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A Coastal Hazard Management Plan for Hokitika

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A Coastal Hazard Management Plan for Hokitika

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A Coastal Hazard Management Plan for Hokitika

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This report to Hokitika Borough Council, Ministry of Transport and Westland Catchment Board proposes a Coastal Hazard Management Plan for Hokitika Borough. The plan recommends a combination of planning, engineering and soil conservation measures to minimise the effects of coastal hazards on property and assets for the term of their useful life (1986-2100 AD). The plan is based on a Coastal Hazard Zone (CHZ) taking into account episodic erosion, long term sea erosion and a predicted rise in sea level.

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CONTENTS

FIGURES

TABLES

Dedicated to Gordon and Esther Nicholls
of Revell Street, Hokitika.

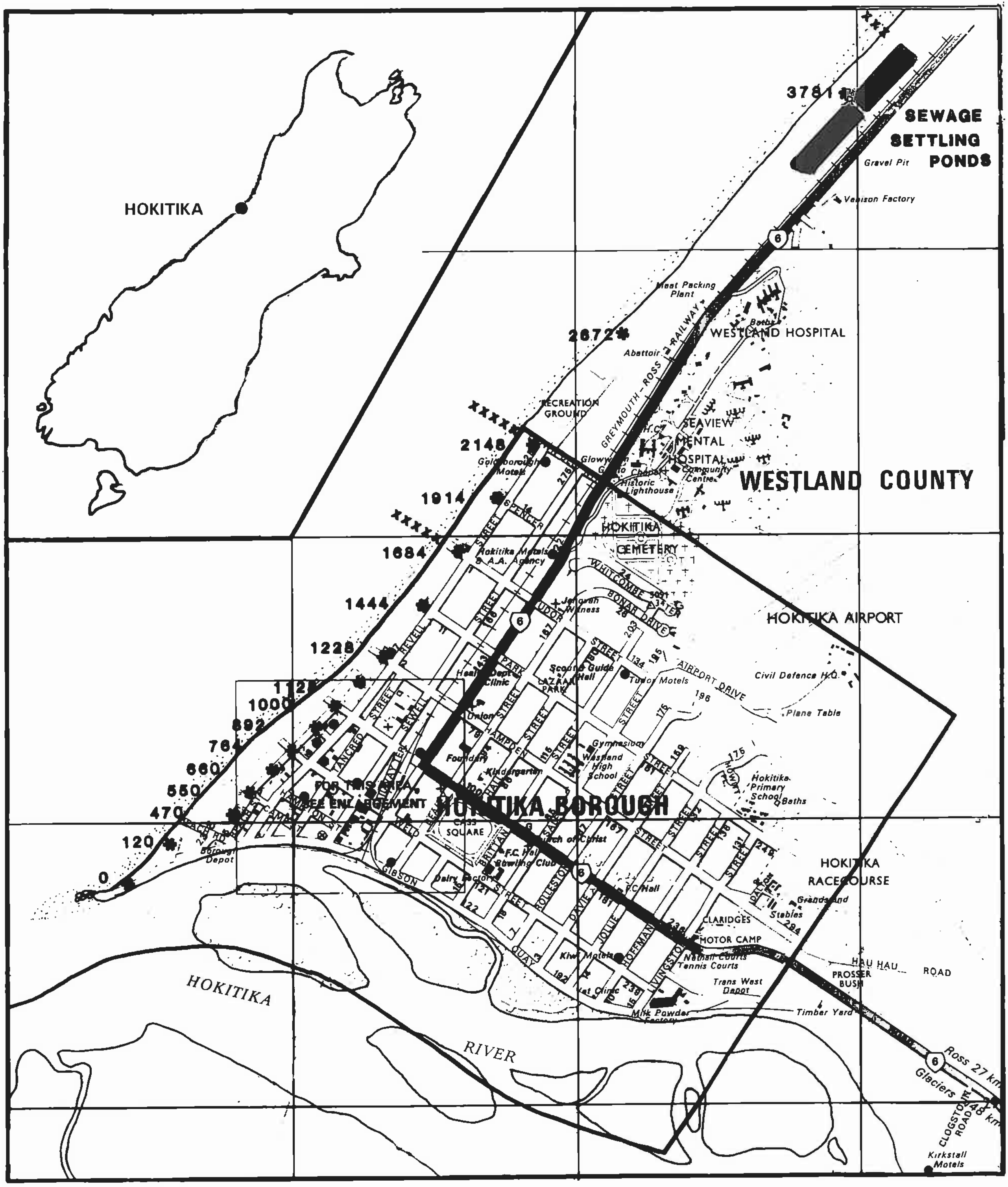


FIGURE 1: Sketch map showing the location of Hokitika Borough and 16 Westland Catchment Board beach-profile sites between the Hokitika River mouth and the sewage settling ponds. Numbers are distances in metres of each profile site north of the river mouth profile. Lines of crosses normal to the coast represent the approximate positions of the proposed groyne field.

SUMMARY

A Coastal Hazard Management Plan is proposed for Hokitika Borough to combat the severe hazards of erosion and flooding from the sea that have affected parts of the borough since 1866. The Management Plan recommends an integrated combination of planning, engineering and soil conservation measures to effectively prevent, mitigate and avoid the effects of coastal hazards on property and assets during the entire period of their structural useful life (1986-2100 AD). The plan is based on a Coastal Hazard Zone (CHZ) comprising Extreme, High and Moderate Risk Erosion Zones and a Moderate Risk Flooding Zone. The 60 to 200 m wide Extreme Risk Zone is subject to severe phases of episodic erosion that occur once every 10 to 30 years. The 0 to 30 m wide High Risk Zone is subject to long-term sea erosion resulting from a predicted 0.6 m rise in sea-level by 2050 AD, and the 0 to 50 m wide Moderate Risk Zone is subject to long-term sea erosion resulting from a predicted 1.5 m rise in sea-level by 2100 AD. The 300 to 800 m wide Moderate Risk Flooding Zone is subject to both inundation from steadily rising ground water in response to the predicted sea-level rise, and from wave overtopping of the foredune during short-term erosion phases.

About $5.2 million of commercial and residential beachfront property is in the Extreme and High Risk Erosion Zones, as is the entire foredune protecting Hokitika's sewage settling ponds from the sea. Residential properties on the east side of Revell Street are in the Moderate Risk Zone. The low-lying basin comprising the Moderate Risk Flooding Zone contains the entire central commercial area of Hokitika and parts of the industrial and residential areas. If no action is taken to either prevent, mitigate or avoid the effects of the identified coastal hazards then all the property and assets within the Hokitika Coastal Hazard Zone are likely to be damaged or destroyed within the period of their useful life.

Elements of both the coastal hazard mapping technique and Coastal Hazard Management Plan outlined in this study may be applied to unconsolidated sedimentary coastlines elsewhere.

INTRODUCTION

Hokitika Borough is located in Westland (Figure 1) on a low-lying fluvial outwash plain bounded by the capricious Hokitika River to the south and the stormy Tasman Sea to the west. Hokitika is the creation of the West Coast gold rush of the 1860s with the first subdivisions being made on the beachfront to the west of Revell Street in 1867, followed by further subdivisions in 1875, 1909, 1951, 1959 and 1974. There are now more than 260 beachfront properties bordering the 2.2 km long sand and gravel Hokitika Beach. The July 1986 capital value of these properties totals $5,192,400 of which $2,601,200 are commercial and $2,591,200 are residential (Mr J Cross, Hokitika Borough Engineer, pers. comm. 1986).

Early in 1983, beachfront residents at Hokitika became concerned at the increasing threat of sea erosion and the Westland Catchment Board (WCB) and Water and Soil Directorate of Ministry of Works and Development (MWD) were asked to investigate the problem and recommend possible solutions. Under the author's supervision coastal processes in the area were studied and relevant background information researched to provide the basis of this paper.

Under the Soil Conservation and Rivers Control Act 1941 and the Water and Soil Conservation Act 1967, WCB has a statutory function towards the prevention and mitigation of coastal erosion and damage by floods. Based on earlier recommendations by the writer WCB approached NWASCA for financial approval to construct rock groynes along the Hokitika foreshore (WCB 1986). The proposal was approved by NWASCA at its 7 October 1986 meeting and a 30% grant provided to meet the capital costs of the first stage of groyne construction. The local share of the costs was provided by HBC and the first stage of groyne construction commenced in November 1986. The groyne has proved successful (Figure 2).

In its decision NWASCA imposed two important conditions. Firstly, that technical approval to proceed with the remaining stages of groyne construction be based on an assessment of data gathered from monitoring the performance of the first stage of construction. Secondly, that WCB pursue with HBC the incorporation of a Coastal Hazard Zone into the Hokitika Borough District Planning Scheme, which became operative in 1980. The second condition involves the implementation of the July 1981 Natural Hazards Policy of NWASCA.

The Second Schedule, clause 8a of the Town and Country Planning Act 1977 states that the District Scheme shall provide for:

> ''The avoidance or reduction of danger, damage or nuisance caused by earthquake, geothermal and volcanic activity, flooding, erosion, landslip, subsidence, silting and wind.''

As will be shown later both erosion and flooding from the sea are the identified hazards threatening property and assets at Hokitika. Although the threat from coastal hazards has been known to the Hokitika Borough Council for some time, no reference is made to it in the operative scheme and the zoning pattern laid down by the scheme does not recognise the threat. In fact one of the primary planning objectives of the scheme is to maintain a compact commercial centre, seeking to encourage retail commercial development along Weld Street and part of Revell Street, areas prone to hazard.

In August 1986 the writer provided evidence on behalf of HBC to the Planning Tribunal, in Greymouth, in relation to coastal hazards at Hokitika. In their decision (C62/86) of September 1986 the tribunal noted that they were satisfied, ''that not only will engineering solutions have to be considered, but almost certainly land use planning solutions will have to be addressed and through the review process, debated and determined. This process will involve a detailed and significant consideration of the future direction and control of development for the whole of the Hokitika central business area''. The tribunal went on further to state, ''that the respondent (HBC) will have to give more comprehensive attention to its overall zoning pattern for the central commercial area if it is to deal effectively with the coastal erosion problem''.

Once a territorial authority has knowledge of the coastal hazards in its area, Section 274 of the Local Government Act 1974 makes it mandatory that the authority refuse to approve any scheme plan for a proposed subdivision if the land is subject to such hazards unless satisfactory provision has been made for the protection of such land from hazards such as erosion and flooding from the sea. By contrast, where the land has already been built upon, Section 641A of the Local Government Act 1974 gives territorial authorities discretionary powers to issue building permits on lands subject to natural hazards for the erection of relocatable buildings, other buildings ''consistent with the use and occupation of the existing building'', and for the alteration, restoration, or resiting of an existing building on such lands.

In the light of the above this paper describes and quantifies the coastal processes responsible for the coastal hazards at Hokitika, and defines a Coastal Hazard Zone which predicts the degree of risk to property and assets. Based on these assessments a Coastal Hazard Management Plan is proposed which encompasses planning, engineering and soil conservation solutions to prevent, mitigate and avoid the effects of erosion and flooding from the sea in the future. The Management Plan encompasses the entire period of the ''useful life'' of new buildings and services at risk which is assumed here to span the next century (1986-2100 AD). As will be shown the problem of coastal erosion and flooding will occur again and again and is quite likely to intensify during the next century.

All heights in this study are given in terms of either provisional mean sea level (MSL) Lyttelton datum, or the level of the highest high water spring tide (HHWS), which is about 1.2 m above MSL. The HHWS was calculated from the 1986 Nautical Almanac and Tide Tables for Hokitika River mouth using Westport as the primary port. Provisional MSL was provided by the Department of Lands and Survey, Hokitika District Office. The Department has yet to define MSL accurately for Westland, hence the use of the word ''provisional''.

THE PROBLEM

When geologic processes (erosion, landslip, flooding, sedimentation) modifying New Zealand's coastlines threaten life, property and assets they are termed coastal, or natural, hazards. The essence of the problem is not that the coastline erodes or is flooded, but that residential, commercial or industrial development has occurred within the hazard zone. In fact about 44% of New Zealand's 11,000 km-long

FIGURE 2: Photograph of rock groyne adjacent to Richards Drive. Sand has been trapped on the updrift (south) side to the left of the groyne raising beach levels and is bypassing northward through the structure. Photo by Paul McGahan, February 1987.

coastlines are unconsolidated sediments which are being intensely modified by coastal processes and the remainder is static hard rock (Gibb 1983). Hokitika Borough borders an unconsolidated sedimentary coastline and as the following published reports in early newspapers and the literature show, has frequently been subject to erosion and flooding from the sea and the Hokitika River since the Borough was founded in the 1860s.

Flooding from the Hokitika River was responsible for inundating low-lying parts of the Borough at least 33 times between 1920 and 1953 (Figure 3) with depths ranging from 0.3 to 1.2 m (3 to 4 m above MSL). The worst recorded flood occurred on 20 February 1935, when houses and business premises were flooded to a depth of 1.2 m and an 18 m span of the Kaniere Bridge was carried out to sea (Cowie 1957). In the 1960s stopbanks were constructed to protect the town and the flood hazard potential of the Hokitika River was consequently reduced.

The 2.2 km long Hokitika foreshore, however, is presently unprotected. According to Sharp (1915), May (1964), newspaper reports and local informants, Hokitika was subject to erosion and flooding from the sea in 1866-1868, 1886, 1913-1914, 1943 and 1951-1953. The present phase of erosion intensified after about 1980, and in 1986 was still continuing. The reports graphically describe the intensity of the hazards and the damage that occurred.

During the 1866-1868 erosion phase, "the back slums of Revell Street were cleaned up in disastrous fashion when the breakers lifted shanties off their piles to new sites further up the beach and washed others out to sea" (May, 1964). "Heavy seas which rapidly succeeded each other . . . washed away every portable article at the rear of the houses, including fences, water-butts and closets, and several out-houses washed completely off their piles, and washing them to and fro like a plaything, until they were utterly smashed to pieces. Between Tudor Street and the Montezuma the waves made clean breaks over the street and tramway into the marshy ground leaving high billows of froth" (*Hokitika Evening Star*, 23 July 1868).

"Before one o'clock on Thursday morning the sea had swept away nearly all the outbuildings between Fowlers stables at the north end of Revell Street and Powells right-of-way. The first substantial building swept away was Tom McDonnell's stables" (*Hokitika Evening Star*, 24 July 1868).

The 1886 erosion phase was not so serious but damaged and destroyed the "back fences and

FIGURE 3: Photograph looking east along Hamilton Street, Hokitika, from the intersection of Tancred and Hamilton Streets, showing flooding. Photo (date unknown) published courtesy of the West Coast Historical Museum.

outbuildings at the back of Revell Street'' (*Hokitika Evening Star*, 2 October 1886).

During the 1913-1914 erosion phase (Figure 4), considered by Sharp (1915) to be the most severe, ''five fully furnished bedrooms were washed away at the rear of the Exchange Hotel. A large store belonging to Messrs McKay and Sons was reduced to matchwood on Wednesday night as it dropped with a heavy thud into the angry sea below. Huge curly breakers were breaking high up on the shore and so great was the force that just after 10.00 pm the end of McKays showroom was so undermined that it was carried down into the waves by its own weight and the breakers quickly cleared the room of its stock'' (*West Coast Times*, 9 April 1914). ''A number of waves washed into Revell Street yesterday. A local borough councillor suggested building a new Revell Street removed from the shore'' (*West Coast Times*, 20 November 1914).

During the 1943 erosion phase ''a heavy sea yesterday caused a considerable inroad to be made into the seashore at the end of Weld Street. Last night waves were pounding in very heavily, at times coming over the banks and . . . a total of six feet of old tennis court crumbled into the sea'' (*The Guardian*, 16 June 1943).

Causes

Some of the factors thought to have contributed to the above phases of erosion are described by Sharp (1915), May (1964) and the early newspaper reports as follows:

1 The Hokitika River ''being forced back by the action of the sea'' to run parallel with the beach ''for some distance, preventing the accumulation of sand and gravel and giving assistance to the breakers''. [1866-1868; 1886].

2 A ''combination of northerly or northwesterly gales and high spring tides''. The Hokitika shoreline is fully exposed to gales from both quarters which generate a southerly drift whereas the shoreline is protected in part from southwesterly winds by offshore river mouth bars. [1866-1868; 1886; 1913-1914; 1943].

3 Removal of ''shingle and driftwood from the beach'' which many consider help to bind the beach. [1886].

4 Lack of any big floods in the West Coast rivers to supply sand and gravel to the beach, hence they were starved. [1913-1914].

5 The Hokitika River arresting or diverting the northerly littoral drift from reaching Hokitika on the lee side of the river. [1913-1914].

6 Seaward extension of the Hokitika River training works in 1913 trapping beach sediment against the south mole consequently starving the Hokitika beach. [1913-1914].

FIGURE 4: Photographs showing the impact of the 1913-1914 erosion phase on property and assets west of Revell Street near Weld Street. Despite such damage development has continued further seaward in the same area during periods of accretion. Top photo looking north; bottom photo looking south. Photos by Ben Thiern, April 1914, published by courtesy of the West Coast Historical Museum.

Despite previous losses of property and assets to the sea along the Hokitika beachfront, the problem has continued because both commercial and residential development has been permitted west of Revell Street. The present phase of erosion has been compounded by the extraction of about 158,000 m^3 of sand and gravel off the Hokitika Beach between 1960 and 1983, with 60,000 m^3 being extracted between 1974 and 1975 and 22,500 m^3 between 1980 and 1983 (Hokitika Borough Council, pers. comm. 1984).

