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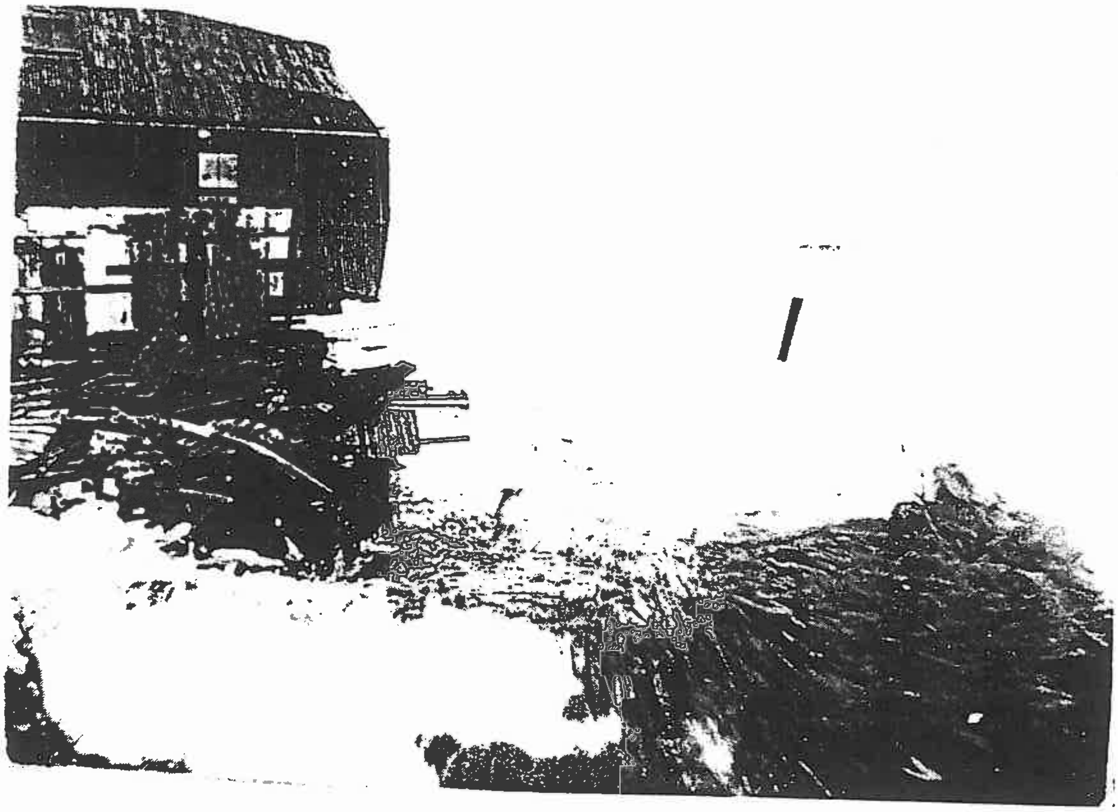

A REPORT ON

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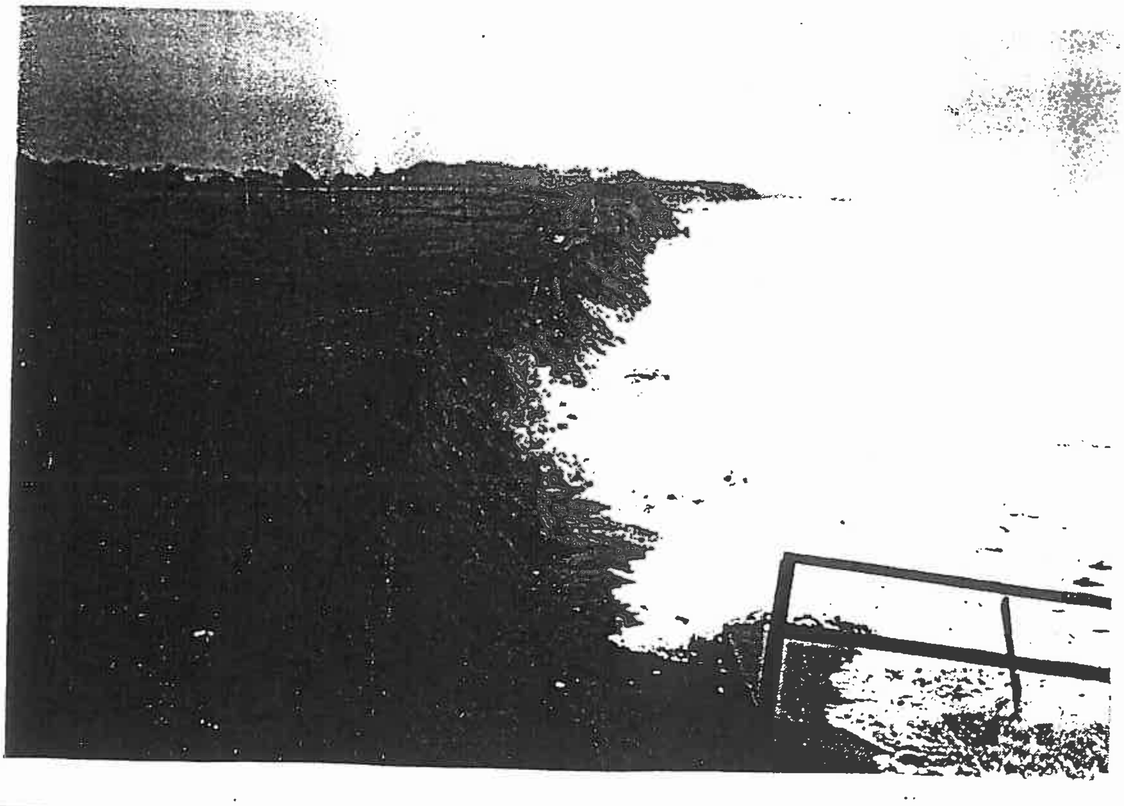
J. L. BENN and D. M. NEALE



A REPORT ON
COASTAL HAZARDS IN THE WEST COAST REGION, SOUTH ISLAND, NEW ZEALAND

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Cover Photographs: Top Photograph - Revell Street, Hokitika, March 1914 (Ben Theim Collection)
Bottom Photograph - Looking south towards Richard's Drive Groyne, Hokitika 20.3.92 (The West Coast Regional Council).

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1. INTRODUCTION

This report examines coastal hazards in the West Coast Region, what processes cause them, and planning/management options available to address them.

The report originates from the statutory obligations The West Coast Regional Council and other authoritive bodies have in addressing natural hazards under the following sections of the Resource Management Act (1991):

"Section 30. Functions of the regional councils under this act -
(1)(c) The control of the use of land for the purpose of...
(iv) The avoidance or mitigation of natural hazards...
(1)(d) In respect to any coastal marine area in the region, the control (in conjunction with the Minister of Conservation) of -
(i) Land and associated natural and physical resources:
(ii) The occupation of space on lands of the Crown or lands vested in the regional council, that are foreshore or seabed and the extraction of sand, shingle, or other natural material from that land:

and

"Section 35. Duty to gather information, monitor and keep records -
..(5) The information to be kept by a local authority...shall include
..(j) Records of natural hazards to the extent that the local authority considers appropriate for the effective discharge of its functions..."

The report also originates from concerns held by the Grey District Council and The West Coast Regional Council about recent erosion at the Karoro oxidation pond and the Hokitika town frontage. The paper was extended beyond these two areas, to provide an overview of hazards affecting the whole coastal zone in the region.

It stems from a consideration of the above information that this paper aims to:

(a) describe the coast and processes acting on it, including wave climate and sediment supply, transport and volumes;

(b) establish net erosion and accretion rates for the region;

(c) identify coastal areas and assets at risk from erosion, accretion and sea flooding;

(d) summarise and evaluate coastal management practices that have been used historically, and options available for future management.

(e) provide recommendations relating to future coastal research, planning and management;

(f) summarise current research on relevant coastal issues and;

(g) provide an annotated bibliography of significant coastal information/research so far produced for the region.

2. DESCRIPTION OF WEST COAST'S SHORELINE

The West Coast's 600km long shoreline between Kahurangi Point and Awarua Point, has a broadly SW-NE alignment that is dictated by uplift along the axis of the Southern Alps. Coastal lands vary widely from low lying dunes, estuary and river bed surfaces of unconsolidated sands and gravels, to steep bedrock coasts that are largely resistant to the sea's force.

The West Coast's beaches are well supplied with sediments (sand and gravel) by the many rivers that flow down to the coast; for example the Buller River carries a bedload of perhaps 214 000$m^3.yr^{-1}$ (Kirk et.al. 1987). Beach type at any location (e.g. sand, gravel, mixed sand-gravel) strongly influences the coastal stability, and depends largely on the sediments supplied from near-by rivers. A broad pattern of beach types is apparent along the West Coast (with a few anomalies in places): South of Hunt Beach-Bruce Bay sand and mixed sand-gravel beaches are most common, mixed sand-gravel beaches dominate from Karangarua to Punakaiki, and sand and mixed sand-gravel beaches are common north of Charleston. This pattern is interrupted by rocky coasts wherever mountain ranges meet the sea.

Offshore, the continental shelf slopes gently off to the Challenger Plateau in the north, whilst towards the south, the sea bed drops off sharply into deep water, offering less protection against waves arriving from the Tasman Sea. Submarine canyons offshore from the Hokitika and Cook Rivers encroach to within 10km of the shore, draining the littoral drift of coastal sediments into deep water and beyond the shelf.

Winds blowing across the Tasman Sea from the north to the southwest sector create waves that ultimately break onto the West Coast's shores. At Punakaiki, Kirk (1988) found that high energy wave events (wave heights > 1.5m at the shore) occur 11% of the time, but waves seldom exceed 3m in height. Due to the process of wave refraction, the waves 'bend' towards the coast and tend to arrive sub parallel to the shore. Approximately twice as many wave events arrive from the southern quarter than from the northern quarter.

The movement of sand and gravel along West Coast beaches by wave action (littoral drift) tends to occur at a similar ratio. That is, drift is predominantly northwards, but is offset somewhat by the occasional northerly storms that push sediments south. Most recent estimates of the net northerly drift rate have included 240 000m^3 per annum at Hokitika (Hicks 1988) and 900 000m^3 at Westport (Kirk et.al 1986, 1987). However, the drift rate is not consistent throughout the West Coast, and there is evidence that some beaches may even have a dominantly southerly drift, for example, beaches north of Westport (Mangin 1973, McPherson 1978, Neale 1989). River loads and drift rates quoted above show that more sediment is shifted by the sea than by even the largest of the West Coast's rivers, which produce some of the highest sediment yields in the world (Griffiths 1979, Griffiths and Glasby 1985). Considering their highly active character, most beaches maintain a surprisingly high degree of stability.

The more significant coastal hazards on the West Coast are summarised in Figure 1: high risk areas are discussed in the text. Beach erosion is the main hazard, while sea flooding and sediment buildup (accretion) can also pose a threat. Not surprisingly, hazards are concentrated between Hokitika and Karamea, where coastal land is the most developed and occupied.

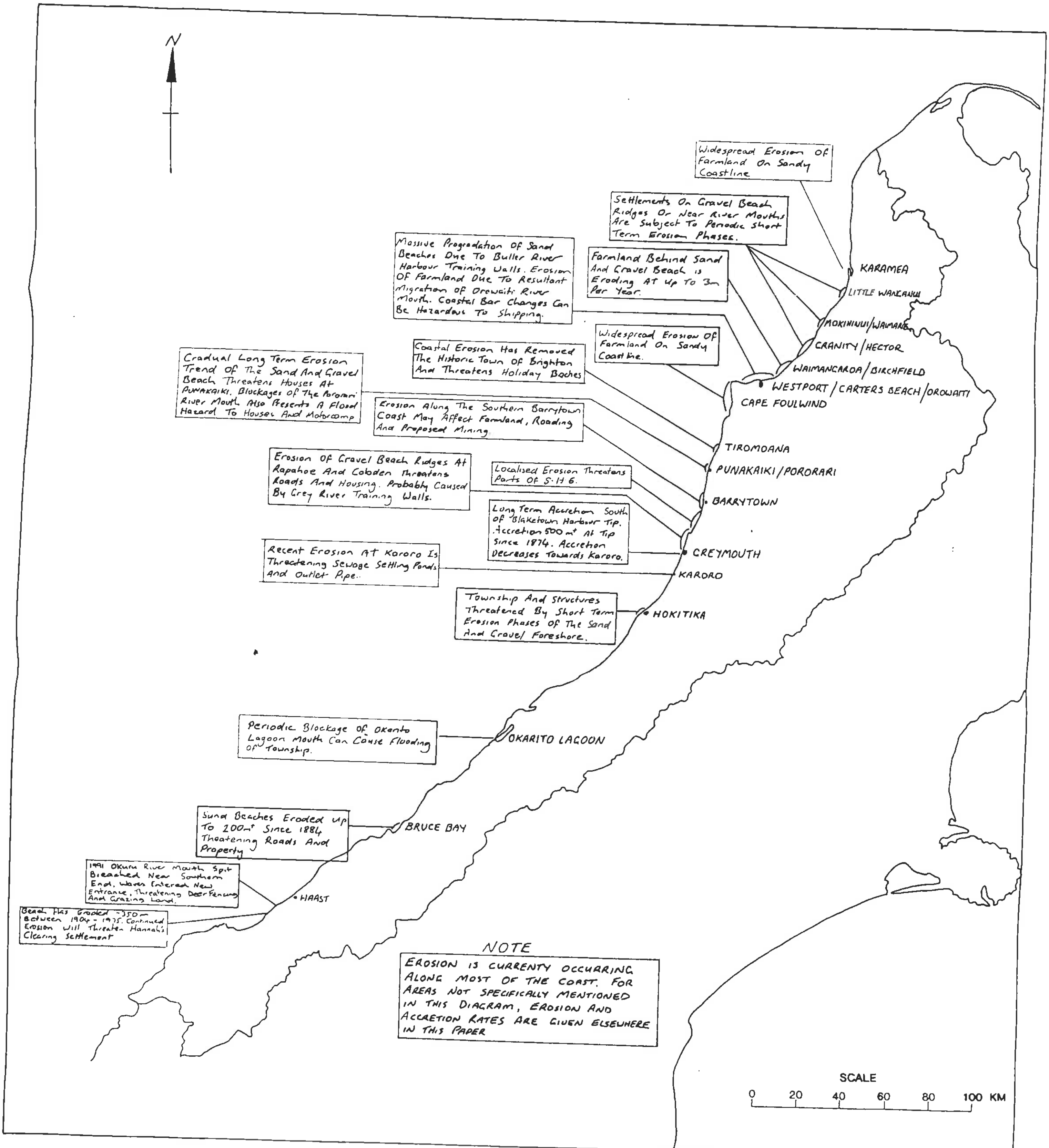


FIGURE 1. Coastal Hazards on the West Coast.

[SEE SEPARATE pdf FOR THIS DIAGRAM IN A3 SIZE]

3. WAVE CLIMATE

Wave action is the principal agent of coastal change, and it therefore has a major effect on the dynamics and erosion hazards of the region's shores. Sea waves are created by the action of wind blowing across the sea surface, forming small ripples that grow progressively larger with the duration, distance and strength of the wind. Winds blowing across the Tasman Sea from the north to southwest sector create waves that ultimately break onto the West Coast's shores. Since New Zealand lies across a belt dominated by westerly winds, the West Coast is on a windward shore, and wave conditions are generally rougher than on the eastern coasts. The 'wave climate' of an area (in this case, the West Coast) describes the long term character of the waves, swells and sea storms that occur there and that impact on the dynamics of the shores.

Measurements of waves from the West Coast and offshore have been made using a number of methods, but only three data sets are of any real worth for assessing the long term wave climate. Reid and Collen (1983) have tabulated records from ship-based observations from 1957-1980, and these have been analysed by Neale (1989), Kirk et.al. (1986) and Okuru Enterprises Ltd (1991): The accuracy of these observations is questionable however. Robin Reid of the Department of Conservation has made one of New Zealand's longest continuous records of daily shore-based wave and beach state observations, at Pororari Beach (Punakaiki) since March 1983 (still ongoing), and these have been analysed by Kirk (1988). Valentine and Macky (1984) analysed data from waverider buoys placed at Ngakawau (3yr record), Westport (2.5yr) and Carter's Beach (1.5yr). Other West Coast wave studies of lesser importance or worth have been made by; Neale (1988), Mangin (1973), Pfahlert (1984), Pickrill and Mitchell (1979), Watters (1953), and AMOCO (1987). Major findings from these studies are summarised here.

Wave height is standard measure of the power of sea waves, and is controlled by the strength and duration of the winds that form them. Being a windward shore, the West Coast is a relatively high energy wave environment. At Punakaiki, Kirk (1988) found that high energy wave events (wave heights at the shore greater than 1.5m) occur 11% of the time, but waves seldom exceed 3.0m height. Valentine and Macky (1984) found that the wave climate at Carter's Beach (average significant wave height 1.37m) is rougher than that at Ngakawau (1.30m), which is in turn rougher than that at Westport (1.16m), while waves greater than 3m height occur at these three sites for about 3% of the time.

The direction of wave approach is another very important parameter, since this controls the directions and volumes of littoral drift, and the effect of structures such as groynes. The best data available on the prevailing angle at which waves approach the shore are given by Kirk (1988) and Kirk et.al. (1986), who found (from two separate data sets) that approximately twice as many high energy wave events arrive from the south than from the north. However, due to the processes of wave refraction, waves 'bend' towards the coast as they move in to shallow water and tend to arrive more or less parallel to the shore. This can locally affect the direction of waves at the shore (particularly at headlands and bays), and has been indicated in refraction diagrams for Westport/Buller (Mangin, 1973, Kirk et.al. 1986), Greymouth/ Rapahoe (Pfahlert, 1984), and Jackson Bay (Okuru Enterprises Ltd 1991).

The greatest changes in the shoreline occur during sea storms when the waves are high and powerful. Sea storms coincide with the passing of depressions across the Tasman Sea, which generate large waves directly towards the West Coast. The low air pressures of the depressions also cause an elevation of the sea surface (known as storm surge) of up to 0.7m (Agnew, 1966). Valentine and Macky (1984) found that typical wave storms last from 1.5 days to about a week, and that the summer months are calmer than other seasons. Anecdotal evidence and casual observations suggest that many of the greatest storm wave events arrive from the north, and that these tend to cause the greatest beach erosion. These observations have been supported by evidence from Mangin (1973), McPherson (1978), Valentine and Macky (1984) and Neale (1989).

It should be noted that this wave information is derived from limited data, and that informed decisions require more knowledge of the wave climate than is presently available. Research priorities for wave studies on the West Coast are:

(a) a full analysis of the ongoing observations at Punakaiki,
(b) a monitoring programme to determine the effects of wave conditions on beach state,
(c) the placement of a permanent offshore wave and sea level recorder on the West Coast, to establish a data base of local data for the region, and;
(d) wave data from the southern parts of the region. Okuru Enterprises Ltd. are believed to be doing some studies at present off Jackson Head, and these should be continued.

4. COASTAL SEDIMENT VOLUME AND TRANSPORT

Sediment is supplied to beaches by river bed load, littoral drift and hinterland erosion. Little research has been undertaken to quantify the contribution of each source in detail. Research carried out thus far has been site specific, with most emphasis being placed on the Cape Foulwind - Westport Harbour improvement studies.

It is accepted that net littoral drift along the West Coast occurs in a northerly direction, although in some localised sites this may be to the south. Great variations exist in the calculated rates of littoral drift. These variations may be attributable to three sources: (1) different techniques of measurement being employed (2) different time scales being considered - short term calculations generally produce larger figures, and (3) different river input calculations.

It was estimated by Furkert (1947) that 3 631 612m^3 of sediment drifted past the Westport harbour bar entrance annually. More recent research has tended to produce much lower figures. For example Gibb (1985) considered littoral drift volumes to range from 0$m^3.yr^{-1}$ at Fiordland, to between 2 000 000$m^3.yr^{-1}$ - 4 500 000$m^3.yr^{-1}$ from about Greymouth northwards (Figure 2). However, Gibb gives no evidence for these calculations. The lowest littoral drift rate yet produced for a West Coast site is from Pfahlert (1984), who suggested that:

"*Estimates of the volume of littoral transport within the study area vary depending upon the method used to make the calculation. Historical accumulation of sediments on Blaketown Beach suggests that net littoral transport in the order of 15 000m^3yr^{-1} occurs. Theoretical calculations suggest that this figure may be as high as 516 000$m^3.yr^{-1}$. Therefore, a magnitude of between $10^4m^3.yr^{-1}$ and $10^5m^3.yr^{-1}$ seems applicable*".

