predict the erosion by up to about 30 m. Even so, the model shows erosion of the Waimataitai Lagoon Barrier and correctly predicts the 250 m retreat at the south end of the Washdyke Barrier. The model (run W43) was then tuned to give a better overall fit to the measured changes along the Washdyke-Opihi shore by increasing K_1 to 0.016 and by using a uniform, reduced rate of rollover (equal to 60% of the calibration rollover rate at Seadown). The K_1 change suggests greater southerly wave energy over this period; the lower and more uniform rollover rates suggest a broader, higher barrier, probably composed of coarser material. This suggests that the assumption of constant rollover rates with time is reasonable for no more than several decades.

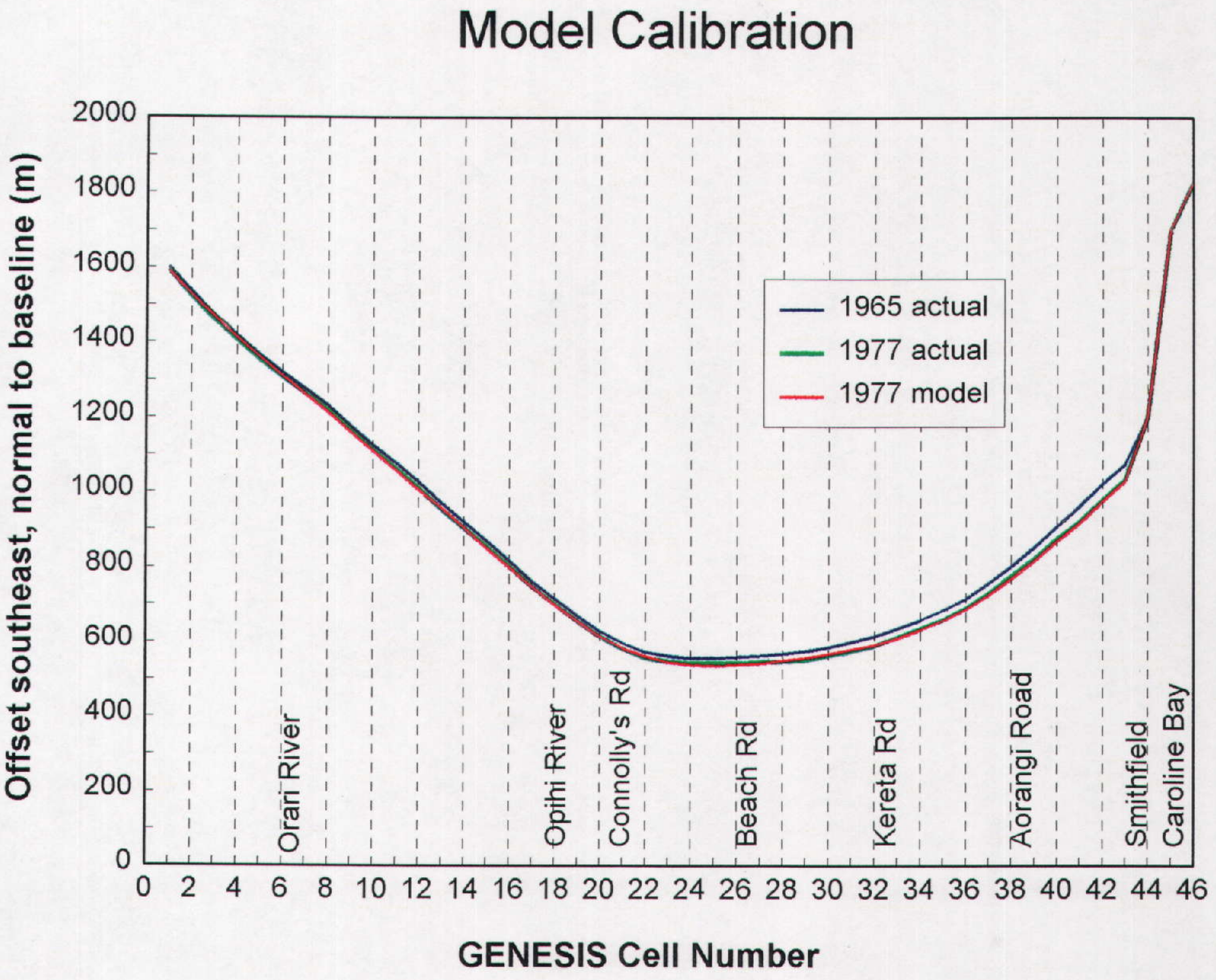
1934-65

This verification run (W50) was the least satisfactory. While the general trend of changes was replicated, the model under-predicted the erosion of the Opihi-Washdyke shore by up to 78 m (Fig. 12). The under-prediction was greatest at Seaforth (cell 36). Verifying the model separately for the periods 1934-56 and 1956-65 shows that this 'excess' erosion occurred mainly in the 1934-56 period.

This pattern of change does not reflect greater erosion associated with littoral drift, but points to greater rollover, apparently where the shore was not temporarily 'buttressed' by stopbanks. Todd (1989) notes that stopbanks were only encountered by the retreating beach after 1967 along the Aorangi Road to Seaforth Road shore, but were encountered before 1956 in the area of Beach and Connollys Roads.

4.3 Discussion

A by-product of the deterministic modelling approach is the creation of a logical framework in which processes and issues requiring further investigation are clearly identified. While the



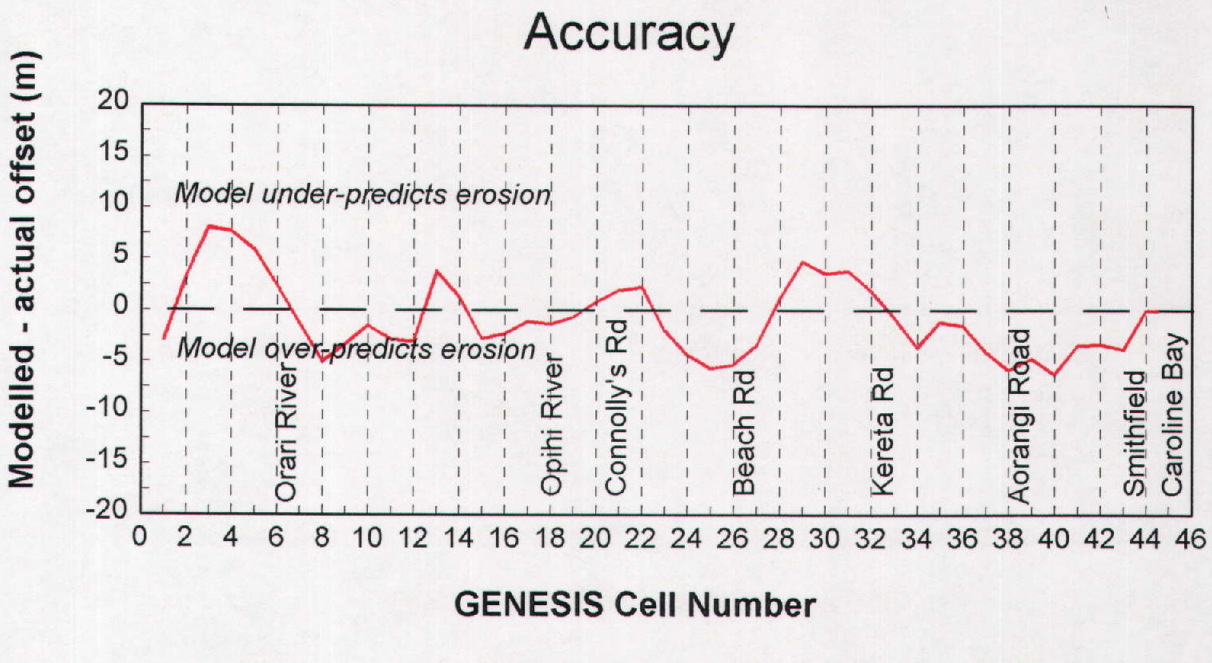


Fig. 9. Results of model calibration run, comparing modelled shoreline changes with actual changes for period 1965-1977.