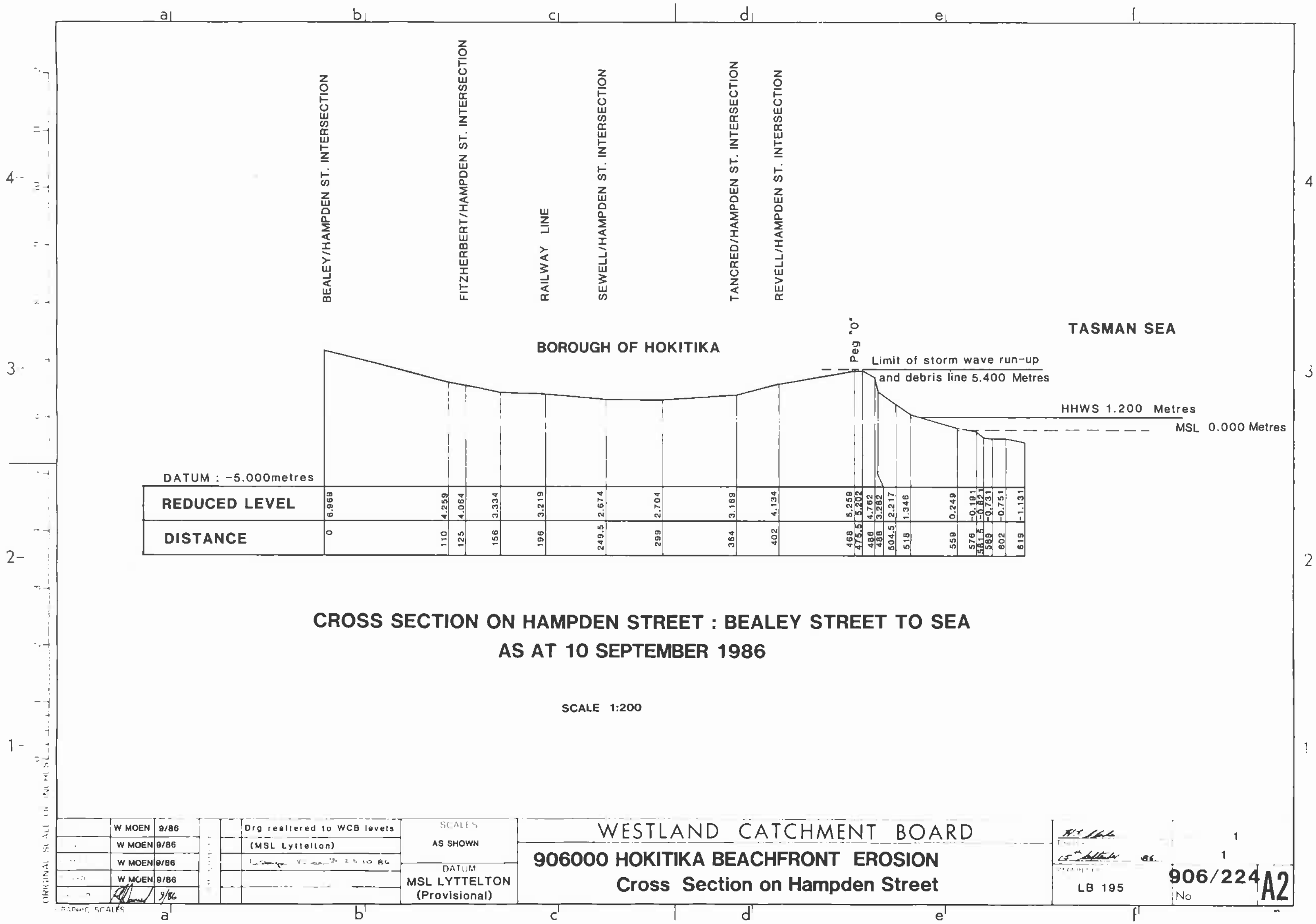
GEOLOGY

Hokitika Borough is situated on late Quaternary aged terraces composed of alluvial and coastal sediments. The northeastern part of the Borough is located on a high gravel terrace capped by loess, tapering in height from about 45 m above MSL at Hokitika Airport to about 15 m at the seaward edge. The terrace is thought by Brown et al. (1985) to have formed during the last Glaciation between 25,000 and 70,000 years ago. It has been truncated along its western edge by a stranded postglacial seacliff abandoned by the sea about 6500 years ago.

The western part of Hokitika is located on a low coastal terrace which tapers in width northward from about 500 m at Hokitika to about 200 m at the sewage settling ponds (Figure 5). The terrace is of Holocene age and is thought to have formed over the last 6500 years since the culmination of the postglacial marine transgression and the cutting of the postglacial seacliff. It lies west of Bealey Street and State Highway 6 (Figure 1) and is composed of gravel beach ridges overlain by dune sands, separated in places by organic peaty deposits and river silts.

Figure 6 is a typical cross-section across the coastal plain along Hampden Street (Figure 1) and shows that the western part of the town is located in a low-lying basin, rimmed by sand and gravel barrier beaches to the seaward (west) and landward (east) sides. The seaward barrier comprises the present-day beach ridge/foredune and ranges in height from 4.3 m above MSL at Beach Street to 6.0 m at Richards Drive, averaging 5.2 m. The landward barrier is a stranded beach ridge averaging 7.0 m above MSL. The low-lying basin averages only 2.6 m above MSL, ranging from 2.4 m to 2.7 m, and rises in height toward Park Street. Groundwater levels within the basin are controlled by the Hokitika River to the south and sea-level to the west and are generally 0.3 to 0.6 m below ground surface (about 2 m above MSL).

FIGURE 5: Photograph looking north from Hokitika towards the sewage settling ponds in the middle distance with State Highway 6 to the right of the ponds. Note the high terrace and post-glacial seacliff east of the highway and the narrow Holocene coastal plain to the west. Photo by J G Gibb, July 1986.



REDUCED LEVEL	6.969	4.259	4.064	3.334	3.219	2.674	2.704	3.169	4.134	5.259	5.202	4.762	3.282	2.217	1.346	0.249	-0.191	-0.821	-0.731	-0.751	-1.131
DISTANCE	0	110	125	156	196	249.5	299	364	402	468	475.5	486	488	504.5	518	559	576	581.5	589	602	619

FIGURE 6: Diagram showing a representative cross-section along Hampden Street between the September 1986 beach and Bealey Street. MSL intersecting the beach is provisional Lyttelton datum determined between 1918 and 1933. HHWS is the position of Highest High Water Spring tides as determined from the New Zealand Nautical Almanac, MOT, 1986.

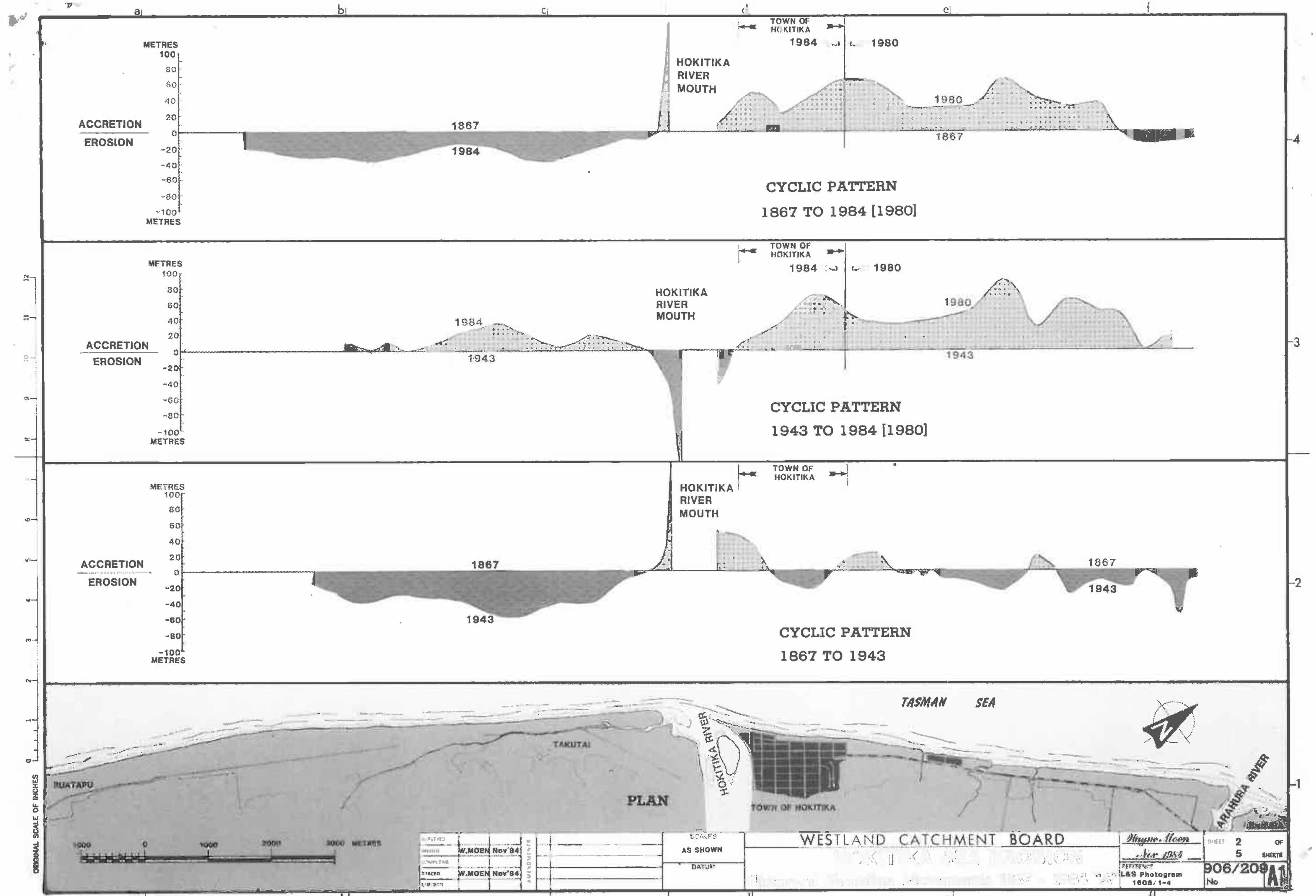


FIGURE 7: Diagram showing long-term historic shoreline trends (1867-1984) between Ruatapu and the Arahura River mouth. Diagram is compiled from Department of Lands and Survey Aerial Plan No 1608 Sheets 1 to 4.

Figure 6 also shows that storm wave runup levels typically reach 5.4 m above MSL which is 1.8 m above the average height of the basin. Should the seaward barrier be breached or lowered by erosion then the basin will be flooded by the sea, such as occurred during the erosion phases of the 1860s and 1910s.

COASTAL PROCESSES

Historic Shoreline Movements

Both long-term shoreline trends and short-term fluctuations were determined from; 1:5000 and 1:2000 scale planimetric maps prepared by the Photogrammetric Branch of the Department of Lands and Survey; cadastral surveys dating from 1867; vertical sequential aerial surveys dating from 1943; MWD Greymouth Residency surveys (1878-1963); early newspaper reports (1868-1943); published work (Bell 1909; Sharp 1915; May 1964; Gibb 1978, 1985a); 14 Westland Catchment Board (WCB) beach profile sites surveyed approximately monthly since June 1983, and from local informants. Figures 7 to 14 and Table 1 summarise the findings.

Long-Term Trends

Figure 7 shows shoreline movements between 1867 and 1984 along 12 km of coastline between Ruatapu and the Arahura River mouth. South of the Hokitika River mouth there was a net retreat over this 117 year period averaging about 25 m (−0.21 m/year), with a maximum movement of 40 m (−0.34 m/year). North of the river mouth, however, there was a net advance over the same period averaging about 40 m (0.34 m/year), with a maximum of 65 m (0.56 m/year). Between 1867 and 1943 there was a net retreat up to 60 m (−0.79 m/year) south of the mouth compared to differential advance and retreat up to 50 m (0.66 m/year) to the north. Between 1943 and 1984, however, the trend reversed and there was a net advance up to 35 m (0.85 m/year) to the south and up to 90 m (2.2 m/year) to the north. Figure 7 shows that shoreline fluctuations are greater adjacent to the Hokitika River mouth.

South of Hokitika River mouth aerial photographs reveal belts of sand dunes on the 0.4 km wide coastal plain striking the present eroding coastline obliquely at 5° (Figure 8). The strike of the truncated dunes suggests that there has been a clockwise realignment of the southern coastline from 027°T to 032°T (True North). North of the river mouth dune belts generally parallel the present coastline. These observations suggest that south of the Hokitika River mouth the coastline is presently out of equilibrium and is retreating in the long-term whereas to the north the coastline may either be advancing or in a state of dynamic equilibrium.

For the 2.2 km long coastline of Hokitika Borough, Table 1 shows average long-term net rates of accretion of 0.6 m/year between 1867 and 1986, ranging from 0.08 m/year up to 1.34 m/year. These results compare well with data in Gibb (1978) which shows a net accretion rate of 0.61 m/year at Hokitika between 1867 and 1975.

Short-Term Fluctuations

Short-term fluctuations of the Hokitika shoreline were determined both from 23 coastal surveys made between 1867 and 1986 and ongoing WCB beach profile surveys made since 1983. Data are summarised in Table 1 and Figures 9 to 12. Although the data base is one of the best in New Zealand, the graphs in Figure 9 highlight a major limitation. They do not allow for shoreline fluctuations that may have occurred between surveys. The limitation is revealed when comparing short-term fluctuations at Beach and Weld Streets where there are 20 surveys with those at Hampden Street and Richards Drive (Figure 9) where there are 11 surveys (Table 1). No significant shoreline fluctuations are evident at the two former streets prior to 1943, whereas at the two latter streets, there are considerable fluctuations. The differences may be explained by a lack of data. Despite the data limitations, Figure 9 highlights several important points:

1 A coastline fluctuating about a mean position (a state of dynamic equilibrium) is indicated for Hokitika rather than a long-term trend of advance from accretion.

2 Short-term erosion at Hokitika occurred in the 1860s, 1880s, 1910s, 1940s, 1950s and 1980s indicating episodic intervals of 20, 30, 30, 10 and 30 years respectively. The 1886 erosion described in the *West Coast Times* of 2 August 1886 is not recorded by a coastal survey. However, the magnitude of the erosion described by early newspapers for 1866-1868, 1913-1914, 1943 and 1951-1953 is recorded by surveys.

3 The worst phase of erosion occurred in the 1910s with successive phases progressively becoming less intense.

4 Short-term accretion occurred in the 1880s, 1930s and 1970s.

5 The amplitude of the erosion-accretion cycle at Hokitika diminishes northwest from 200 m at Beach Street to 80 m at Hampden Street to 70 m at Tudor Street to 60 m at Richards Drive.

6 During the erosion-accretion cycle extremely rapid short-term rates occur compared to long-term rates, with accretion up to 130 m/year and erosion up to 54 m/year.

7 Erosion-accretion peaks generally have a northerly offset along the 2.2 km shoreline indicating a northerly migration of short-term cycles of erosion-accretion.

TABLE 1 Long-term and short-term erosion-accretion data for 14 selected Westland Catchment Board (WCB) beach profile sites along the Hokitika foreshore. All measurements of accretion (+) and erosion (−) are in terms of WCB beach profile bench marks. ND = No data. Net rates are for entire survey periods which range from 1867-1986 for profiles 3 to 14 and from 1943-1986 for profiles 1 and 2.

	1 RIVER MOUTH	2 GRAVEL CRUSHER	3 BEACH ST. HOUSES	4 CAMP STREET	5 CENTRAL MOTORS	6 WELD STREET	7 SOUTHLAND HOTEL	8 STAFFORD STREET	9 STAFFORD ST. NORTH	10 HAMPDEN STREET	11 TUDOR STREET	12 RICHARDS DRIVE	13 MOSS FACTORY	14 SETTLING PONDS	DATA SOURCE
KM NORTH	0	0.2	0.47	0.55	0.66	0.764	0.892	1.00	1.128	1.228	1.684	2.148	2.672	3.781	
SURVEY YEARS															
1867	ND	ND	+24	+10	−9	−16	−2	+10	+20	+26	0	−13	−47	+20	AP 1608 A, B
1878.9	ND	ND	+13	+39	ND	+47	ND	ND	ND	ND	ND	ND	ND	ND	GR 1035
1880.7	ND	ND	+71	+79	ND	+85	ND	ND	ND	ND	ND	ND	ND	ND	GR 1358
1891	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	−14	ND	AP 1608 A, B
1911.8	ND	ND	+4	+40	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	GR 5133
1912.5	ND	ND	−13	+41	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	GR 5133
1914	0	0	−20	−30	−35	−45	−40	−35	−20	−20	−25	−20	ND	ND	Local Inform.
1914.83	ND	ND	−12	−25	−30	−33	−38	ND	ND	ND	ND	ND	ND	ND	AP 1608 B
1932	ND	ND	+75	+67	ND	+28	ND	ND	ND	ND	ND	ND	ND	ND	GR 5133
1933	ND	ND	+70	+56	ND	+66	ND	ND	ND	ND	ND	ND	ND	ND	GR 4725
1937	ND	ND	+64	+67	ND	−7	ND	ND	ND	ND	ND	ND	ND	ND	GR 5133
1943.5	+63	+66	+26	+20	+24	+20	+16	+11	+12	+7	−22	−14	−22	−20	AP 1608 A, B
1951.3	+12	+38	+33	+26	+15	+10	+20	+24	+26	+25	−8	−6	−14	ND	AP 1608 A, B
1958	ND	ND	ND	+33	+35	+30	+37	+42	ND	ND	ND	ND	ND	ND	AP 1608 A, B
1971	+36	+63	+88	+80	+76	+72	+70	+65	+63	+56	+33	+38	+20	ND	AP 1608 A, B
1979.4	ND	ND	+54	+70	ND	+64	ND	+52	ND	+44	+41	+25	ND	ND	N.Z.F.S.
1981.9	+14	+28	+51	+40	+36	+35	+35	+48	+45	+43	+24	+27	+7	ND	AP 1608 A, B
1983.6	+60	+27	+44	+35	+37	+38	+33	+45	+56	ND	ND	ND	ND	ND	WCB
1984.3	+22	+28	+20	+26	+36	+36	+42	+57	+58	+52	+45	+30	+6	ND	AP 1608 A, B
1984.8	+18	+14	+27	+15	+15	+20	+21	+37	+43	+37	+35	+18	+29	+49	WCB
1985.5	+82	+125	+125	+100	+90	+75	+50	+35	+22	+16	+26	+19	+44	+50	WCB
1985.9	+115	+135	+150	+145	+112	+75	+58	+45	+26	+11	0	+15	+15	+59	WCB
1986.8	+130	+155	+180	+170	+110	+85	+60	+70	+45	+35	-2	+6	+9	+35	WCB
CUMULATIVE DISTANCE (m)	+67	+89	+156	+160	+119	+101	+62	+60	+25	+9	-2	+19	+56	+15	
NET RATE m/yr	+0.56	+0.75	+1.31	+1.34	+1.0	+0.85	+0.52	+0.50	+0.21	+0.08	−0.02	+0.16	+0.47	+0.13	

FIGURE 8: Photograph looking south from about 1 km south of Hokitika, towards Mount Cook, showing belts of vegetated sand dunes on the Holocene coastal plain. Note the change in dune alignment. Photo by J G Gibb, July 1986.