Pfahlert continues;

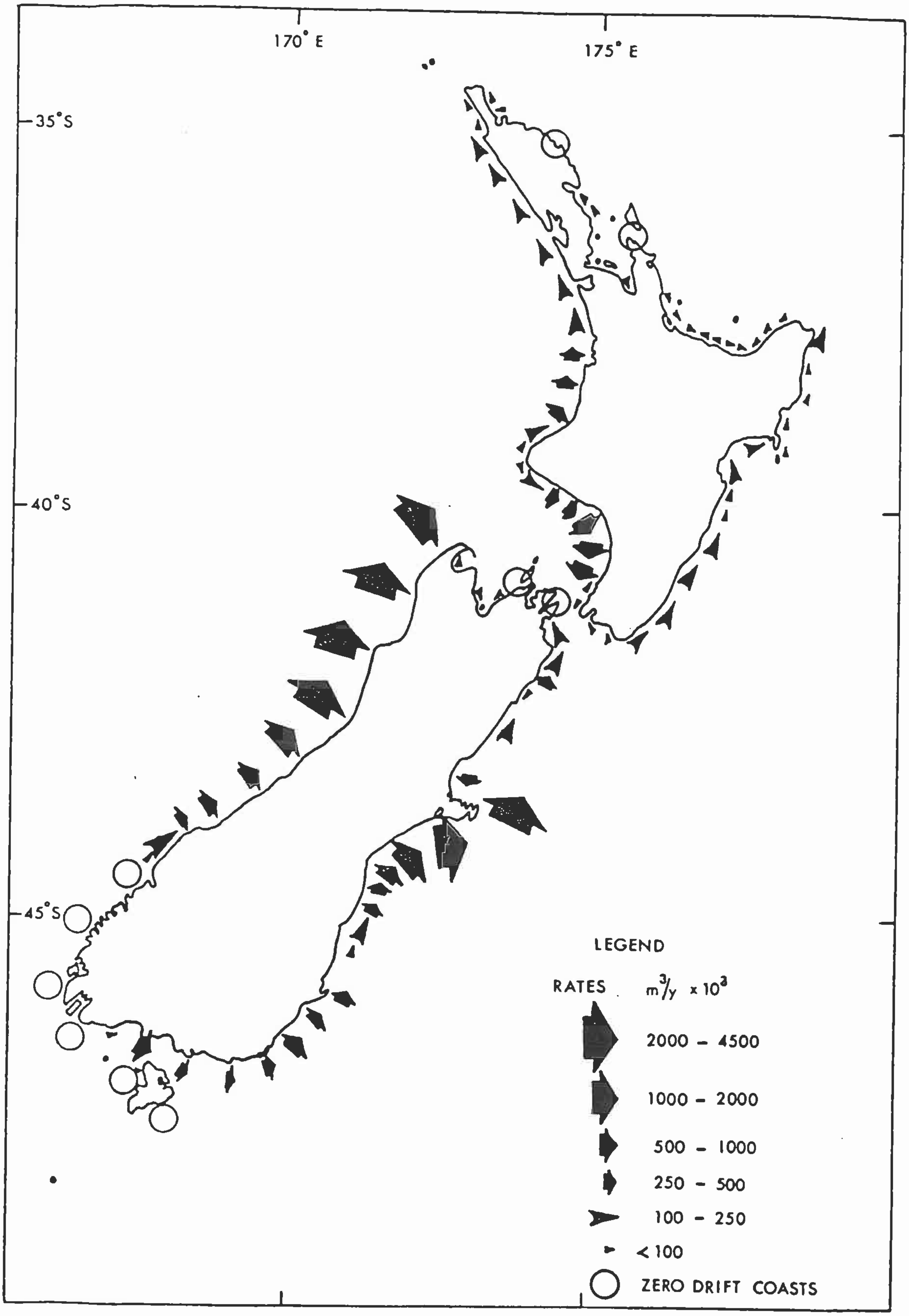


FIGURE 2. Inferred Rates of Littoral Drift of Sand and Gravel (Gibb 1985).

"There is no evidence that littoral sediment transport is in the order of $10^6 m^3.yr^{-1}$, which Furkert (1947) maintained was present. If it is accepted that littoral drift may be one or two orders of magnitude less than that implied by Furkert, the occurrence of extensive coastal erosion along virtually the whole length of the West Coast is more easily understood".

The latest research published (e.g. Hastie et.al. 1986, Kirk et.al. 1986,1987, and R.W. Morris and Associates 1988) suggests that on the basis of very detailed and extensive studies, about 900 000$m^3.yr^{-1}$ of sediment drifts past the Cape Foulwind - Buller River mouth area. Kirk (1990) also suggests nearly 1 000 000m^3 of littoral drift occurs along the Barrytown coast annually. Other researchers have produced a variety of littoral drift rates between the extremes of Turner (1953) and Pfahlert (1984). Turner (1953) concluded that at least 3 822 750$m^3.yr^{-1}$ of littoral drift occurred through an area of 2.59km^2 (one square mile) off the Buller River mouth.

5. RIVER SEDIMENT SUPPLY TO THE COAST

The rivers of the West Coast are a major source of sediment to the coast. Furkert (1947) estimated that the rivers between Cape Foulwind and the Cascade River supplied 12 232 800m^3 of detritus to the ocean annually. Of this he suggested about a third was incorporated in the littoral drift system.

Griffiths and Glasby (1985) presented data on the input of river derived sediment to the continental shelf. They suggest that of the suspended sediment total, between 2% and 5% would be bedload. Although, they do not stipulate what portion of this is contributed to the longshore drift system, it is likely to be approximately equal to the bedload.

The following table is a summary of Griffiths and Glasby's results.

TABLE 1. RIVER DERIVED SEDIMENT SUPPLIED TO WEST COAST SHELF

River	Suspended load ($m^3.yr^{-1}$ x 10^3)	Bed load % of suspended load	
		2% ($m^3.yr^{-1}$ x 10^3)	5% ($m^3.yr^{-1}$ x 10^3)
Karamea	404	8	20
Mokihinui	2 880	58	144
Buller	1 750	35	88
Grey	3 110	62	156
Taramakau	9 930	199	497
Hokitika	12 000	240	600
Haast	17 200	344	860
Kapitea to MacKenzie	80 100	1 602	4 005
Hollyford	75	2	4
Fiordland	81 300	1 626	4 065

When examining sedimentary processes at Westport Harbour, Kirk et.al.(1987) calculated that an average total sediment load for the Buller River was 1 070 000$m^3.y^{-1}$ (based on calculations methods of Griffiths 1979, 1981). Of this total between about 15% and 30% was assumed to be in the sand size range and therefore the river would contribute between about 107 000 - 214 000$m^3.yr^{-1}$ to the Westport bar.

6. SEDIMENT ACCUMULATION

Although coastal erosion currently extends almost the entire length of the West Coast, significant historical long term accretion (sediment accumulation and progradation of the shoreline) has occurred at three sites. These are at Farewell Spit (outside the region), around the Buller River mouth and at Blaketown Beach. Of these, Farewell Spit is the only one to be in a state of natural accretion. The Buller River mouth area and Blaketown Beach are accreting due to the influence of the harbour works at Westport and Greymouth harbours respectively. However, Kirk et.al. (1987) note that surveys prior to the commencement of harbour construction at Westport indicated that:

"The 'natural' shorelines of the Westport inlet were highly unstable and were undergoing very rapid accretion <u>before</u> insertion of any obstruction to the littoral drift...The development of the training walls has thus complicated a natural phenomenon rather than generated an entirely new bypassing system."

As with littoral drift data, those data presented for sediment accumulation vary at least an order of magnitude between the results of early research and those of more modern research.

Furkert (1947) calculated that at Farewell Spit, sediment was accumulating at a rate of 3 440 475$m^3.yr^{-1}$. He noted that between 1851 and 1936, the average width of the spit over its entire length (25km) had increased 73m, and the tip at low water mark had extended 610m. Gibb (1978) observed that the Farewell Spit had prograded a total of 2563m between 1851-1975 (between H.W.M.) at a rate of 20.5$m.yr^{-1}$).

For Westport, Furkert (1947) calculated that between 1911 and 1927 more than 382 272$m^3.yr^{-1}$ had accumulated around the Buller River mouth. Wood (1934,1943) undertook similar investigations around Westport. Between 1891 and 1934, Wood (1934) found that over an area of 8.7km^2 an average of 504 603$m^3.yr^{-1}$ had accumulated. Wood (1943) also found that in the nine years between 1934 and 1943, an average of 555 476$m^3.yr^{-1}$ had accumulated, making a net total of 29 435 175m^3 since the inauguration of the harbour works. Extending Wood's study, Furkert (1947) computed that a total of 49 695 750m^3 had been deposited in an area between the Orowaiti River, 1.4km east of the Buller, to a position about 4km west of the Buller River. Furkert states:

"...it seems reasonable to conclude that during the past 54 years, one and a quarter million cubic yards (955 687m^3) per annum has lodged at the harbour works, and as a consequence of their construction."

More recent studies by Mangin (1973) and Kirk et.al. (1987) have produced results comparable with each other, but much lower than those of Furkert (1947), or Wood (1934, 1943).

For the period 1875-1973, Mangin (1973) presented the following accumulation rates (Table 2) for an area extending about 1.4km each side of the Buller River mouth, and above the low water mark. It was noted by Mangin that periods of rapid sediment accumulation were associated with harbour work extensions, while periods of lesser accumulation occurred when no harbour works were undertaken. Kirk et.al. (1987) produced similar results, for the same area (Table 3).

TABLE 2. Volumetric Change Around Westport Harbour (Adapted from Mangin 1973)

East Side of the Harbour (North Beach)		
Period	Quantity ($m^3 \times 10^3$)	Mean Rate ($m^3.yr^{-1} \times 10^3$)
1875 - 1934	4 911	83
1934 - 1944	187	19
1944 - 1969	3 065	122
1969 - 1973	972	243
Total 1875 - 1973	9 135	93

TABLE 2. Continued

West Side of the Harbour (Carter's Beach)		
Period	Quantity ($m^3 \times 10^3$)	Mean Rate ($m^3.yr^{-1} \times 10^3$)
1875 - 1934	4 557	77
1934 - 1944	434	43
1944 - 1969	1 916	77
1969 - 1973	1 192	298
Total 1875 - 1973	8 099	83
Total Deposition 1875 - 1973 (North Beach and Carter's Beach) 17 234 x $10^3 m^3$ Difference between East and West = 1 036 x $10^3 m^3$ on East (Carter's Beach).		

TABLE 3. Accretion Around Westport Harbour 1870 - 1979.
Volumes above LWOST (Kirk et.al. 1987).

Period	Carters Beach		North Beach	
	Quantity ($m^3 \times 10^3$)	Mean rate ($m^3.yr^{-1} \times 10^3$)	Quantity ($m^3 \times 10^3$)	Mean rate ($m^3.yr^{-1} \times 10^3$)
1870 - 1879	1 480	165	2 110	235
1879 - 1883	-	-	1 151	288
1879 - 1887	1 180	147	-	-
1883 - 1892	-	-	526	58
1887 - 1892	647	129	-	-
1892 - 1901	989	110	754	84
1901 - 1911	695	70	-	-
1901 - 1921	-	-	1 004	50
1911 - 1921	298	30	-	-
1921 - 1941	293	15	809	40
1941 - 1960	339	18	-	-
1941 - 1961	-	-	172	9
1961 - 1973	-	-	334	28
1961 - 1979	508	28	-	-
1973 - 1979	-	-	109	18
Total	6 430		6 970	

As mentioned, the harbour works on the Grey River have been responsible for sediment accumulation on Blaketown Beach. The most detailed study of this area yet undertaken is by Pfahlert (1984). He found that the area around Karoro (between the southern end of the aerodrome and the northern end of South Beach) had accumulated 178 813 m^3, at an average rate of 6 165$m^3.yr^{-1}$ between the MHWM's of 1911 and 1940. For the 5km of beach south of the Blaketown harbour tip, Pfahlert found that between 1874 and 1980, a total of 1 446 841 m^3 had accumulated at an average of 15 061 $m^3.yr^{-1}$, He concluded that most of the sediment had originated from the Grey River and was supplemented by northerly littoral drift from the beaches south of Greymouth. Table 4 summarises Pfahlert's results.

On the geological time scale, massive progradation of beach surfaces has produced coastal plains at Haast, several locations in South Westland, Mahinapua to Taramakau, Barrytown, the greater Cape Foulwind area and Karamea. These are all signs of shoreline accretion since sea levels 'stabilised' approximately 5-6000 years ago.

TABLE 4. Volume and rate of sediment accumulation on Blaketown Beach for the five survey periods between 1874 and 1980 (Adapted from Pfahlert 1984).

Dates	Years	Volume change ($m^3 \times 10^3$)		Mean rate of accumulation ($m^3.yr^{-1}$)
1874 - 1895	21	397		19
1895 - 1905	10	136		14
1905 - 1925	20	287		14
1925 - 1940	15	302		20
1940 - 1980	40	326		8
Total		1 448	Average:	15

7. UNDERSTANDING COASTAL HAZARDS

To appreciate why coastal erosion occurs it is necessary to understand basic principles of processes operating in the coastal zone.

A coast can be thought of as the zone of interaction between the hydrosphere, lithosphere and atmosphere. The zone is thus subjected to a wide range of processes making the coastal environment very dynamic. Beaches are the most dynamic landform known, continually changing under the action of waves, winds and currents. A beach can be defined as a three dimensional body of unconsolidated sediment, resting upon a basement, and through which a continuous stream of sediment passes both along and across the beach.

Therefore, sediment on a beach has a finite time at any point within the system. Knowing this, sediment budgets can be calculated to determine the rate and volume of sediment passing a point, for example a headland (Figure 3).

If repeated surveying of the beach at that point shows sediment volume to have decreased, the beach is in an erosional phase; if an increase is evident aggradation is occurring. A beach may also erode if there is a net migration of the shoreline landward. This situation occurs commonly on barrier beaches, where sediment is washed from the beach crest down the backshore slope, and over time the whole beach migrates landward.

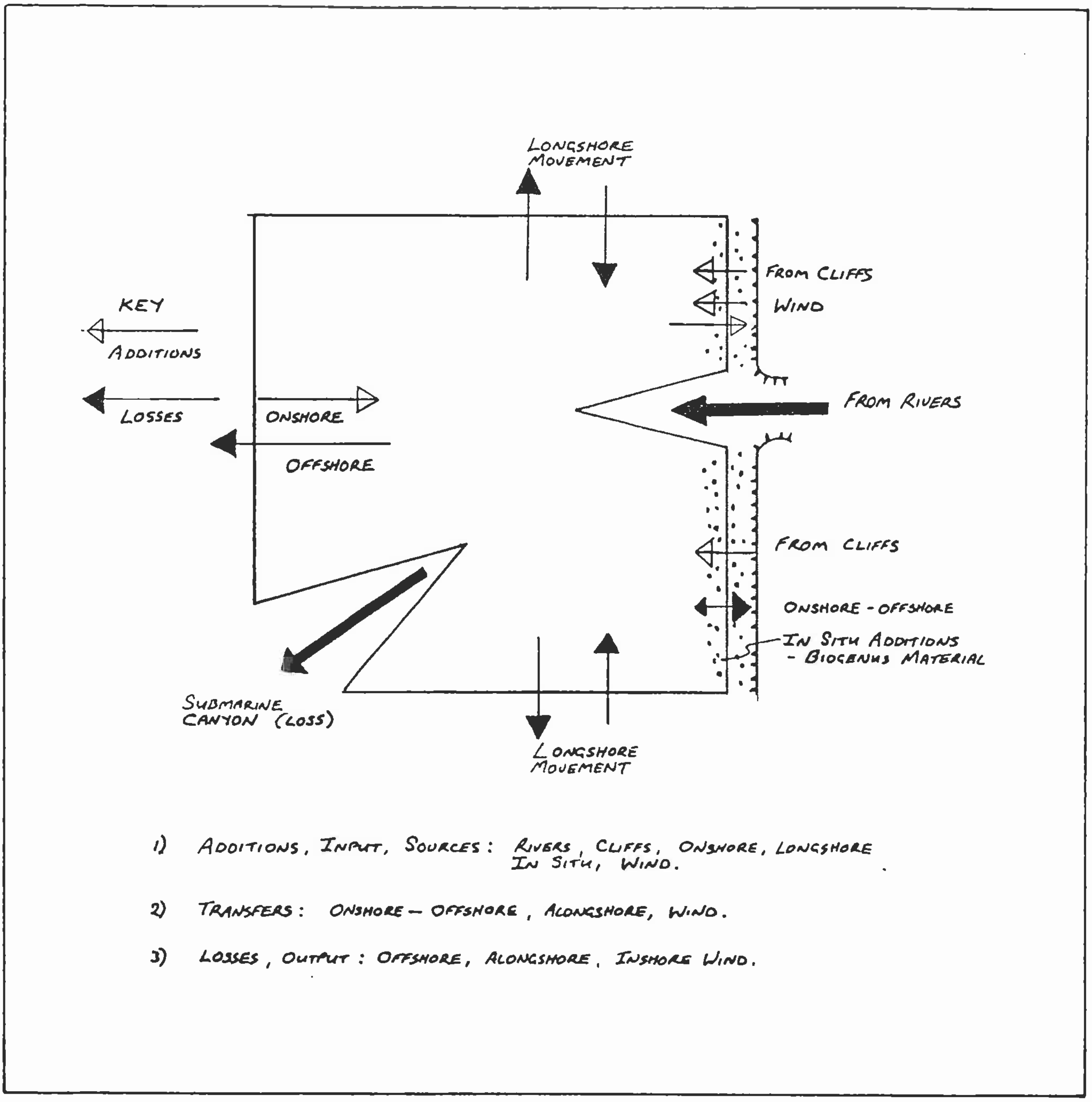


FIGURE 3. Sediment Budget Diagram.

After a period of repeated surveying, a beach cross section envelope, or sweep zone becomes evident. This sweep zone (Figure 4) reflects short term changes in beach form, appearance and volume. These changes are dependent on the prevailing weather and wave conditions; usually swell waves (long flat waves of low energy that have travelled outside their area of origin) promote beach accretion by transporting sediment onshore, whereas storm waves (short steep waves of high energy, generated nearby) activate erosion by moving sediment offshore, or by overtopping the beach, washing sediment down the backshore Persistent trends of change may affect a beach, resulting in a shift of the sweep zone as a whole, either to the landward or seaward, resulting in erosion or accretion (Figure 4). Over a period of time, small fluctuations in erosion or accretion phases may deviate from the long term trend. Thus, a short term record may not be indicative of the long term trend. For planning purposes it is therefore important to determine if present circumstances represent short term 'noise' or the long term trend (Figure 4). Typical causes and magnitudes for long term sweep zone changes are given in Table 5.

TABLE 5 Time Scales of Beach and Coastal Changes
Note the overlap in the range of responses (Kirk 1982).

Time Scale (Years)	Geological and Environmental Factors Producing Changes	Response Magnitude Horizontal Change (metres)
Short term ($\leq 10^{-2}$)	- single storms, storm surges	$\pm$0.1 TO 5.0
Quasi-seasonal and Annual (10^{-1} to 10^{0})	- periods of storminess with higher than average sea - possible coincidence of storms with spring tides - annual cycle of sea level changes	Dynamic Equilibrium $\pm$ 1.0 to 25
Historical (10^{1} to 10^{2})	- storm cycles of 2-20 years, with sea level changes - secular sea level changes of 10cm/century - possible shore-normal sediment budget changes	Trends of instability $\pm$ 10 to 50
Long term (10^{2} to 10^{3})	- climate changes (storminess, wind directions) - post-glacial sea level rise to near present ca. 6 000 BP and possible changes of $\pm$ 1-2m since - sediment budget changes from terrigenous, marine and biogenic source areas	Chronic Erosion, Deposition $\pm$ 50 to 100

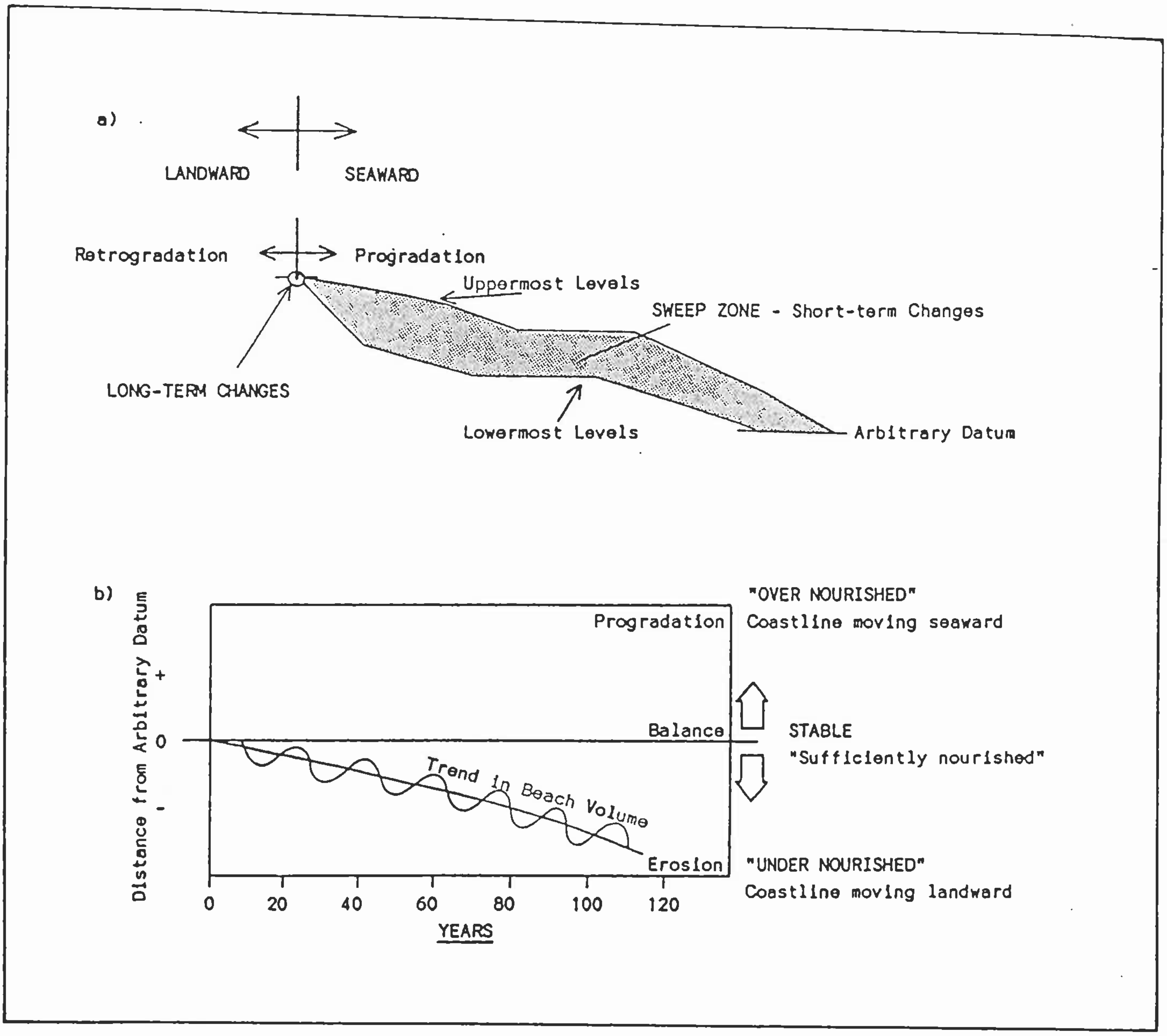


FIGURE 4. Beach Profile Sweep Zone Changes (Kirk 1982).