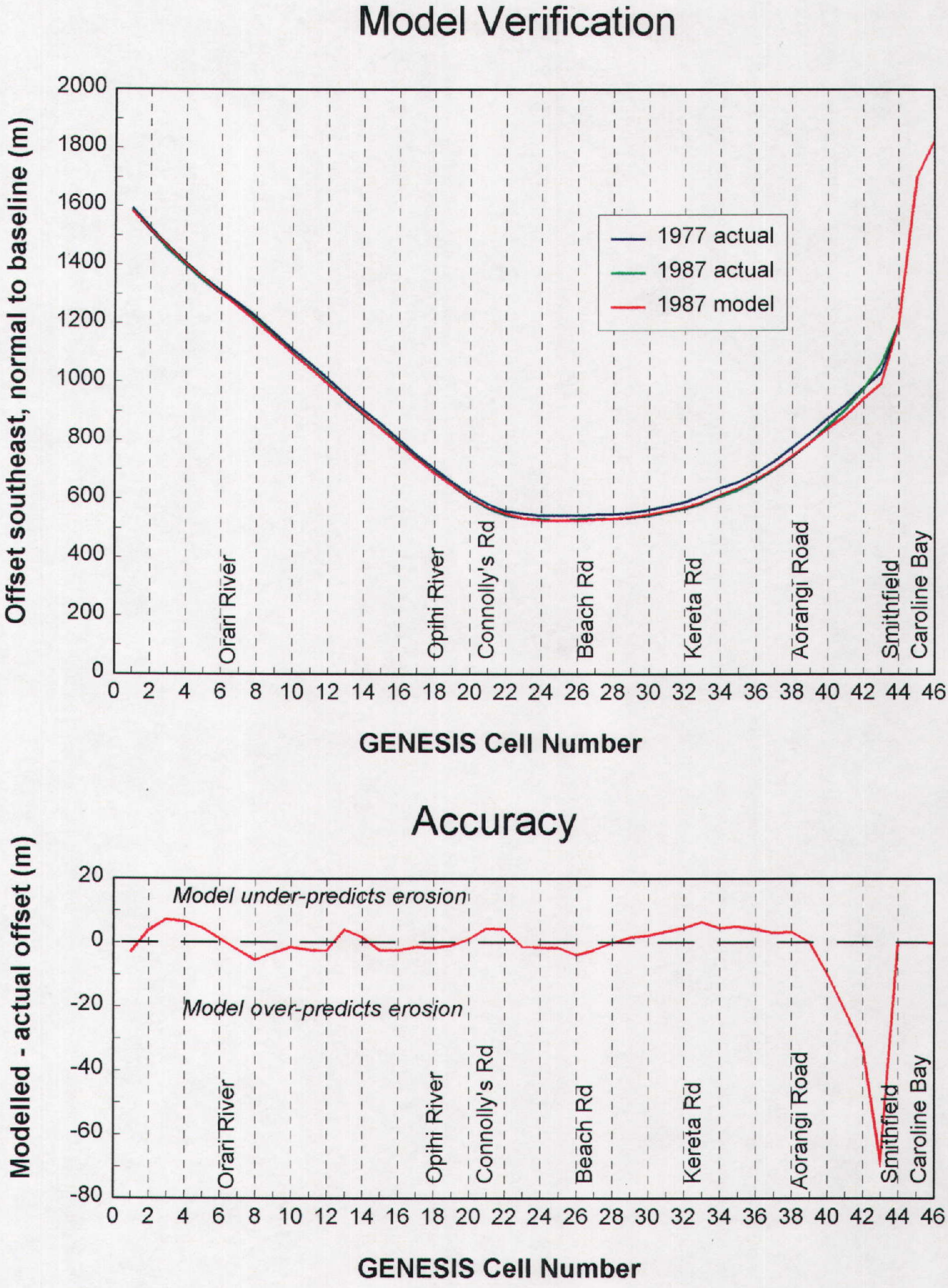


Fig. 10. Results of model verification run, comparing modelled shoreline changes with actual changes for period 1977-1987.

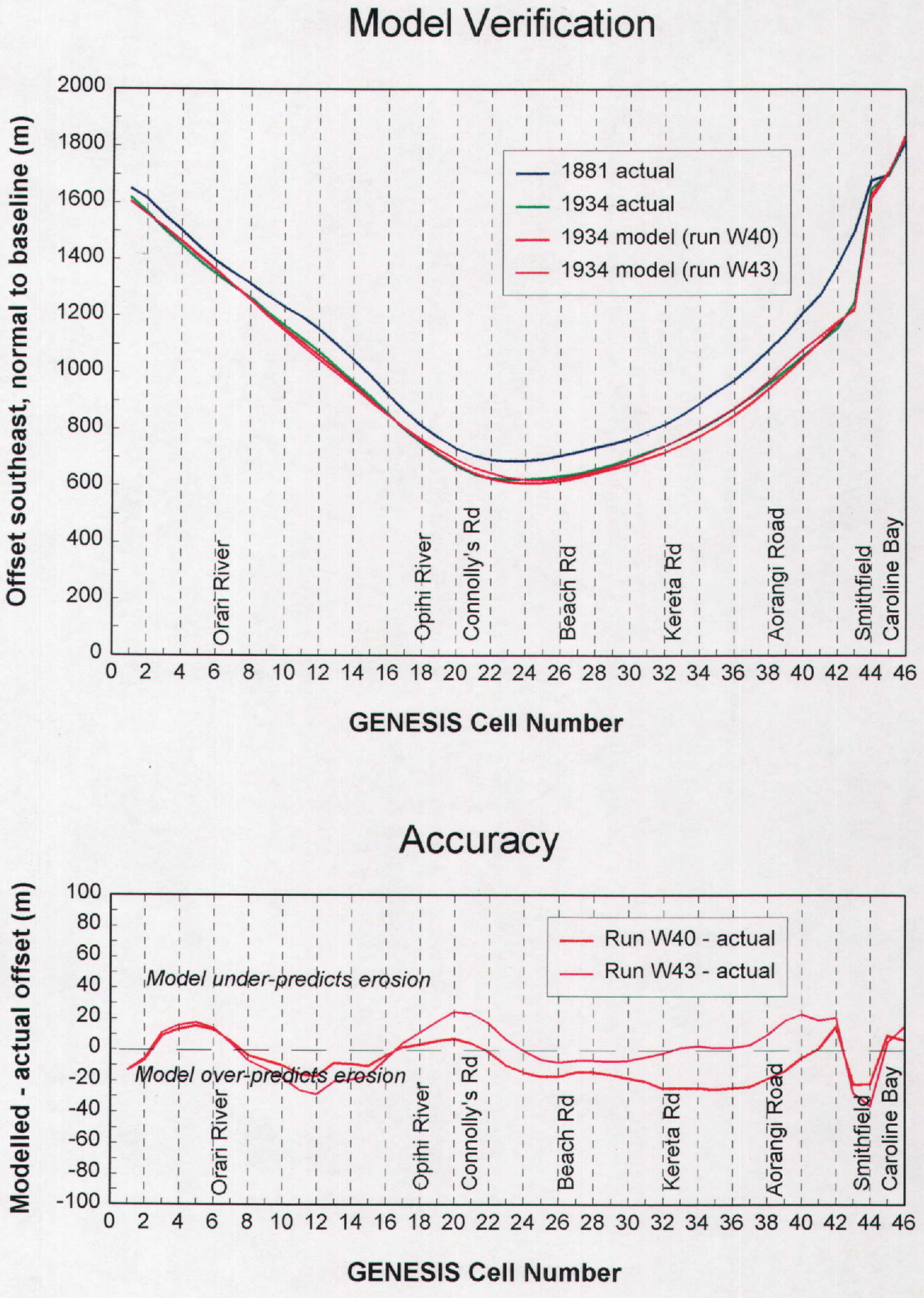
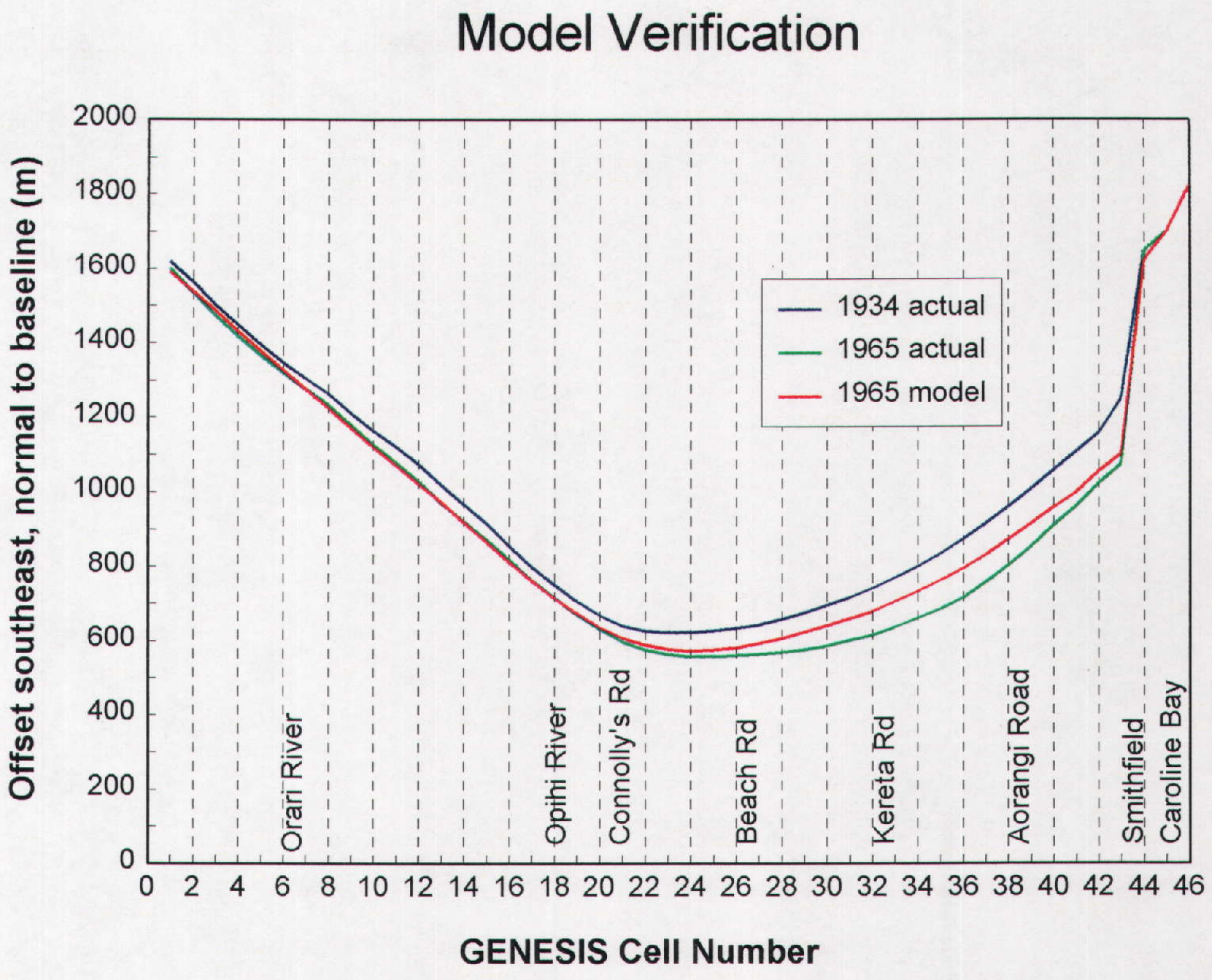