Figure 10 shows the pattern of shoreline fluctuations along the Hokitika foreshore for six survey periods between 1867 and 1984 and for the entire 117 year survey period. Short-term fluctuations similar to those shown in Figure 9 are evident along the entire foreshore. However, for any survey period during the last 117 years differential movements are clearly evident. For example during the periods 1943-1951 and 1981-1984 short-term erosion was occurring at the southern end of Hokitika whilst short-term accretion was occurring to the north. Figure 10 reveals that the surveys were made at stages of the short-term cycle and may not have coincided with the accretion or erosion peaks.

The worst phase of erosion that occurred during 1913-1914 may have been intensified by human activity. According to Sharp (1915) the main causes of the erosion were firstly, the Hokitika River arresting or diverting the northerly littoral drift from reaching Hokitika on the lee side of the river, and secondly, extension of the river draining works seaward in 1913. The extension caused accretion against the south mole and a starving of the downdrift (Hokitika) shoreline. By May 1915, however, sand was bypassing the training walls (Sharp 1915). The timber mole on the true left bank (south) has since been destroyed so that this factor no longer poses a problem and has not contributed to the present erosion phase.

Figure 11 shows comparative cross-sections of the beach surveyed in 1914 by Sharp (1915) and in 1984 by WCB. The beach can be seen to extend some 70 m further inland in 1914 compared to the position in 1984.

Present Erosion Phase

Figure 12 shows the onset and progression of the present erosion phase which commenced in the late 1970s/early 1980s with the formation of an erosion trough at the southern end of the beach. The trough intensified opposite Beach Road in 1980 before migrating northward and further intensifying opposite Weld Street, peaking in 1984. By 1985 the erosion trough had migrated northward to lie opposite Stafford and Hampden Streets. From 1985 to 1986 erosion had spread northward to Richards Drive (Town Belt North) and beyond. Fortunately for the southern part of Hokitika, rapid accretion started to occur after 1984 (see Table 1) and by September 1986 the shoreline was as far seaward as has ever been recorded by surveys (see Figure 9).

Gibb (1985a) recorded erosion trough migrations northward of 310 m in 7 months (1980), 530 m in 12 months (1981), and 870 m in 8 months (1984/85) at rates between 44 and 109 m/month. Erosion rates of 10 m/month of the foredune adjacent to the trough were measured. Sharp (1915) and early newspapers

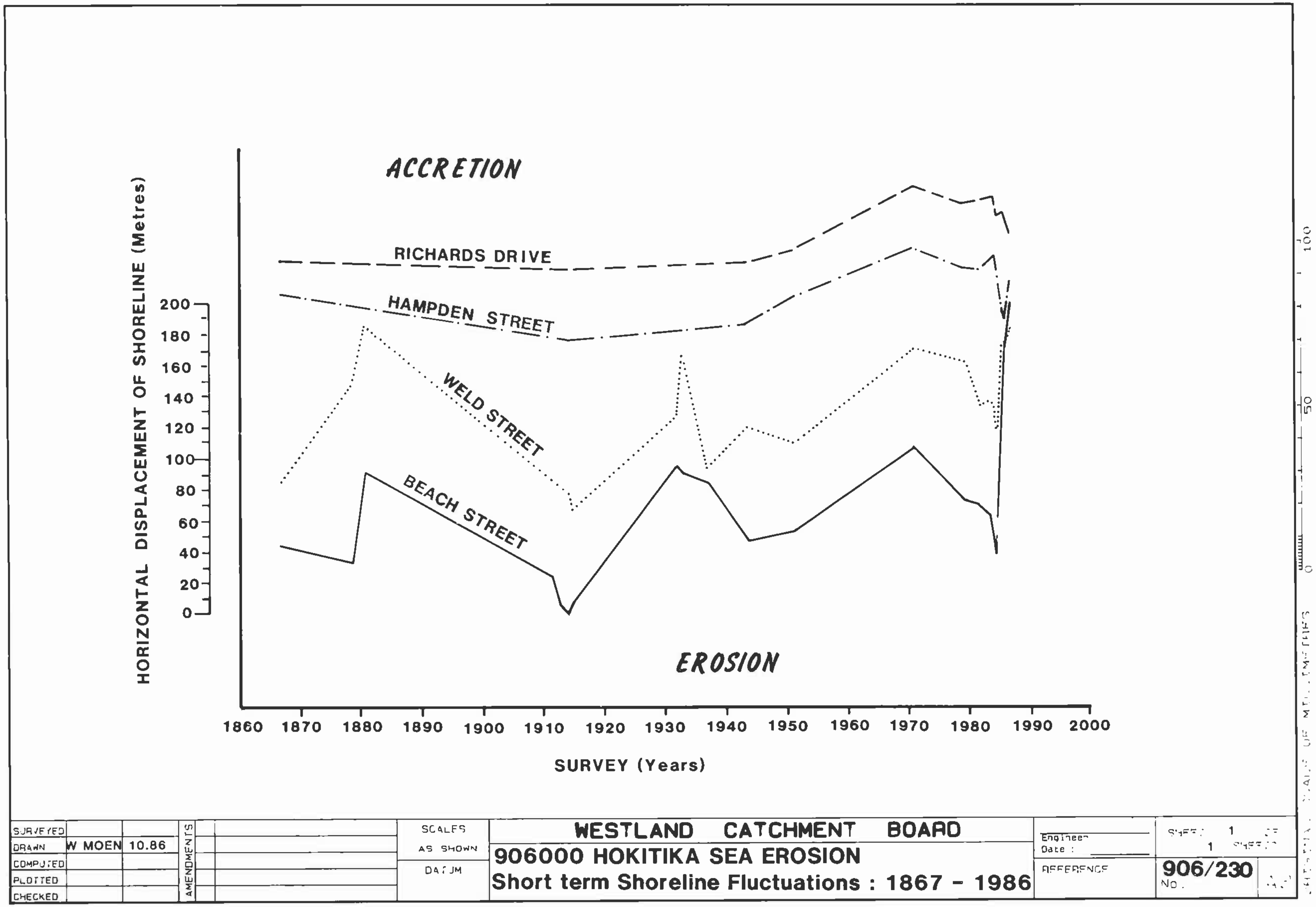


FIGURE 9: Diagram compiled from data in Table 1, showing the short-term episodic cycle of erosion and accretion at four representative sites along the Hokitika foreshore between 1867 and 1986.

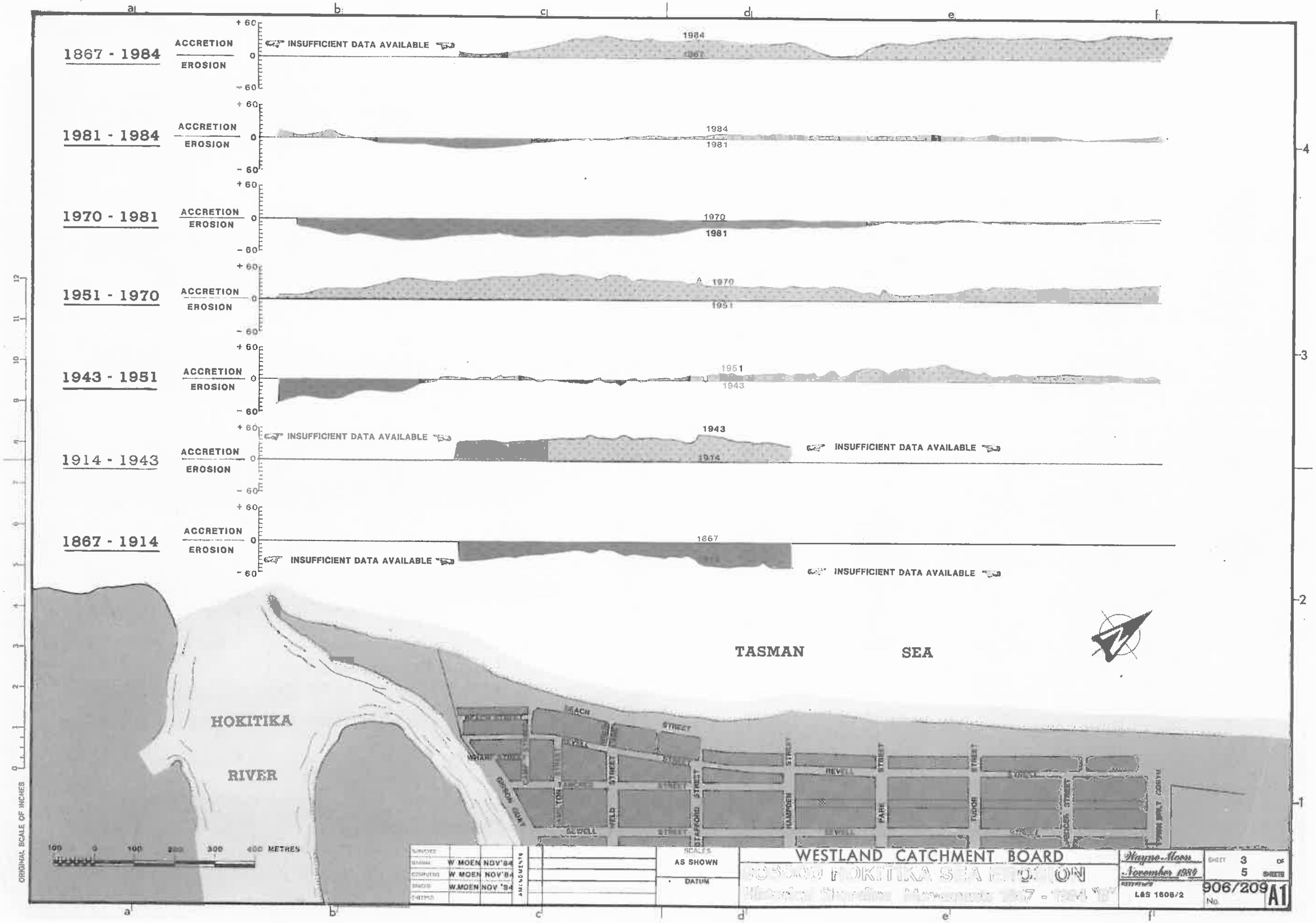


FIGURE 10: Diagram showing both long-term (1867-1984) and short-term fluctuations (six survey periods) of the Hokitika shoreline. Diagram is compiled from Department of Lands and Survey Aerial Plan No 1608 A&B.

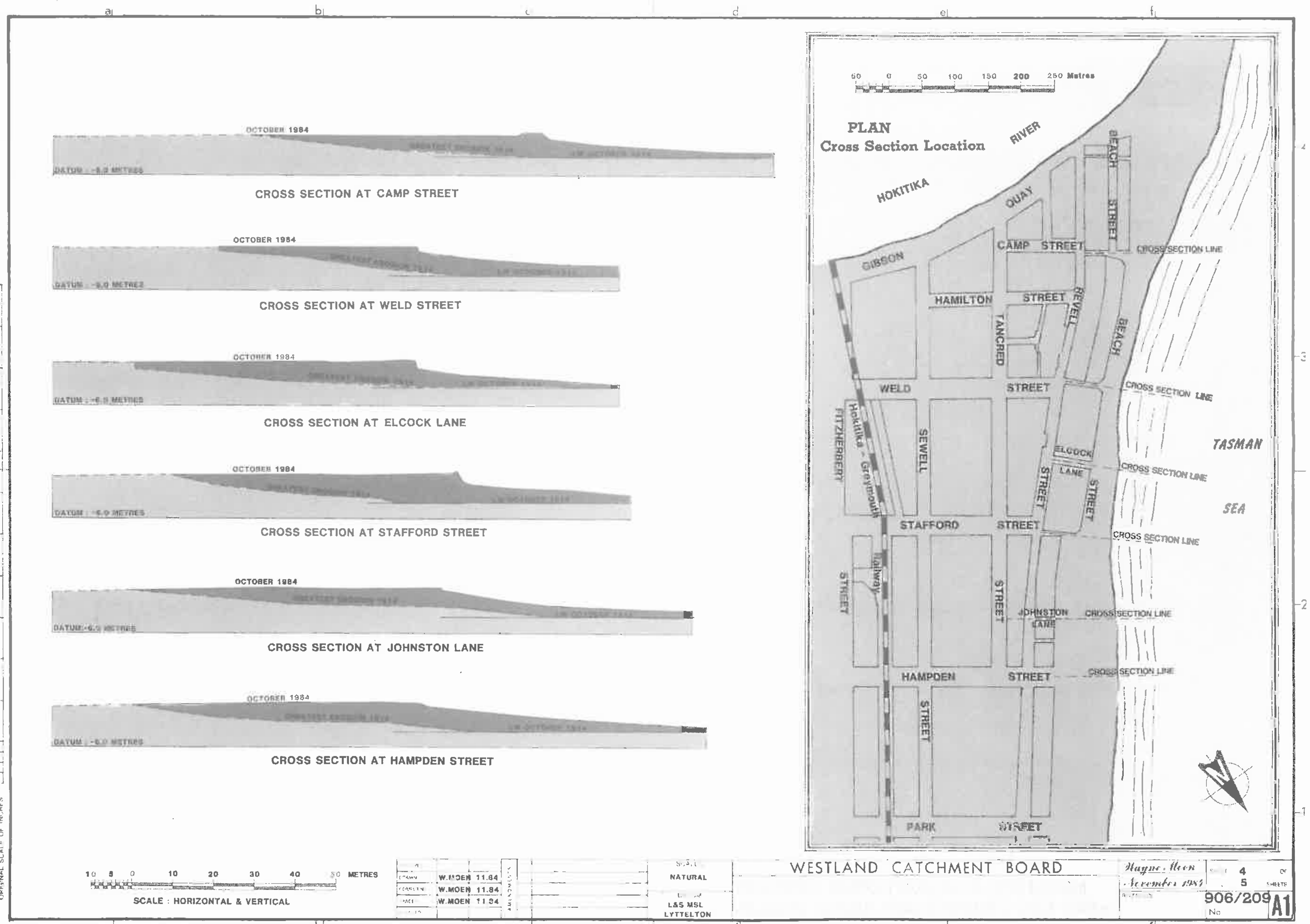


FIGURE 11: Diagram comparing positions of beach profiles after the 1913-1914 and 1983-1986 erosion phases along the south Hokitika shoreline. The October 1984 profiles were surveyed by Westland Catchment Board at exactly the same positions as the profiles surveyed by Sharp (1915) in October 1914.