8. THE DYNAMICS OF SAND BEACHES AND MIXED SAND-GRAVEL BEACHES

Significant differences exist in the morphologies and processes of pure sand beaches and mixed sand-gravel beaches, both of which are common on the West Coast.

8.1 Sand Beaches

Sand beaches often develop in areas of low wave energy where the turbulence of the waves is low enough to allow the smaller sand grains to settle on the bed. Examples of such areas are in bays with shallow water where wave energy is reduced by friction with the seabed ('shoaling') or in the lee of rocky headlands where energy is lost due to the bending of waves toward the shoreline ('refraction'). Carter's Beach in the lee of Cape Foulwind is an example of this on the West Coast.

Sand beaches can also occur on more exposed coasts, such as the Karamea coastal plain. These form as a result of the area's geology: the rocks that supply the coast are such that they do not readily form shingle or gravel particles and are alomost entirely ground down into sand. The beaches can therefore be composed only of the material that is supplied to them - this is known as the 'Source Area Effect'.

Because sand beaches are composed of fine sediments that cannot form steep slopes, the foreshore surface porfiles are generally broad and at a low angle. A typical sand beach has a height range of about 5m and a slope of about 1-3° over the 150 - 200m distance from the high tide berm to the outer sand bar. Often formed at, or near the crest of the beach is a dune of fine sands that are blown landward off the foreshore by persistent sea breezes. Stabilised dunes dare usually vegetated with sand-binding plants that promote further dune growth.

Sand beaches change form in response to the wave conditions by redistributing the sand within the beach 'compartment'. Figure 5 shows the two main types of beach forms. Low swell waves can persist for weeks at a time, and tend to push sand grains up the beach to form a berm at the high tide level, giving the foreshore an accreted (built up) appearance. Episodic storm conditions, which seldom occur on the West Coast for more than a week at a time, drag sand down from the berm and dune to form a submarine bar that causes waves to break well offshore and thus release their energy in shallow water over a much greater width of beach. The stability of sand beaches depends on their ability to provide sand from the upper beach and backshore for the natural construction of offshore bars. Natural sand dunes (which are sometimes built on, or damaged by human activity) thus provide reservoirs of sand that are an important component of active sand beaches.

8.2 Mixed Sand-Gravel Beaches

Zenkovich (1967) noted that mixed sand-gravel beaches were relatively rare on a world scale, and that they were more complex in process and morphology than either pure sand or pure gravel beaches. Nonetheless, mixed sand-gravel beaches do predominate along many of the West Coast's high energy exposed shores. The rock (mostly schist) brought down from the Southern Alps is ground by the rivers and sea into a range of particle sizes, dominated by sand (up to 2mm diameter), and round, flattened gravel (approximately 20-200mm diameter). On some beaches, the sediments are thoroughly unsorted (for example Cook River to Greymouth), while other beaches consist of a steep-faced gravel ridge, with a flat sand bed below mid-tide level (for example Rapahoe, Granity).

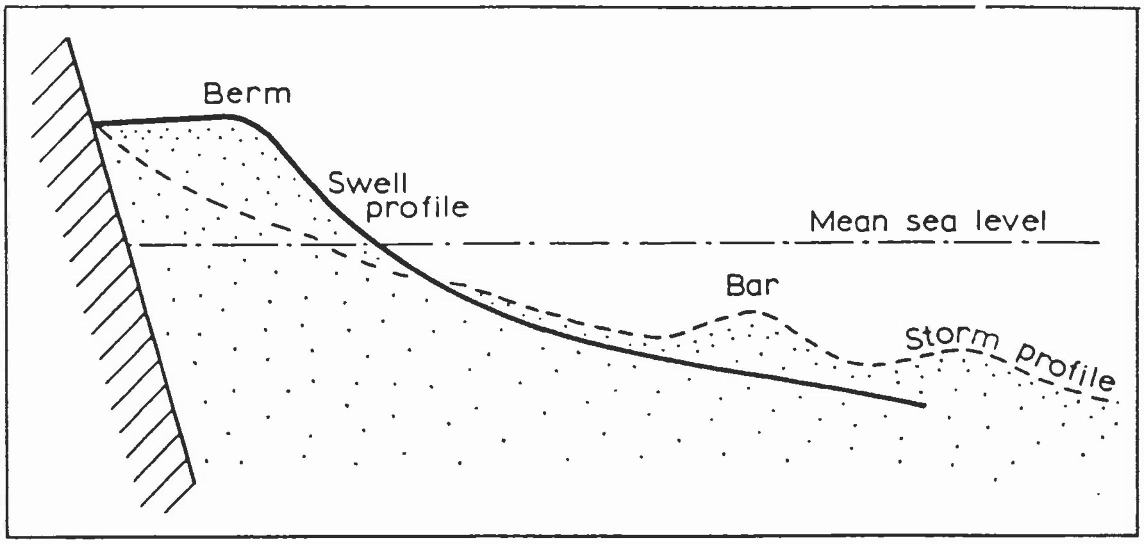
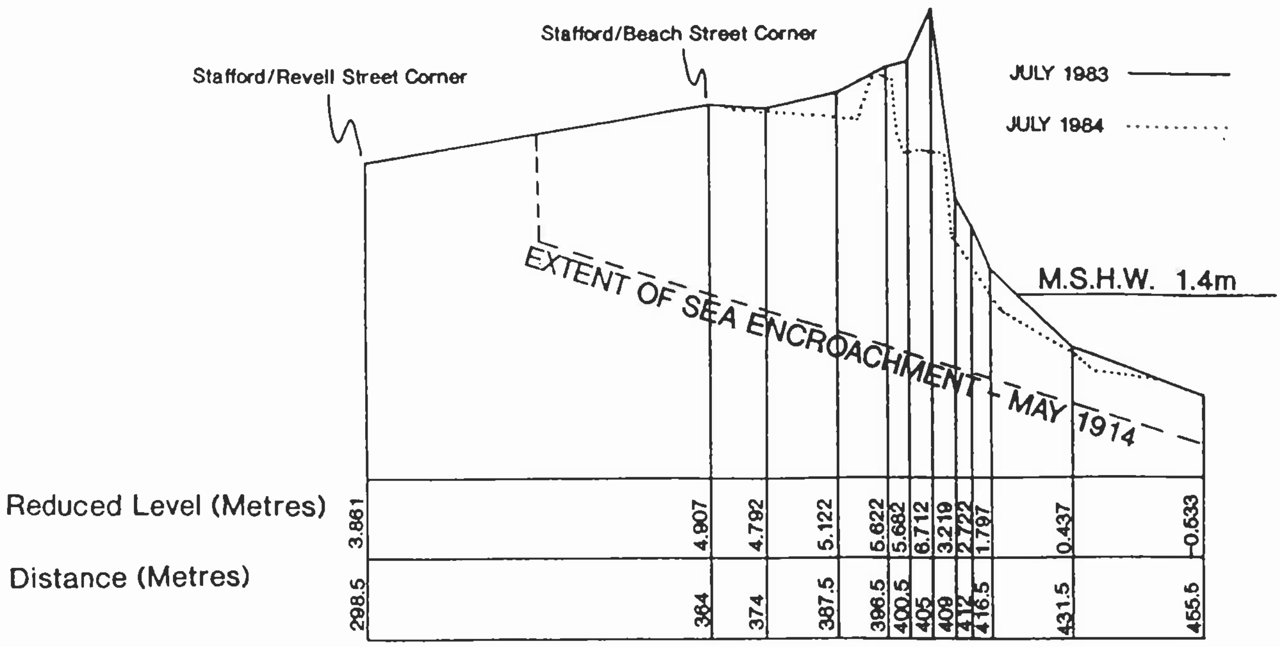
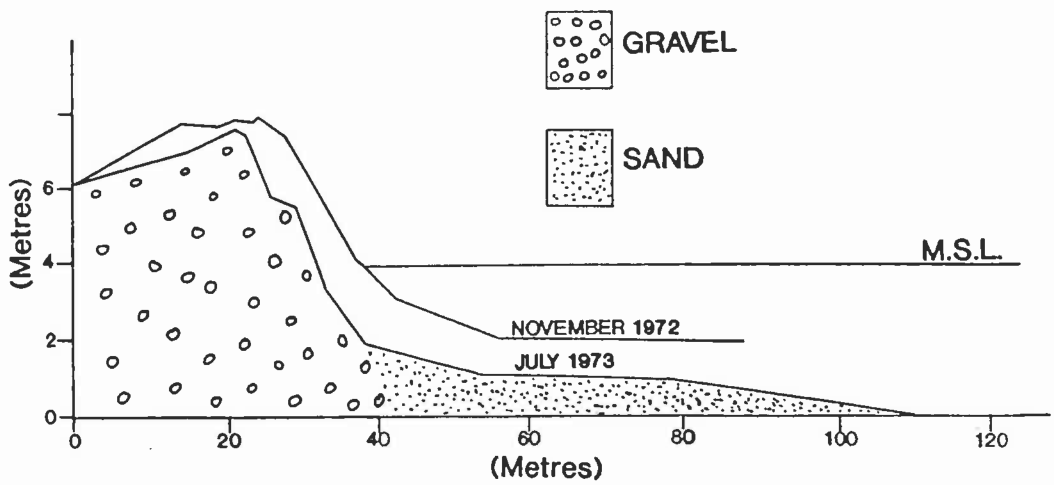


FIGURE 5. Sand Beach Storm and Swell Wave Profiles. Note the Position of the Berm and Bar (Pethick 1984).



Hokitka Beach Profiles; Representative Of Beaches Composed Of Completely Mixed Sand-Gravel Across The Foreshore

(Adapted From Westland Catchment Board, 1984)



Granity Area Beach Profiles; Representative Of Those Beaches Consisting A Steep-Faced Gravel Ridge. With A Flat Sand Bed Below Mid-Tide Level. (Adapted From Mangin 1973, Profile 12, P64)

FIGURE 6. Mixed Sand-Gravel Beach Profiles on the West Coast.

Examples of foreshore profiles taken from these two types are shown in Figure 6. These beaches are generally steeper and have greater relief than sand beaches, with foreshore slopes of around 5 - 12°. Sand dunes are low or absent from these beaches, since there is a deficient supply of fine sand to be blown from the foreshore.

While some sand-gravel beaches redistribute sediments across the foreshore in a similar way to sand beaches, others (particularly the shingle ridge beaches) do not tend to move sediments offshore in response to storm wave conditions. Instead, the stability of shingle ridge beaches depends on their ability to drain the wash of storm waves into their coarse matrix. Natural backshore streams and drainage channels (which are often filled in for development) help to achieve this function, and are thus an important component of this process.

It is of interest to note that mixed sand-gravel beaches on the West Coast are considerably different to those on the East Coast. The large body of scientific information that has been compiled for East Coast beaches does not therefore necessarily apply to the West Coast situation (most of this research has been produced by staff and students of the Geography Department, Canterbury University and the Timaru branch of the Canterbury Regional Council. Refer to Todd 1988). Hence, more research is required to improve the understanding of the dynamics of this type of beach on the West Coast.

9. COMMON SEA LEVEL FLUCTUATIONS

For general intents and purposes, these fluctuations can be discussed as a separate issue from global sea level fluctuations because of the shorter time scales at which they occur.

The erosive wave energy on a foreshore can be intensified due to superelevation of normal water levels at the shore. This leads to higher, steeper waves with more energy breaking on the shore, and is relatively common during storm events. In extreme cases all of the following features may be superimposed onto the local mean sea level.

9.1 Astronomical High Spring Tides are caused by the gravitational pull of the earth, moon, and sun. High (and low) spring tides occur when the moon, earth and sun are aligned every 14-15 days (Figure 7).

9.2 **Wave Set Up** is the superelevation of the mean stillwater level occurring shoreward of the breakers, due to the onshore mass transport of water by wave action alone. Water level from the break zone to the shore progressively increases (Figure 8).

9.3 **Wind Set Up** causes a rise above normal water levels due to the action of wind stress on the water surface. Water 'piles' up at a shore (as in seiches at lakeshores).

9.4 **Barometric Uplift** occurs during storms when atmospheric pressure decreases. Sea level rises 0.85cm for every millibar decrease in air pressure (wind set up combined with barometric uplift is called storm surge).

When these factors combine to produce higher waves at the shore, it follows that higher levels of the beach (the upper foreshore, crest, backshore) are affected, due to greater uprush limits occurring. In these conditions material on the foreshore is commonly lost offshore and alongshore, and sediment from the beach crest is washed down the backshore slope (overtopping). Saltwater inundation of the hinterland can also occur.

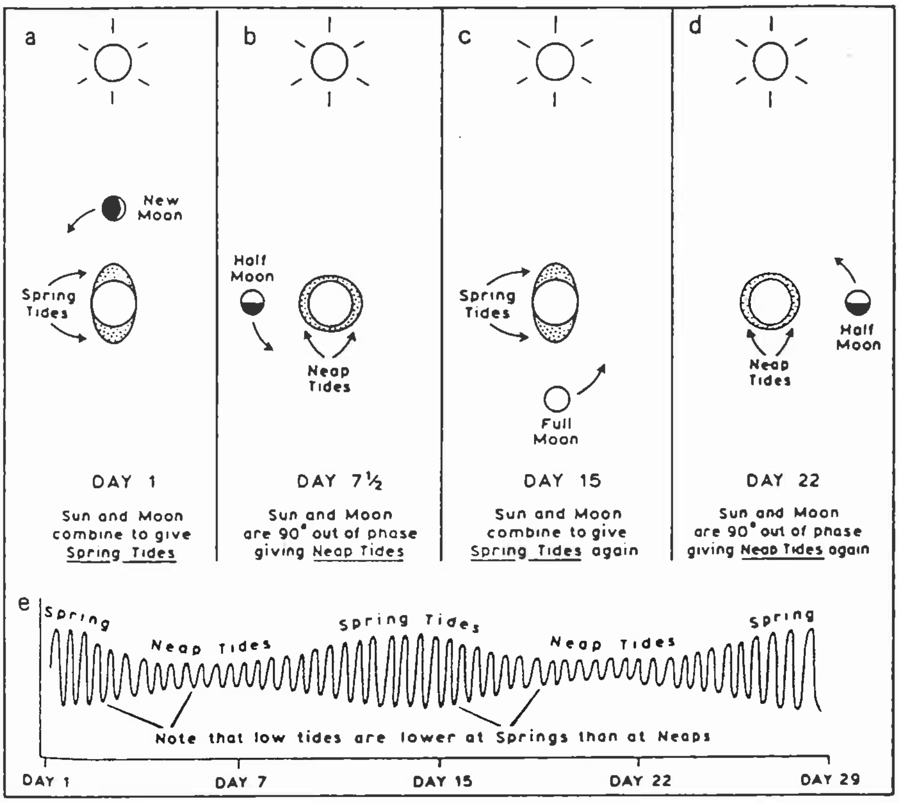


FIGURE 7. Tidal Cycles During the Lunar Month (Pethick 1984).

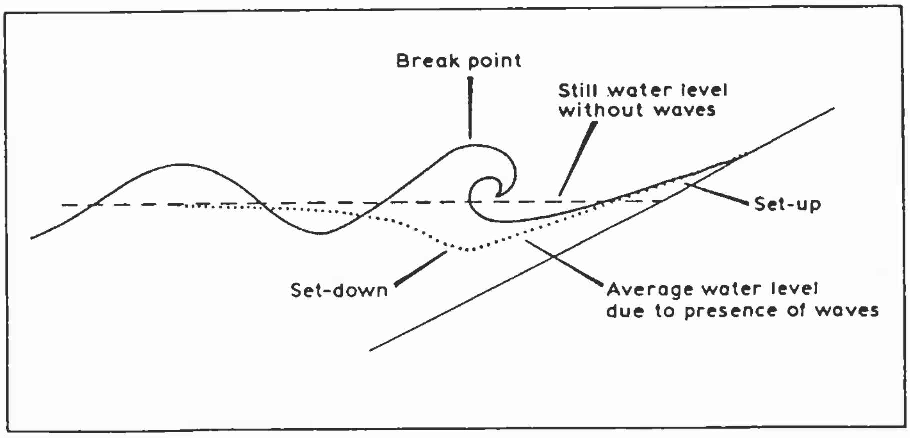


FIGURE 8. Wave Set Up (Pethick 1984).

10. TSUNAMI

Tsunami are commonly and incorrectly called tidal waves, when in fact, *THEY HAVE NOTHING TO DO WITH THE TIDES.* They may thus be additive to the tides. Tsunami are most commonly caused by shallow earthquakes, especially when dip slip faulting occurs. However, they are also created by landslides into water, submarine slides, turbidity currents, volcanic eruptions, and nuclear explosions.

Two types of tsunami exist. Far-field tsunami are generated remotely from the affected coast and thus a warning time is available. Far-field tsunami could strike the West Coast from any direction in the Tasman Sea. Figure 9, shows travel times for tsunami to reach New Zealand. It can be seen that warning times of up to 15 hours may exist, but times may be considerably less than this, depending on the point of generation. Near-field tsunami are generated close to the affected coast and no effective warning time is available.

In the open ocean, tsunami travel as waves of very long length and very low amplitude. The Coastal Engineering Research Centre (1973) state that wave lengths of 160km and an amplitude of only 0.65m is not unreasonable. Tsunami also travel extremely rapidly, with speeds in excess of 885km/hr (500 knots) being recorded. Tsunami can transform into the large destructive waves that 'characterise' them upon reaching the relatively shallow water of the continental shelf.

"Other factors of considerable importance concern the directivity of the seismic activity, the dispersal paths of the waves, the geometry of the target sea bed and coast, and by no means least, the form of human occupancy the waves encounter" (Kirk 1990).

The West Coast is 'buffered' from tsunami to a certain degree by an extensive continental shelf to the north which reduces the speed and energy of tsunami, although deep water does occur close to the West Coast to the south, especially at the Hokitika and Cook canyons. Despite the protection offered by the continental shelf, damage has been caused by tsunami on the West Coast, and the potential for catastrophic damage still exists. Kirk (1990) notes that the East Coast is more prone to far field tsunami than the West Coast, and Ridgway (1984) states:

"The hazard from tsunami of distant origin is perceived to come mainly from the South American coast....The regions of the highest risk are from the Bay of Plenty to Akaroa and from New Plymouth to Westport."

Several tsunami have struck the West Coast, but only minor damage has resulted (De Lange and Healey 1986). Benn (1992) records two more possible oceanic tsunami in the region and two lake tsunami - one on Lake Rotoroa and one on Lake Brunner. Details of all recorded cases are given in Appendix 1.