Fig. 11. Results of model verification runs, comparing modelled shoreline changes with actual changes for period 1881-1934. Run W40 uses calibration run parameters, run W43 uses tuned parameters.



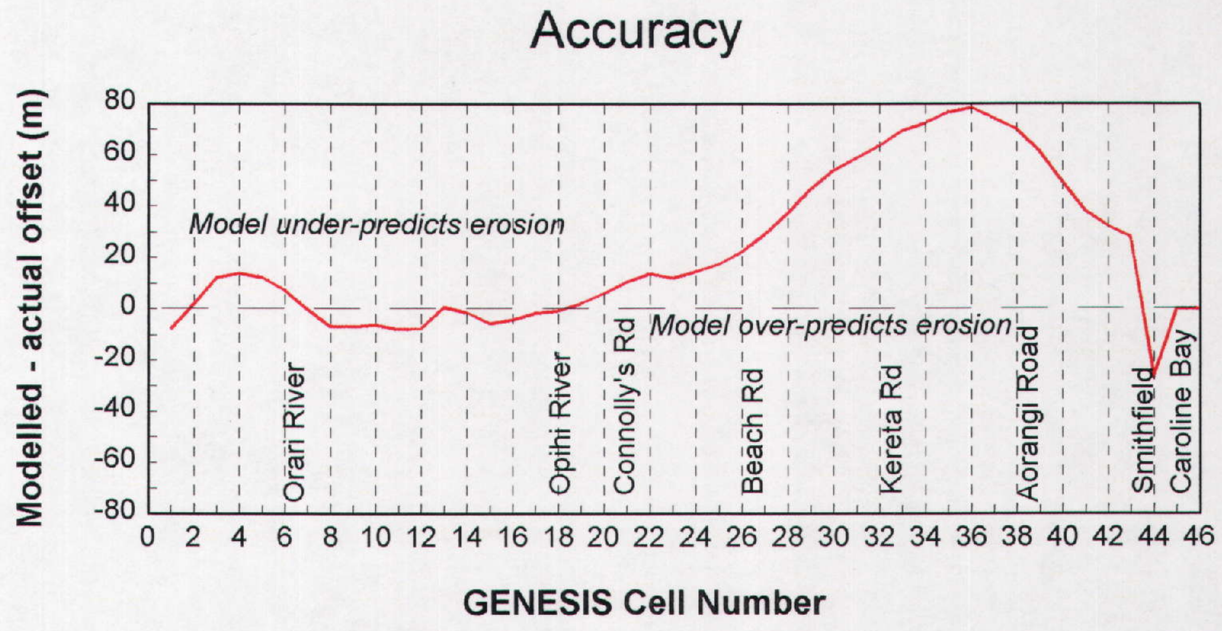


Fig. 12. Results of model verification run, comparing modelled shoreline changes with actual changes for period 1934-1965.

above calibration and verification exercise has been reasonably successful, it has highlighted that longshore divergence in the littoral drift rate is not the dominant cause of shoreline retreat along the Opihi-Washdyke shore. The dominant process is rollover, with abrasion also being important.

Taking the case of the calibration period, from 1965-1977, the total shoreline retreat can be broken down into the components due to each process. For the south end of the Washdyke barrier, the retreat components are:

Rollover	24 m
Abrasion	5 m
Littoral drift	13 m
Total	42 m

while along the Seadown barrier, the average retreat components are:

Rollover	17 m
Abrasion	5 m
Littoral drift	3 m
Total	25 m

These figures are important advances in our understanding of the study shore, as is the finding that the littoral drift 'quarry' is substantially limited to the Smithfield to Seadown section of the beach barrier. Nonetheless, they highlight the limitations of the GENESIS model to this shore.

GENESIS only dynamically models the littoral drift process; rollover and abrasion are introduced only as external effects which do not change alongshore or with time during the running of the model. In fact, both rollover and abrasion are dynamic processes, driven by the wave climate, and controlled by the nature of the beach material and the beach morphology, all of which are functions of time and distance alongshore. The need for temporal and spatial control on rollover, particularly, is evidenced by the model 'tuning' required for the 1881-65 period.

The upshot is that, unless we can assume that future rollover and abrasion rates do not change much from those of the past 20 years, the GENESIS model is limited in the extent that it can be used to predict future shoreline positions. What is really required for the study shore is a model that dynamically incorporates the rollover and abrasion processes as well as littoral drift. For this to be successful, however, requires considerably more research and documentation of the rollover and abrasion processes. Such a model should also incorporate the variable nature of the backshore (due, for example, to irregular stopbanks, paleo-riverbeds, and washover lobes), local adjustments of the beach profile (as when the profile steepens as the beach encroaches on a stopbank), and keep track of the total amount of available gravel.

Given these limitations, probably the best use of GENESIS is to predict future shorelines assuming current rollover and abrasion rates, then to make qualitative assessments of the effects of changing abrasion and rollover rates with time. For example, abrasion rates are expected to decline exponentially with time as the remaining gravel stock becomes finer in size and more resilient; conversely, rollover might be expected to accelerate as the beach material size and stockpile of gravel decreases. Rollover might also be expected to increase with a rise in sea-level.

Another limitation shown by the verification of historical shoreline changes is the wave record. Any trends or decadal-scale variations in the historical wave record have not been represented.

Finally, it is clear that more research is required into the input of river gravel to the study shore: first into the amount of material supplied, but more importantly into the processes by which the material is dispersed and mixed into the beach barrier. The simple 1-d littoral sediment budget model employed by GENESIS may not adequately represent this process.

5. Simulation Runs

5.1. Overview

The original intention of the study was to use the calibrated model to predict the future shoreline change over the next 50 years, first assuming no change to the existing controls, then with changes in sea level, wave climate, and river sediment supply. However, given the findings of the calibration and verification exercises, a reduced set of modelling objectives that focus on littoral drift effects seems prudent. These are:

- to predict the future shoreline change over the next 50 years assuming no change from the conditions assumed for the calibration
- to assess how far the shore would be liable to erode if the erosion was due only to divergence in the littoral drift (ignoring the effects of rollover and abrasion)
- to predict the future shoreline change over the next 50 years assuming decreased wave energy from the southerly quarter and increased wave energy from the easterly quarter, in line with the New Zealand Climate Change Programme's (1990) scenarios of possible future climate associated with global warming.

Sea-level changes can affect the littoral drift computations made by the GENESIS model by way of the effect of a changing water depth on wave refraction. However, as demonstrated by the GENESIS study of Pegasus Bay (Hicks, 1993), for a 0.5 m sea level rise, which is towards the more extreme scenarios of sea-level rise over the next 50 years (Salinger and Hicks, 1990), this effect is very subtle and is liable to be insignificant compared to the uncertainty associated with future rollover rates, particularly if these are likely to change with a changing sea-level[2]. Likewise, the uncertainties concerning the input of river gravels and the model's ability to handle them warn against using the model to investigate any effects of changing river supplies.

5.2. Status Quo: 1987-2040

The status quo simulation run for 53 years into the future involved a continuation of the conditions of the calibration period, i.e., the same '10-year representative' wave climate, boundary conditions, rollover and abrasion rates. The predicted shoreline (run W50) is shown on Fig. 13. It shows a maximum of 220 m of retreat at the southern end of the Washdyke barrier. Going north along the Seadown shore, the retreat reduces from

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[2] The same logic justifies ignoring the effect of sea-level change on the historical shoreline changes.

150 m near Aorangi Road to 70 m near Connolly's Road. As during the calibration period, the rollover process dominates the retreat.