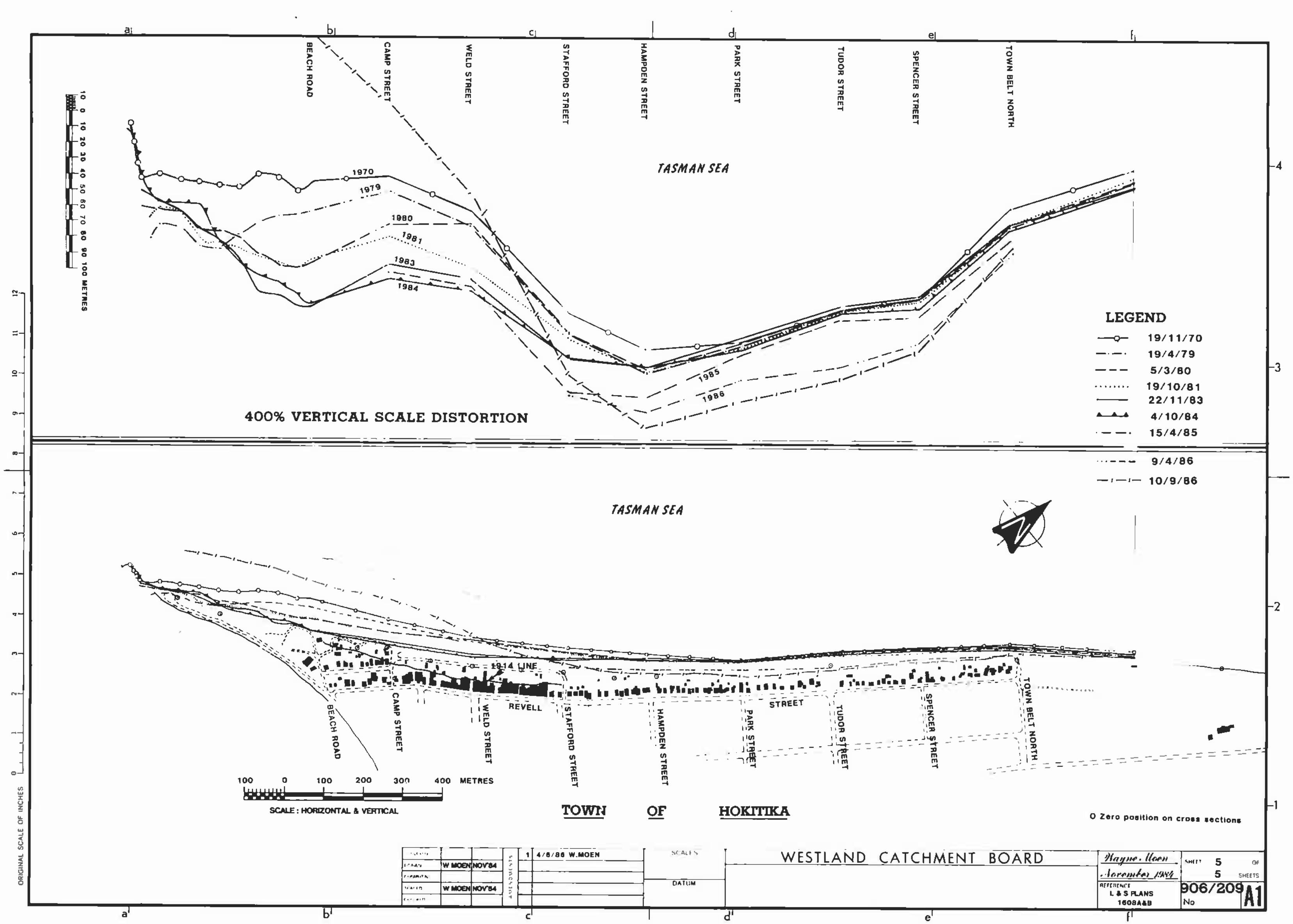


FIGURE 12: Diagram showing the onset of the present erosion phase at Hokitika in the 1970s, followed by the onset of accretion at southern Hokitika after April 1985. The diagram is compiled from both Westland Catchment Board surveys and from vertical sequential aerial photographs. The position of the 1914 erosion scarp is also indicated.

report similar patterns, with the trough migrating along the entire 2.2 km Hokitika foreshore before dissipating north of Richards Drive.

Figures 13 and 14 quantify beach-plus-dune erosion-accretion volumes above the level of approximate Mean Low Water Springs (MLWS). The volumes are minimum values as the erosion-accretion volumes of the nearshore seabed could not be quantified as beach profiling did not extend beyond MLWS. Figure 13 covers the 1.228 km long southern Hokitika foreshore between the Hokitika River mouth and Hampden Street, and Figure 14 covers both the 0.92 km long northern Hokitika foreshore between Hampden Street and Richards Drive and the 1.633 km long foreshore between Richards Drive and the sewage settling ponds to the north (see Figure 1).

By September 1986 the southern Hokitika foreshore had advanced by up to 160 m (Table 1), following severe erosion up to 65 m between the late 1970s and early 1984. Figure 13 shows that between June 1984 and September 1986 about 504,600 m^3 of sand and gravel accumulated at a net rate of 225,270 m^3/year. Despite changing wind and wave climate patterns during the 2.24 year period, deposition rates remained remarkably uniform, averaging 18,772 m^3/month, ranging from 4,660 m^3/month (May/June 1985) to 62,780 m^3/month (February/March 1985).

While accretion has been dominant along the southern Hokitika foreshore, erosion has dominated the foreshore north of Hampden Street (Figure 14). The most severe erosion occurred between December 1984 and September 1985 in the section between Hampden Street and Richards Drive, with the foredune retreating by up to 34 m (Table 1). During this nine month period about 175,790 m^3 of material was eroded at a net rate of 19,530 m^3/month, the rate ranging from 3,350 m^3/month up to 39,650 m^3/month (Figure 14).

Figure 14 shows that between December 1984 and April 1985 there was a three month lag before the onset of erosion between Richards Drive and the sewage settling ponds during which time about 85,000 m^3 of sediment was deposited along the 1.633 km long foreshore. However, between April and October 1985 about 156,970 m^3 of material was eroded at a net rate of 26,160 m^3/month.

Between September 1985 and September 1986 Figure 14 shows a reversal between Hampden Street and Richards Drive, from rapid erosion to a net accretion of about 9,150 m^3 of material. The decline in erosion along the northern Hokitika foreshore and the persistent accretion along the southern foreshore suggest that the present phase of erosion is migrating north to be replaced by accretion.

A comparison of accretion and erosion volumes for the lengths of foreshore shown in Figures 13 and 14 indicates a very close agreement in rates during the period December 1984 to September 1985. During this nine month period the rate of erosion along the shoreline between Hampden Street and Richards Drive (0.92 km) averaged 21 m^3/m/month (19,530 m^3/month) compared to a rate of accretion of 17 m^3/m/month (20,804 m^3/month) along the shoreline between Hampden Street and the Hokitika River mouth (1.228 km). The close agreement between erosion-accretion rates during the nine month period, suggests that the amount of sediment being transported and deposited on the Hokitika foreshore is equivalent to the amount being eroded and transported out. On this basis a net northerly longshore drift of beach sands and gravels above low tide level of 230,000 to 250,000 m^3/year is inferred. The volume is an absolute minimum as we do not know the volume of longshore drift taking place in the surf zone below low tide.

Influence of Hokitika River Discharge

Figure 15 shows sequential changes in the configuration of the shoreline about the Hokitika River mouth on 10 occasions between 1943 and 1984. The patterns revealed by the vertical sequential aerial photographs are:

1 A permanent updrift-seaward-offset of the shoreline about the mouth (Figure 16).

2 Oscillations up to 120° [255°-015°T] in the position of the discharge channel with time.

3 Erosion of the Hokitika shoreline is associated with a river discharge offset to the south and the southerly growth of a spit from the true right bank. As the southern shoreline accretes the Hokitika beach erodes.

4 Accretion of the Hokitika shoreline is associated with a river discharge offset to the north and the northerly growth of a spit from the true left bank. As the southern shoreline erodes the Hokitika beach accretes.

5 Accretion of both northern and southern shorelines is associated with river discharge straight out to sea.

6 During periods of both erosion and accretion the Hokitika beach has an uneven plan form composed of troughs and bars. The troughs are associated with beach erosion and the bars with accretion.

Both the Arahura and Totara River mouths north and south of the Hokitika respectively, have a similar configuration to the updrift-offset shoreline configuration at the Hokitika River mouth (Figure 16). According to Lynch-Blosse and Kumar (1976) such a configuration is caused by the outgoing flow of the river during ebb-tide acting as a "dynamic natural jetty". The long-term effect of the "jetty", or "semi-permeable

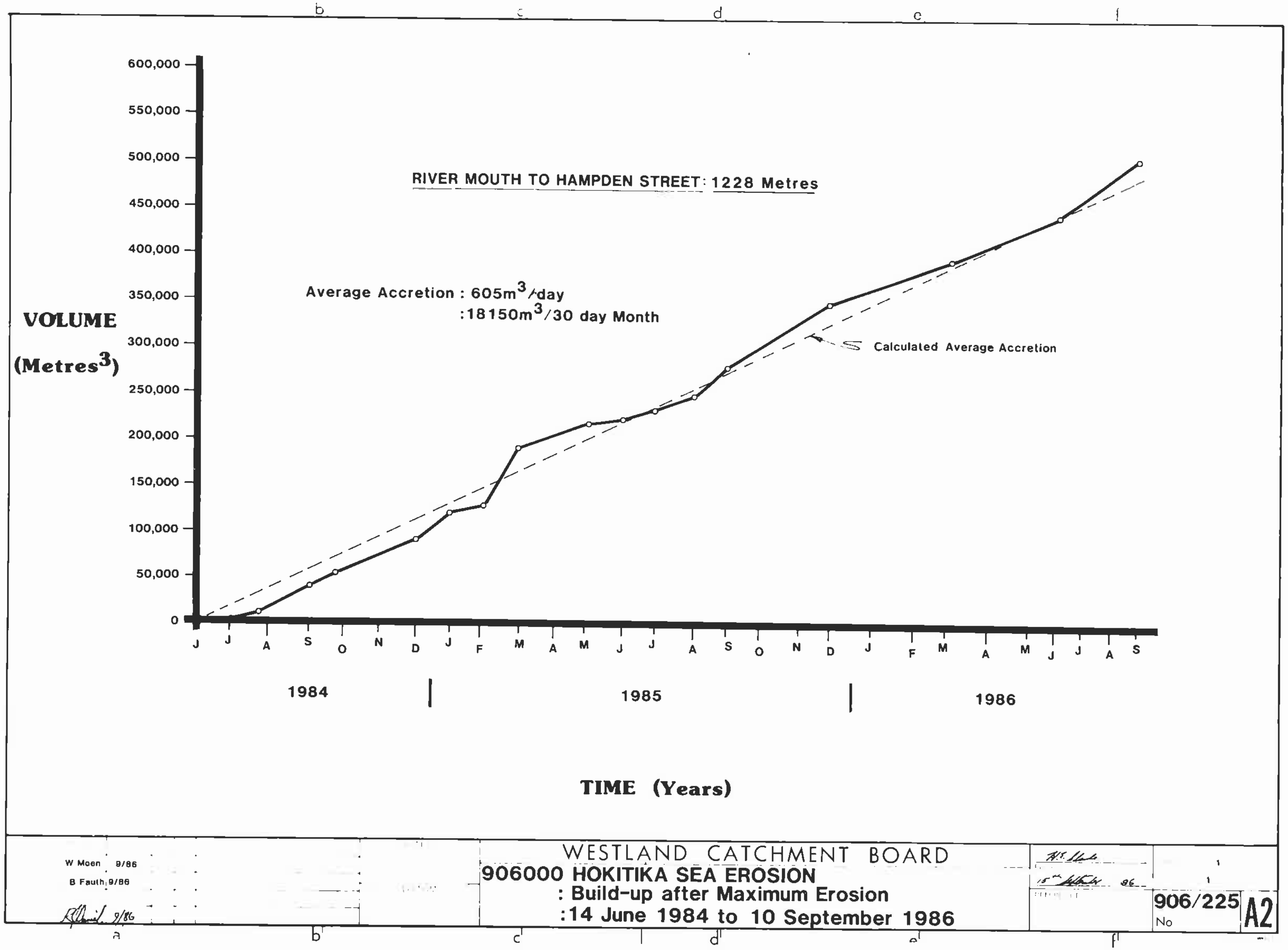


FIGURE 13: Diagram showing the rate of accumulation of beach gravels and sands above low tide mark, between June 1984 and September 1986, along the southern Hokitika shoreline between the river mouth and Hampden Street. The graph is compiled from monthly beach survey data by the Westland Catchment Board.

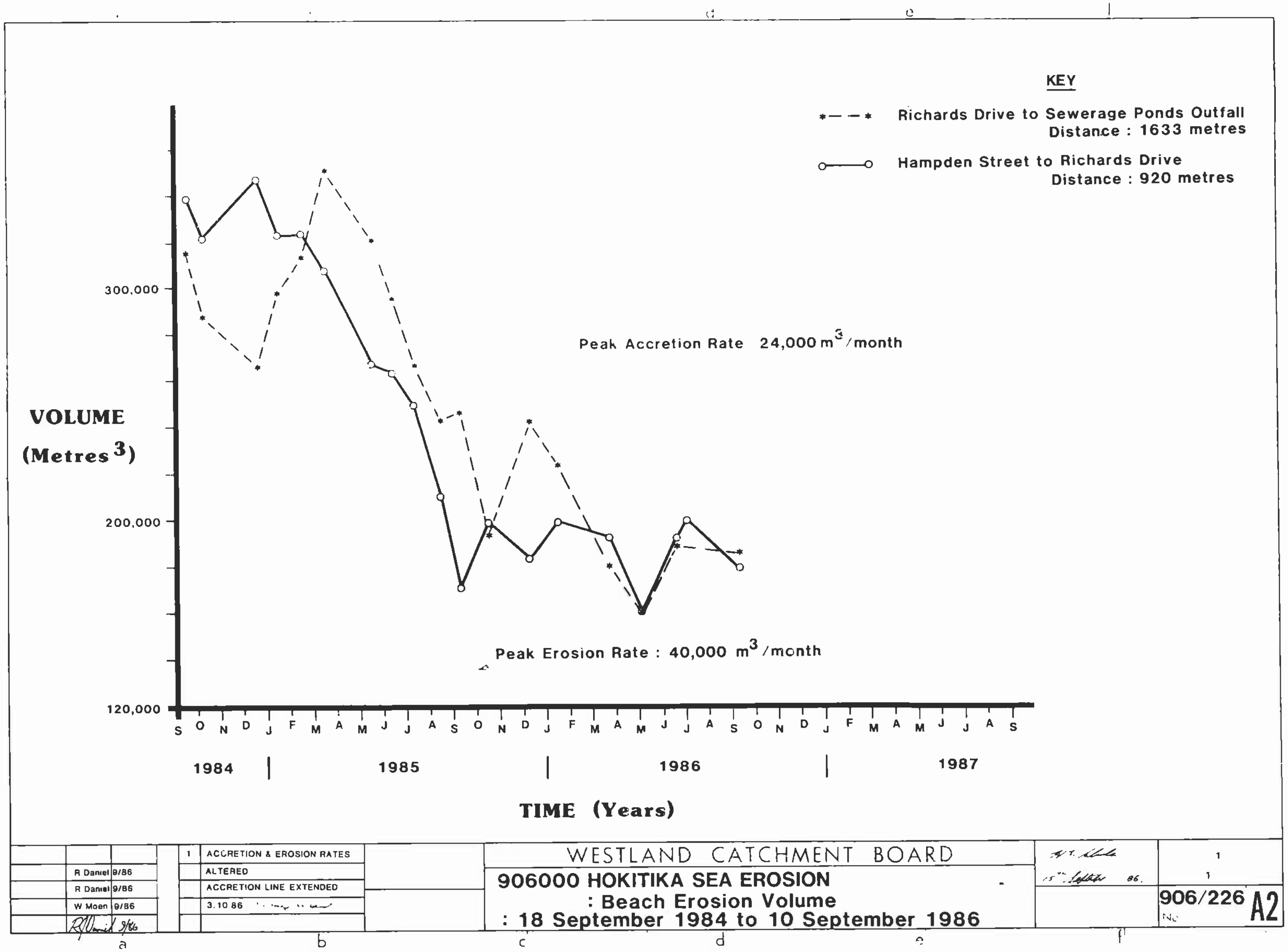


FIGURE 14: Diagram showing the rate of erosion of the beach and foredune above low tide mark, between September 1984 and September 1986, along the northern Hokitika shoreline between Hampden Street and Richards Drive and between Richards Drive and the sewage settling ponds. Graphs are compiled from Westland Catchment Board monthly beach surveys.

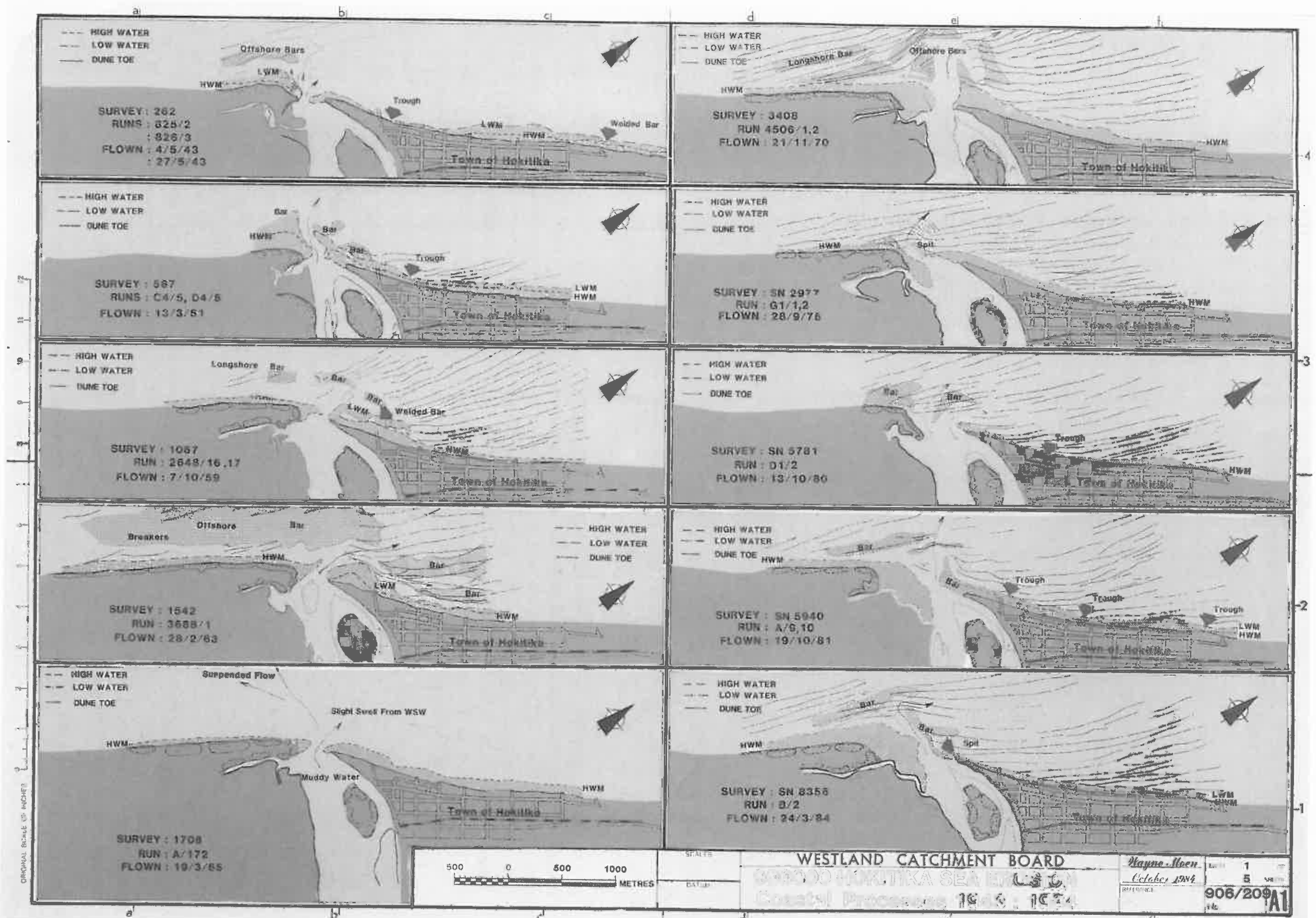


FIGURE 15: Diagram showing coastal processes operating around the updrift-seaward-offset Hokitika River mouth, including changes in mouth configuration between 1943 and 1984. Diagrams are from zoom transferscope plots from vertical sequential black and white aerial photographs. Net longshore drift is northeast. Offshore bars are inferred from breaking waves.