The four civil defence plans covering the West Coast Region (Grey, Buller, Westland and Tasman District Civil Defence Plans) all acknowledge the threat of tsunami suggesting that all low lying coastal settlements within their respective districts may be threatened. Adding to this, it should be noted that oceanic tsunami could affect settlements at some considerable distance inland, along low lying river flats. Also, a number of lake shore communities are at risk from tsunami, generated from earthquake shocks and landslides in particular. These communities include Rotoroa (Lake Rotoroa), St Arnuad (Lake Rotoiti), Moana and Iveagh Bay (Lake Brunner), and Hans Bay and Sunny Bight (Lake Kaniere). The risk is noted by Hawley (1984):

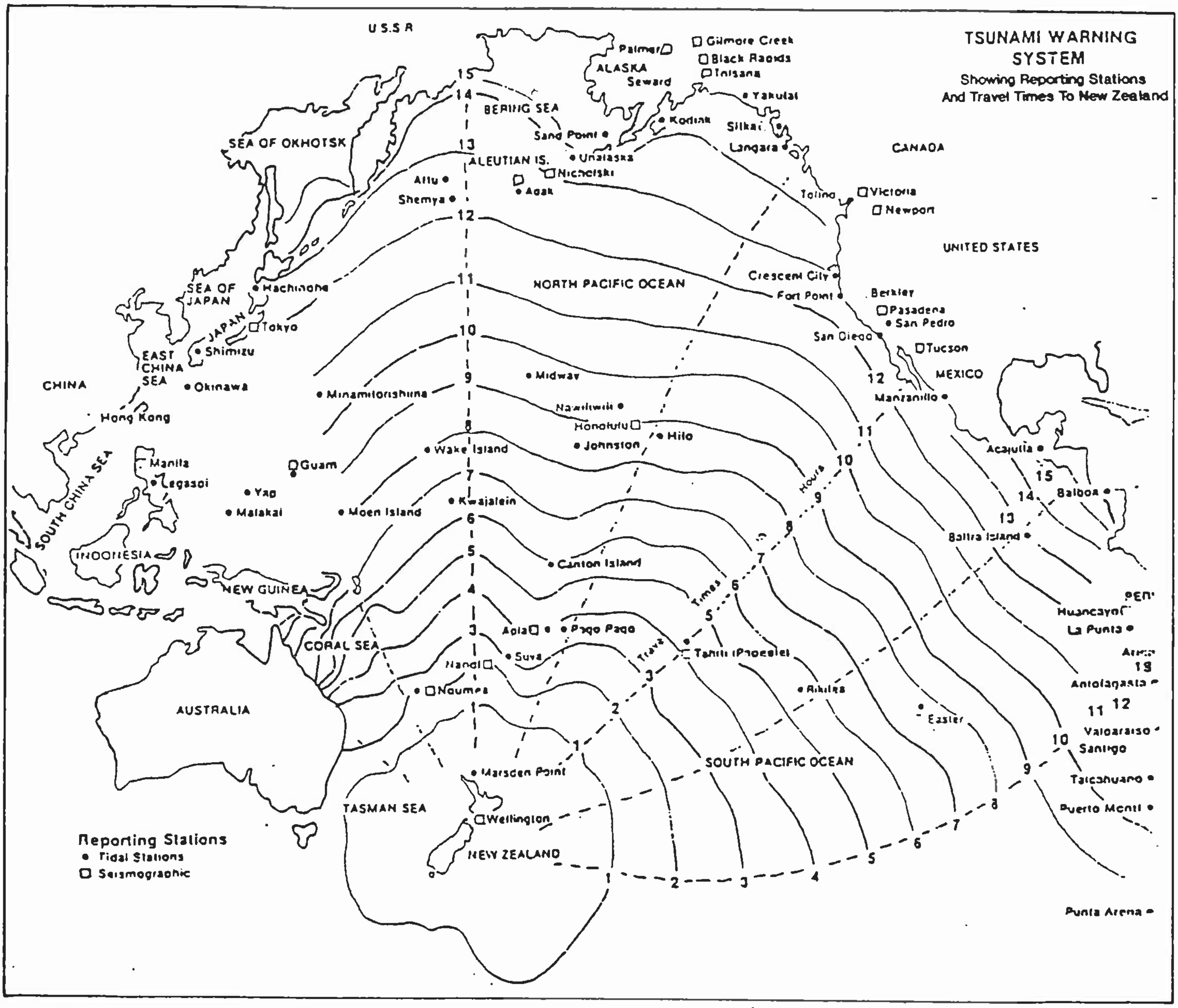


FIGURE 9. Tsunami Travel Times to Reach New Zealand (Kirk 1990).

"There is evidence of very large rock avalanches having occurred in the Southern Alps in the past...A remote, but real possibility exists that one of these may fall into a lake (natural or "hydro") and create a wave of damaging proportions."

Ridgway (1984) observes that predicting the time of tsunami generation is practically nil (relates to earthquake prediction), and that additional problems arise because many moderate to large earthquakes don't produce tsunami, yet small magnitude earthquakes can (e.g. Gisborne earthquake 1947, De Lange and Healey 1986).

Ridgway (1984) continues to note that for far field tsunami it is impossible to give a good estimate of wave heights as these will vary from one place to another and will be different for each tsunami. For local (near field) tsunami Ridgway states:

"Our historical record does not go back far enough to really access the potential danger from local tsunami, although it must be recognised that a potential danger certainly does exist".

11. SEA LEVEL RISE

In recent years numerous predictions have been made concerning the rate of sea level rise due to global warming. The variations in the data have been so great as to make future planning and management decisions of the coastal zone extremely difficult.

In New Zealand and elsewhere, the sea level rise debate in its early stages, was marked by politicking and poorly informed speculation. Only recently has this debate become based on clearer thinking with solid facts. A benchmark paper by Hannah (1988, Department of Survey and Land Information), analysed yearly mean sea levels since 1899 from tidal gauges sited at Auckland, Wellington, Christchurch and Dunedin. He concluded that mean sea levels around New Zealand had risen constantly since 1900 by an average of 1.18 ± 0.8 mm per year, and found no evidence in this data to suggest an accelerated rate in the rise over time. Also, at present there was insufficient evidence to support the hypothesis of any significant increase in mean sea level trends since 1950. Hannah stated:

"..for practical planning purposes, it is suggested that a sea level change within the range of 9-20cm by 2025 and 18-40cm by 2050 be adopted".

Gibb (1988, Department of Conservation), compared Hannah's data with a range of sea level predictions based on global climate modelling, with the majority of information sourced from the Northern Hemisphere. He suggested that atmospheric warmining by the years 2030 - 2050 A.D. could produce an average mid range eustatic sea level rise of +0.4m by 2050 A.D. and +1.2m by 2100 A.D. Gibb concluded:

"To be on the safe side planners, managers and developers of the coastal zone should allow for a +0.5m increase by 2050 A.D. and a +1.5m increase by 2100 A.D.".

Based on Hannah's data, Kirk (1991) commenting on the Barrytown ilmenite mining project said:

"For the Barrytown mining operation the sea level rise to be expected over the project life could be in the range of 18-40cm, it being prudent to adopt the upper of these limits. These predictions have the considerable scientific merit of being based on carefully evaluated data deriving directly from the New Zealand coast. In this sense they are technically the best presently available estimates and in an earlier version were presented as a report in Parliament".

It would thus make sense for The West Coast Regional Council, and other bodies administering the West Coast's coastal zone to adopt Hannah's (1988) sea level rise predictions for planning purposes, until such time that better or more relevant data become available.

Appendix (2) gives a summary by Peter Russell (Department of Conservation, Christchurch) of important points made at a seminar on 'Climate and Sea Level Change' held at the University of Canterbury, 9 April 1988.

12. COASTAL HAZARD AREAS ON THE WEST COAST

This section of the paper identifies coastal hazard areas, from south to north within the West Coast region. Where possible, the hazards are discussed in terms of erosion and accretion rates, sea flooding frequency, assets at risk, past remedial measures used, and proposed management methods that have yet to be implemented. Figure 10 illustrates the erosion and accretion rate data so far produced for the entire region.

Hannah's Clearing

Measurements made by Gibb (1978) show that the beach at Hannah's Clearing (North Jackson Bay) has eroded -350m between 1904 and 1975, at a rate of -5.0m yr^{-1}. Continued erosion could threaten Hannah's Clearing settlement (houses and baches). Little recent data exists for the area.

Bruce Bay

Erosion of -220m of foreshore between 1884 and 1950 occurred at a rate of -3.33m.yr^{-1} (Gibb 1978). The northern section of the bay is most affected, threatening State Highway 6, to the extent that rock protection works have had to be positioned. No recent analyses have been made to determine erosion trends since 1950.

Okuru River - Turnbull River Mouth Lagoon

In 1991 the river mouth changed position and broke through the spit near the southern end. Ocean waves entered the lagoon through the new entrance and eroded land near the motels, threatening large amounts of deer fencing and grazing land.

Hunt's Beach

Severe erosion was reported by locals, suggested that between 1930 - 1975, -300m of erosion occurred at a rate of -6.67m.yr^{-1} (Gibb 1978). If erosion continues at this rate, a number of whitebaiter's baches could be endangered. No accurate measurements from ground surveys, or aerial photographs have been made.

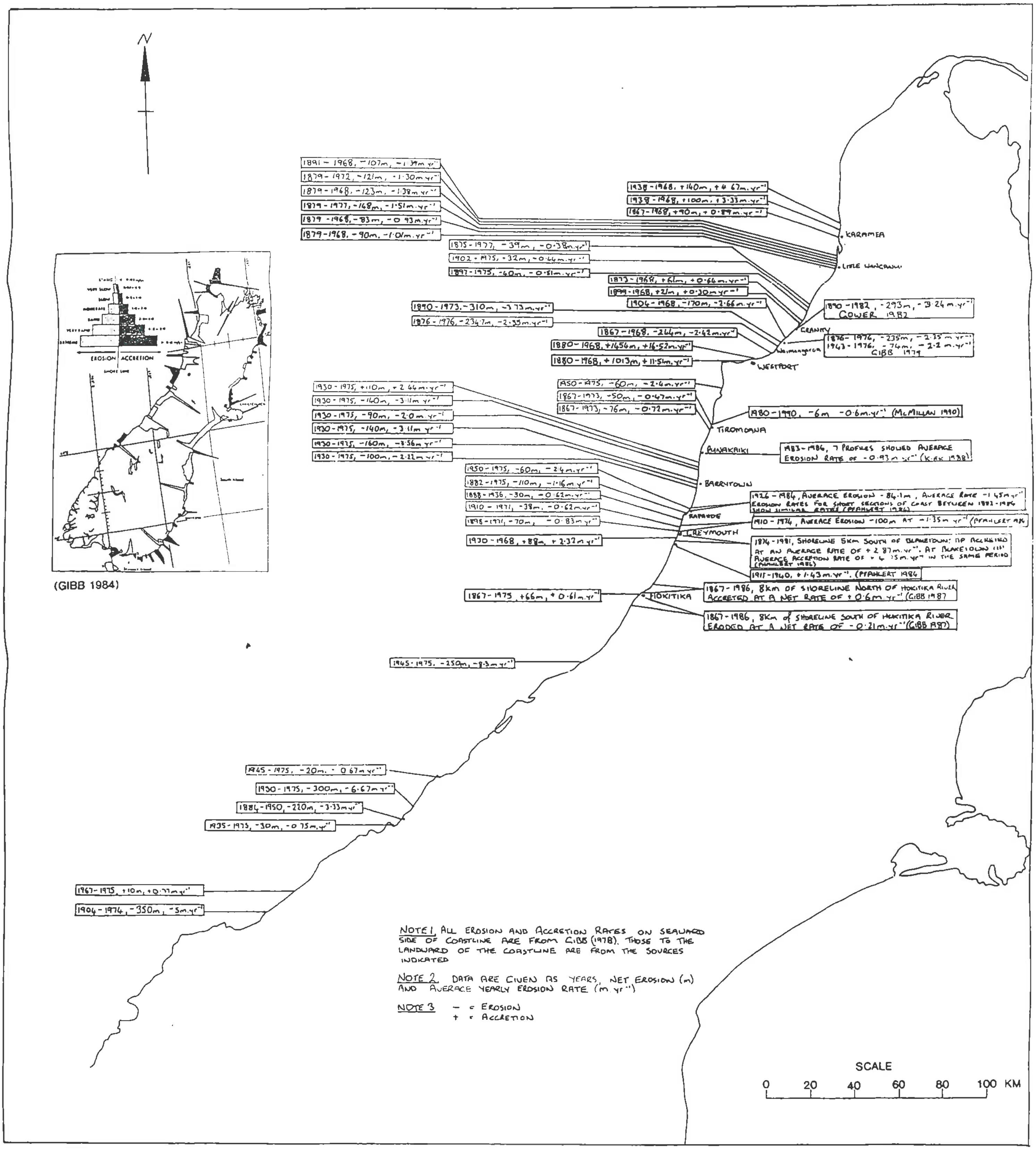


FIGURE 10. Coastal Erosion and Accretion Rates.

[SEE SEPARATE pdf FOR THIS DIAGRAM IN A3 SIZE]

Okarito

Littoral drift, low river discharges and calm seas often lead to lagoon mouth blockages at Okarito. River water backs up behind the barrier beach, raising the lagoon level by 1-2m (Westland Catchment Board 1986), and posing a flood threat to the settlement. The problem has been recognised since early European occupation of the area and various schemes to alleviate the problem have been presented over the years. Most have focussed on river mouth training works. Most recently the Westland Catchment Board (1986) proposed a training wall on the southern bank of the lagoon, and a stopbank around the settlement, to keep the lagoon mouth open and to stop flooding from the lagoon and estuary. As yet the scheme has not been implemented. However, planning measures by the Westland District Council require flood levels to be 1m above the 1985 flood level (2.8202m above the normal lagoon level).

Hokitika

The Hokitika town frontage has been affected by periods of erosion since mid last century. These erosion phases appear to be fluctuations in the long term stability of the shoreline. Severe erosion periods occurred in 1868, 1914, 1943, and the 1980's. The 1868 and 1914 phases were most severe. The 1868 case was attributed to the river mouth forming a channel parallel to the town frontage up to Park Street (Rochfort 1868, Appendix 3). The 1914 erosion phase was caused by training works on the river's south bank trapping littoral drift sediment, thus starving the Hokitika town foreshore of sediment (Sharp 1915).

All four erosion phases were considered by Gibb (1987) to be related to the southerly orientation of the river mouth. Whilst this would have certainly had some influence, the view is over simplistic, being based on scant evidence. For example, the 1868 erosion phase occurred when the river mouth was actually directed to the north. Also, the erosion and accretion phases are due to a combination of river discharge, river mouth dynamics, and sea conditions. Gibb (1987) indicates shoreline fluctuations in the order of 140m occur along the Hokitika frontage (Appendix 4).

On several occasions properties in Beach Street and Revell Street have been destroyed or badly damaged during erosion phases. More recently the ocean outfalls from the Hokitika oxidation ponds and from Seaview Hospital have both been badly affected by erosion, and the oxidation ponds themselves may be affected in the near future (Appendix 5).

Several protection schemes have been undertaken to protect the Hokitika foreshore. The first was a series of groynes built in 1867, which were reported to have been successful in reducing the effects of heavy seas and depositing sand on the beach (Rochfort 1870). River training and protection works were recommended by Coode (1880) for the purposes of improving the port, were in place by 1913, and in fact contributed to the erosion phase of 1914. The 1914 erosion episode re-exposed the 1867 protection works, and was combatted by the construction of another five groynes along the beach front (Sharp 1915). More recently, extensive studies by Gibb (1986, 1987) and the Westland Catchment Board (1984, 1986) led to the construction of groynes at Richards Drive in 1986 and the oxidation pond in 1991.

The original proposal by the Westland Catchment Board (1984) was to build a 1km long rock revetment wall from near the river mouth along the beach to Stafford Street, and it was noted by the Board in 1986 that:

"In 1965 rock was placed at the north side of the Hokitika River mouth to train the river and to protect the foreshore. The river training works have been stable. However the adjacent foreshore protection rock slumped and was relocated in January 1979 by further rock 20 metres inland".

Of the 1979 works the Catchment Board reported in 1984 that:

"In January 1979 rock protection work was placed at the southern end of the spit. The rock work appeared to be very successful in that the beach built up rapidly. With the present cycle, however, the seas have got round the back of the rockwork and the rock is now a sea wall out from the spit".

A proposal by Gibb (1987) to include coastal hazard zones over parts of the town threatened by coastal erosion, sea flooding (storm surge) and sea level rise in the Hokitika Borough Scheme was not adopted. Ad hoc measures such as dumping excavated spoil and concrete onto the beach in recent years have been completely ineffective and environmentally inappropriate. Short term erosion phases are likely to continue to affect the Hokitika beach front properties in the foreseeable future.

It is worth noting that the extreme river flooding that occurred in Hokitika on the 1st September 1947 was attributed to northerly drifting coastal sediments pushing the Hokitika River mouth northwards in a similar fashion to that described by Rochfort (1870). This nearly blocked the river mouth completely causing the river to 'back up' to the extent that water overflowed the bank and inundated the town.

The Greymouth Evening Star (2.9.1947) recorded the Hokitika Harbour Master as saying:

"The whole trouble...was the drift of sand from the south, creating a bank at the mouth of the river and thus preventing the water from getting away. Since the south training wall had been washed away, there has been nothing to stop the sea from washing right into the mouth of the river, swinging the entrance away to the north and blocking the direct outlet...

There is also the additional risk that with the river continually edging north, the town will be more and more exposed to sea erosion".

Karoro

Despite a long term trend of accretion, due to the Grey River mouth works, the beach at Karoro has recently eroded up to 19m in the last 3 years (Grey District Council Survey 1992). Several sections of the Karoro oxidation ponds outfall pipe have succumbed to the erosion, and the ponds themselves may be threatened in the near future. If this trend continues several industrial properties will also be affected. Gravel extraction may contribute to the problem and a monitoring programme has been initiated (See next section).

To the north of the oxidation pond, erosion is affecting the Watson Creek/Domain Terrace Reserve area. Protection material has been placed along the true right bank of Watson Creek to assist in preventing erosion to the beach side of the reserve.

In a letter (dated 21.4.1992), replying to a concerned local resident, the Grey District Council said of the erosion at Watson Creek:

"Any attempt to put through a straight cut to the sea will only solve the problem in the short term as the next heavy sea will block this outlet. The creek will once again move in a northward direction as it will be influenced by the northerly drift of the sea...blockages of the creek mouth have caused backing up and flooding problems in the lower Domain Terrace and Kowhai Street areas. Nature has created its own remedy to this problem through the creek outleft moving north. The creek has created a longer drainage path so that it can drain away under the beach gravels without the problem of blockages".

Greymouth (South Beach to Blaketown)

This shoreline has undergone long term accretion since the construction of the Grey River training works in 1884. The northerly drift of sediment along the coast has been arrested by the works (and possibly sediment from the Grey River), and has built the beach up at a rate of at least +15 000$m^3.yr^{-1}$ (Pfahlert 1984, Appendix 6).

Gravel is extracted along this beach by some five operators at a current licensed rate of about 18 000$m^3.yr^{-1}$, approximately equal to the natural accumulation rate (Pfahlert's 15 000$m^3.yr^{-1}$ figure may be an underestimate, as a significant section of the beach along the aerodrome frontage was not included in the calculations). Recent applications for renewal of these licenses may increase the licensed extraction to nearly 90 000$m^3.yr^{-1}$ (Table 6). This may create a new erosion problem, or may add to the existing erosion phase at Karoro. Inaccurate reporting of extracted volumes by licensees is also of concern. To help ensure erosion does not result, a beach profiling monitoring programme has been commenced by The West Coast Regional Council and Department of Conservation (Figure 11). Conditions on mining licenses have also been implemented by the Ministry of Commerce, Energy and Resources Division (Appendix 10).

TABLE 6 Gravel Extractions - Blaketown to Karoro Beach

Current Licenses

Operator	Mining License	Period	Years	Volume Extracted ($m^3 \times 10^3$)	Annual Extraction ($m^3.yr^{-1} \times 10^3$)
Buckley	1705	1.7.89 - 31.12.90	1.5	2.918	1.945
Buckley	2462	1.7.89 - 30. 6.91	2.0	6.489	3.244
Baxter	1690	1.7.89 - 30. 6.91	2.0	5.512	2.756
Williams	1685	1.1.89 - 30. 6.91	2.5	6.400	2.560

Proposed/Renewed Licenses

Operator	Current License	New Licence	Volume Requested ($m^3.yr^{-1} \times 10^3$)	Volume Permitted under previous licenses ($m^3.yr^{-1} \times 10^3$)
Buckley	1705	3209	50	6
Baxter	1609	3211	5 - 7	5
Williams	1685	3235	10	6
Pipe Company	-	3250	20	6

Note: The volumes permitted under previous licences are well in excess of what the Licensees have previously declared in taking off the beach. The licensees cite greater demand for aggregate as the reason for increasing the permitted volume.

Cobden

The 'groyne effect' of the Grey River works that causes accretion in Blaketown has also caused erosion of the beach at Cobden, at a sediment loss rate of about 22 000$m^3.yr^{-1}$ (Pfahlert 1984, Appendix 6). Beach gravel periodically washes across the road to Point Elizabeth and the road will probably succumb to erosion if its present position is maintained. If erosion continues, houses, properties and the Cobden dump may be threatened. At Cobden, Gibb (1978) measured -70m of erosion at a rate of -0.83$m.yr^{-1}$ between 1898 and 1971. However, more detailed and updated measurements are required for this area.

Rapahoe

Erosion here of about -1.5$m.yr^{-1}$ (Pfahlert 1984, Appendix 6) may also be caused by the Grey River works. The beach front road has been rendered unstable by progressive erosion, but buildings are not yet threatened although the beach is very close to the hotel. At the northern end of the settlement, State Highway 6 runs across a mudstone hillslope that has been undercut by the sea at a rate of -2.4$m.yr^{-1}$ between 1950 and 1975 (Gibb 1978).

Coast Road

Much of this coast is bedrock, little affected by coastal erosion, but in localised areas State Highway 6 traverses unconsolidated materials being undercut by the sea. Protection works for the road and coastal baches have been constructed at several places along this coast (e.g. Twelve Mile).