These figures agree well with Todd's (1989) empirical predictions of retreat to the year 2050:

	Range (m)	*Most likely* (m)
Mid-Washdyke barrier	120-240	190
Aorangi Rd	60-260	155
Connolly's Rd	65-150	70.

This agreement lends confidence to both modelling approaches, at least for the 50-year future time frame

For the 12.5 km of shore between Smithfield and the Opihi mouth over the 1987-2040 period, the total loss of beach material predicted by the model is 1,460,000 m^3 (530,000 m^3 to abrasion and 930,000 m^3 to net northwards littoral drift). Although the abrasion rates may reduce somewhat with time, as the following section shows, the littoral drift potential is unlikely to diminish much for thousands of years. Since Benn (1987) measured a total of 1,465,000 m^3 of gravel in storage along this length of shore, the indication is that without significant inputs of river gravel or renourishment, the life of this barrier is only of the order of 50 years. Progressively more frequent barrier breaching and hinterland flooding, and accelerated rollover, are foreseen as the barrier material is exhausted.

This short time frame focuses the need for a better understanding of the present river gravel inputs and rollover and abrasion processes. Given that any significant effects to the system from a change in climate would occur over a much longer time, climate change effects over the next 50 years are essentially academic to the Washdyke situation.

5.3. Equilibrium shoreline

Starting with the 1987 shoreline, the model was run on into the future assuming shoreline change was induced only by divergence in littoral drift (i.e., rollover and abrasion were ignored). The purpose was to assess, given the current wave climate, how far the shore would need to retreat until there was zero net littoral drift. For this task, to speed up the computer runs (which involved thousands of years of real time), the K_1 efficiency parameter in the transport model was increased by a

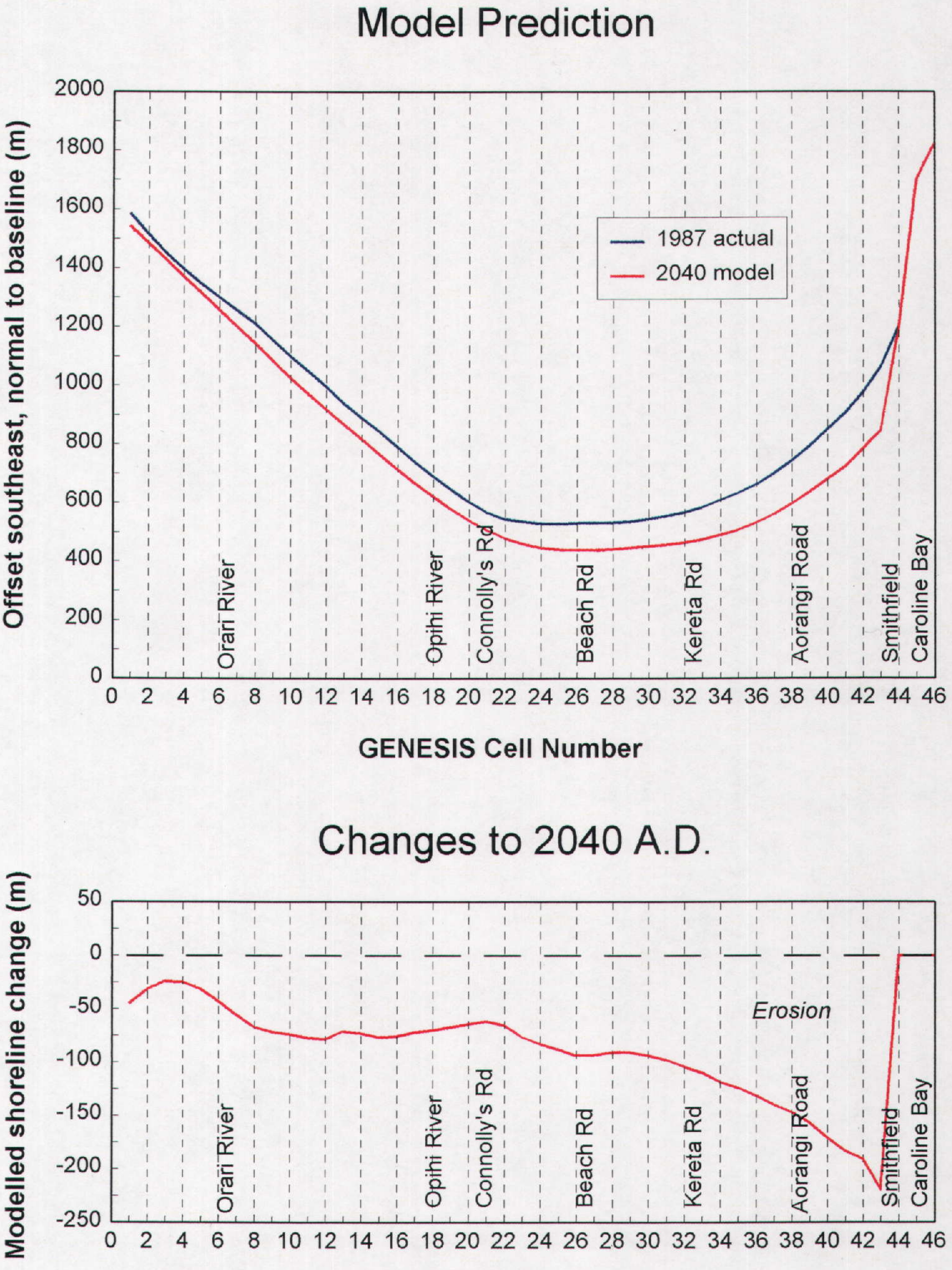

Fig. 13. Results of model prediction run, modelling shoreline changes from 1987 until 2040 A.D.

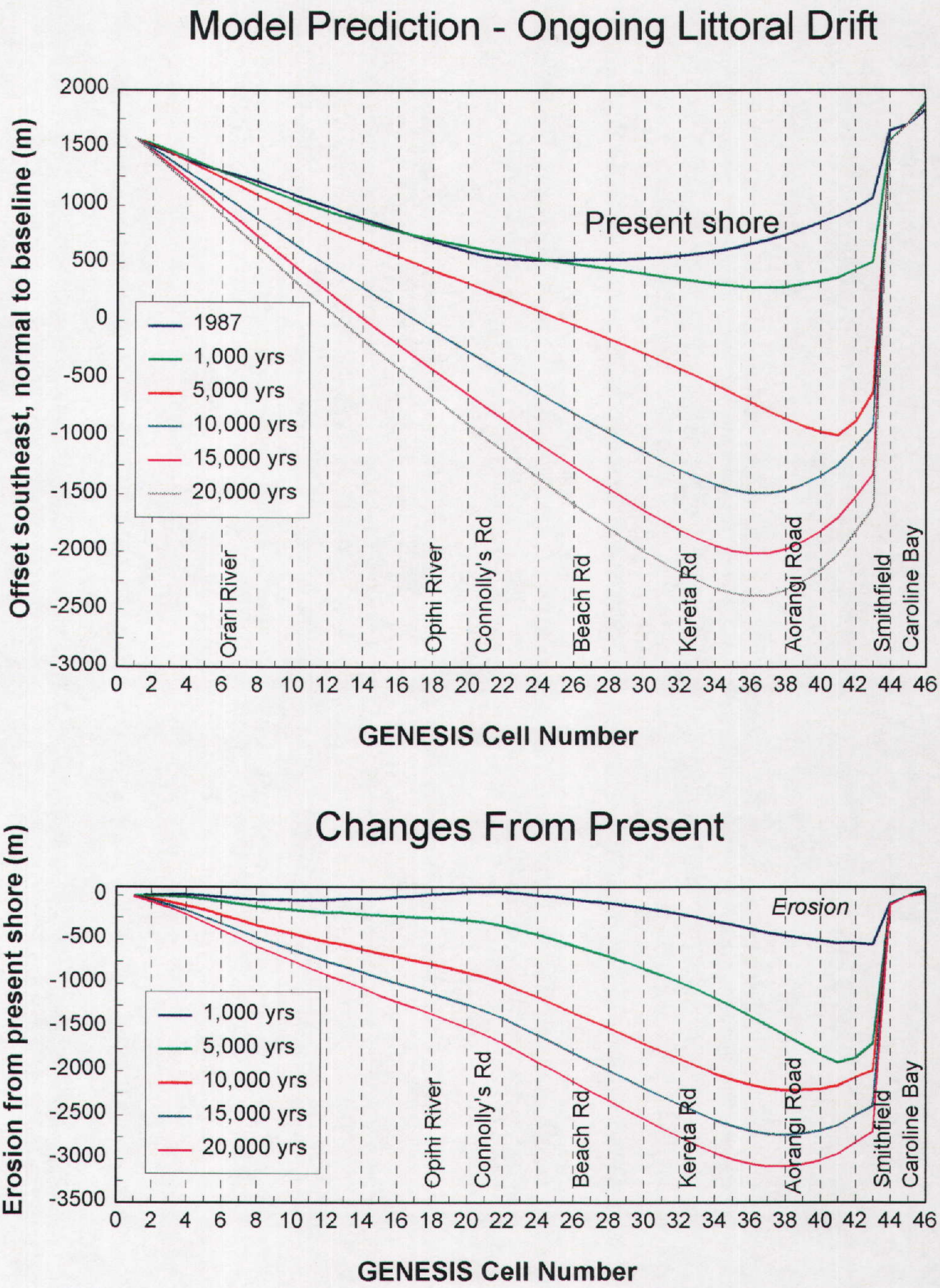

Fig. 14. Predicted shoreline positions after prolonged erosion due only to littoral drift.

factor of 100[3]. Fig. 14 (run W46) shows that the shore would initially retreat sharply for approximately 2 km at Washdyke, then the erosion 'bite' would gradually broaden northwards and the point of maximum erosion would migrate northwards. Allowing for the acceleration given the model, some 5000 years would be required for the first 2 km of retreat at Washdyke, and another 15,000 years for a further 1 km.