FIGURE 16: Photograph looking north towards Hokitika. Net (?) longshore drift direction is towards top of picture. Note the updrift-seaward-offset configuration of the Hokitika River mouth. Photo by J G Gibb, August 1984.

groyne'', is to trap longshore drift on the updrift side causing a periodic starving of the downdrift shoreline. In the case of the three rivers mentioned above the updrift shoreline is consistently the southern shoreline and the downdrift shoreline is to the north. Hence, a predominant net northerly longshore drift occurs between the Totara and Arahura River mouths.

Despite the long-term updrift-seaward-offset configuration of the Hokitika River mouth the oscillatory nature of the river discharge appears to have a pronounced effect on the adjacent beaches. Based on Figure 15 and observations made during the present short-term erosion-accretion cycle these effects may be summarised into three major situations (Figure 17). The situation of ''dynamic equilibrium'' (Figure 17) occurs when the river discharges straight out to sea and is common during and shortly after floods (Bell 1909). During dynamic equilibrium transverse bars comprising the sub-tidal delta are arranged symmetrically about the mouth and accretion of both the southern and northern shorelines occurs.

When the river discharge is offset south then it acts most effectively as a barrier to the net northerly drift. Sediment accumulates along the updrift (southern) shoreline thus starving the downdrift (northern) shoreline, causing erosion. The process is assisted by the ebb-tide jet from the river which forces sediment to bypass the river mouth further seaward. Sediment from the updrift shoreline that would normally bypass the mouth close inshore and feed the Hokitika shoreline, either accumulates on the southern side of the sub-tidal delta as bars, or bypasses the Hokitika shoreline completely before coming ashore north of the town.

When the river discharge is offset north then sediment bypassing occurs more efficiently (Figure 17) and the downdrift shoreline accretes (Figure 18). The net northerly drift of sediment bypasses the river mouth close inshore, combining with Hokitika River-derived sediment to form shoals and bars on the downdrift side of the sub-tidal delta. During the combination of flood tides, low swell conditions and low flows in the river the shoals migrate landward to weld on to the 800 m-long stretch of beach between the river mouth and Weld Street (Figure 18). Coarse sediment from the welded lobate bars is then distributed northward along the foreshore in slugs or pulses by longshore currents which become predominant along the Hokitika coastline about 900 m north of the river mouth opposite the Southland Hotel (Gibb 1985a).

Figure 15 suggests that the onset of the present phase of erosion at Hokitika began when the river mouth offset to the south in the mid 1970s. Sometime after

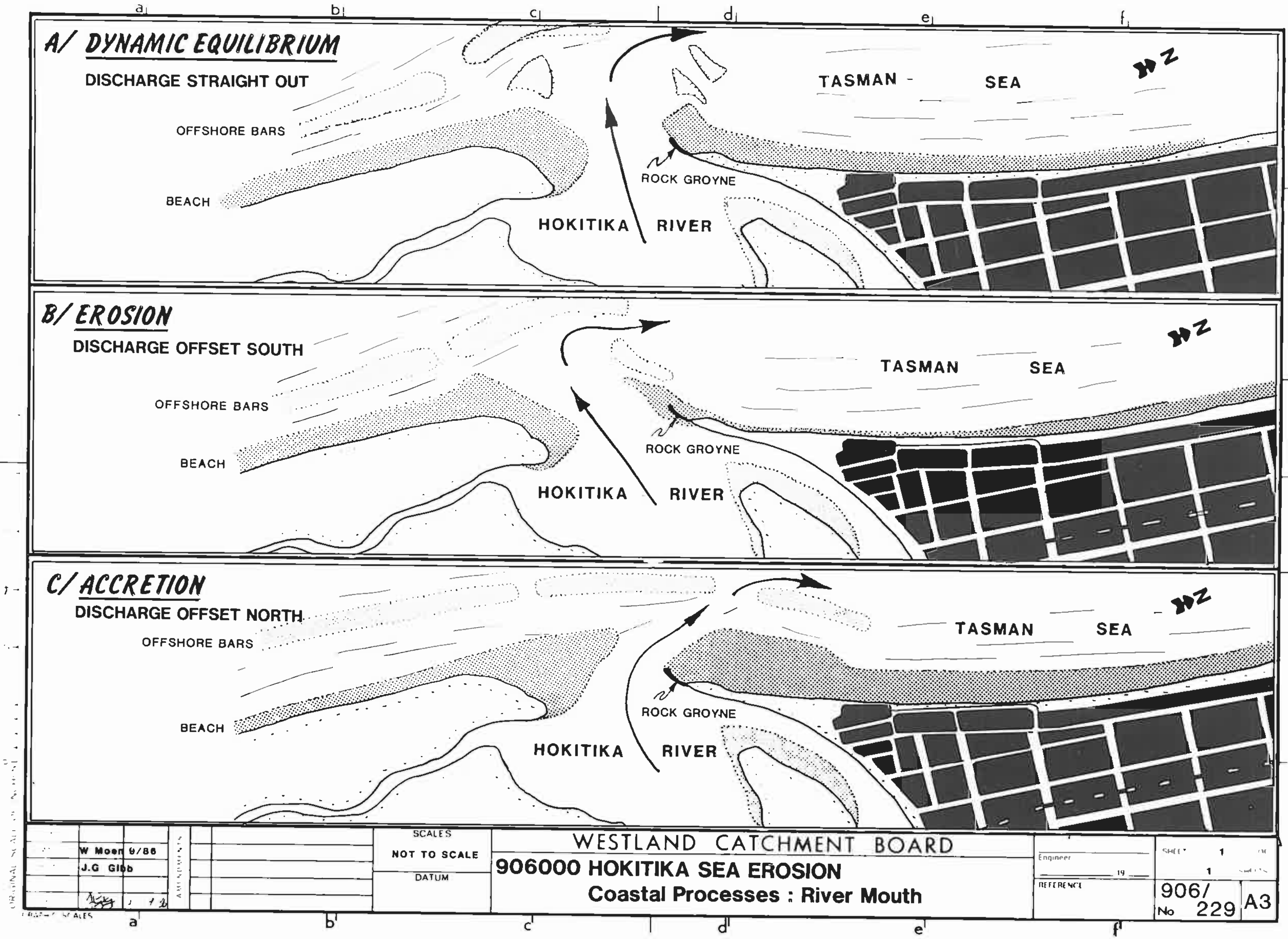


FIGURE 17: Conceptual diagram, based on Figure 15, of the three major positions of the Hokitika River mouth that affect the northern and southern shorelines. When the river discharge is straight out both shorelines are in equilibrium. When offset south, the northern shoreline erodes and southern shoreline accretes. When offset north, the northern shoreline accretes and southern shoreline erodes.

FIGURE 18: Photograph looking north showing the Hokitika River mouth with a northerly offset and accretion updrift (north) of the mouth. Breakers offshore from the accretion define bars migrating shoreward of sediment bypassing the river mouth. Note the erosion trough north of the accretion which is migrating north followed by the accretion. Photo by J G Gibb, March 1985.

March 1984 the river offset north and accretion began to occur immediately along the southern Hokitika shoreline (Figure 18).

Fitzgerald (1984) observed patterns similar to those occurring at Hokitika at Price Inlet in South Carolina. He described how the updrift orientation of both the ebb-tide channel and updrift skewed ebb-tide delta resulted in updrift accretion and downdrift erosion, whereas the downdrift orientation of the ebb-tide channel and downdrift skewed delta resulted in downdrift accretion and updrift erosion. He noted how the landward migration and attachment of bar complexes to the downdrift shoreline during flood tides and constructional waves was the dominant mechanism of shoreline accretion, a pattern observed at Hokitika. Fitzgerald also observed how the formation of bar complexes on the sub-tidal delta caused greater wave refraction resulting in a localised reversal in the net longshore transport direction in the protective lee of the delta, along the downdrift shoreline. The southerly growth of a spit from the true right bank of the Hokitika River to eventually produce a southerly offset of the discharge channel may have a similar cause.

Wave Climate and Longshore Drift

There is reported to be a strong net northerly longshore dirft along the South Island West Coast (Holmes 1919; Furkert 1947; Gibb 1979) especially at Hokitika (Sharp 1915). Evidence from natural gravel tracers consistently indicates that the net northerly drift is about 95% of the gross drift for many places along the West Coast (Gibb 1979). For the study area the following evidence supports the contention of a predominant net northerly drift.

The Hokitika coastline strikes SW-NE trending from about 032°T south of the Hokitika River mouth to 055°T between the mouth and Weld Street, to 035°T north of Weld Street. Deep ocean swell data for the period 1957-1980, tabulated in Reid and Collen (1983) and summarised as swell roses in Figure 19, show that 68% of all ocean swell observed from ships seaward of Westland approaches from 180° to 270°T (S-W), ranging from 61% in winter to 68% in autumn to 70% in spring and summer. Such a dominance in prevailing swell would generate a net northerly longshore drift from waves striking the shoreline at an oblique northerly angle. Figure 19 shows that only 19% of the swell approaches from 315° to 045°T (NW-NE); ranging

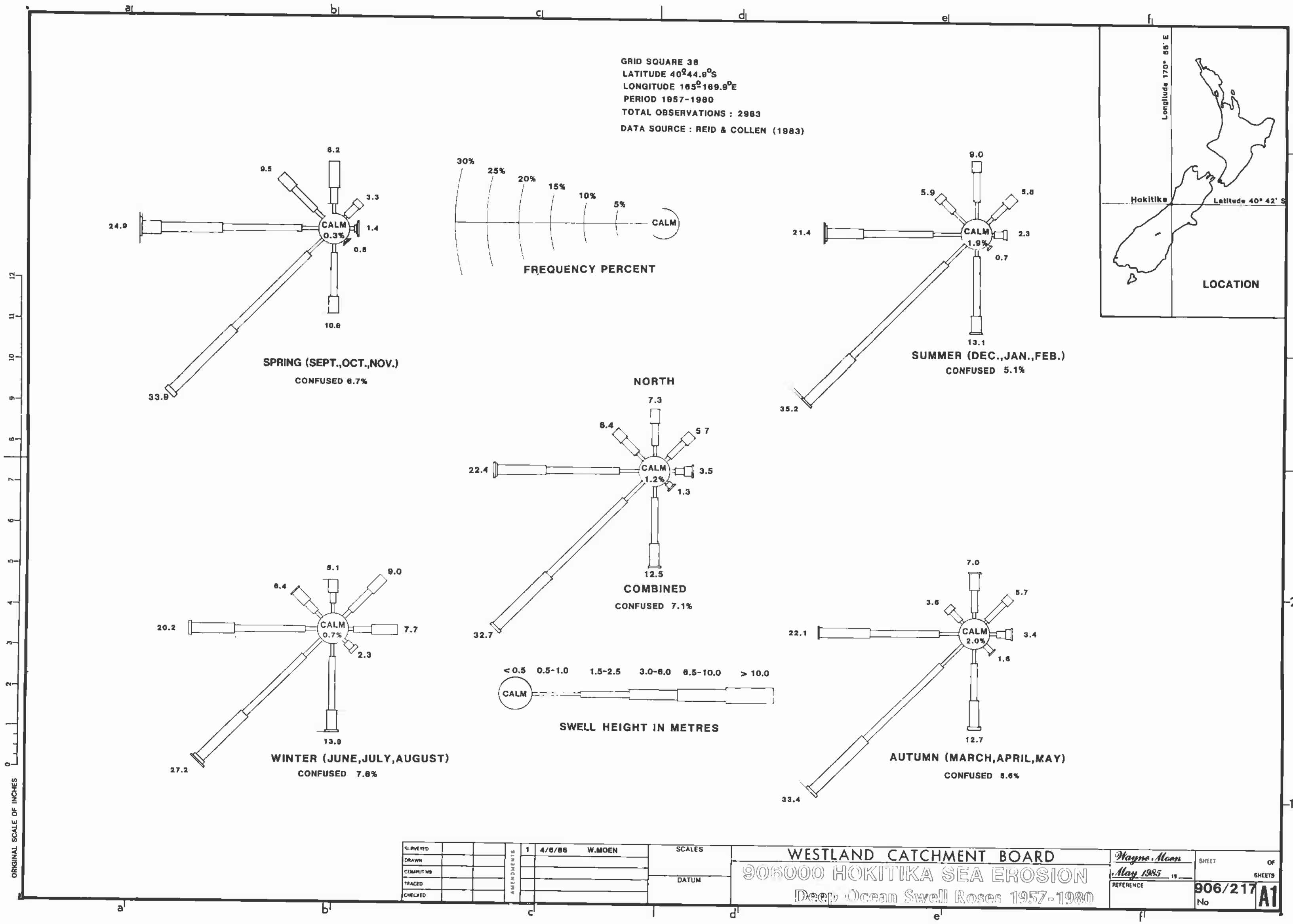


FIGURE 19: Diagram showing ocean swell roses for the sea area west of Hokitika, supplied from ships' observations made between 1957 and 1980. Roses were constructed from tabulated data in Reid and Collen (1983).

from 16% in autumn to 21% in winter, spring and summer. Such a swell suggests that a counter southerly drift would occur at Hokitika about 20% of the time.

Between 26 September and 11 November 1984 daily wave climate and longshore drift observations were made at five sites along the Hokitika foreshore adjacent to Camp Street, Stafford Street, Tudor Street, Richards Drive and the sewage settling ponds. The main object of the 48-day programme was to determine the pattern of longshore drift under a representative set of wave approaches.

Over the 48-day period 87, 87, 87, 85 and 91% of all breaking waves approached from SW-S for the above five sites respectively and 13, 13, 11, 13 and 9% from NW-N. For all but the Camp Street site 77 to 87% of the observations recorded a northerly drift, 4 to 13% a southerly drift, with zero drift occurring 9 to 14% of the time. Velocities averaged 0.58 to 0.75 m/s to the north and 0.23 to 0.53 m/s to the south. At Camp Street, however, the current flowed north for 54% of the time, south for 20% and had a zero drift for 26% of the time, the latter occurring mostly during wave approaches from the SW-S. The Camp Street site was opposite the sub-tidal river delta and the currents and wave patterns were modified by shoals and bars (Gibb 1985a). For all sites there was little evidence of a counter southerly drift being generated from waves approaching from the SW. However, for waves approaching from the NW-NE a northerly drift counter to the wave approach was observed for 30 to 50% of the time.

For a point 500 m offshore from Hokitika wave angles measured by Gibb (1985a) from 11 vertical aerial photograph surveys taken between 1943 and 1984 showed waves approaching from 283±7°T, with angles of incidence at the beach of 12 to 30° NE (Beach Street), 10 to 22° NE (Hampden Street) and 8 to 15° NE (Richards Drive). The high wave angles and longshore drift observations reveal a strong well developed northerly longshore current during SW-W seas, except in the lee of the sub-tidal delta between Camp Street and the Hokitika River mouth, and a counter drift during NW-N seas.

At Greymouth, Pfahlert (1984) recorded 63.5% of waves approaching from the SW-W over a 12 month period from the beach between April 1983 and March 1984, with 67% observations recording a northerly drift and 33% a southerly drift. The average velocities of these currents were 0.31 m/s to the north and 0.44 m/s to the south. Pfahlert's observations show remarkable agreement with the deep ocean wave approach data used in this study despite the difference in the periods of observation.

During November 1984 spar buoys placed in the Hokitika River were jetted out to sea beyond the surf zone. Measurements were made during an ebbing tide with 0.6 to 0.8 m-high SW-W swells and with river discharge offset to the north. Most buoys either returned directly to the beach between the mouth and Beach Road or circulated in a gyre in the same area before coming ashore. One, however, drifted 3 km north, parallel with the shore, just seaward of the sub-tidal delta shoals and longshore bar at velocities decreasing from 0.35 m/s to 0.19 m/s, averaging 0.22 m/s. The results indicate that during SW-W seas there is a net landward current occurring across the sub-tidal delta downdrift of the discharge channel and a river assisted northerly longshore current seaward of the longshore bar, which at the time lay about 100 m offshore.

Natural gravel tracers of serpentinite and nephrite (greenstone) occur in the Hokitika River and Arahura River 8.5 km north, but not in the Totara River, lying 16.7 km south of the Hokitika. In November 1984 observations were made of beach gravels every 2 to 3 km between the Totara and Arahura Rivers (25.2 km), and every 100 m either side of the Hokitika mouth for 1 km. Serpentinite and greenstone were found to extend along the entire beach between the Hokitika and Arahura Rivers (8.4 km), but only for a maximum distance of 600 m south of the Hokitika River mouth. Further observations of beach gravels in 1985 and 1986 revealed the same dispersion pattern of Hokitika River-derived gravels. These observations indicate that the net northerly drift of coarse sand and gravel at Hokitika is about 93% of the gross drift which is in close agreement with observations by Gibb (1979) elsewhere along the West Coast. Large waves of fine beach gravels and coarse sands separated by troughs of coarse lag gravels and angular boulders were also observed, indicating a pronounced net northerly drift of beach gravels in slugs or pulses along the Hokitika Beach north of Camp Street. The slugs of gravel were composed of rafts of very well rounded schist—quartz—granite populations and rafts of subangular to rounded greywacke—serpentinite—hornfels populations. The very well rounded gravels have most probably originated from the Totara River, having bypassed the Hokitika River mouth during net northerly transport. The subangular gravels have probably originated directly from the Hokitika River.