Barrytown

Gibb (1978) found that the southern half of the Barrytown Flats have receded up to -3.5$m.yr^{-1}$ since 1930. Kirk (1991) notes that:

"At the southern terminus of the flats, the highway is under attack from erosion, there being less than 20 metres from the highwater mark to the road edge. Random tipped rock is being periodically dumped in a vain attempt to halt this erosion. The potential exists for the road to be cut in time of storm".

Erosion may also affect farmland and the proposed ilmenite mining operation on the flats. Jones (in prep.) examines the coastal dynamics of Barrytown Flats in detail.

Punakaiki - Pororari

Kirk (1988) identifies large short term beach changes as well as a long term erosion trend averaging -0.6$m.yr^{-1}$ on the Pororari Beach at Punakaiki village. Waves periodically wash onto beachfront properties, causing limited damage which may worsen if the erosion trend continues. Occasional blockage of the Pororari River mouth during low flows and calm seas can cause flooding of the adjacent campground and other properties (Appendix 7).

Tiromoana - Woodpecker Bay

This section of coast has eroded an average of -63m since 1867 at an average rate of $-0.5m.yr^{-1}$ (Gibb 1978), obliterating much of the historic town of Brighton. State Highway 6 is very close to the sea at the Fox River, and several baches a little further north are threatened by erosion.

Okari - Tauranga Bay

Gibb (1978) measured erosion of $-2.4m.yr^{-1}$ on this coast from 1950 - 1975. This is mostly affecting farmland on the coastal strip, although a gravel road linking Okari Lagoon with Cape Foulwind will be affected if the trend persists. Coastal changes at Tauranga Bay are thought to be caused by channel changes in a stream at the bay's southern end, and possibly natural re-alignment of the pocket beach. Grazing land has been eroded and the road to the seal colony is threatened.

Westport (Carter's Beach - North Beach)

Extensions to the Buller River mouth training walls have been mostly responsible for profilic accretion of Carter's Beach to the west, and North Beach to the east (Appendix 8). Kirk et.al. (1987) estimated that about 6 400 000m^3 and 7 000 000m^3 of sediment accumulated on Carter's Beach and North Beach respectively, between 1870 and 1979. Gibb (1978) found the beaches to have accreted at up to $11.5m.yr^{-1}$ and $16.5m.yr^{-1}$ respectively, being an overall progradation of about 1.0km and 1.5km respectively on each beach.

Sedimentary processes associated with these changes have posed problems for shipping and navigation over the river mouth bar and intensive dredging of the bar and river channel has been required. Numerous alternatives for managing the port have been considered over the years, including tidal compartment enlargement, further river training works, offshore breakwaters, bar fluidisation and relocating the port to Cape Foulwind. This is the most extensively studied section of coast in the region with regard to coastal dynamics.

Orowaiti

Accretion of north beach has forced the mouth of the Orowaiti Lagoon to migrate eastwards at an average rate of $48m.yr^{-1}$ since 1954 (1600m in total). This has caused erosion of farmland on the southeastern banks of the mouth's channel. Random (and illegal) dumping of car bodies has not been successful in combating erosion.

Proposals by the landowner to construct training works on the east bank were rejected by consent authorities, who considered them unlikely to be effective.

Granity - Ngakawau - Hector

The history of stability on this coastline is uncertain. Gibb (1978), McMillan (1983) and Neale (1989) suggest that large fluctuations within the long term stability occur, while Gower (1982) gives a long term erosion rate of $-3.24m.yr^{-1}$ between 1890 and 1982 (total -293m).

Some buildings have been affected by recent erosion and sea flooding, notably Granity School and parts of Ngakawau. A seawall built at Granity School in 1960 fell into disrepair and was replaced by a gravel mound faced with concrete slabs, in favour of other protective measures that were considered (Appendix 9). Ad hoc dumping of railway irons and coal wagons on the Ngakawau beach have proven unsuccessful.

Mokihinui River - Waimarie Settlement

The coast around Waimarie settlement has a history of erosion and sea flooding. Between 1875-1977, coastal erosion averaged $-0.44m.yr^{-1}$ (Gibb 1978). However, in the last 10 - 15 years, the coast has shown considerable stability. A ridge of beach gravels was bulldozed up to the back shore in 1978, to prevent the settlement from sea flooding. An extensive stopbank was built in the late 1970's, along the south river bank, near the river mouth, to prevent bank erosion and river flooding of the settlement (i.e. stabilising the river mouth position).

In June 1992, local residents resurrected the idea of a Westland Catchment Board plan (prepared in 1973), to build a 100m long foreshore groyne, in an effort to minimise future erosional effects. The proposed groyne is to be a continuation of the Mokihinui River stopbank, and is intended to build up the foreshore in front of the settlement, by trapping northerly drifting beach sediments. The proposal is being considered by staff of The West Coast Regional Council and Department of Conservation.

Little Wanganui - Kongahu

Gibb (1978) found that this coast has been eroding since 1879 at between $-0.93m.yr^{-1}$ and $-1.51m.yr^{-1}$. Farmland is affected along most of the coast, and State Highway 67 near Little Wanganui is occasionally affected by sand dune blowouts. In 1937 Kongahu School had to be moved inland because of the erosion (Gibb 1978).

13. GENERAL COASTAL MANAGEMENT ISSUES

A variety of coastal protection methods have been used on the West Coast to prevent or minimise coastal erosion and sea flooding. The methods used in each case have been site specific with little regard for the adjacent coastal environment, or the long term stability of the beach involved.

'Hard' engineering options have been most favoured, with groynes, seawalls and river mouth training works being built at several locations. Ad hoc 'hard' solutions have included the random dumping of car bodies, the construction of small scale concrete revetment walls, and excavated spoil and rubble on a number of beaches, mainly by private landowners. It is worth noting that apart from large scale, expensive river training works associated with harbour development (Westport, Greymouth, Hokitika), other works specifically aimed at controlling beach movements have failed to control natural coastal dynamics.

A realisation that 'hard' engineering options are expensive to design, build, and maintain, and are often ineffective against wave action, has recently lead to the wider adoption of 'soft' management options. These have included coastal hazard mapping and zoning (Hokitika Borough Council), minimum floor levels for new buildings at Okarito (Westland District Council), building controls within 200m of the mean high water mark in Buller (Buller District Council), relocation of Kongahu School in 1937 (Gibb 1978), and a dune stabilisation programme by the Department of Conservation, involving Pingao planting and dune fencing at Punakaiki. In 1988, the Buller County Council proposed to undertake a coastal hazard mapping project, for the section of coast between Punakaiki to the Kohaihai River. The coast was divided into sections depending on "*their priority of urgency for attention*" (Buller County Council 1988). These were scheduled as:

(a) Very Urgent	(i)	Westport to Gentle Annie Rock (Mokihinui)
	(ii)	Punakaiki
(b) Urgent	(i)	Little Wanganui to Karamea River
(c) Not So Urgent	(i)	Karamea to Kohaihai River
	(ii)	Charleston to Cape Foulwind

Although not yet implemented, the Buller District Council (which superceded the Buller County Council and others) intends on pursuing the coastal hazard mapping project to compliment its planning measures mentioned above. Beach mining controls have also been implemented by the Department of Conservation, Ministry of Commerce and The West Coast Regional Council. For example, aggregate mining is prohibited on the Hokitika foreshore as well as a number of other eroding beaches. Soft options have the advantage of being less expensive and have less environmental impact than hard structures (i.e. they don't alter natural processes).

The full range of management options are given in Table 7, adapted from Ford, Witt and Murray (1984).

When considering appropriate management action for a particular section of coast, it is imperative that the following points are taken into account.

1) Coastal dynamics are examined in detail and well understood.

2) All options are considered in relation to effectiveness, the value of assets being protected, environmental impacts (including effects on adjacent shorelines) and expense, including design, construction and maintenance.

3) 'Hard' structures are carefully designed following guidelines set out by the U.S. Army, Coastal Engineering Research Centre (1973).

4) Random, ad hoc methods such as dumping car bodies and rubble be strongly discouraged, as these measures usually <u>promote</u> erosion by scouring and undercutting, rather than reducing erosion.

5) The method adopted is monitored to assess its performance. Information derived from this will be of use in future management decisions.

TABLE 7. Comparison of Erosion Control Measures (adapted from Ford et.al. 1984)

Erosion Control Measures	Advantages	Disadvantages	Comments
A. No Action	(i) Beach continues to behave naturally	(i) Property and improvements are lost by continued erosion	This approach is only practical where threatened property is of limited value, and its loss can be accepted.
B. Relocate Development	(i) Effectively solves the beach erosion problem (ii) Beach continues to behave naturally	(i) Public reaction against relocation is usually strong (ii) Compensation payments may be prohibitive	In spite of its apparent drawbacks it may be cheaper in the longer run in some areas
C. Rock Revetment	(i) Well suited to emergency erosion control	(i) Only effective if properly designed and constructed (ii) Adversely affects the beach	Should only be used in emergency situations
D. Groynes	(i) May be effective in building up beach on updrift side	(i) Doesn't prevent erosion - merely transfers it	Only useful in conjunction beach nourishment or if erosion on down-drift side is acceptable
E. Offshore Breakwaters	(i) May be effective in building up beach on updrift side (ii) Shelters beach from storm attack	(i) Cost is usually prohibitive (ii) Results in erosion on downdrift side	Cost is prohibitive unless other benefits are provided, e.g. small craft harbour
F. Beach Nourishment	(i) Increases buffer zone width (ii) Enhances natural beach	(i) Sources of nourishment sand not always close by	Could involve the dumping of gravel on the upper foreshore or relocation of dredge disposal. Appears to be the best approach to erosion problems in the study area
G. Sand and Gravel Conservation	(i) Beach continues to behave naturally (ii) Very little cost involved	(i) Gravel may no longer be mined or disturbed	May include mining and access restrictions and promotion of dune growth
H. Inundation Control	(i) Minimal disturbance to natural beach behaviour (ii) Low cost	(i) Won't stop long term erosion or severe short term erosion	Suitable for beaches prone to short term erosion. May include channelling, fencing or planting aiming to reduce the landward reach of waves, driftwood and gravel during storms

14. CURRENT RESEARCH

At present, several investigations are examining various aspects of coastal dynamics within the region. These are summarised below.

14.1 Thesis

Perhaps the most detailed project currently in progress is an M.Sc. thesis being prepared by Craig Jones, Geography Department, Canterbury University, Christchurch.

The study aims to investigate the highly dynamic wave environment on the exposed, high energy coast at Barrytown. Emphasis is being placed on the importance of strong, constant onshore winds creating a variety of coastal sediments, morphologies and processes on a local scale. The thesis is due to be completed by October 1992.

14.2 Coastal Cross Section Profiling

The West Coast Regional Council, Department of Conservation and Grey District Council have established a series of beach cross section profiles between the Blaketown river training works and the Taramakau River. The Grey District Council have positioned a profile at the Karoro sewage pond outfall, to monitor beach erosion around the outfall (the beach has been in an erosional phase for the last few years). The West Coast Regional Council and Department of Conservation have jointly established six profiles at the old Blaketown Surf Club, Merrick Street, Miro Street, South Beach Holiday Park, Paroa Hotel and Pandora Road (Figure 11).

These profiles are surveyed once a month (commencing February 1992), with the aim of establishing the magnitude of beach changes and a sediment budget. The objective of this is to determine if gravel extraction (present extracted volumes and applied for, future volumes) has any effect on the beach, with particular reference to the coastal erosion problem at Karoro. The Grey District Council have agreed to survey the Karoro outfall profile on, or as close to the same day as the other profiles are surveyed.

Profile benchmarks have been established by the Department of Conservation, the former Westland Catchment board and post-graduate university research students at a number of sites in the region. These have been positioned in areas affected by erosion, accretion and/or mining activities, but they have not been regularly re-surveyed.

14.3 Sea State Observations

Department of Conservation staff have been recording daily sea state observations at Punakaiki as part of their weather readings since October 1983. Measurements taken include wave height, period and approach angle. This is one of the longest continuous records of its type in New Zealand.

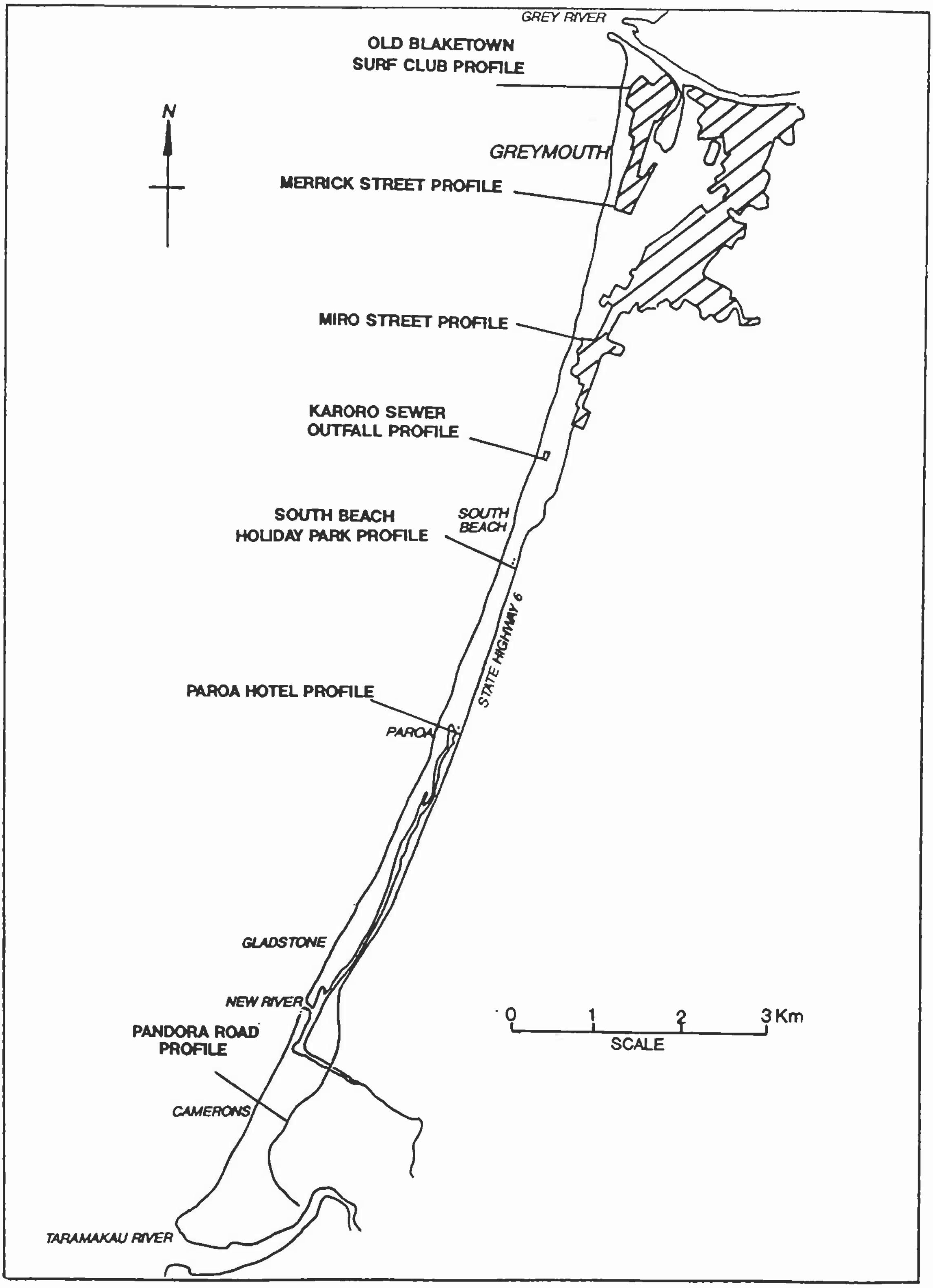


FIGURE 11. Greymouth - Taramakau Coastal Cross Sections.

15. RECOMMENDATIONS

On the basis of the information presented in this paper, it is recommended that the West Coast Regional Council and other coastal management authorities consider the following for future coastal planning and management in the region.

15.1 Management Recommendations

(a) In accordance with Section 30(1)(d) of the Resource Management Act (1991), The West Coast Regional Council and the Department of Conservation should continue to co-operate on relevant coastal hazard issues, as the two bodies have differing, but complementary areas of knowledge and expertise.

(b) Administrative bodies should strongly discourage random, ad hoc protection methods (e.g. car body dumping, unauthorised seawall constructions), as these more often than not, contribute to the initial problem.

15.2 Planning Recommendations

(a) Hannah's (1988) sea level rise predictions of 9-20cm rise by 2025 A.D. and 18-40cm rise by 2050 A.D. should be adopted by The West Coast Regional Council and other coastal planning bodies in the region, as these are the best data presently available.

(b) Where appropriate, The West Coast Regional Council and the Department of Conservation shold advocate for the adoption of planning measures that reduce coastal hazards. Such measures could include, for example, buffer zoning and building restrictions.

15.3 Research Recommendations

(a) Update existing erosion and accretion rates (e.g. Gibb 1978, Mangin 1973) for the region by means of aerial photograph analysis, ground surveys and field measurements. This information would help to establish short term fluctuations and long term trends in shoreline positions.

(b) Coastal monitoring programmes be established and maintained. Such monitoring should include beach cross section profiles, sequential vertical and oblique aerial photographs, and ground photographs for the purpose of visually recording the magnitude and frequency of coastal change.

(c) Wave climates and sea states should be analysed to determine the effects that these have on beach morphology. This should include the positioning of a permanent offshore wave and sea level recorder off the West Coast, the analysis of the Department of Conservation's raw data from the Punakaiki wave observations. Also, Okuru Enterprises Ltd are believed to be gathering wave data around the Jackson Head area and if possible, this information should be obtained, and the programme continued.

(d) When possible, West Coast administrative bodies should support relevant university thesis research, as this is a cost effective means of obtaining detailed information.

(e) Future research should be focussed on areas of concern outlined in this paper (Sections 2 and 12), particularly those areas where assets of high capital value are threatened.

16. CONCLUSION

This paper has discussed coastal processes, hazards and management issues relating to the West Coast region. The paper was prepared combining the expertise and resources of The West Coast Regional Council (Greymouth) and the Department of Conservation (Hokitika), as encouraged by Section 30(1)(d) of the Resource Management Act.

It was observed that the region's 600km coastline is composed predominantly of mixed sand and gravel beaches and pure sand beaches, separated by numerous rocky headlands. Mixed sand and gravel beaches and pure sand beaches were shown to be very different in processes and morphology. Mixed sand and gravel beaches usually occur on open, high energy coasts, and are composed of sediments ranging in size from coarse sand to boulders. Most morphological change occurs on the steep foreshore face under the action of swash and backwash. The mixed sand-gravel beaches of the West Coast appear to behave differently to those studied on the East Coast in that they respond to wave action more like pure sand beaches. However, more research is required to determine the exact behaviour patterns of the West Coast's mixed sand-gravel beaches.

Sand beaches most commonly occur in shallow bays, or down drift of rocky headlands, where wave energy is relatively low due to wave refraction. Sediment can be transported between bars on the nearshore bed, and berms on the low angle foreshore, depending on whether low energy swell waves or high energy storm waves strike the shore.

Erosion is currently the most widespread coastal hazard throughout the region. In many cases the current erosion phase appears to be a short term fluctuation in a long term semi-stable trend. However, extreme erosion has been recorded at some sites. For example, at Hannah's Clearing, -350m of erosion occurred between 1904 and 1974, at an average rate of $-5.0m.yr^{-1}$. Historically, erosion episodes have caused considerable damage at some sites. Most notable have been the erosion phases at Hokitika, which have resulted in severly damaged properties in Revell Street and Beach Street. Playing fields have been lost at Granity School, much of the historic town of Brighton has been lost, and many farmland frontages are affected. At present, erosion threatens sewage oxidation ponds at Hokitika and Karoro, a number of roads, including State Highway 6 in numerous places and State Highway 67 near Little Wanganui. Rediential properties, roads and other assets threatened, include those at Hokitika, Karoro, Cobden, Rapahoe, Waimangaroa and Granity.

Large scale river mouth training works at Greymouth and Westport have been mostly responsible for the two significant historical sites of coastal accretion. Evidence suggests that at Westport the shoreline may have been accreting before the harbour works commenced, although at a much more sedate rate. Sediment accumulation at port entrances can be a hazard to shipping as at the bars at Greymouth and Westport, and littoral drifting sediment can block river mouth's causing back up flooding, for example, Okarito Punakaiki, and Hokitika.

Storm surge presents a flooding threat to a number of low lying areas. Sea flooding affects many of the areas that are affected by erosion, for example Hokitika, Punakaiki, Waimangaroa-Granity. On occasion roads can be blocked by floodwaters and debris as has occurred at North Beach Road between Cobden and Point Elizabeth.

Tsunami have the potential to cause catastrophic damage not only on the coast, but also to a considerable distance inland on low lying river flats. Several tsunami have struck the West Coast, although damage to date has been minimal. Near-field tsunami pose the biggest threat because of the ineffective warning time they provide. Far-field tsunami are most likely to come from the western South American coast, with a maximum of 15 hours warning time, although this could be considerably less, depending on where the tsunami originate.

Coastal hazards (particularly erosion) operate on different scales in time and space and thus a variety of planning and management methods are required to address this. A number of techniques have been used in the region historically. The most common have been the employment of 'hard' options; both officially approved and ad hoc foreshore structures have been built to combat coastal erosion. It could be strongly argued that none of these structures have been successful in the medium to long term (i.e. tens of years or longer). More recently, 'soft options' such as building restrictions and zoning have been implemented, proving to be economical and effective, and allowing the beaches to behave naturally.