These figures suggest that while the study shore in not currently in a state of littoral-drift equilibrium (after its littoral drift supply from the south was interrupted at the Port of Timaru), the forces driving it towards a new equilibrium configuration are not dramatic.

5.4. Change in future wave climate

Again beginning with the 1987 shoreline, the model was run until 2040 using two different wave climate scenarios. The first scenario involved doubling the energy of waves arriving from the easterly quarter and halving the wave energy from the southerly quarter (equivalent to increasing and decreasing, respectively, the wave height by a factor of 1.414). The second scenario was similar but more extreme, with the wave energies changing by a factor of four (and the wave heigths by a factor of two).

These scenarios were consistent with those adopted by the New Zealand Climate Change Programme (Salinger and Hicks, 1990), which assumed increased easterly winds and decreased southerly winds on the South Island east coast. While Salinger and Hicks did not quantify these changes, the x2 and x4 wave energy factors used here are considered to be towards the extreme end of any likely changes.

Fig. 15 shows that this easterly 'rotation' of the wave energy would reduce the erosion rate along the Washdyke barrier, particularly at its southern end, but would have little effect on the shore north from Kerata Road.

Unfortunately, GENESIS is only capable of modelling the effect of the changed wave climate on the longshore transport. Probably as (or more) important would be the effects of changes in the wave climate on the rollover and abrasion processes. A general amelioration in the wave climate, resulting in a reduction in the total wave energy, should decrease the rate that these processes occur, but it is not yet possible to say by how much.

Thus while the likely consequences of the climate change scenarios assumed by the New Zealand Climate Change Programme would be towards lessening the erosion rate at

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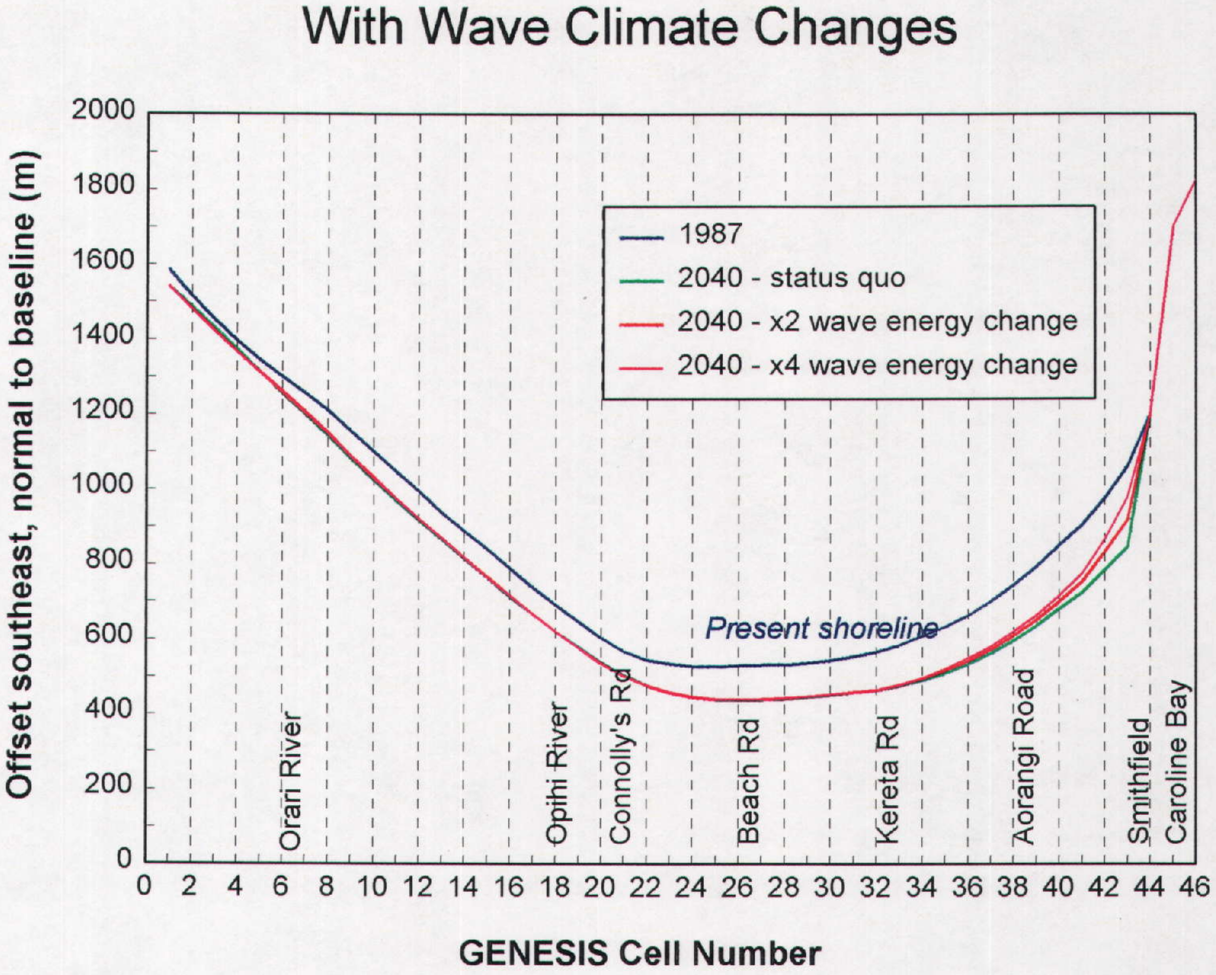
[3] Checks were run to ensure that the model did not develop numerical instabilities due to this 'acceleration'. This was done by comparing such accelerated runs with runs for the equivalent time period using the normal K_1 value.



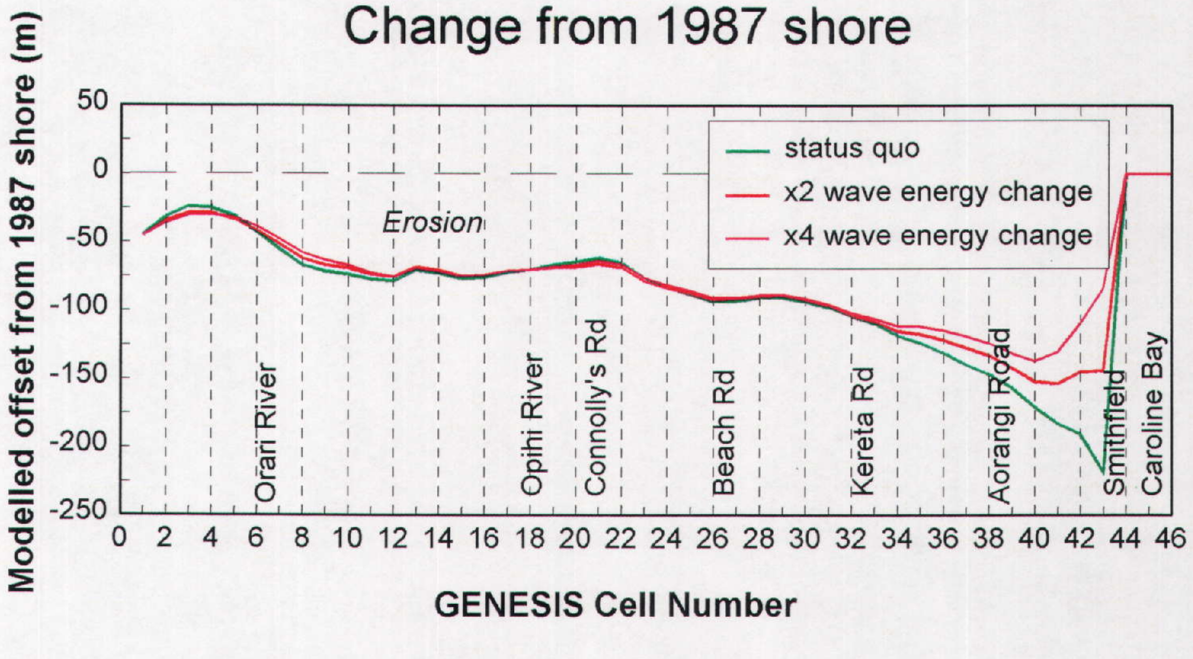


Fig. 15. Results of model runs with changed future wave climate. Changes involve increasing wave energy from easterly quarter and decreasing wave energy from southerly quarter, first by a factor-of-two and then by a factor-of-four. Starting shore was 1987. Model was accelerated to run 5,000 years.