All these observations suggest that the net northerly longshore drift in the study area is about 90% of the gross longshore drift. The rate of transport of beach gravels and coarse sands above MLWS is of the order of 230,000 to 250,000 m^3/year to the north. The rate of northerly transport of medium and fine sand below lower tide level is not known, but calculations by Furkert (1947) suggest that the rate could exceed the beach transport rate by an order of magnitude.

COASTAL HAZARD ZONE (CHZ) ASSESSMENT

The study has identified the following coastal hazards most likely to damage or destroy property and assets within the Hokitika Borough during the period of their useful life:

1 Retreat of the foredune from sea erosion,

2 Inundation of property by the sea.

Before considering a Coastal Hazard Management Plan to combat the problem of the identified coastal hazards it is essential to quantify the degree of risk that property and assets within Hokitika Borough are likely to be exposed to, within the period of their useful life.

A Coastal Hazard Mapping (CHM) technique developed by the author (Gibb 1981; 1985b) is currently used in New Zealand to predict the effects of coastal hazards on property and assets within the period of their useful life. The concept and techniques were first developed during a study of natural hazards along the 147 km long Waiapu County coastline, North Island East Coast (Gibb 1981). The techniques have since been accepted at both central and local government levels and by the Planning Tribunal, and more than 600 km of the New Zealand coastline mapped. The most recent studies were of beachfront developments at Pauanui (Gibb and Aburn 1986) where about $15 million worth of assets are at risk, and at Riversdale (Gibb 1986) where about $4.08 million of beachfront assets are at risk.

CHZ Assessment Technique for Sea Erosion

Long-term trends of either shoreline advance, retreat or dynamic equilibrium may be discerned for most of the New Zealand coastline from survey and geologic data spanning the last several millenia. The process though is not regular along unconsolidated sedimentary coasts but takes place in a series of episodic short-term fluctuations (Figure 20) like those observed at Hokitika. Such movements are often unpredictable and are likely to occur within a period as short as one year (Gibb 1985b).

For each of the three trends shown in Figure 20, R is the net rate of accretion or erosion and S the maximum range of short-term fluctuations. Factor R varies according to influences such as fluctuations in sediment supply, changes in sea-level and modifications to the coastline and nearshore seabed. Factor S varies mostly according to the magnitude of either one or a cluster of severe onshore storms superimposed on the long-term trends.

Assessing the extent of any CHZ must take both R and S factors into account and consider whether the past trend is likely to continue unmodified into the future or reverse. Therefore, to define a CHZ we first need to ascertain whether Hokitika Beach has a history of erosion, accretion or dynamic equilibrium. Second, we must judge whether the past trend is likely to continue into the future or change. Third, we must establish the magnitude of storm-induced erosion.

To assess the extent of a CHZ for Hokitika the following equation of Gibb and Aburn (1986) is used where:

$$CHZ = [X + R]T + S \qquad [1]$$

Where X is the rate of shore retreat caused by sea-level rise, R is the long-term (historic) rate of erosion or accretion, T is an assessment period, and S is the maximum short-term erosion-accretion. The technique is based on the principles embodied in Figure 20 and predicts the likely position of the shoreline at specified times in the future.

To calculate Factor X, Gibb (1985b) and Gibb and Aburn (1986) have used the Bruun Rule (Bruun 1962; 1983) which states that "for a shore profile in equilibrium, as sea-level rises, beach erosion takes place in order to provide sediments to the nearshore so that the nearshore seabed can be elevated in direct proportion to the rise in sea-level" (Bruun 1962). Bruun (1983) determined the practical approximation of shoreline movement X to be:

$$X = \frac{\ell a}{h} \qquad [2]$$

Where X is the rate of shore retreat, ℓ is the length of profile of exchange, a is the rate of sea-level rise, and h is the maximum depth of exchange (closure depth) between nearshore and offshore sediments (Figure 21).

GREENHOUSE EFFECT AND RISING SEA-LEVEL

Solar radiation reaching the surface of the earth warms it to about 20°C. Within the first 10 to 15 km of the earth's atmosphere, the partial trapping of thermal radiation (infrared) from the earth by radiatively absorbing particles or molecules such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chloro-fluorocarbons and ozone helps to increase global temperatures (Dickinson and Cicerone 1986). The process is commonly referred to as the "greenhouse" effect and the gases as "greenhouse" gases.

Before the industrial revolution of the 1850s atmospheric CO_2 levels were 260 to 280 p.p.m.v (parts per million by volume) but have since risen to current levels around 340 p.p.m.v. (Raynaud and Barnola 1985; Pearman et al. 1986). At Baring Head, Wellington, New Zealand, a site representing some of the cleanest air conditions available anywhere on earth, the concentration of CO_2 has risen from about 325 p.p.m.v. in 1971 to about 344 p.p.m.v. in 1985 (Manning and Pohl 1986). Like CO_2 increases, atmospheric CH_4 levels have risen from a pre-industrial minimum of 0.8 p.p.m.v. to current levels around 1.6 p.p.m.v. (Stauffer et al. 1985, Dickinson and Cicerone 1986; Abelson 1986) and N_2O levels have risen about 9% since 1600 (Pearman et al. 1986).

Concurrent with the trend of increasing levels of

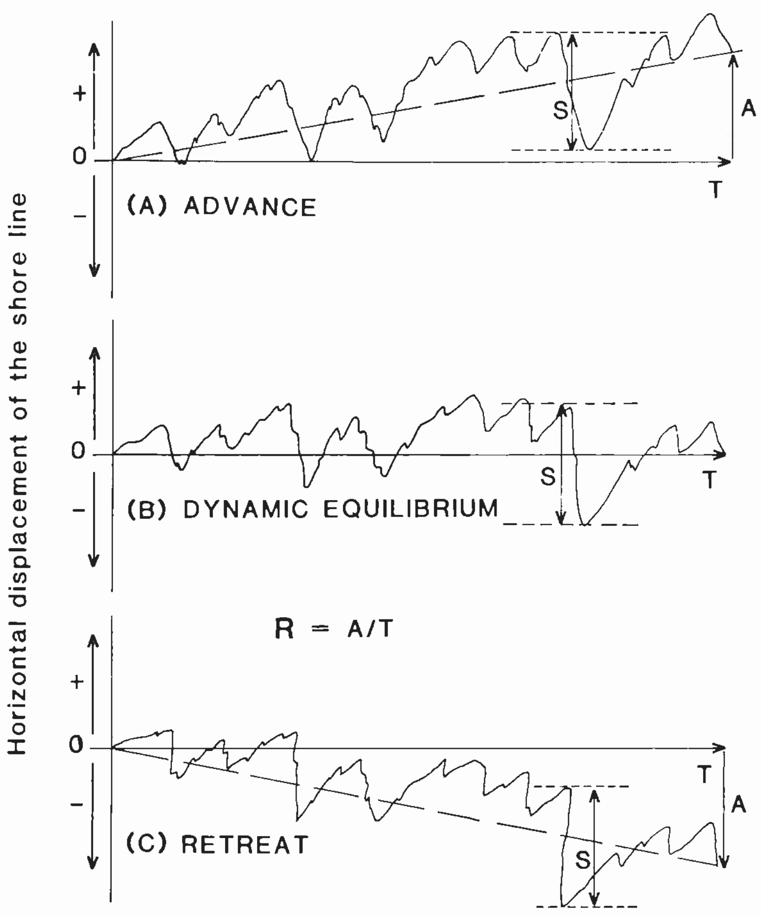


FIGURE 20: Diagrams showing short-term fluctuations, S, in the position of the shoreline (seaward toe of foredune), and long-term trend, R, where R is the net rate of movement in m/year calculated by dividing the horizontal distance, A, by the survey time interval, T. (A) is advance seaward from net accretion. (B) is fluctuating about a mean position indicating dynamic equilibrium. (C) is retreat landward from net erosion.

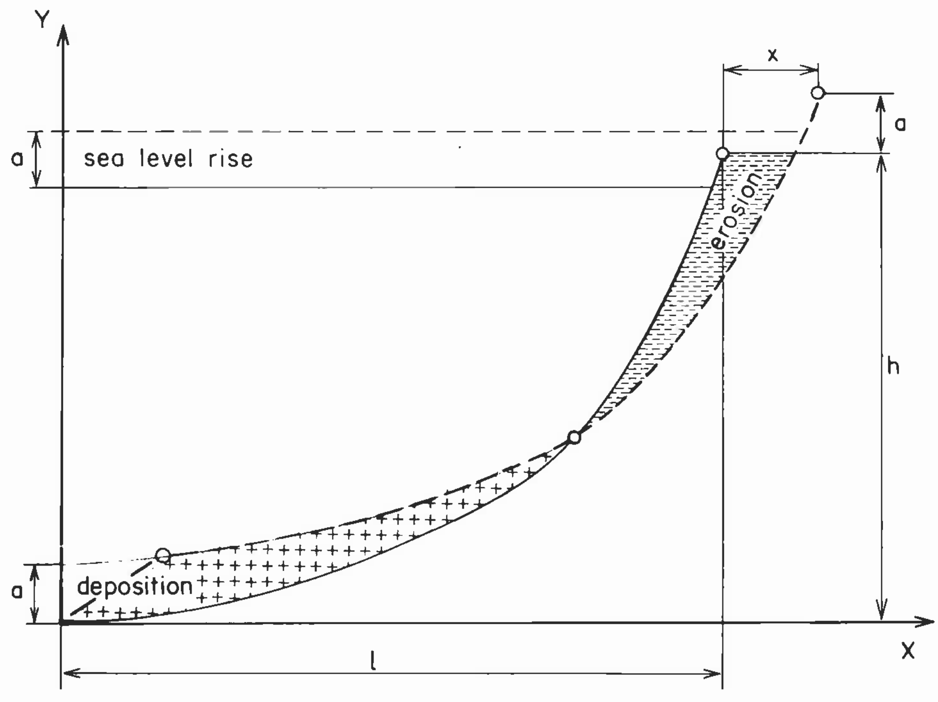


FIGURE 21: Diagram showing the Bruun's effect of translation of the beach profile during sea-level rise, resulting in shore erosion and deposition of sediments on the nearshore seabed (adapted from Bruun 1983, Figure 1). a=sea-level rise; h=limiting depth of beach sediments; l=distance to limiting depth; X=erosion amount.

''greenhouse'' gases over the last 100 years global mean temperature has risen about 0.6°C (Jones et al. 1986) and eustatic sea-level by 120 to 150 mm (Gutenberg 1941; Fairbridge and Krebs 1962; Gornitz et al. 1982; Barnett 1983). The most recent study by Barnett (1983) recorded a net rate of rise in global sea-level of 1.51 ± 0.15 mm/year since 1900 which accords with evidence from New Zealand (Figure 22). Most analysts now conclude that each doubling of atmospheric CO_2 is likely to generate an average temperature increase of 1.5° to 4.5°C with polar regions warming up by as much as 6° to 9°C. Doubling of CO_2 concentrations is predicted to occur between about 2030 and 2085 AD (National Academy of Sciences 1983; Wigley and Schlesinger 1985; WMO 1986). Increases of ''greenhouse'' trace gases such as CH_4 and N_2O during the next 65 years could double or even quadruple the present effects causing global warming of at least 1°C and possibly more than 5°C by 2050 AD (Dickinson and Cicerone 1986).

Although a doubling of atmospheric CO_2 is predicted to benefit forestry and farming in some areas, the global warming associated with the ''greenhouse'' effect will result in a proportionate increase in the rate of eustatic sea-level rise. Heating the entire ocean by 1°C would raise its level by 600 mm (Henderson-Sellers and McGuffie 1986) and a change of only 0.1% in the global land ice cover would produce a sea-level change of over 50 mm (Clark 1982). Thus, the combination of both thermal expansion of the upper ocean waters together with the melting of continental and alpine glaciers would contribute to an accelerated sea-level rise over a relatively short period of time.

Sea-Level Rise Predictions

Hoffman et al. (1983), the National Academy of Sciences (1983), Thomas (1986) and WMO (1986) have predicted rates of eustatic sea-level rise resulting from the ''greenhouse'' effect, up to the year 2100 AD (Figure 23). Although Hoffman et al. (1983) predict low and high values of 562 mm and 3450 mm by 2100 AD they favour a prediction lying between the mid-range high and mid-range low values shown in Figure 23. Thomas (1986) also favours his mid-range values although his lower and upper limits range from 900 mm to 1700 mm by 2100 AD. The National Academy of Sciences (1983) predicts a rise of 700 ± 180 mm by 2080 AD (Figure 23) and the Conference at Villach, Austria, of 9 to 15 October 1985 (WMO 1986) a rise of about 500 to 1000 mm over the next 50 years.

Although the predictions in Figure 23 cover only the next 114 years, the period encompassing the structural life of most beachfront properties and assets around New Zealand, progressive global warming could eventually result in the disintegration of the marine-based part of the West Antarctic ice sheet. Such a disintegration would cause a 5 to 7 m rise in eustatic sea-level (Clark 1982; National Academy of Sciences 1983; Thomas 1986). However, estimates of between 200 to 300 years have been made by Bentley (1983) and Hughes (1983) for this event, a period well beyond the structural life of most beachfront assets in New Zealand.

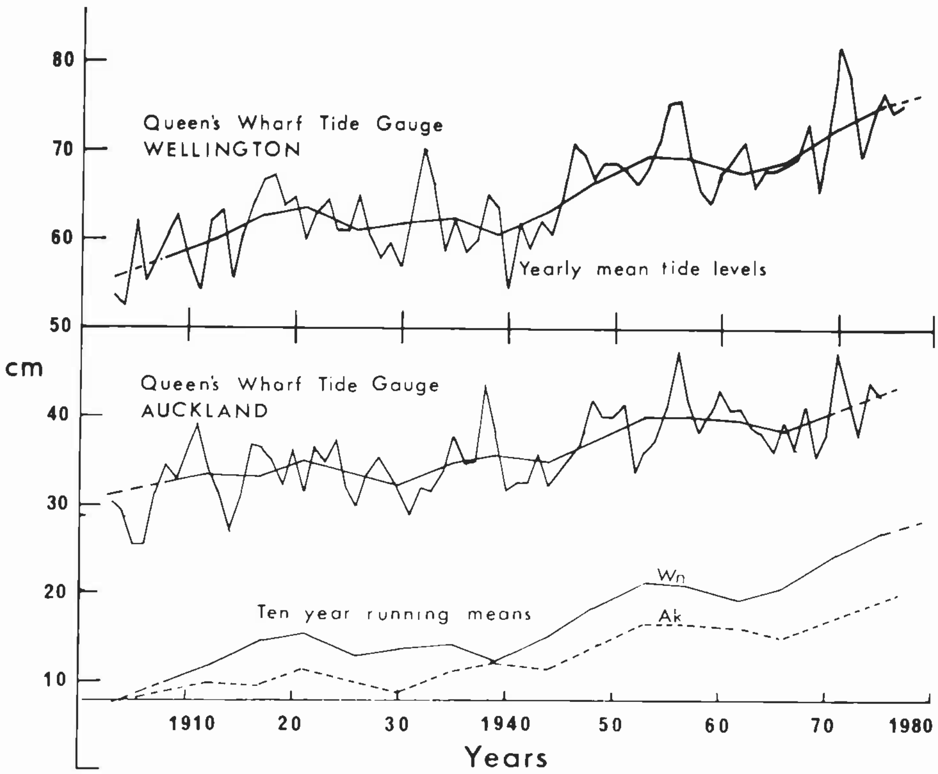


FIGURE 22: Diagram showing fluctuations in mean tide levels (1903-1977), with respect to the adjacent land, for tidal stations at Auckland and Wellington. Yearly values were smoothed by calculating 10 year running means. The similar pattern of the Auckland and Wellington means suggests a rising eustatic sea level. The offset of the mean suggests different site specific factors. From: Gibb 1979, Figure 6.7.

TABLE 2 Assessment of CHZ widths along Hokitika Beach at 14 selected WCB beach profiles. Where (X + R)T is positive, CHZ width is S. Where (X + R)T is negative, CHZ = (X + R)T + S. Factor T is 64 years (1986-2050AD) for CHZ_1 assessment and 114 years (1986-2100AD) for CHZ_2 assessment. Factor X is 0.6 m by 2050 AD (0.0094 m/year) and 1.5 m by 2100 AD (0.0132 m/year). Factors R and S are adopted from Table 1. Recommended CHZ widths are rounded to the nearest 5 m.