A series of recommendations are made regarding the management, planning and research requirements for the region's coastline. A continuance of co-operation between The West Coast Regional Council, Department of Conservation and the district councils, is recommended as is the discouragement of practises that adversely affect the beach environment. An improved understanding of processes, increased monitoring and an accommodation for future sea level rise is advocated.

17. ACKNOWLEDGEMENTS

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AGNEW, R. (1966): Storm Tides in the Tasman Sea. New Zealand Journal of Geology and Geophysics, v9, No. 3, p 239-242.

This report gives some estimates for storm surge (superelevation of the water level due to storms, etc) on the West Coast of the North Island. A storm surge in 1965 raised the sea level up to 2.6ft above the predicted tide level and the causes of this are discussed.

AMOCO (NEW ZEALAND) EXPLORATION LTD (1987): Toropuihi Exploration Well: Waste Dispoal, Biological and Oceanographic Considerations. A Report Prepared by Kingsett and Associates, Marine and Environmental Consultants Auckland for AMOCO (NZ) Ltd, 126pp.

This is an environmental impact report for an investigation of the potential hydrocarbon reserves in an area below the seabed off the northwestern coast of the South Island near Kahurangi Point. Among other (mostly ecological) aspects, the report examines the oceanography (winds, waves and currents) of the area (pp16-45). Current flows are dominated by the Westland Current and its offshoot the D'Urville Current. The Westland Current is driven by southwesterly wind flows, but it is far from steady. Regional variations in the flow patterns occur, and local variations due to upwelling are a significant factor. Net surface flows may vary from up to 1 knot northwards to 0.4 knots southwards. The impactions of currents and wave climate in the area are dicussed with regard to oil spills and navigation.

ANON. (1976): Okarito Lagoon Scheme Deferred. Soil and Water, v 13, No. 1, p 24.

An article noting the deferrence of a Westland Catchment Board proposal to train the Okarito Lagoon outlet to arrest its southerly migration. The history of the problem is summarised, and the need for planning measures is recommended.

APPENDIX TO THE JOURNALS OF THE HOUSE OF REPRESENTATIVES (1896): Correspondence between the Westport Harbour Board, Public Works Department and Sir John Coode (Harbour designer) is presented. Mainly concerns the design details and cost of the harbour construction. The article gives a good description of beach changes relating to the harbour construction and noted that L.W.M. had extended seaward of the west and east beaches and that great shoaling had occurred around the harbour entrance. Reasons given for this were a combination of natural causes and the harbour construction. Good plan and cross section profiles accompanying the article.

APPLIED GEOLOGY ASSOCIATES (1990): Gold Mining At Sandfly Beach, South Westland; Mining Proposals And Environmental Considerations, 10pp.+ Maps and Photographs.

Small scale foreshore mining of coastal blacksands has occurred at Sandfly Beach (South Westland) for over 100 years by individuals and companies. A mining licence for a strip of beach, lagoon and swamp was met with strong opposition from agencies wishing to reserve the area as National Park. This report describes the area, the mineral deposits, proposed mining details, land rehabilitation and environmental considerations. The coastal morphology of the area is described as a typical West Coast exposed beach, that has a prograded profile containing a barrier beach, lagoon and swamp area. Steep foreshore profiles, sparse vegetation and much driftwood on the beach indicate recent erosional activity with associated beach crest overtopping. At nearby Gillespies Beach, Gibb (1978) determined there had been 20 metres of erosion in the last 30 years.

BECK, A.W. (1973): Sawyer's Creek Investigation at Blaketown Lagoon. Unpublished report to the Westland Catchment Board, Greymouth. 10pp.

Report discusses the tidal flows of the Blaketown Lagoon based on a series of flow gaugings taken at the Preston Road Bridge. Due to the difference in water levels above and below the then present weir, outflow from the lagoon continued for 3 hours after low water into the Grey Estuary. Maximum inflow into the lagoon occurs about one hour before high tide. Maximum inflows are about 28.3 cumecs on a spring tide and 22.6 cumecs on a neap tide. Zero flow occurs just after high tide. After high tide, the rate of outflow increases rapidly to maximum of about 21.2 cumecs on a spring tide. This rate is maintained for about one hour after high tide, then there is a steady fall in the rate of flow until zero flow is reached about eight hours later when the tidal cycle recommences. It appears that most of the inflow is expelled out of the lagoon during the tidal cycle.

CAMBELL, W.D. (1878): On Beach Protection. Transactions of the New Zealand Society, v11, p 146 - 149

Discusses the use of groynes to protect the Hokitika beach front, on the basis of similar successes in Britain. The author proposes six timber groynes of 66 yards length. However, he mistakenly expects to have a resultant buildup of sand on both sides of the groynes.

COODE, J. (1879): Greymouth Harbour. In Appendices to The Journals of House of Representatives, E9, p 5-11.

This report quantifies rainfall, river flow, tidal ranges and volumes in the Grey River, and the design specifications of training walls to constrict the width of the river mouth to enhance river mouth scouring of the bar. The report is detailed with plans.

COODE, J. (1879): Hokitika Harbour. Appendices to the Journals of the House of Representatives, E9, p 9 - 13.

This report quantifies rainfall, river flow, tidal ranges, and tidal volumes in the Hokitika River, and recommends training works to constrict the width of the river mouth to induce scouring of deeper bar depths for the port. The scheme is detailed in writing and plans.

COTTON, C.A. (1956): Coastal History of Southern Westland and Northern Fiordland. Transactions of the Royal Society of New Zealand, v83, No. 3, p 483-488.

The coast of southern Westland may be described as 'compound', in that various processes have contributed to its development and that it has passed through a succession of five episodes of coastal history since the inception of an outline not far distant from, and similar in a general way to, that of the shoreline of today. These episodes are independent of, or supplementary to, the changes that must have been brought about by downward and upward movements of ocean level resulting from the Pleistocene world-wide glaciations.

DEPARTMENT OF LANDS AND SURVEY (1979): Coastal Reserves Investigation; Buller County and Borough of Westport: Final Report. Department of Lands and Survey, Nelson, 56pp.

A brief description of the coastline between the Punakaiki River in the south and the Kahurangi River in the north is given, followed by details of coastal communications and access, population, ownership, illegal occupations, proposals, priorities and significance, and national ratings of proposed reserves. The rest of the report is comprised of maps of specific parts of coastline with accompanying details including aerial photograph reference, location, legal description, areas (crownland, legal road etc), zoning, and a general summary.

DEPARTMENT OF LANDS AND SURVEY (1985): Coastal Resource Investigation, Westland and Hokitika Borough. Department of Lands and Survey, Hokitika, 67pp.

This report identifies and discusses coastal resources in the Hokitika Borough and Westland County, with the aim of promoting better management of the coastal resources. The coast is broken down into physical and biological, cultural and commercial resources. Legislation and agency implementation, land tenure and coastal issues are also discussed. Coastal processes are described in very general terms.

FURKERT, R.W. (1947): Westport Harbour. Transactions of the Royal Society of New Zealand v76, p 373-402.

One of the first papers to describe in detail the coastal processes as they affect the Westport Harbour area. The paper presents data on wind and current directions, sedimentation and littoral drift, and possible solutions to improving the harbour entrance channel. Most winds and waves were found to come from the south west and west; however, waves refracted around Cape Foulwind and approached the Buller River mouth from the north and north west. Measurements of littoral drift volume indicated that about 3 631 600m^3 must pass Cape Foulwind annually; Rivers between Cape Foulwind and the Cascade River were thought to deliver 12 300 000m^3 to the ocean, of which about 3 631 600m^3 (1/3) is contributed to littoral drift.

"A supply of material on the beaches as much as indicated above, plus the large deposition measured, plus the moderate erosion recorded to the north, plus the accretion at Farewell Spit, all seen to indicate that a drift across the harbour mouth at Westport of the order of four to five million cubic yards per annum (3 058 000 - 3 822 000$m^3.yr^{-1}$) must be faced as soon as all the storage space formed by the projecting moles is full".

Proposals are then given for various options of channel improvement. These include (1) Increased dredging to increase channel depth (2) Increasing the estuarine tidal compartment to improve channel scouring (3) extending the moles to increase littoral drift storage space (4) construct an island breakwater for a dredge to work in most weather conditions - would form an offshore sea bed 'hole' for additional littoral drift storage (5) a groyne extended from Tauranga Point to trap littoral drift for a period long enough to justify the cost of the groyne.

<u>GIBB, J.G. (1978):</u> Rates of Coastal Erosion and Accretion in New Zealand. New Zealand Journal of Marine and Freshwater Research, v12, No. 4, p 429-456.

This paper presents erosion and accretion rates from around the New Zealand coastline since early European settlement. Measurements were calculated from sequential cadastral maps and plans, vertical aerial photographs and field measurements. The paper presents the most extensive data of its type for the West Coast region, with 90 measurements being made from 45 sites between Karamea and Jackson Bay.

<u>GIBB, J.G. (1979):</u> Late Quaternary Shoreline Movements in New Zealand. Unpublished Ph.D. Thesis, Geology Department, Victoria University.

A section of this thesis describes coastal changes around the Westport and Waimangaroa area. The effects of the Westport Harbour works on coastal stability are noted:

"Between 1890 and 1905 the updrift coast advanced at 8.2m/year and the downdrift coast at Waimangaroa retreated at the same rate. Old survey plans of the downdrift shoreline show that it was static between 1867 - 1884 prior to the commencement of jetty construction...The southern section of the 30km stretch of coast at Karamea is eroding and the northern section is accreting. About 85km north of Karamea River sand is accumulating on the downdrift (northern) headland at Whanganui Inlet".

Between 1943-1976 at Waimangaroa, about -74m width of coast was eroded at a rate of $-2.2 \pm 0.1 m.yr^{-1}$. Since 1876 a net retreat of -235m is recorded over the past 100 years. *"The oblique strike of Holocene dune belts to the present shoreline is evidence that the coast is in the process of realigning".*

<u>GIBB, J.G. (1985):</u> The Problem of Sea Erosion at Hokitika, Westland, New Zealand, and Possible Solutions. Australasian Conference on Coastal and Ocean Engineering, Christchurch, p 381-390.

"Despite a long-term (117yr) trend of advance to dynamic equilibrium, the 2.2km-long Hokitika shoreline is subject to episodic short-term cyclic erosion-accretion up to 140m amplitude with associated flooding. Severe erosion occurs once every 30-50 years, migrating northwards as an erosion trough destroying property and assets in its wake. The cycles are natural but became a problem during accretionary phases, when development was allowed to encroach into the Coastal Hazard Zone (CHZ), on the west side of Revell Street. Making suitable provisions in the Hokitika Borough District Planning Scheme both prevent further development in the CHZ and relocate existing threatened assets over the next 30 years is the preferred solution. Groynes and the training of the river mouth north provide possible other solutions but they cannot be guaranteed".

<u>GIBB, J.G. (1986):</u> A Coastal Hazard Management Plan to Combat the Problem of Erosion and Flooding from the Sea at Hokitika, New Zealand. A Report by the National Water and Soil Conservation Authority to the Hokitika Borough Council, Ministry of Transport and Westland Catchment Board, 64pp.

This report is a development of, and complimentary to the 1985 report summarised above, with basically the same findings.

<u>GIBB, J.G. (1987):</u> A Coastal Hazard Management Plan For Hokitika. Water and Soil Technical Publication, No. 29, National Water and Soil Conservation Authority, 44pp.

This is the third and final report by Gibb on coastal erosion at Hokitika. It is similar to the 1985 and 1986 reports summarised above, incorporating and developing ideas from those reports (especially the Coastal Hazard Zone theme).

<u>GOWER, R. (1982):</u> Beach Morphology and Coastal Erosion, Granity Area. Unpublished Report, Westport Harbour Master, 15 pp.

Granity has a high energy pure shingle barrier beach, subjected to unlimited wave fetch and a northward current. A minor current runs obliquely along the coast from Cape Foulwind to Granity, veering seaward to Ngakawau. Buller River floodwaters can flow up to 2.4km directly offshore. Tracer and dredge dumping experiments (details not given) show that Buller River gravels are a source for Granity beach, and that the location of dredge dumping affects the stability of the beach. Figures are given for dredge volumes, sea level rises and erosion rates. Erosion is thought to be related to sea level rise and possible Buller River works.

<u>GOWER, R. (1987):</u> Westport: Planning for the Future. Unpublished Report, Westport Harbour Master, 15pp.

Provides a general review of the harbour works and the costs of running the harbour at Westport, and the harbour's role in Westport's future development. The harbour sedimentation problem is addressed as are the historical proposals for a harbour at Cape Foulwind. Wave climate data is given as: 5% of waves have a period of <7 seconds (100m wavelength). Wave periods of 12-14 seconds are common (~300m wavelength). Maximum wave heights 1km offshore were 6m with periods between 6-20 seconds. Sediment transport rates are summarised as 1 000m^3/day in the layer of water 1-2m from the sea bed. On the sea bed and below the 1m layer the volume was greater. In heavy weather the volume of suspended sediment at the surface alone was calculated at >1 000m^3/day.

<u>GRIFFITHS, G.A. and GLASBY, G.P. (1985):</u> Input of River Derived Sediment to the New Zealand Continental Shelf: I. Mass. Estuarine, Coastal and Shelf Science, v21, p773-787.

The input of river-borne sediments to the New Zealand Continental shelf is calculated for all major river basins in New Zealand. The data are compatible with measured sedimentation rates on the New Zealand continental shelf. Specific sediment yields are amongst the highest recorded in the world.

"Limited data and evidence from river sedimentation and reservoir studies suggest that bedload ranges from 2 to 5% of the suspended load. In total, the rivers on the West Coast of the South Island (between Fiordland and Farewell Spit) deliver 212$\pm$ 40m^3/year to the continental shelf."

HAGYARD, T. GILMOUR, I.A., and MOTTRAM, W.D. (1969): A Proposal to Remove Sand Bars By Fluidisation. New Zealand Journal of Science, v12, p851-864.

"A method is proposed whereby fluidisation is utilised to intercept coastal movement of sand and thereby allow the dissipation of sand bars in harbour entrances. The results of preliminary design calculations are given together with the approximate costs for the harbour of Westport, New Zealand".

Accepted methods for dealing with bars and how these relate to the Westport bar are described. It was concluded that if engineering difficulties could be solved economically *"then fluidised interception of littoral drift promises to give perhaps 40ft (12m) water depth at Westport Harbour".*

HANNAH, T. (1988): Analysis of Mean Sea Level Trends in New Zealand From Historical Tidal Data. Report of the Department of Survey and Land Information, No. 2, 41 pp.

Yearly means of sea level data from four New Zealand tide gauges (Auckland, Wellington, Lyttelton and Dunedin) from as early as 1899 are analysed. It is concluded that MSL has been rising constantly around the N.Z. shoreline, on average, by approximately $1.2mm.yr^{-1}$ since 1900. There is no evidence of accelerated rise in this data, and there is at present insufficient evidence to support the hypothesis of any significant increase in mean sea level trends since 1950. Extrapolations suggest an average rise in MSL around the NZ coastline of approx 9cm over the next 40 years and 25cm over the next 100 years.

HASTIE, W.J., KIRK, R.M. and LUMSDEN, J.L. (1986): Options for Improving Entrance Conditions at Westport Harbour, New Zealand. Proceedings of the First Australasian Port, Harbour and Offshore Engineering Conference 1986, p 321-325.

Incorporates sediment and morphology data included in the Kirk et.al. 1986, 1987 papers. The paper provides a description of morphologies around the harbour including 1) The river bed and banks upstream of the tidal limit (river controlled sedimentation) 2) wharf and channel area (influenced by river and tides) 3) the submarine bar and delta complex off the harbour entrance (river, wave, tide and inshore currents are active) 4) the two prograding beaches adjacent to the training walls where waves and wind are the main agents of change.

Wave climate data summarised from Valentine and Macky (1984) showed average significant wave height was 1.16m with an average period of 7.5 seconds. Predominant swell direction was westerly (27%) followed by southwesterly (21%), north westerly (13%) and northerly (10%). Wave refraction analysis showed Carter's Beach to be in equilibrium with wave angle, but waves moved at an angle across the harbour, producing west-east drift.

The outer bar was comprised of mainly littoral drift sediment while the inner bar was composed of littoral drift and river sediments. Longshore transport rate was calculated at $900\ 000m^3.\ yr^{-1}$, mostly within a zone between the shore and 10m depth. Average annual river contribution to bar sediments was considered about 15% of littoral drift total ($106\ 700m^3.yr^{-1}$). Using Brunn's (1978) formula, Westport harbour was found to be dominated by sediment bar by-passing.

HICKS, D.M. (1988): Uplift, Sea-level Rise, Shoreline Stability, and Hazard Management at Hokitika. Report to Hokitika Borough Council, Water Sciences Division, Department of Scientific and Industrial Research, 20 pp.

Information on Hokitika coastal hazards is given, additional to Gibb's (1987) report. Hokitika River sediment discharge is estimated to be 360 000$m^3.yr^{-1}$, and northerly drift to be 240 000$m^3.yr^{-1}$. The Hokitika River is suggested to be the major influence on shoreline changes. A reduction in Gibb's hazard zone widths is recommended if other remedial measures are to be taken as well.

KIRK, R.M. (1988): Coastal Erosion and Inundation at Punakaiki Village (Pororari Beach), Westland, 1983-1986. Unpublished report to Department of Conservation, 28pp.

Pororari Beach is mixed sand and gravel shore that undergoes short-term beach envelope changes of about 200m^3/m of beachfront (total 154 200m^3) as well as a long term erosion trend averaging 0.6$m.yr^{-1}$ (total 647$m^3.yr^{-1}$). The coastal erosion and flooding hazards are an immediate threat to the assets of Punakaiki village. An analysis of a four year continuous beach and wave observation programme at the beach (still ongoing) shows that high energy events (wave heights greater than 1.5m) occur 11% of the time, but seldom exceed 3.0m. The ratio of northward to southward transport in high energy conditions is about 2:1 northwards.

KIRK, R.M., HASTIE, W.J., and LUMSDEN, J.L. (1986): Sedimentary Processes Operating Around the Entrance to a River Mouth Port, Westport, New Zealand. New Zealand Journal of Marine and Freshwater Research, v21, p337-347.

This report presents results of wave climate, tidal inlet hydraulics and sand sediment by passing at Westport Harbour. The results are complementary to, and extend those of previous research (Hastie, et.al. 1986). Net eastward longshore drift occurs at 900 000$m^3.yr^{-1}$ across the harbour inlet. About 90% of drift bypasses the inlet through the inner and outer bars and the transverse channel across the inlet. River load sediment contributes about an order of magnitude less to the bar complex than the annual littoral drift. The tidal compartment is considered to contribute little to the scouring of the entrance because of the predominance of bar bypassing. Modifying littoral drift patterns may be the most effective means of improving navigational depths in the harbour.

KIRK, R.M., HASTIE, W.J., LUMSDEN, J.L. (1987): Harbour Entrance Morphology and Sediments at a River Mouth Port, Westport, New Zealand. New Zealand Journal of Marine and Freshwater Research, v20, p689-691.

Entrance morphologies and sediments at Westport Harbour Entrance were studied in detail. The most common morphology found was two submarine bars separated by a traverse channel running between Carters Beach and the inlet channel. Sediments were analysed for grain size, grain shape (rollability) and mineralogy. Results indicated longshore sediment transport was predominantly from west to east. Both the inner and outer bar can be modified by floods in the Buller River (the outer one to a lesser extent). Sediments can bypass the entrance either by bar bypassing (only if the inner bar is present) and tidal bypassing. Observations of the saltwater wedge indicated that river sediments will accumulate at the upper limit of saltwater penetration in the Buller River.

KIRK, R.M., IN ASSOCIATION WITH MURRAY NORTH LIMITED. (1991): Barrytown Ilmenite Project - Coastal Geomorphology of the Barrytown Flats As It Relates to Environmental Impact and Mining: A Report to Westland Ilmenite Limited, 30pp.

Describes the nature of the Barrytown coastal landform system particularly as it relates to mining operations for ilmenite sands as proposed by Westland Ilmenite Ltd. The wave climate is summarised from earlier publications (e.g. Kirk, 1988), and the Barrytown coast is divided into three broad units, from the stable/accretional northern section, to the strongly erosional southern section. Potential impacts from mining are indentified to be; positive impacts by augmentation of the coastal sand budget and lowering of back beach water tables, and negative impacts by raising coastal groundwater tables and siltation of backshore water bodies. Adequate buffer zone widths are defined and a monitoring programme is proposed.

KNOX, G.A. (1976): A Short-term Ecological Study of Blaketown Lagoon, Greymouth, New Zealand. Mauri Ora, v4, p 101-120.

Discusses the results of a short term hydrological and biological investigation of Blaketown Lagoon. The history of lagoon modifications are discussed as are the characteristics of the lagoon and surrounding vegetation. The construction of a weir at the lagoon's entrance was found to have altered inflow and outflow and raised water levels by 0.67m. Salinity was decreased significantly. Nutrient levels in the lagoon were high and sediment analysis showed silt-clay fractions of over 90% with large quantities of organic matter. Dominant organisms were species characteristic of estuaries with very low salinities.