Washdyke, this cannot be quantified. Moreover, it is unlikely that any such effects would occur soon enough to extend the barrier life much beyond the 50 year time frame determined above.

5.5. Discussion

This modelling exercise has been reasonably successful insofar as the assumptions on future rollover and abrasion rates and insignificant river gravel inputs are correct. Clearly, however, there are large uncertainties with these factors, particularly the rollover process which appears to be the dominant control on historical shoreline retreat. Thus the predictions of the GENESIS model should only be taken as indicative.

A more definitive deterministic result awaits:

- further documentation and research into the rollover process, abrasion, and river gravel supplies
- the development/improvement of physically-based models of these processes, including their response to waves and sea-level changes
- the development of a numerical shoreline model that adequately integrates these processes
- an improved and extended record of sea-level and directional wave data for the study area.

In the meantime, it is felt that a workable appreciation of the likely future positions of the study shoreline can be found by merging the results of this study with the discussion and purely empirical shoreline predictions of Todd (1989). Todd found that a model of the form

$$y = \exp(t^k)$$

where y is the offset of the shoreline from a baseline, t is time, and k is a coefficient less than -1, provided a good overall fit to shoreline movements between 1934 and 1987. By calibrating k at each of many points alongshore and then extrapolating the relationship for each point with time, he derived future shoreline positions. Although lacking any consideration of physical processes and so being susceptible to unrealistic extrapolation, this approach implicitly incorporates the dominant time trends in the underlying processes. It is recommended that the Todd model be checked and revised as necessary regularly at 10 year intervals into the future.

6. Recommended Further Work

As outlined above, reliable and accurate predictions of future movements of the Washdyke-Opihi shoreline require further investigations, particularly of the rollover and abrasion processes and inputs of river sediment. This work should aim first to document these processes and their forcing factors, then to derive conceptual and physical models for them. Suggestions for this work are detailed below. The separate items would individually suit Masters studies, or they could all be addressed in a PhD study. The PhD study would ensure greater focus.

6.1 Rollover

To document the rollover process, the current network of beach profiles should continue to be surveyed at regular intervals. The survey should include the landward toe of washover lobes, and the area of the washover lobe should be calculated. Supporting information should include the barrier crest height, beach slope, the 'interception' of any stopbanks, the size of the beach and washover material, and, ideally, a record of storm waves and sea-level during washover events. If conducted for a PhD study, consideration should be given to developing a deterministic numerical model. The work should include assessment of the special effects of stopbanks on the rollover process. This could be combined with an analysis of hinterland flooding associated with barrier breaching by storm waves.

6.2 Abrasion

Important questions include confirming the rate of abrasion and assessing the degree to which abrasion is reducing the size of barrier material and any consequent effect on barrier height and shape. Regarding the rate of abrasion, fundamental questions include the distance that clasts travel on a beach in a year - not necessarily with any net longshore movement, the active volume that suffers abrasion, and the time to 'work over' the total volume of material in storage in a gravel barrier. Reductions in size of barrier material might be identified in a transect of samples through a barrier. The size of the barrier material should be analysed every decade, using a sampling strategy adequate to cover local variations in sediment texture.

6.3 River Inputs

The size and fate of inputs of gravel from the Opihi River might best be established by a sediment budget type study following a major river flood. This could involve a series of surveys of gravel storage in the river mouth lagoon and on the beach and shore faces for some distance to either side of the river, including the size characteristics of any material accreting onto the beachface. The extent of gravel deposition in the nearshore and its return to the beach could be investigated. This could suit an opportunistic Master's study. A baseline survey would need to be maintained in order to know the pre-flood conditions. This could become part of the routine profile monitoring programme for this coast.

7. Modelling potential elsewhere on the Canterbury coast

Following the experience and results gained from this study and from the similar modelling study of Pegasus Bay (Hicks, 1993), some comment can be made as to where else on the Canterbury coast the GENESIS model, or some similar model or modification of it, might be productively used for predicting future shorelines.

7.1 Further applications of GENESIS

In short, the possibilities are limited for the further use of GENESIS in its original form. This is because GENESIS is designed principally to model shores where significant longshore gradients in the littoral drift rate occur, since it is divergence in the longshore transport rate that creates erosion and convergence in it that induces deposition. The ideal shore situation for GENESIS is where hard structures - either natural or artificial - interrupt a strong net littoral drift. Superficially, the coast north of Timaru meets this criterion, but as this study has shown, the model's usefulness is limited by its inability to dynamically model several other time-dependent, wave-driven processes (i.e., abrasion and rollover) that influence shoreline retreat.

The most suitable location for further GENESIS modelling would be South Beach, on the south side of Timaru Harbour. There, while abrasion must still occur, there is no rollover and the situation is simply one of an attached breakwater interrupting a strong northerly littoral drift.

The sedimentary coast from the Pareora River mouth south to the Waitaki River mouth is not suited to GENESIS for several reasons. First, the predominant erosion process is cliff erosion, which cannot be modelled dynamically by GENESIS. Second, the orientation of this shoreline changes only very gradually alongshore, which means that erosion/deposition associated with littoral drift divergence will be relatively insignificant. For example, even if the littoral drift rate increased by 30,000 m^3/yr along this 30 km or so of coast, the resulting erosion rate would be only 1 m^3/m/yr, which is about the same as the gravel loss rate due to abrasion that was estimated in this study.

The beaches of Banks Peninsula would not be suited for GENESIS, since, being bayhead beaches, they experience no net littoral drift. The accretion occurring at these beaches is associated with onshore transport, whereby sand transported northwards around Banks Peninsula is swept shoreward by waves as the sand passes bay entrances.

The northern end of the Canterbury Bight, from the Rakaia River mouth north to Birdlings Flat, offers some scope for the use of GENESIS or a similar model, at least to gain some insight into the patterns of Holocene shoreline evolution and possibly to predict future trends in the stability of the Lake Ellesmere outflow channel. The accretion occurring at Birdlings Flat appears to be substantially due to the stalling of the northwards littoral drift regime by the Banks Peninsula headland. The evidence from beach ridges and changes in historical patterns of erosion suggest that as the low-cliffed shore of the Rakaia River fan has retreated and the northern end of the Kaitorete Barrier has accreted, the 'pivot point', marking the transition from erosion to accretion, has migrated north past the southern corner of Lake Ellesmere. The present outflow channel from the lake occurs where the shore erosion has intersected the lake. If this hypothesis is true, then it is likely that the southern end of the Kaitorete barrier will get progressively narrower and the Ellesmere entrance may broaden. A model study of this situation might confirm this hypothesis and establish the time frame of the changes.

7.2 Need for a modified model

To model the Canterbury shore from the Waitaki mouth to Banks Peninsula properly requires a pseudo 2-d numerical model that dynamically includes littoral drift, rollover, abrasion, cliff erosion, and river gravel inputs. Unfortunately, such a model does not exist. Given its requirements, it would be more practical to design and code a new model, possibly utilising existing sub-routines from other models, rather than simply attempting to expand an existing model such as GENESIS.

The specifications for such a model would include:

- a complete, dynamically forced sediment budget analysis of each shore cell during each model time step
- wave, sea-level, or some other time-dependent forcing of littoral transport, rollover, abrasion, cliff erosion, and river gravel supply and dispersal from river mouths
- a littoral transport model specific to gravel
- a quasi 2-d capability to allow the height and steepness of gravel barriers to change as a function of the wave energy, the beach material size, and the composition of the backshore (e.g., as stopbanks were encountered)
- reduction in barrier material size as a function of wave-driven abrasion
- a boundary condition file that specified variations in the nature of the backshore
- explicit inclusion of mean sea-level and tidal constituents
- the ability to accept time series of nearshore waves and gravel supplies from rivers

- like GENESIS, this new model could rely upon external models such as RCPWAVE to supply refracted wave information.

Clearly, further research into the dynamics of most of these processes, improved estimates of river gravel yields, and records of waves in the area are required before such a model can be formulated. The Washdyke to Orari shore would be the natural location to pilot this model.