Profiles:	1	2	3	4	5	6	7	8	9	10	11	12	13	14
a_1	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094	0.0094
l_1	800	800	800	800	800	800	800	800	800	800	800	800	800	800
h_1	14	15	14	15	15	15	15	15	15	15	15	16	15	16
X_1	-0.54	-0.50	-0.54	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50	-0.47	-0.50	-0.47
R_1	+0.56	+0.75	+1.31	+1.34	+1.00	+0.85	+0.52	+0.50	+0.21	+0.08	-0.02	+0.08	+0.47	+0.13
T_1	64	64	64	64	64	64	64	64	64	64	64	64	64	64
$(X+R)T_1$	+1	+16	+49	+54	+32	+22	+1	0	-19	-27	-33	-27	-2	-22
S_1	130	155	200	200	145	130	110	105	85	80	70	60	95	80
CHZ_1	-130	-155	-200	-200	-145	-130	-110	-105	-105	-110	-100	-90	-100	-100
a_2	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132	0.0132
l_2	800	800	800	800	800	800	800	800	800	800	800	800	800	800
h_2	14	15	14	15	15	15	15	15	15	15	15	15	15	16
X_2	-0.75	-0.70	-0.75	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.66	-0.70	-0.66
R_2	+0.56	+0.75	+1.31	+1.34	+1.00	+0.85	+0.52	+0.50	+0.21	+0.08	-0.02	+0.08	+0.47	+0.13
T_2	114	114	114	114	114	114	114	114	114	114	114	114	114	114
$(X+R)T_2$	-22	+6	+64	+73	+34	+17	-21	-23	-56	-71	-82	-66	-26	-60
S_2	130	155	200	200	145	130	110	105	85	80	70	60	95	80
CHZ_2	-150	-155	-200	-200	-145	-130	-130	-130	-140	-150	-150	-130	-120	-140

HOKITIKA CHZ ASSESSMENT

Sea Erosion

Equation [1] is used to calculate a CHZ for erosion at Hokitika at the 14 WCB beach cross-section sites listed in Table 1 and located on Figure 1. Table 2 tabulates values for factors X, R, T and S for each cross-section for assessing the width of the Hokitika CHZ. CHZ widths are given in Table 3 and the entire CHZ is shown on Figure 24.

Factor T

For T, periods of 64 years (1986-2050 AD) and 114 years (1986-2100 AD) are adopted (Table 2) as long-term planning periods for the assessment of the CHZ for several reasons. They encompass the "useful life" of commercial and residential buildings, and services at Hokitika. The adopted periods also allow both for the recurrence of at least two short-term episodic erosion-accretion cycles (10-30 years), and for the averaging out of long-term sea-level trends and fluctuations in sediment supply. Should a period less than 64 years be adopted then it is highly likely that a short-term, shoreline fluctuation would be interpreted as a long-term trend, thus producing erroneous predictions (see Figure 9).

Factor R

For R the long-term (1867-1986) erosion-accretion rates listed in Table 1 are adopted for Table 2. These rates reflect the average flux of sediment eroded and deposited along the Hokitika foreshore over the last 119 years and range from +0.08 to +1.34 m/year for accretion and −0.02 m/year for erosion (Table 2).

Factor S

For S the landward position of the toe of the foredune during the severe short-term erosion phase of the 1910s is adopted as the maximum landward limit of such episodic erosion. Values for Factor S range from 60 to 200 m (Table 2).

Factor X

Equation [2] is used to calculate values for X (Table 2) at each cross-section. Global sea-level has risen at about 1.5 mm/year during the last century, the rate increasing to 2.6 mm/year in New Zealand since the 1940s (Gibb and Aburn 1986). However, there is a general consensus amongst scientists working on sea-level predictions that the rate of rise during the past century will not continue unmodified but will increase sharply during the next century (Figure 23) as a result of the "greenhouse" effect. Therefore, using equation [2] to calculate X, mid-range values for factor a are adopted from Figure 23 of 9.4 mm/year (0.6 m) for the period 1986-2050 AD, and 13.2 mm/year (1.5 m) for the period 1986-2100 AD (Table 2).

Factors h and ℓ (equation 2) are not so easy to determine because no offshore data are available for

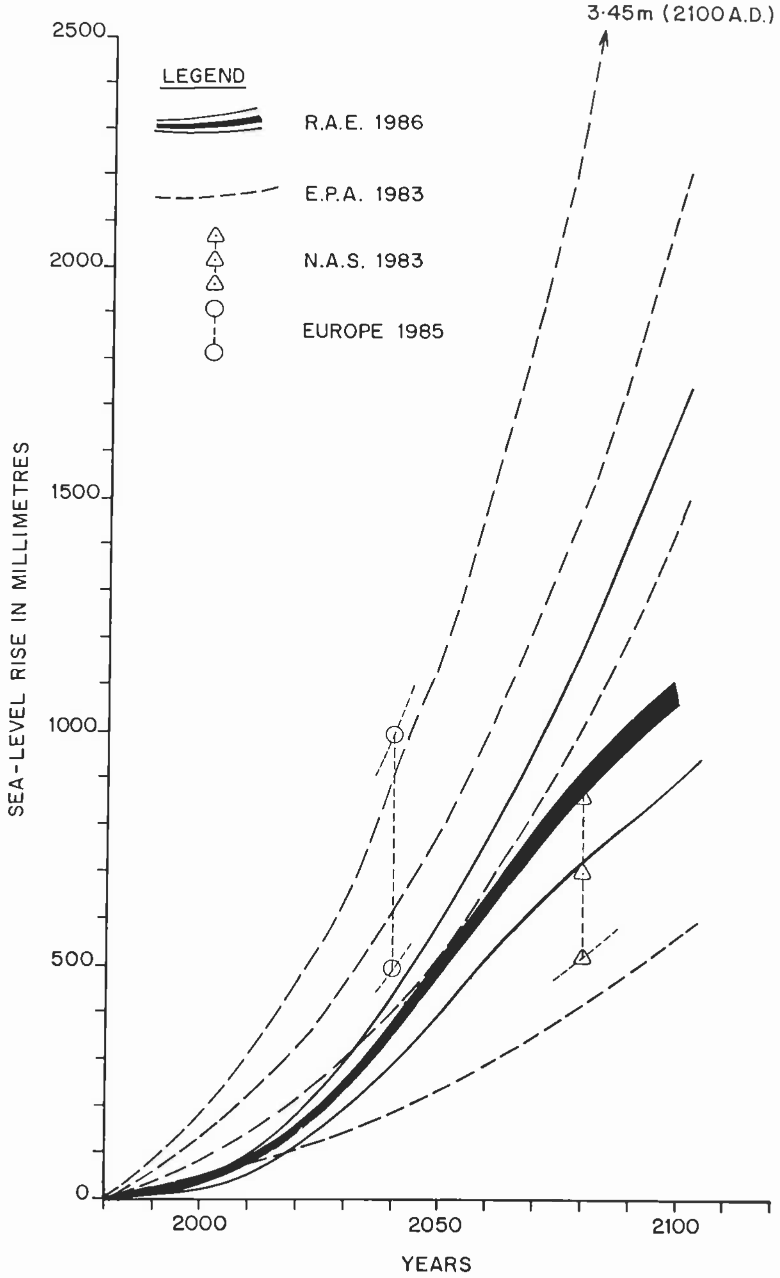


FIGURE 23: Diagram showing sea-level rise predictions for the next century (1986-2100 AD) plotted by the writer from the following data sources: RAE, Royal Air Force Establishment, Farnborough (Thomas 1986); EPA, United States Environmental Protection Agency (Hoffman et al. 1983); United States National Academy of Sciences (NAS 1983); Europe, Conference at Villach, Austria (WMO 1986).

Hokitika. However, data are available for the Greymouth area where Pfahlert (1984) has carried out extensive research on beach and nearshore sediment distribution and transport along 25 km of coastline and seabed. Because the Greymouth section of coastline is exposed to the same wave energy as Hokitika and the sediments are similar it is assumed here that the closure depth, h, determined for Greymouth from Pfahlert's study is similar for Hokitika.

For factor h (equation 2), offshore surficial sediment data in Pfahlert (1984) suggest that the 10 m contour approximates the limiting depth. His data indicate that most onshore-offshore and longshore transport of beach sediment is confined between the beach and the 10 m contour, which lies about 750 m offshore of Greymouth. Using a theoretical procedure developed by Hallermeier (1981), involving the use of 12 months of wave data and sediment parameters, Pfahlert calculated a closure depth of about 11 m for the sea area south of Greymouth, the contour of which lies about 850 m offshore.

Assuming a similar shore-parallel bathymetry at Hokitika and similar nearshore sediment transport processes, a value of 10 m is adopted for the closure depth and 800 m for ℓ, the inferred distance from the beach to the 10 m contour. For Table 2, factor h is the 10 m depth contour below MSL plus the average height of the present-day foredune above MSL determined from each WCB cross section. It is assumed that the distance ℓ to the 10 m contour from the beach is uniform at each WCB cross section (Table 2).

Extreme, High and Moderate Risk Erosion Zones

Figure 24 shows the full extent of the Hokitika CHZ

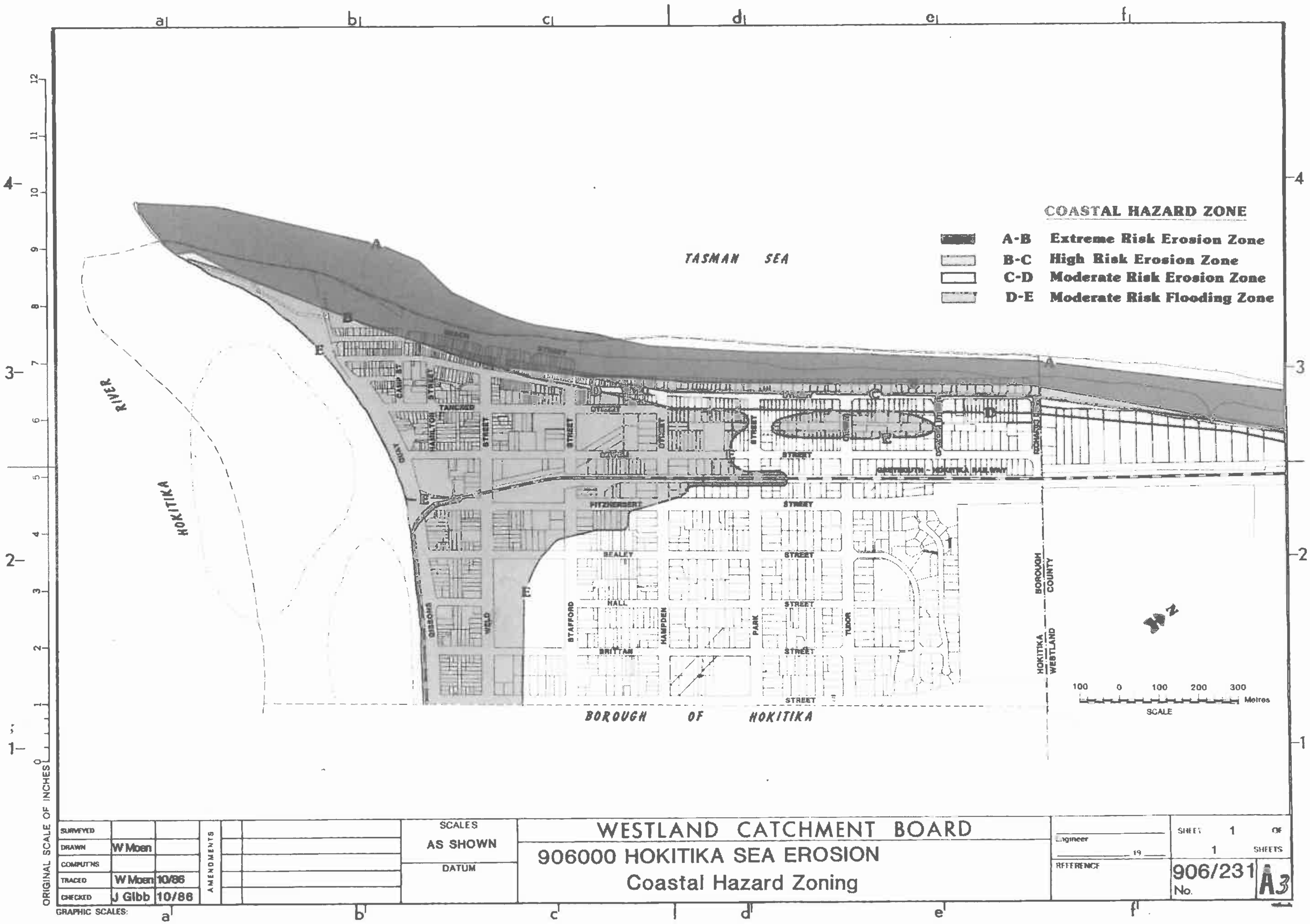


FIGURE 24: Indicative plan showing the Hokitika CHZ in relation to public and private property and assets. The CHZ is compiled from data in Table 3 and comprises Extreme (Line A-B), High (Line B-C) and Moderate Risk (Line C-D) Erosion Hazard Zones and a Flood Hazard Zone (Line D-E), beyond which risk from coastal hazard is considered low to very low.

TABLE 3 CHZ widths relative to WCB beach profile bench marks, for Extreme, High and Moderate Risk Zones. Distances west (W) are seaward and normal to the shoreline and distances east (E) are landward and normal to the shoreline. CHZ widths are calculated from data in Table 2. Values are rounded to the nearest 5 m.

PROFILES	1	2	3	4	5	6	7	8	9	10	11	12	13	14
EXTREME RISK ZONE	130 W 0 E	155 W 0 E	180 W 20 E	170 W 30 E	110 W 35 E	85 W 45 E	70 W 40 E	70 W 35 E	65 W 20 E	60 W 20 E	45 W 25 E	40 W 20 E	45 W 50 E	60 W 20 E
Net Width (m)	130	155	200	200	145	130	110	105	85	80	70	60	95	80
HIGH RISK ZONE	0 E 0 E	0 E 0 E	20 E 20 E	30 E 30 E	35 E 35 E	45 E 45 E	40 E 40 E	35 E 35 E	20 E 40 E	20 E 50 E	25 E 55 E	20 E 50 E	50 E 55 E	20 E 40 E
Net Width (m)	0	0	0	0	0	0	0	0	20	30	30	30	5	20
MODERATE RISK ZONE	0 E 20 E	0 E 0 E	20 E 20 E	30 E 30 E	35 E 35 E	45 E 45 E	40 E 60 E	35 E 60 E	40 E 75 E	50 E 90 E	55 E 105 E	50 E 90 E	55 E 75 E	40 E 80 E
Net Width (m)	20	0	0	0	0	0	20	25	35	40	50	40	20	40
TOTAL CHZ WIDTH (m)	150	155	200	200	145	130	130	130	140	150	150	130	120	140

plotted from values in Table 3. For erosion, the zone ranges in width from 120 m in the north to 200 m in the south. The CHZ has been subdivided into zones of Extreme, High and Moderate Erosion Risk, which lie adjacent and parallel to each other. The Extreme Risk Zone represents the area affected by the maximum short-term erosion recorded since 1867 and includes the entire beach-foredune system. This zone is susceptible to short-term episodic erosion that is likely to occur at least once every 10 to 30 years. The Extreme Risk Zone increases in width southwards, from 80 m at the sewage settling ponds to 200 m at Beach Street (Table 3). Within this zone buildings and services are likely to be damaged or destroyed and the settling ponds breached and destroyed once every 10 to 30 years.

The High Risk Zone encompasses the area susceptible to sea-level induced erosion resulting from a predicted sea-level rise of 0.6 m between 1986 and 2050 AD. Figure 24 shows that only properties north of Stafford Street and west of Revell Street are affected by the High Risk Zone, which ranges in width from 5 m adjacent to the Moss Factory to 30 m between Tudor Street and Richards Drive (Table 3). The zone does not extend south of Stafford Street because historical sediment accretion rates indicate that sediment accumulation in this area will override the effects of the predicted 0.6 m sea-level rise. Within the High Risk Zone all the buildings and services west of Revell Street are likely to be damaged or destroyed during the next 64 years.

The Moderate Risk Zone encompasses the area susceptible to sea-level induced erosion resulting from a predicted sea-level rise of 1.5 m between 1986 and 2100 AD. Figure 24 shows that the properties north of Weld Street and east of Revell Street are included in the Moderate Risk Zone, which ranges in width from 20 m opposite the Southland Hotel and river mouth to 50 m opposite Tudor Street (Table 3). The zone does not extend between the Gravel Crusher and Weld Street owing to substantial accretion overriding the effects of the predicted 1.5 m sea-level rise. Within the Moderate Risk Zone buildings and services immediately east of Revell Street are likely to be damaged or destroyed during the next 114 years.

Landward of the Moderate Risk Zone the risk from sea erosion to property and assets, within the period of their useful life (1986-2100 AD), is considered to be low to very low. However, should sea-level rise exceed the predictions of 0.6 m by 2050 AD and 1.5 m by 2100 AD then sea erosion will accelerate proportionately. Equally, if the rise is less than these values then the extent and rate of erosion will be proportionately less at Hokitika.

Hokitika CHZ Assessment for Sea Flooding

The area of Hokitika Borough most susceptible to flooding is the low-lying basin (see Figure 6) which contains all the central commercial area and part of the industrial and residential areas. The basin averages only 2.6 m above MSL (1.4 m above HHWS), ranging from

2.4 to 2.7 m. During severe floods in the Hokitika River houses and business premises within the basin have been flooded to a depth of 1.2 m (about 4 m above MSL) several times during the last century. Flood levels do not appear to have exceeded 1.2 m, suggesting that the heights of the barrier ridges surrounding the basin control the level of flood waters. The lowest point around the basin is the 4.3 m high foredune at Beach Street.

No data are available for flood levels in the Hokitika basin resulting from inundation by the sea. However, early newspapers report flooding from the sea during the erosion phases of the 1860s and 1910s. A "number of waves" were reported washing into Revell Street in 1913-1914 and the "waves made clean breaks over the streets and tramway into the marshy ground leaving high billows of froth" in 1866-1868. During severe erosion phases exacerbated by a rising sea-level the height of the foredune is likely to be lowered to 4 m or less. Storm wave runup levels presently exceed 5 m above MSL which means that flooding of central Hokitika by the sea will occur once the foredune is lowered in elevation or breached.