KNOX, G.A., MILLHOUSE, D., FENWICK, C.D., and SAGAR, P. (1976): Report on a Preliminary Investigation or Okarito Lagoon, Westland. Estuarine Research Unit, Department of Zoology, University of Canterbury, 41pp.

Much controversy surrounded the future of Okarito Lagoon between a logging industry or preserving the area as a major stand of virgin forest (and White Heron breeding ground). *"In spite of this interest in Okarito Lagoon practically no information was available on the lagoon ecosystem".* This report thus describes the lagoon's physical characteristics, vegetation, water quality, sediments, wildlife and a catchment model. As far as coastal morphology is concerned the lagoon is noted as a bar built tidal estuary covering about 20km^2 and ranging between 1-5m deep. When the mouth is open there is a tidal range of 2.1m in spring tides and 1.2m in neaps, thus considerable tidal flushing occurs. Sediments showed a transition from sand and rubble in the lagoon's seaward reaches, to fine terrestrial sand in the upper reaches. At present the lagoon's outlet is at the south of the spit, although evidence suggests the lagoon has breached the beach in several places. The main natural change in the lagoon is slow sedimentary infilling. However, *"A detailed study of the morphology of the sand spit and associated islands, and of beach erosion and buildup will be required before the stability of this system can be assessed".*

MacPHERSON, J. (1980): Physical Environment of Okarito Lagoon, South Westland, New Zealand. Unpublished Report, New Zealand Forest Service and Forest Research Institute, 24 pp.

This paper discusses the physical hydrology and sedimentation of Okarito Lagoon in relation to the effects of logging in adjacent forests. Detailed information is given on tidal levels and flows throughout the lagoon, as well as freshwater and storm flows, and suspended sediment inputs. It is concluded that logging proposed for minor catchments away from the lagoon's edges would not have a significant effect on the lagoon dynamics.

<u>MacPHERSON, J.M. (1981):</u> Hydrology of Okarito Lagoon and the Inferred Effects of Selective Logging in Okarito Forest. New Zealand Journal of Marine and Freshwater Research, v15, No. 1, p 25-29.

An extension of the above report, with similar findings and conclusions.

<u>MANGIN, C.M. (1973):</u> Coastal Processes and Development in the Southern Karamea Bight. Unpublished M.SC. Thesis, Geography Department, University of Canterbury, 112pp.

" The 60km of beach between Cape Foulwind and Gentle Annie Point exhibits a distinct gradation from fine sand to coarse gravel from south to north. The wave environment is characterised by swell waves although storm waves recur on a 10 to 30 day frequency cycle. Littoral drift relates specifically to wave conditions, moving generally northwards from the Buller River, while gravels move south from the Mokihinui River. Beach morphology changes relate to the cyclic pattern of wave energy. Changes in beach volume are greatest around Westport Harbour where pulsational transport occurs. The long term evolution of the coastline may be related to both the post-glacial adjustment of the coast to rising sea level, and the construction of Westport Harbour. At present, accretion west and east of the Buller River is occurring, while north of the Orowaiti erosion of up to 1.5m/yr is occurring. These recent changes may have been accelerated by Westport Harbour works".

<u>McMILLAN, B.A. (1983):</u> Coastal Erosion, Granity School. Letter from Ministry of Works and Development to Education Department, 28 April 1983, 6pp.

Granity beach is shingle beach ridge and backshore with fine sand offshore of mid-tide, which aerial photo analysis shows to undergo short-term movements while retaining long-term stability. The Granity School grounds were reclaimed from the active beach system and is therefore under threat from short-term erosion, while the school itself is probably not threatened. All other development in Granity township is set back from the coastal erosion hazard. It is recommended that the seaward boundary of the school (and perhaps some assets) be resited further landward.

<u>McPHERSON, R.I. (1978):</u> Geology of Quaternary Ilmenite-Bearing Coastal Deposits at Westport. New Zealand Geological Survey Bulletin 87, 95pp + maps.

Information to do with coastal dynamics in this report include:
p12; Modern shoreline changes, spit changes and spit asymmetry. Notably, suggestions of southward longshore drift south of Waimangaroa, derived from spit/creek mouth asymmetry and from imbrication patterns of beach gravel.
p78-9 There are no gold-bearing creeks between Punakaiki and the Buller River (useful as natural tracers?).
p80; Evidence of northward drift quoted from Hutton (1950) from the presence of central Westland heavy minerals in Barrytown dredge concentrate.
Sediment analysis (mostly mineralogical) of beach and other sands throughout the report.

NEALE, D.M. (1989): Buller Coastal Hazard Assessment and Management Programme (CHAMP) Options Potentially Available for Managing Coastal Erosion and Flooding Hazards at Granity-Ngakawau. Unpublished Report for Department of Conservation and Buller County Council, 26 pp.

This collection of four separate papers and letters from 1988-89 assesses the current situation with regard to coastal hazards in the Granity-Ngakawau area, and recommends actions to be taken. The reports concur with the paper by McMillan (1983), and add further information on the dynamics of this coastline, including an analysis of the West Coast wave climate from ship-based observations and a discussion on littoral drift at the locality from wave refraction analysis. Information is probably insufficient to determine even the direction of net drift here, and wave energy on this coast is high: On this basis, groynes and seawalls are not favoured for this situation. Setbacks limits, loss-bearing and 'soft' engineering options are the best approaches to take.

NEALE, D.M. (EDITOR) (1990): West Coast First Order Coastal Resource Inventory. Department of Conservation, Hokitika, 200pp.

As part of a nationwide exercise to map and describe existing information on the conservation values and human uses of New Zealand's coasts, this volume summarises the character of the West Coast's coastal environment. The 600km of coast is subdivided into 63 'coastal units' and existing knowledge of each unit is described in some detail. Coastal hazards and uses are two of the numerous aspects covered.

NEVENS, T.H.F. (1938): Erosion at Westport Aerodrome. Proceedings of the New Zealand Institute of Engineers, v24, Part 2, p 487-497.

This paper describes the levelling of coastal dunes for the construction of the Westport Aerodrome, and the subsequent problems of wind erosion, sea erosion and sea flooding. Described in detail are the vegetation changes prior to, and after airport construction, and the processes responsible for erosion and flooding at the aerodrome. Proposed methods of alleviating the problem are evaluated.

NEW ZEALAND CEMENT HOLDINGS LIMITED (1986): Westport Harbour Improvement Proposals. Unpublised Internal Report 10pp.

"On the 5 and 6 June 1986 a "workshop" at which the problems of operating the Westport Harbour were discussed and examined, was held at New Zealand Cement Holdings Office in Westport". Following the "workshop" a report of the proceeding was prepared by R.W. Morris and Associates Consulting Engineers Limited, and extracts from this report are given in this report.

NORRIS, R.M. (1978): Late Cenozoic Geology of The West Coast Shelf Between Karamea and The Waiho River, South Island, New Zealand. New Zealand Oceanographic Institute Memoir 81, p 3-27.

A detailed account of the structural geology of the West Coast Continental Shelf is given in this report. The structure is dominated by the Cape Foulwind Fault which extends at least from Kahurangi Point to Jackson Head and is associated with an en-echelon series of open folds. Late Pleistocene and Holocene sediments of the Hawera series rest unconformably on Late Tertiary and Early Pleistocene rocks. The Hawera series includes many unconformities, filled gullies and channels, and buried glacial deposits south of Hokitika. The present shelf is undergoing rapid sedimentation everywhere, except for the Hokitika and Cook canyons.

"Although much of the shelf is blanketed with flat lying Haweran sediments varying from about 5m to 120m thick, the shelf south of the Mikonui River is covered with as much as 300m of marine sediments interbedded with an unknown amount of glacial material".

<u>OKURU ENTERPRISES LIMITED (1991):</u> Environment Impact Assessment for the Proposal to Export Bulk Water from Tuning Fork Creek via Tanker Loading Facilities in Jackson Bay. 76pp plus appendices.

This is an environmental impact assessment for a proposal to pipe and ship freshwater out from the vicinity of Jackson Bay, South Westland. The report analyses wave data taken from Reid and Collen (1983), and also contains wave refraction diagrams for the Jackson Bay area. It discusses these with regard to navigation, and the logistics involved in the construction and placement of the submarine pipe and monobuoy system. Professional reports in the appendicies include McGann, R: The Climate of Jackson Bay. N.Z. Meteorological Service, Wellington, and Monro, I.S., and Young, P.G: Jackson Bay Wave Refraction Study.

<u>PFAHLERT, J.J. (1984):</u> Coastal Dynamics and Sedimentation at Point Elizabeth, West Coast, South Island, New Zealand. Unpublished M.Sc. Thesis, (Geography Department), University of Canterbury, 306pp.

This thesis examines sedimentation, wave patterns and historical changes around the Blaketown - Rapahoe coastline. Three separate sediment transport regimes were found to exist parallel to the shore: (1) a littoral drift zone landward of the 11.22m isobath in which significant longshore and onshore transport occured (2) a shoal zone in which neither strong nor negligible transport occurred and (3) an offshore zone in which negligible transport occurred. A two way longshore drift system was found to exist to both the north and south, at between $10^4 m^3.yr^{-1}$ and $10^5 m^3.yr^{-1}$. A low beach sediment supply to the beach and high wave energy gave net erosion rates between -1.35m.yr^{-1} and -2.4m for the study area. Most sediment from the Grey River was deposited on the continental shelf with only minor amounts being deposited on the beach, as some evidence indicated a yield of 322kt/yr and beach accumulation at Blaketown Tip is about 15 000$m^3.yr^{-1}$.

Main results found were that about 2/3 of waves approach the coast from the W-SW and 1/3 approach from NW-N quarter. Mean and significant wave heights are given as 1.5m and 2.4m respectively, and mean and significant wave periods are given as 10.1 and 12.2 seconds respectively. On the open coast longshore currents were to the north 67% of the time and to the south 33% of the time. However, in Rapahoe Bay southerly drift occurred more than 50% of the time due to wave refraction around Point Elizabeth. Except for Blaketown Beach all of the coastline was retreating. At Blaketown, sediment is accumulating at about 15 000$m^3.yr^{-1}$ and the coastline is prograding at an average of +2.9$m^3.yr^{-1}$ (accumulation is most rapid at the Tip and decreases southwards). Cobden Beach is losing sediment at a rate of about 22 000$m^3.yr^{-1}$ with shoreline retreat of -1.35$m.yr^{-1}$ Rapahoe's beach sediment loss occurs at 3 500$m^3.yr^{-1}$ with shoreline retreat at -1.45$m.yr^{-1}$. The Thesis is accompanied by many plans, profiles and detailed sediment analysis.

PICKRILL, R.A. and MITCHELL, J.S. (1979): Ocean Wave Charactertistics Around New Zealand. New Zealand Journal of Marine and Freshwater Research, v13, No. 4, p 501-520.

Nearly 17 years of wave records from deep water and shore-based stations are used to describe the ocean wave characteristics around New Zealand. Data used from the West Coast is sparse, taken only from Mangin (1973) at Westport, and two other minor sources. New Zealand's western coasts are exposed, high energy shores: the wave environment is mixed, and consists of locally generated westerly and southerly storm waves, and swell waves generated to the south. The prevailing waves are 1.0-3.0m high and 6-8 s period. There are no strong seasonal rhythms, only shorter period cycles of wave height (5 day) associated with similar quasi-rhythmic cycles in the weather.

REID, S.J. and COLLEN, B. (1983): Analysis of Wave and Wind Reports from Ships in the Tasman Sea and New Zealand Areas. New Zealand Meteorological Service, Ministry of Transport, 74pp.

Data from ship reports of swell, wave and wind conditions held by the NZ Meteorological Service for the years 1957-80 have been accumulated into areas and are used to obtain a range of statistical information. However, the West Coast (Areas 36 & 37) is not on any major shipping routes and is therefore data-sparse, and there are a number of other sources of error in the data set. The data are presented in summary form on charts and in detail on microfiche. N.B. these date have been used for a number of wave climate studies on the West Coast, including Kirk et.al. (1986), Neale (1988) and Okuru Enterpries Ltd (1991).

ROCHFORT, J. (1870): On Changes in the Hokitika River. Transactions of the New Zealand Institute, p 199 - 206.

Describes the coastal erosion problems of 1865-68 that caused a loss of property along Revell Street, Hokitika. The problem is attributed to changes in the channel and mouth configurations of the Hokitika River (which are shown in plan drawings), and was combatted by the construction of groynes on the beach and by training of the river channel. In this case, beach erosion was caused mainly by the river flowing parallel along the beachfront as far as Park Street.

R.W. MORRIS AND ASSOCIATES (1989): Cape Foulwind Port Feasibility Study, 1987-1988, Executive Summary. Unpublished Report for Milburn New Zealand Limited, 29p.

An executive summary that reviews research carried by various organisations and individuals relating to coastal dynamics and the construction of a port at Cape Foulwind. Coastal parameters discussed include oceanographic data, sediment and seabed studies and bathymetry, meterological and geological data. The report outlines several options for harbour construction methods and design, costs and environmental impacts.

"The study indicates there are no physical, geological, meteorological, oceanographic or environmental conditions present in the Cape Foulwind locality that would prevent harbour development that could not be overcome by 'State of the art' techniques now known to harbour engineering".

RUSSELL, P. (1986): Plan Shape and Orientation of West Coast Beaches. Unpublished M.Sc Report to the Geography Department Coastal Group, University of Canterbury.

Recent studies in beach morphology indicate that geometric shape can be applied to beaches to describe their state of equilibrium. Eighteen West Coast beaches were studied in this respect, and only one, the Waita Beach near Haast came close to satisfying four accepted conditions for equilibrium. It was observed that most beaches were eroding, with the exception of beaches at Greymouth and Westport, which are accreting under the influence of artificial structures. The dominant foreshore direction was found to be to the NNW-WNW, while the main wave direction was from the SW. A number of spits point to the south (i.e towards the main wave direction), and this was attributed to wave refraction around rocky headlands to the south of river mouths. Where large spits point northwards, no headlands existed and normal longshore currents prevailed.

"It is apparent from this study that there is no clear relationship between beach shape and erosion/accretion trends. Because of the nature of the wave environment, all natural, open beaches are undergoing erosion. Beaches are merely orientated to face swell waves that have undergone refraction".

SHARP, H.H. (1915): Erosion of the Sea Beach Fronting the Town of Hokitika and the Remedial Measures Adopted. Proceedings of the New Zealand Society of Civil Engineers, p90 - 120.

Describes the coastal erosion problems of 1914 that caused a loss of property along Revell Street, Hokitika. The problem is attributed primarily to natural changes in the adjacent Hokitika River mouth, but also to the construction of training walls in 1913 at the mouth of the river. Erosion took place mostly during northerly gales and spring tides. The construction and effect of five groynes along the beachfront is described in detail, and sketches show beach profile changes and a shoreline plan. A general discussion on beach dynamics, littoral drift and protection works is also included.

SIMPSON, R.A., and FYSON, J.H. (1971): Westport Harbour Entrance. New Zealand Engineering, p266-271.

The paper summaries investigations into the cause of entrance shoaling at Westport and the efficiency of dredging in relation to alternative means of harbour improvement. The then recent breakwater extensions combined with the narrowing of the entrance are described and the effects these have on entrance stability. It was concluded that river discharges of between 850 and 1130 cumecs would 'smooth' the bar out and remove between 26160-52318m^3 of sediment within one or two days. Up to 5 231 836m^3 aggradation occurred within 2 months and other lesser but very large erosions and aggradations occurred continually. From the conditions these were presumed to be northward movements generally in gushes which could have occurred more than once between recording dates. The measurements took no account of suspended sediment. On a calm day the volume of sediment transported directly to the bar in the layer between 1m and 2m was at a rate of about 920m^3/day.

"No bedload or higher level samples were taken but the volume transported below the 3.5ft (1m) level would be much greater than in the layer observed. With 1-1.2m high seas, sediment transport was found to be in excess of 920m^3/day at the surface alone".

The tidal compartment volumes for Westport Harbour are given as 7 645 476m^3 at High Spring Tides and 4 247 486m^3 at Low Neap Tides.

<u>SUGGATE, R.P. (1989):</u> The Post Glacial Shorelines and Tectonic Development of the Barrytown Coastal Lowland, North Westland, New Zealand. New Zealand Journal of Geology and Geophysics, v32, p443-450.

The Barrytown coastal flats display a succession of 11 post glacial shorelines, situated at different levels both along and across the flat. This paper discusses the development and tectonic history of these shorelines, and Suggate concludes that the highest and most landward shorelines are the oldest, progressively getting younger at lower levels towards the current shore position. Along the flat, different elevations of old shorelines is attributable to a singular 3m movement of the Canoe Fault, probably about 6 500 years before present.

<u>VALENTINE, E.M., and MACKY, G.H. (1984):</u> Sea Wave Climate at Ngakawau, Westport and Carter's Beach, v1 and v2. Hydraulics Section, Central Laboratories, Ministry of Works and Development, Lower Hutt, v1, 32pp (text); v2, 153pp (diagrams).

Wave rider accelerometer buoys were placed at the sites named for totals of about 3, 2.5, and 1.5 years respectively. Though 32% of the records were lost or rejected, this is one of the most extensive accurate wave records available for the West Coast. The wave climate at Carter's Beach (average significant wave height 1.37m) is rougher than that at Ngakawau (1.30m), which is in turn rougher than that at Westport (1.16m). The Buller coast is subjected to waves generated by the predominant west and southwest winds, and to the more northerly waves generated by passing depressions. Waves arriving at Westport and Ngakawau from south of about due west are considerably modified by refraction, while Carter's Beach is not fully protected by the Steeples and Cape Fouwind. It appears possible that the highest waves at these sites arrive from the northwest or north, more or less without refraction. The sea tends to be calmest in the summer months, but other seasons do not show significant differences.

WESTLAND CATCHMENT BOARD (1984): Hokitika Beach Front Erosion, 15pp.

This report presents a design proposal for a rock revetment wall to protect the Hokitika town frontage from coastal erosion, extending from near the river mouth to Stafford Street, a distance of 1km. It was considered that ultimately the wall be up to 6.5m high to protect assets worth $ 2.3 million in 1981 terms, from the beach back cutting to its 1914 position.

The report outlines coastal processes responsible for the erosion and gives details about historical erosion events, particular the 1914 event which was the last major one to effect the town. Erosion was considered to be cyclic, with a long term severe cycle operating about once every 80 years and a short term yearly cycle, with fluctuations in the order of $-7.5m.yr^{-1}$.

WESTLAND CATCHMENT BOARD (1986a): Okarito Township, Proposed Flood and River Protection Scheme, 15pp.

Okarito township is located on an old gravel beach ridge with a tidal estuary to the east and Okarito Lagoon to the north. On numerous occasions the township has been flooded due to increased river discharges or the lagoon mouth getting blocked by drifting beach sediments, thus 'backing up' the lagoon waters. This report examines several options to alleviate the problem, and is accompanied by maps, photographs and cross section profiles. Little detail of the coastal dynamics causing lagoon outlet blockages is given.

WESTLAND CATCHMENT BOARD (1986b): Hokitika Beach Sea Erosion. Application for Grant Assistance, Rock Groyne Proposal, September 1986, 28pp.

This is a progression of the Catchment Board's 1984 report. The 1km long revetment wall proposal in 1984 was abandoned, as well as other proposals including river mouth training works, coastal hazard mapping, relocation and do nothing. In its place a series of three rock groynes at right angles to the beach, combined with minor renourishment on the downdrift side of the groynes was adopted (two of the groynes have been built to date).

The report reiterates historical erosion phases, coastal processes and protection works outlined in the 1984 report, and presents new plans and data for the three groynes.

WESTLAND ILMENITE LIMITED (1990): Barrytown Ilmenite Project, Environmental Impact Assessment.

Contains a summary and discussion of Kirk (1990) as part of the draft Environmental Impact Assessment for the Barrytown Ilmenite mining proposal.

APPENDIX 1

TSUNAMI RECORDED ON THE WEST COAST

13 August 1868

An earthquake in northern Chile generated this Tsunami. At Westport a bore 1.2-1.5m high was recorded (De Lange and Healy 1986). Far field tsunami.

22 February 1913

This tsunami was associated with a magnitude 6.8 earthquake centred near Westport (epicentre 41.85°S, 171°E).

"At Westport the tide was extraordinarily high, sufficiently so that a campsite close to the sea was flooded. Strong seiches were reported in the river at Westport. At Ngakawau, the tide was 0.9 - 1.5m above normal high spring tide. At Karamea, the tide was reported as the highest for years. A Cape Foulwind, the sea receded suddenly during the floodtide. At the time it was a spring tide so only a small additional wave height would be required to achieve the results noted. A number of coastal landslides were reported as a result of the earthquake and these may have induced the tsunami, which was restricted to an 85km stretch of coast" (De Lange and Healy 1986). Near Field Tsunami.

16 June 1929

The Murchison earthquake (magnitude 7.6, 41.8°S, 172.2°E, Eiby 1968) was responsible for one oceanic tsunami and possibly two lake tsunami.