8. Conclusions

1. A reasonably good calibration and verification of the GENESIS shoreline evolution model was achieved for the Washdyke-Opihi shore for the period 1965-87. However, this calibration involved making the assumptions of zero gravel input from the Opihi and Orari Rivers and constant rates of abrasion and rollover of gravel into the backshore, which may not hold true for modelling future shoreline positions.
2. The shoreline retreat for at least the latter half of this century appears to have been dominated by the rollover process. The effect of littoral drift is secondary.
3. The barrier from Washdyke to Seaforth appears to serve as a 'quarry' to supply a net northerly littoral drift of about 20,000 m^3/yr.
4. Running the model to the year 2040 A.D., with no change of controlling parameters from the present, indicates a further 220 m of erosion at Washdyke, with the erosion decreasing alongshore to the north.
5. The future shorelines predicted in this study agreed well with the empirical predictions of Todd (1989).
6. By about 2040 A.D., it appears possible that gravel losses to northward littoral drift and abrasion will have exhausted the gravel currently stored in the Washdyke-Seadown barrier. Progressively more frequent barrier breaching, washover events, and hinterland flooding are foreseen as that time approaches.
7. Under the present wave climate, the Washdyke shoreline would need to retreat of the order of 3 km inland before a shoreline configuration with zero net littoral drift was attained. With adequate supplies of backshore gravel and no rollover or abrasion, this amount of retreat would take thousands of years. However, the retreat may occur much more rapidly following a permanent loss of the Washdyke barrier.
8. An increase in easterly wave energy and a decrease in southerly wave energy, in line with the future climate change scenarios adopted by the New Zealand Climate Change Programme, would diminish gravel losses and erosion due to littoral drift along the Washdyke barrier, but would not affect the retreat associated with abrasion and rollover unless there was an overall reduction in wave energy. Given the slow rate expected of any climate change, it is unlikely that favourable climate change effects would significantly

delay the destruction of the Washdyke barrier much beyond the predicted 50 year time frame.

9. Further documentation and research into the rollover process, abrasion, and river gravel supplies is recommended. A wholly reliable deterministic model for the study shore can only be developed after these factors are understood and incorporated into a model tailored for the study shore. In the meantime, it is recommended that planning should take account both of this study and the empirical shoreline predictions of Todd (1989).
10. The GENESIS model, or one similar, might be productively used to simulate shoreline change at Timaru's South Beach and between the Rakaia mouth and Birdlings Flat. Elsewhere along the Canterbury Bight, a more complex model of the type recommended here for the Washdyke-Orari shore is required.

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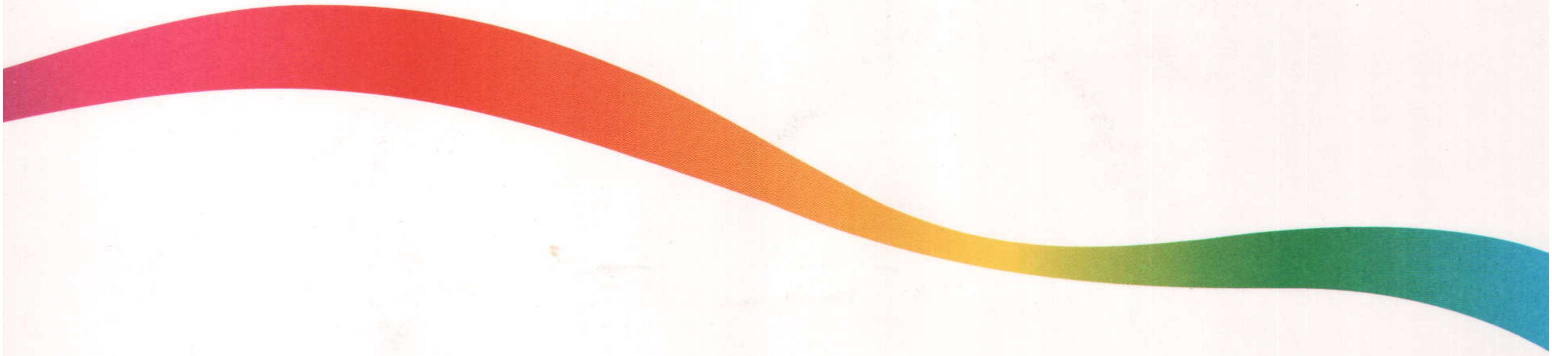


SUMMARY OF REPORT ON: "MODELLING HISTORICAL AND FUTURE CHANGE OF THE WASHDYKE-OPIHI SHORELINE"

1) INTRODUCTION

This report is the second of a series which describes the modelling of possible changes to shoreline position for various sections of the Canterbury coast which may occur as a result of long-term climatic changes.

Although the debate on "Greenhouse induced climatic changes" has been on-going for some time, the currently available global models and national scenarios for change reveal very little on what could happen to the coast line within the Canterbury Region. The purpose of these reports is to identify the sections of coast which could be at potential risk from global climate change induced variations to coastal processes, so that ongoing coastal resource management decisions can be undertaken in an informed matter based on scenarios which are relevant to the regions coast.

The Washdyke-Opihi shoreline was chosen as the second section of coast to be modelled due to the high rates of historical erosion and large capital value of assets located along this section of coast.

The modelling was undertaken by NIWA under contract to the Canterbury Regional Council.

2) MODEL OPERATION AND PERFORMANCE

The generation of future shoreline positions was undertaken by using a numerical "1-line" shoreline evolution model (GENESIS) developed in USA. The model calculates shoreline change based on longshore variations in littoral drift. Input data was required on the deep water wave climate, offshore bathymetry, longshore transport, sediment inputs, and the geometry of the beach profile. Unfortunately the GENESIS model is limited by its inability to dynamically model several other time-dependent, wave driven processes such as abrasion and rollover which the study revealed have a major influence on shoreline retreat along the Washdyke-Opihi coast.

To achieve the best calibration for the Washdyke-Opihi shoreline, the model reach extended 23km from Caroline Bay to the start of the cliffed coastline north of the Orari River. Some simplifications were required to model the hard shore and port structures at the south end of the model reach. The model was run with a spatial resolution of 500m.

With six historical shoreline fixes being available, there was an abundance of choices over which period to use for calibrating the model. It was decided to use the most recent 1965-77 and 1977-87 periods for model calibration, and principal verification. These periods were used as the shoreline fixes were more likely to be reliable; the wave and beach profile data come from this period; and since rollover rates appear to be time dependent, the most recent period would be the most appropriate. The other earlier periods were used to check the verification.

A reasonably good calibration and verification of the model was achieved with calibration errors being less that ±6m for all sites between Washdyke and Opihi. However, this calibration involved making the assumptions of zero gravel input from the Opihi and Orari Rivers, and temporally constant rates of abrasion and rollover, all of which may not hold true for modelling future shoreline positions. Testing the calibrated model against shoreline changes in the 1881-1934 period produced an over prediction of erosion by up to 30m. A better overall fit was achieved by increasing the wave energy due to greater effect of southerly storms, and by reducing the rollover rate due to a broader, higher barrier composed of coarser material. Similar testing of the calibrated model against the 1934-65 shoreline changes, produced an under prediction of up to 78m at the south end of Seadown. This pattern was assumed to be due to differentiate rates of rollover produced by different sections of beach being not temporarily restrained by stopbanks.

There are two important results of the calibration and verification exercise. The first is that the dominant process responsible for shoreline retreat along the Washdyke-Opihi shore has been rollover rather than longshore variation in the littoral drift rate. For example, during the calibration period, rollover was responsible for 57% of the retreat at south Washdyke, and 68% of the retreat at Seadown. These results highlight the limitations of the GENESIS model which only dynamically models the littoral drift process. The need for temporal and spatial control on rollover is evidenced by the model 'tuning' required for the 1881-1965 periods. A consequence of the calibration results is that in using the model to predict future shoreline positions, it must be assumed that future rollover and abrasion rates do not change from those of the past 20 years. To overcome the limitations of these assumptions, it is necessary to make qualitative assessments of the effects of changing abrasion and rollover rates with time.

The second important result is that under the model assumptions of nil sediment input from the south or from the erosion of the hinterland, the source of material for littoral drift processes is substantially limited to that already present on Washdyke beach. This implies that at some time in the future this supply will be exhausted resulting in progressively more frequent barrier breaching, washover events, and hinterland flooding.

3) SIMULATION RUNS

The original intention of the study was to use the calibrated model to predict the future shoreline changes over the next 50 years, first assuming no change from the present controls and processes, then with changes in sea level, wave climate and river sediment supply as forecast in the New Zealand Climate Change Programme scenarios. However, given the findings of the calibration and verification exercises, the study objectives were amended to the following:

a) To predict the future shoreline change over the next 50 years assuming no change from conditions and processes used for the calibration period.
b) To assess how where and when an equilibrium shoreline position would develop if future erosion was only due to littoral drift processes.
c) To predict the future shoreline change over the next 50 years assuming decreased wave energy from the southerly quarter and increased wave energy from the easterly quarter,which is in line with the New Zealand Climate Change Programme scenario.

From the original objectives; the effect of sea level rise over the next 50 years is liable to be insignificant compared to the uncertainty associated with future rollover rates, and the uncertainties concerning the input of river gravel and the model's ability to handle them warn against using the model to investigate any effects of changing river supplies.

The results of the different simulation runs are as follows:

a) Status Quo 1987-2040

Involved a continuation of wave climate, rollover and abrasion rates from the calibration period. The predicted shoreline (figure 1) shows that there a continuation of the existing trend of decreasing erosion in a northward direction. Maximum retreat of 220m (average 4.15m/yr.) is predicted at south Washdyke, reducing to 150m (2.83m/yr.) at Aorangi Road, and 70m (1.32m/yr.) at Connolly's Road. As with the calibration period, rollover is the dominate process of retreat.

The good agreement between the predicted retreat figures from the model and those obtained by earlier empirical predictions (SCCB publication, Todd 1989), lends confidence to both modelling approaches, at least for the 50 year future time frame.