The rapid acceleration in the rate of sea-level rise predicted to occur over the next century will also lead to flooding of the low-lying Hokitika basin by raising groundwater levels. Such levels are presently 0.3 to 0.6 m below ground surface, or about 1 m above high spring tide level. By 2050 AD a predicted sea-level rise of 0.6 m would raise groundwater proportionately to the level of the ground surface turning the basin into a swamp. By 2100 AD a predicted sea-level rise of 1.5 m would raise groundwater levels to such an extent that a 1 m deep lake would fill the basin.

Based on the above, flood levels of 3 m are adopted for a 1 in 50 year event and 4 m for a 1 in 100 year event. For the Moderate Risk Flooding Zone defined by Line E on Figure 24, the approximate position of the 4 m contour is adopted. The contour was defined from a preliminary survey made by Westland Catchment Board.

COASTAL HAZARD MANAGEMENT PLAN

The identified hazards of erosion and flooding from the sea will continue to threaten property and assets at Hokitika in the future. The increasing rate of sea-level rise will result in a proportionate increase in the frequency, magnitude and extent of these hazards also. Therefore, in the long-term public good it is important that Hokitika Borough Council take steps now to combat erosion and flooding from the sea and thereby reduce the risk to life, property and assets. To be effective it is important that actions taken are integrated and coordinated through a Coastal Hazard Management Plan. Prevention, mitigation and avoidance options are open to Council through an integrated combination of planning, engineering and soil conservation measures applicable to the Zones of Risk identified in Figure 24.

Objective

The objective of the Coastal Hazard Management Plan is to provide guidelines for the prevention, mitigation and avoidance of the effects of coastal hazards on property and assets in Hokitika Borough and for the monitoring of such hazards.

Definitions and Assumptions

1. **Coastal Hazards** at Hokitika of the last century will not continue into the future unmodified but will increase in magnitude, frequency and extent during the next century. The increase will be caused principally by a predicted acceleration in the net rate of global sea-level rise from about 1.5 mm/year (1886-1986) to about 13 mm/year (1986-2100 AD).
2. **The Rock Groynes** along the Hokitika foreshore can be expected to fail during the period of the useful life (1986-2100 AD) of the beachfront assets and services they protect. The groynes will not prevent groundwater levels rising in the central Hokitika basin in response to rising sea-level. Rather than being fully preventive the groynes are seen here as a mitigating measure.
3. **Useful Life** is the structural life of buildings and services. For New Zealand the minimum structural life is about 100 years.
4. **Relocatable Buildings** are structures which can be completely removed off the property and out of the Coastal Hazard Zone at short notice and the essential services disconnected with ease.
5. **Prevention Measures** are those taken to protect life, property and assets within a Coastal Hazard Zone from coastal hazards during the entire period of their useful life.
6. **Mitigation Measures** are those taken to protect life, property and assets within a Coastal Hazard Zone from coastal hazards during part of their useful life.
7. **Avoidance Measures** are those taken to remove and/or exclude life, property and assets from a Coastal Hazard Zone so that they are not threatened, damaged or destroyed during the entire period of their useful life.

Extreme Risk *Erosion* Zone

The Extreme Risk Erosion Zone is the "front line" for the entire CHZ and is subject to the short-term 10 to 30 year cycle of erosion and accretion. This zone is delineated by Lines A and B in Figure 24. Unfortunately for Hokitika this zone contains both commercial and residential property and assets. The severity of the hazard is such that buildings and services are likely to be damaged or destroyed during erosion phases. The following options, or combinations thereof, are designed to reduce risk.

1. Planning

1.1 Encourage the relocation of existing buildings and services landward of the Coastal Hazard Zone over the next 10 to 30 years before the onset of another erosion phase.

1.2 No new buildings should be permitted.

1.3 Rezone the land under extreme erosion risk to recognise the degree of risk and to promote land uses compatible with that risk.

2. Engineering

2.1 **Hokitika River:** Investigate the feasibility of training the Hokitika River mouth so that the river discharges permanently northwards and seawards. Training walls along the true left and right banks of the river should be spaced sufficiently to allow severe floods to pass unimpeded to the sea and not to cause serious outflanking of such works during floods. The training wall along the true left bank must not extend seaward or it will trap and deflect the net northerly drift of beach sediment causing erosion at Hokitika. The training wall along the true right bank should extend an adequate distance seaward to prevent the growth of a southerly spit across the mouth. The training works should be angled in such a way as to prevent the Hokitika River from flowing along the Hokitika foreshore.

2.2 **Groynes:** Reduce the amplitude of the short-term erosion-accretion cycle by constructing a groyne field between Hokitika Borough and the sewage settling ponds. To obtain optimum results the groyne field should be established between Weld Street and the north end of the sewage settling ponds as this stretch of foreshore is dominated by a net northerly longshore drift of the order of 240,000 $\pm$ 10,000 m^3/year. No groynes should be constructed between Weld Street and the Hokitika River mouth as this area is dominated by onshore-offshore sediment transport and is a feeder zone for the net northerly drift.

Construct the first groyne at Richards Drive commencing with the lower foreshore section followed by the upper foreshore section. Construct to dimensions and standards set by Westland Catchment Board allowing for increases in both height and length of the groyne as appropriate, depending on the rate of adjustment of the beach updrift and downdrift of the structure.

Construct the second groyne at the north end of the sewage settling ponds in accordance with dimensions and standards set by Westland Catchment Board, allowing for increases in both height and length as appropriate. Commence construction about one month after the first stage of the Richards Drive groyne.

Increase the initial height of the Richards Drive groyne along its entire length by one metre. The timing of this stage of construction is to be governed by the updrift and downdrift beach adjacent to the groyne having reached equilibrium after the first stage of construction. Commence construction one to two months after the first stage depending on performance.

Depending on the performance of the 2 m-high Richards Drive groyne, either increase the height by a further metre along its entire length or construct a third groyne between Hampden and Tudor Streets. The choice of site for the third groyne is to be determined Westland Catchment Board and should be governed by where the accretion wedge updrift (south) of the Richards Drive groyne pinches out. It may be possible to proceed with this stage three to four months after construction of the Richards Drive groyne depending on its performance.

Depending on the length of the accretion wedges protecting the foredune, allow for construction of either further groynes as required or the vertical and horizontal extension of the existing groynes during late 1987.

During construction of all stages replenish the upper foreshore updrift and downdrift of the groynes with gravels compatible with those on the beach. The volume and rate of replenishment should be in proportion to the rate of loss of beach sediment to counteract the effects of the loss.

3. Monitoring

3.1 Westland Catchment Board should continue to monitor the beach and foredune between the Hokitika River mouth and the sewage settling ponds at approximately monthly intervals. The monitoring programme should continue until the erosion phase has passed and accretion has become predominant.

3.2 During monthly surveys the direction of offset of the Hokitika River discharge channel should be recorded.

3.3 Prior to construction of the groyne field Westland Catchment Board should carry out a detailed levelling survey of the beach updrift and downdrift of the proposed sites for each groyne. A contour plan of the beach should be produced from the levels and a resurvey of the beach should be made every two weeks for the first two months following construction. After two months the resurvey interval should be increased as appropriate to approximately monthly intervals in accord with 3.1 above. During the monitoring survey provision should be made to resurvey the beach after significant onshore storms.

4. Dune Conservation

4.1 Sediment deposited on the beach during the onset of the present accretionary phase and sediment trapped updrift of the groynes should be utilised to increase the height and volume of the foredune between the seaward property boundaries and the beach.

4.2 To counteract the effects of a rising sea-level the present average height of the foredune of 5.2 m should be increased to 7 to 8 m above MSL. This could be accomplished by either mechanically moving the sediment from the beach during phases of maximum accretion and shaping the height, or by allowing onshore winds to do the work and trapping the sand with suitable fencing and salt tolerant grasses. If sand is to be moved mechanically then the work should be carried out only after the groyne field is established and a wide, stable beach has formed.

4.3 Provision should be made for protective salt tolerant vegetation to cover and protect the foredune to counteract the effects of wind erosion.

5. Mining

5.1 Mining of sand and gravel should not be permitted on the beach between the Hokitika River mouth and Little Houhou Creek to the north. Extraction of sand and gravel should be strictly controlled from the lower reaches of the Hokitika River and from the foreshore south of the Hokitika River mouth. Both these areas are important sources of sediment for Hokitika Beach.

5.2 Westland Catchment Board should be consulted on the application of suitable controls for mining of both beach and river sand and gravel in the area. The object of the controls is to reduce any adverse impact on the Hokitika foreshore.

High Risk *Erosion* Zone

The High Risk Erosion Zone is subject entirely to long-term sea erosion caused principally by a predicted 0.6 m rise in sea-level over the next 64 years (1986-2050 AD). This zone is delineated by Lines B and C on Figure 24. Line B is the predicted shoreline position in the next 10 to 30 years and Line C is the predicted position in the next 64 years (2050 AD). Therefore, buildings and services within this zone with a useful life exceeding 10 to 30 years are likely to be damaged or destroyed from erosion. Buildings and services with a useful life less than 10 to 30 years should be able to see out their life. The High Risk Erosion Zone includes the residential properties west of Revell Street between Stafford Street and Richards Drive. Protection of property and assets within this zone is largely dependent on the effectiveness of the controls set out above to combat coastal hazards at the "front line" in the Extreme Risk Erosion Zone. The following planning controls are applicable to the High Risk Erosion Zone.

1. Planning

1.1 Encourage the relocation of existing buildings with a useful life exceeding 10 to 30 years, landward of the Coastal Hazard Zone.

1.2 No new buildings should be permitted.

1.3 Allow extensions and alterations to existing buildings as appropriate, provided such work does not prolong the useful life of such buildings beyond 2000-2020 AD.

1.4 Rezone the land under high erosion risk to recognise the degree of risk and to promote land uses compatible with that risk.

Moderate Risk *Erosion* Zone

The Moderate Risk Erosion Zone is subject entirely to long-term sea erosion caused principally by a predicted 1.5 m rise in sea-level over the next 114 years (1986-2100 AD). The zone is delineated by Lines C and D on Figure 24. Line C is the predicted shoreline position in 2050 AD and Line D is the predicted position in 2100 AD. Therefore, buildings and services with a useful life of 64 to 114 years are likely to be damaged or destroyed within the period of their life by sea-level induced erosion. The Moderate Risk Erosion Zone includes Revell Street and the residential properties to the east between about Stafford Street and Richards Drive and commercial properties to the west between Stafford and Weld Streets (Figure 24). Risk to property and assets within this zone is dependent on the success of measures to combat coastal hazards in the Extreme Risk Erosion Zone. The following planning controls are applicable to the Moderate Risk Erosion Zone:

1. Planning

1.1 New buildings should be relocatable and land not subject to hazard should be set aside for such relocatables.

1.2 Allow extensions and alterations to existing buildings as appropriate, provided such work does not prolong the useful life of such buildings beyond 2050 AD.

1.3 Rezone the land under moderate erosion risk to recognise the degree of risk and to promote land uses compatible with that risk.

Moderate Risk *Flooding* Zone

The Moderate Risk Flooding Zone is subject to both temporary flooding from the sea during severe erosion phases with a return period of 10 to 30 years, and permanent flooding from rising groundwater levels in response to a predicted sea-level rise of 1.5 m by the year 2100 AD. The zone is delineated by Line E on Figure 24 which marks the approximate position of the 4 m contour. The Moderate Risk Flooding Zone encompasses the central commercial area of Hokitika and also industrial and residentially zoned land. Because flooding within this zone is most likely to be passive in nature, houses and business premises are unlikely to be destroyed. Ground floor levels, however, will suffer extensive flood damage and rising groundwater level will make the area uninhabitable once it becomes a shallow lake. Both engineering and planning solutions are essential to combat flood risk in this area.

1. Engineering

1.1 Flooding of the low-lying Hokitika basin from heavy seas overtopping the foredune can be prevented and mitigated by implementing the erosion control measures set out above for the Extreme Risk Erosion Zone.

1.2 The stopbank protecting Hokitika Borough from flooding from the Hokitika River will need to be raised in proportion to the rising sea-level to prevent overtopping and breaching.

1.3 Investigate the possibility of controlling rising groundwater levels by pumping water out of the central Hokitika basin into the Hokitika River, from a system of inter-connecting drains.

1.4 Measures should be taken to protect essential services such as sewage pipe lines, electrical and water supplies from the effects of rising groundwater levels.

1.5 If options 1.1 to 1.4 prove too costly then all development within this area should be relocated and resited on lands not subject to natural hazards.

2. Planning

2.1 All building permits for new and existing buildings should be subject to the design of the floor level and construction of the building taking the following flood levels into account:

(a) 3 m above MSL for buildings with a useful life not exceeding 2050 AD.

(b) 4 m above MSL for buildings with a useful life exceeding 2050 AD.

2.2 Toxic and noxious chemicals should be stored in a manner and position which prevents danger or damage or risk of pollution in the event of inundation.

2.3 Materials capable of floating should be restrained to prevent them from damaging, or being washed from, the premises.

2.4 Rezone the land under moderate flood risk to recognise the degree of risk and to promote land uses compatible with that risk.

CONCLUSIONS

1 Over the last 119 years (1867-1986) the 8 km long shoreline south of the Hokitika River has eroded at a net rate of −0.21 m/year compared to the northern 8 km which has accreted at a net rate of 0.6 m/year.

2 Despite the long-term trend of net advance the 2.2 km long Hokitika shoreline is in dynamic equilibrium punctuated by short-term episodic cycles of erosion/accretion with cycles commencing near Beach Street and migrating northwards, the fluctuations decreasing from 200 m at Beach Street to 60 m at Richards Drive.

3 Short-term erosion phases peaked in the 1860s, 1880s, 1910s, 1940s, 1950s and 1980s indicating a periodicity of 10 to 30 years compared to short-term accretion phases which peaked in the 1880s, 1930s and 1970s indicating a periodicity of 40 to 50 years.

4 The 1980s erosion phase at Hokitika is migrating north and is being replaced by an accretion phase, with net erosion rates of 26,000 m^3/month and net deposition rates of 19,000 m^3/month being recorded between 1984 and 1986.

5 The short-term erosion/accretion cycle is strongly influenced by fluctuations of the updrift-seaward-offset Hokitika River mouth. When the mouth offsets south the Hokitika shoreline erodes, when offset north the shoreline accretes, and when discharging straight out to sea the updrift (south) and downdrift (north) shorelines are in equilibrium.

6 At Hokitika the net northerly drift of sand and gravel in response to a persistent S-W swell is about 90% of the gross drift and is of the order of 240,000 ± 10,000 m^3/year. Transport rates for sand below low tide mark are not known.

7 The predicted increase in the net rate of global sea-level rise from 1.5 mm/year during the last century to about 13 mm/year during the next century would result in a progressive change from a shoreline in a state of dynamic equilibrium to a trend of long-term erosion between Weld Street and the sewage settling ponds. The prediction should be taken seriously as the rate of sea-level rise in New Zealand has increased to 2.6 mm/year since the 1940s and global temperature has risen during the last century.

8 Severe short-term erosion coupled with flooding from the sea and rising groundwater levels are the major hazards threatening property and assets at Hokitika. The accelerated rise in sea-level will result in a proportionate increase in the magnitude, frequency and extent of these hazards, particularly flooding.

9 The $5.2 million of commercial and residential properties along the 2.2 km long Hokitika foreshore, and the foredune impounding the sewage settling ponds to the north, are in an Extreme to High Risk Erosion Zone. These assets are likely to be damaged or destroyed during the next 64 years (1986-2050 AD) by sea erosion.

10 Residential properties on the east side of Revell Street are in the Moderate Risk Erosion Zone and are likely to be damaged or destroyed within the next 64 to 114 years (2050-2100 AD).

11 The Moderate Risk Flooding Zone is a low-lying basin averaging 2.6 m above MSL and contains the entire central commercial area of Hokitika and industrial and residentially zoned land. A predicted sea-level rise of 0.6 m by 2050 AD will raise groundwater levels proportionately turning the basin into a swamp. A predicted sea-level rise of 1.5 m by 2100 AD will raise groundwater levels to form a 1 m deep lake in the basin.

12 No reference is made to coastal hazards at Hokitika in the operative District Planning Scheme and the zoning pattern laid down by the scheme does not recognise the threat.

13 Hokitika Borough Council should incorporate the Hokitika Coastal Hazard Zone into its District Scheme accompanied by appropriate land use policies and objectives to cover land within the hazard zone.

14 Hokitika Borough Council should be encouraged to adopt the integrated Coastal Hazard Management Plan set out in this report.

15 The potential problem of erosion and flooding from the sea at Hokitika is of such a magnitude that it may be beyond the resources of the Borough to effectively deal with. Continued assistance from regional and central government resources may be required.

RECOMMENDATIONS

1 That Hokitika Borough Council (HBC), Ministry of Transport (MOT) and Westland Catchment Board (WCB) endorse and adopt this report.

2 HBC, MOT and WCB adopt the Coastal Hazard Management Plan outlined in this report to prevent, mitigate and avoid the coastal hazards of erosion and flooding from the sea affecting Hokitika Borough and the sewage settling ponds.

3 As a matter of regional importance, the West Coast United Council (WCUC) should become involved and adopt this report with a view to developing an appropriate regional policy to prevent, mitigate and avoid the effects of coastal hazards along the West Coast.

4 HBC incorporate the Hokitika Coastal Hazard Zone into the Hokitika Borough District Planning Scheme and formulate appropriate land use planning policies and objectives.

5 All building permits issued by HBC for properties within the Hokitika Coastal Hazard Zone should take into account the degree of risk the buildings will be exposed to during the period of their useful life.

6 WCUC and WCB urgently request the Department of Survey and Land Information to accurately define MSL for Westland in accord with other regions around New Zealand.

7 WCB continue to monitor the present erosion phase (1980s) and the performance of the groynes, and establish two precise automatic tide gauges at suitable West Coast locations to both monitor future MSL trends and fluctuations over the next century and to validate the sea-level predictions noted in this report.

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