The loss of beach material predicted by the model for the Washdyke-Opihi coast over the 1987-2040 period is 530,000m^3 to abrasion and 930,000m^3 to net northward littoral drift. Since the total loss is similar to the total gravel in storage over the 12.5km length of beach, the indication is that without significant inputs of river gravel or renourishment, the life of this barrier is only in the order of 50 years. progressively more frequent barrier breaching and hinterland flooding, and accelerated rollover, are foreseen as the barrier material is exhausted.

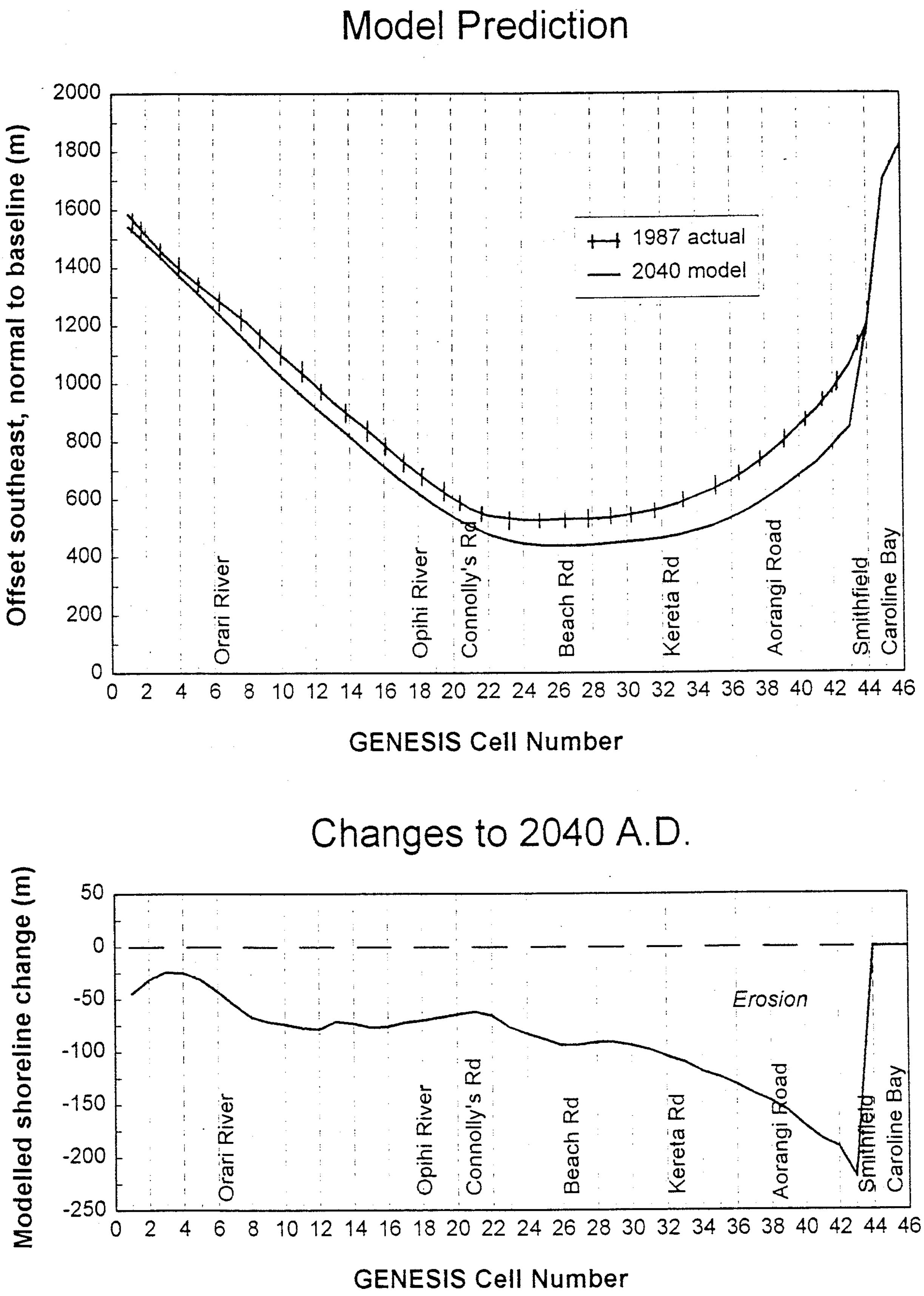
b) Equilibrium shoreline

The purpose of this simulation was to assess, given the current wave climate, how far the shore would need to retreat until there was zero net littoral drift, hence obtain an equilibrium shoreline position. The results showed that the shore would initially retreat sharply for approximately 2km over the next 5000 years at Washdyke, and then a further 1km over another 15,000 years with the point of maximum erosion migrating northward to approximately Seaforth Road. The results of the simulation suggest that the forces diving the study shore towards a new equilibrium configuration following the interruption of gravel supply from the south by the Port of Timaru are not dramatic.

c) Change in future wave climate

Two wave scenarios were used; the first involved doubling the energy of waves arriving from the easterly quarter and halving the wave energy from the southerly quarter, and the second was similar but more extreme case of changing the wave energies by a factor of four. Changes of these magnitudes are considered to be towards the extreme end of any likely climate induced changes.

The modelled results of this easterly 'rotation' of the wave energy was to reduce the erosion rate along the Washdyke barrier, particular at the southern end where the retreat distance by the year 2040 was reduced by 70-90m from the status quo



Model Prediction

Changes to 2040 A.D.

Fig. 1 . Results of model prediction run, modelling shoreline changes from 1987 until 2040 A.D.

situation. The model showed there would be little effect on the erosion rates north of Kereta Road.

However, while GENESIS can only model the effects of the changed wave climate on longshore transport, probably as important is the effects on rollover and abrasion processes. In general, any reduction in the rate of retreat due to these processes would not occur unless there was an overall reduction in wave energy. Given the slow rate expected of any climate change, it is unlikely that favourable climate change effects would significantly delay the destruction of the Washdyke barrier much beyond the predicted 50 year time frame.

4) IMPLICATIONS OF RESULTS

a)Due to the limitations of the model assumptions on future rollover and abrasion rates and the insignificant river gravel inputs, the predictions of the GENESIS model should only be taken as being indicative.

It is recommended that planning should take account of both this study and the empirical shoreline predictions of Todd (1989).

b)Under status quo conditions, the model indicates that by 2040 AD., a further 220m of erosion will occur at Washdyke, 150m at Aorangi Road, and 70m at Connolly's Road.

This magnitude of retreat will effect drainage and coastal stopbanking right along the Washdyke to Opihi coast, and will almost totally remove both Washdyke and Opihi mouth lagoons. The Timaru sewer line and milliscreening plant should not be effected by beach retreat within this time frame.

The effects of climate change scenarios are likely to have little influence on the rates of shoreline retreat over the next 50 years.

c)The model indicates that shoreline retreat will continue to be dominated by rollover processes.

A short term solution for reducing rollover effects would be to increase beach heights by periodically bulldozing backshore material back up onto the beach crest. Consideration should be given to experimenting with this type of control along part of the Washdyke barrier.

d)By about 2040 AD., it appears possible that gravel losses to northward littoral drift and abrasion will have exhausted the gravel currently stored in the Washdyke-Seadown barrier. Progressively more frequent barrier breaching, washover events, and hinterland flooding are likely as that time approaches.

It is unknown at this stage whether the dumping of dredge spoil from the Port of Timaru at the inshore dump site 1km off the Washdyke beach will have any positive long-term effect in reducing sediment losses. Another possible solution is to renourish the beach from a landward source.

5) FURTHER MONITORING AND INVESTIGATIONS

A reliable prediction model for the Washdyke-Opihi shore can not be developed until there is further documentation, research and understanding of rollover, abrasion, and river gravel input processes. In particular the following monitoring and investigations should be undertaken

a) Rollover: Continue to survey the existing beach profile network at regular intervals.

Establish a record of storm waves and sea levels during washover events.
Assess the effects of stopbanks on the rollover process.

b) Abrasion: Determine the absolute sediment volume stored in the beach at decade intervals.
Establish the average distance travelled by sediment clasts on a beach in a year.
Establish the active volume which suffers abrasion.
Assess the degree to which abrasion is reducing the size of beach material and the effect on barrier height and shape.

c) Sediment Inputs: Determine the size and fate of inputs of gravel from the Opihi River by establishing a sediment budget type study following a major river flood.
Establish the volume of gravel released to the beach due to erosion of the hinterland, and the effects of abrasion and weathering on this material.
Verify the sediment inputs to the beach system from inshore dumping of Port of Timaru dredge spoil.

d) Modelling: Update the empirical shoreline predictions of Todd (1989) at 10 yearly intervals.
Develop a numerical model tailored to the study shore which can dynamically handle littoral drift, rollover, abrasion, and gravel inputs.

Many of the above investigations could separately be suitable for university Masters Thesis studies, or a more co-ordinated approach could be taken via a PhD doctrinal study. Consideration should be given to the Regional Council funding these investigations options.