"This earthquake was accompanied by a large rotational slump at Whitecliffs about 20km south of Karamea. An area of sea floor was uplifted as a result involving a region of 196 000m^2 and a vertical motion of about 16m. Prior to the earthquake this area was an average of 3m below sea level...It is possible that this event is responsible for the 2.5m tsunami reported at Karamea. The weather conditions at the time were bad and a cyclone was centred over the Tasman Sea to the west of the South Island. Newspapers reported heavy seas at Greymouth, New Plymouth and Auckland on 19 June. This would make the observance of a tsunami difficult, especially since the waves reported due to the storm were in excess of 6m. However, the lighthouse keepers at the Cape Farewell Spit lighthouse noted that, in addition to damage caused directly by the earthquake, materials including tools were swept away by a high tide which followed the earthquake. The following day it was found that a big tide had breached part of the spit exposing a large Maori burial ground" (De Lange and Healy 1986).

At Lake Rotoroa during the Murchison earthquake, the Greymouth Evening Star (20.6.1929) reported that:

"Lake Rotoroa rocked from side to side like a huge basin of water being tipped out. Half an hour after the main shake, the water receded from the hotel shore and exposed the lake bed for 50 yards. It then came back in a series of large waves. The bridge over the Gowan River at the lake was torn from its piles and banks of the river and was hurled upstream. The wrecked structure was carried still further upstream by the Gowan waters, which were temporarily flowing back into the lake. The water then returned back to its normal course".

The same paper reports a disturbance of the waters at Lake Brunner saying:

Lake Moana (Brunner) sank down in the middle then came up like a typhoon".
All Near Field Tsunami.

25 May 1960

After the Fiordland earthquake (magnitude 7, epicentre 44.2°S, 167.7°E, Eiby 1968), unusual 'tides' were recorded in Greymouth, either being well ahead, or well behind the tide's scheduled time of arrival along the coast. In Greymouth:

"...the water rose and dropped 3 feet or so for no apparent reason. The Blaketown lagoons presented an unusual picture with quite a vigorous current flowing into them at various times then receding just as urgently" (Greymouth Evening Star 25.5.1960).

10 May 1962

The Westport earthquake (magnitude 5.9, epicentre 41.65°S, 171.32°E, focal depth 12km, Eiby 1968), caused a disturbance of the sea at Charleston. The Greymouth Evening Star (12.5.1962), reported that:

"Off the coast of Charleston the sea appeared to boil".

No other information is given.

28 March 1964

The source of this tsunami was the Alaskan earthquake (Magnitude 8.4). much damage occurred around the north Pacific but in New Zealand it was barely noticable and poorly recorded. In Greymouth a maximum sea level rise of 0.4m for 20 minutes was recorded (De Lange and Healy 1986). Far Field Tsunami.

APPENDIX 2

**Summary of Discussions From A Seminar On "Climate And Sea Level Change"
9 April 1988 (P.G. Russell, Department of Conservation, Christchurch)**

Speakers:		
	Brian Lawrence	)PHD students, University of
	Steve Wood	)Canterbury - Physics Department
	Dr Bob Kirk	-University of Canterbury Geography Department
	Dr Blair Fitzharris	-University of Otago Geography Department
	Dr Chris Kissling	-Planning Director, Canterbury United Council

Summary

1. NZ climate is highly variable although trends shows some warming is occurring.

2. Sea level reached present level only 5000-6000 years ago.

3. Many facts and assumptions are simplified by people not expert in this field.

4. Interaction of all atmospheric processes is still very poorly understood. Predictions depend on 8 different numerical model and 18 scenarios predicting sea level rise differing between a few mm and 7m i.e. there is no consensus among scientists.

5. Ozone depletion over Antarctica is a fact and is getting deeper each year, but it is not known why.

6. Kirk said that the gross simplification of the issue was "bad science and comes close to politicing". He was disturbed by the tendency of policy makers to drop the "ifs" and "buts" from scientific papers.

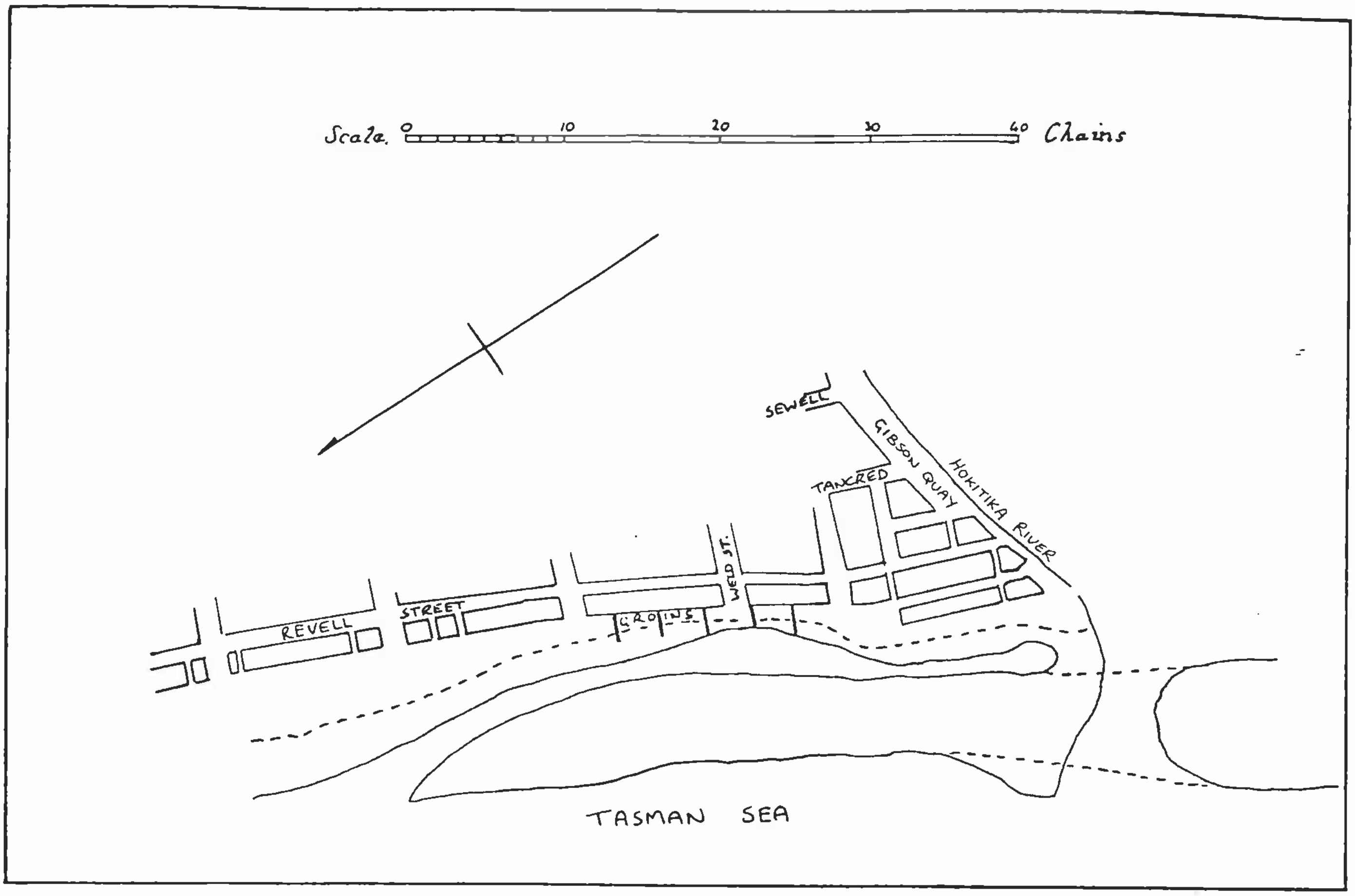
7. Sea level rise has been going on for years in places and that sea level is the net effect of all influences acting on it. These influences are not addressed by many scientists. There is a very large data deficiency in the Southern Hemisphere.

8. Many incidents of sea level rise have coincided with a higher frequency of storm events. SEA LEVEL DOESN'T ERODE COASTS - WAVES DO.

9. It is unreasonable to assume a general sea level rise in NZ which is so tectonically active. Everywhere around NZ there are coasts rising and falling relative to sea level, and they don't occur at uniform rates. Only two records are known in NZ and they are of poor quality.

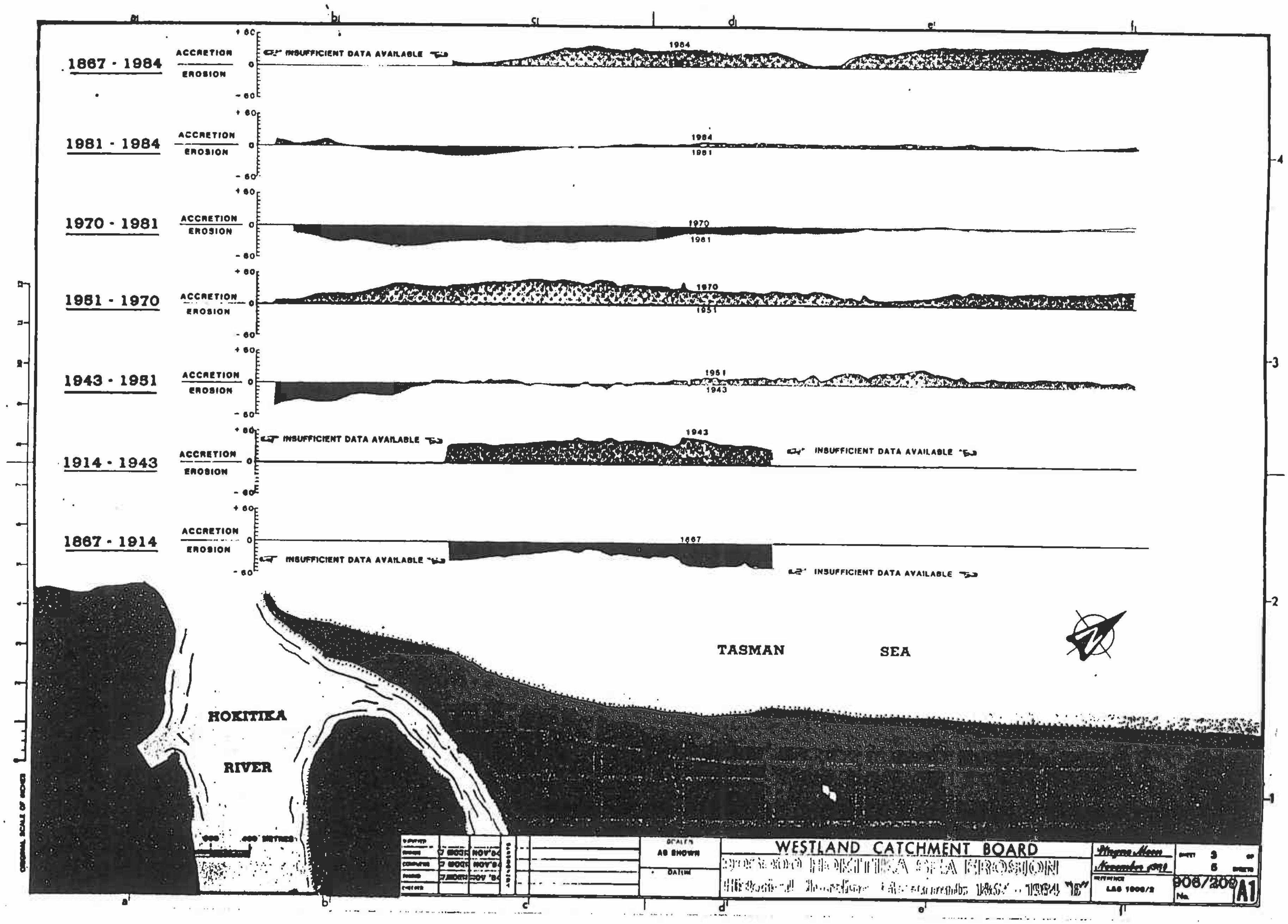
10. There should be no concerns about rising sea level in general, in NZ, in light of existing information. Numerical amounts, e.g. 20cm in 5 years is unjustified information and public announcement of this is alarmist and sensationalist. By the same token, it would be prudent not to regard future sea level change in New Zealand as a risk factor.

APPENDIX 3.



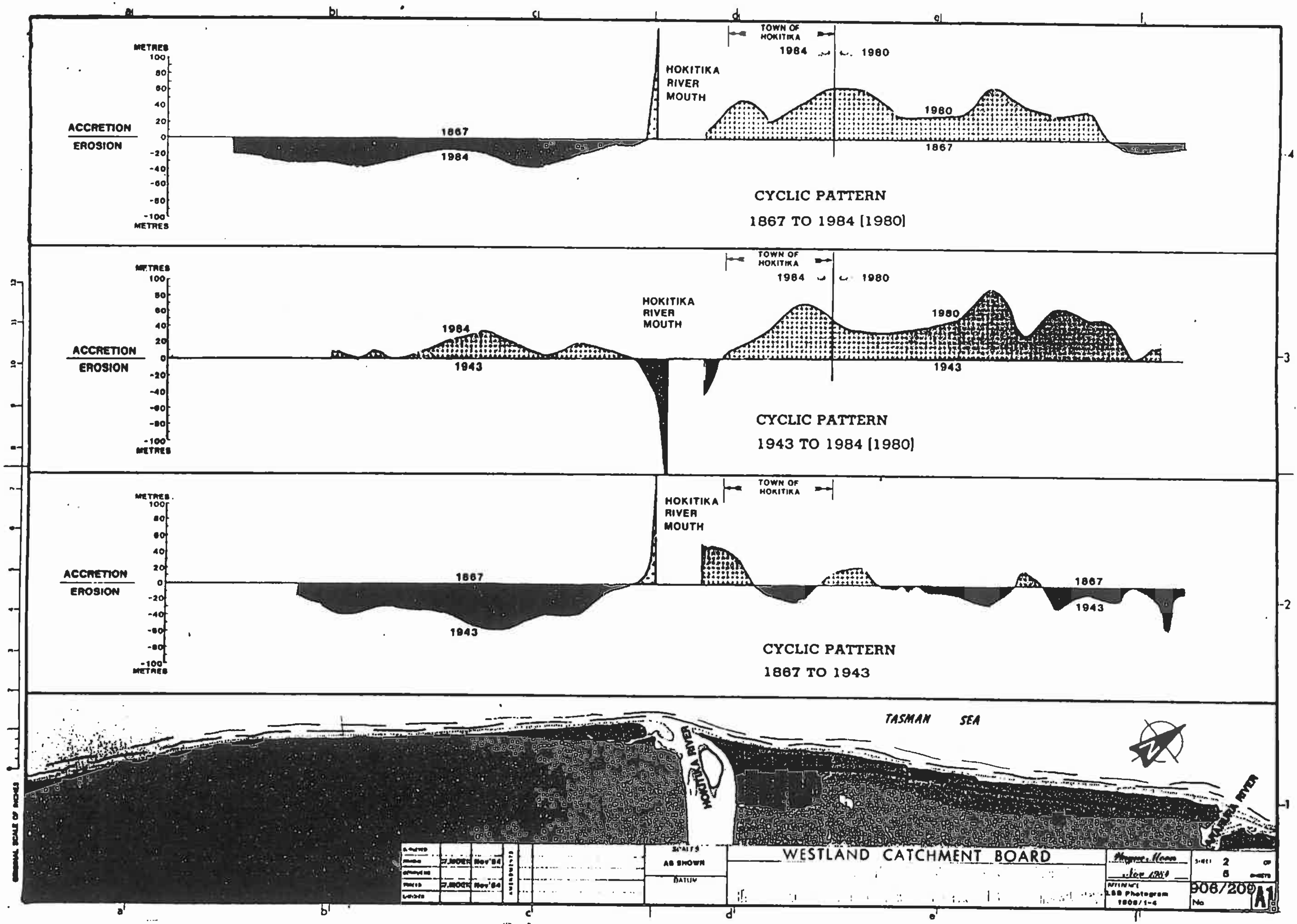
1868 River and Beach Changes at Hokitika (Rochfort 1870).

APPENDIX 4.

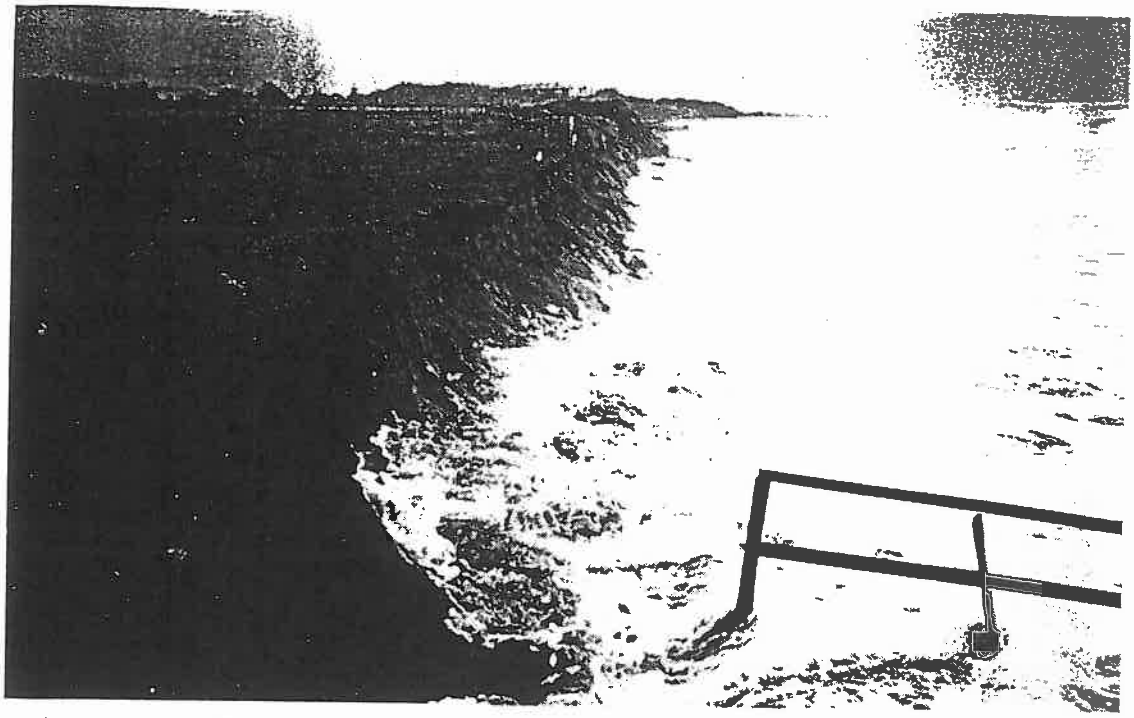


Historical Shoreline Movements, Hokitika 1867-1984. (Westland Catchment Board 1986, Gibb 1987).

APPENDIX 4 CONTINUED.



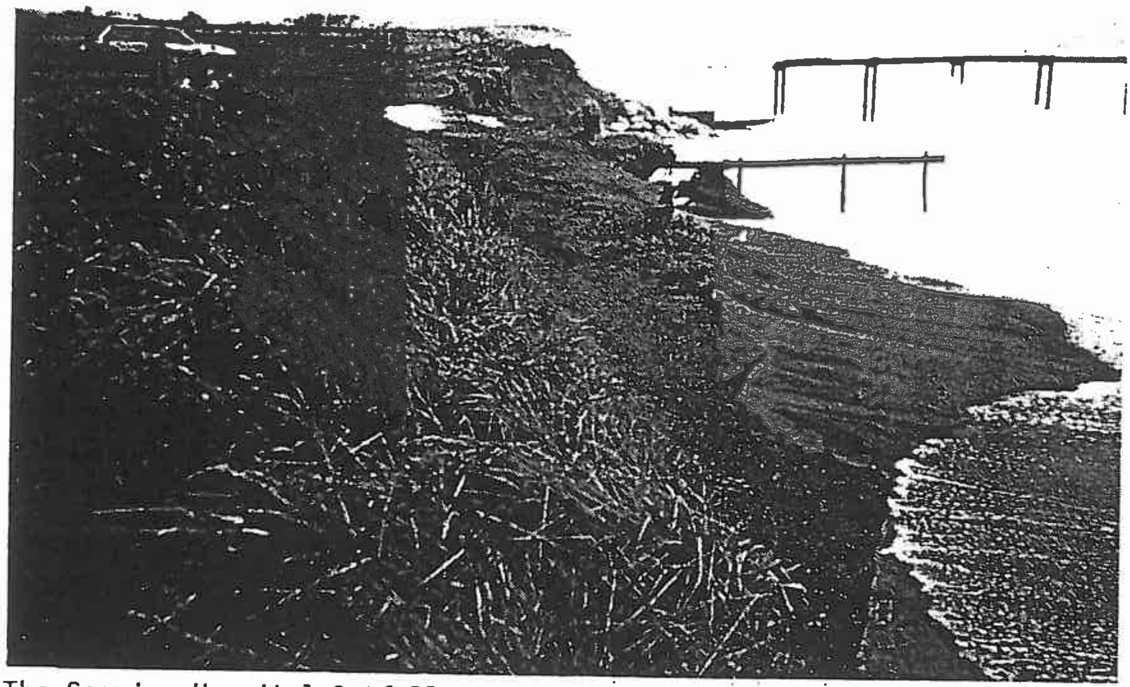
Historical Shoreline Movements, Hokitika 1867-1984. (Westland Catchment Board 1986, Gibb 1987).



Looking South Towards Richard's Drive Groyne. Note the Wooden Fence in the Top Centre and the Concrete Floor and Rails from and Old Shed in the Right Foreground.

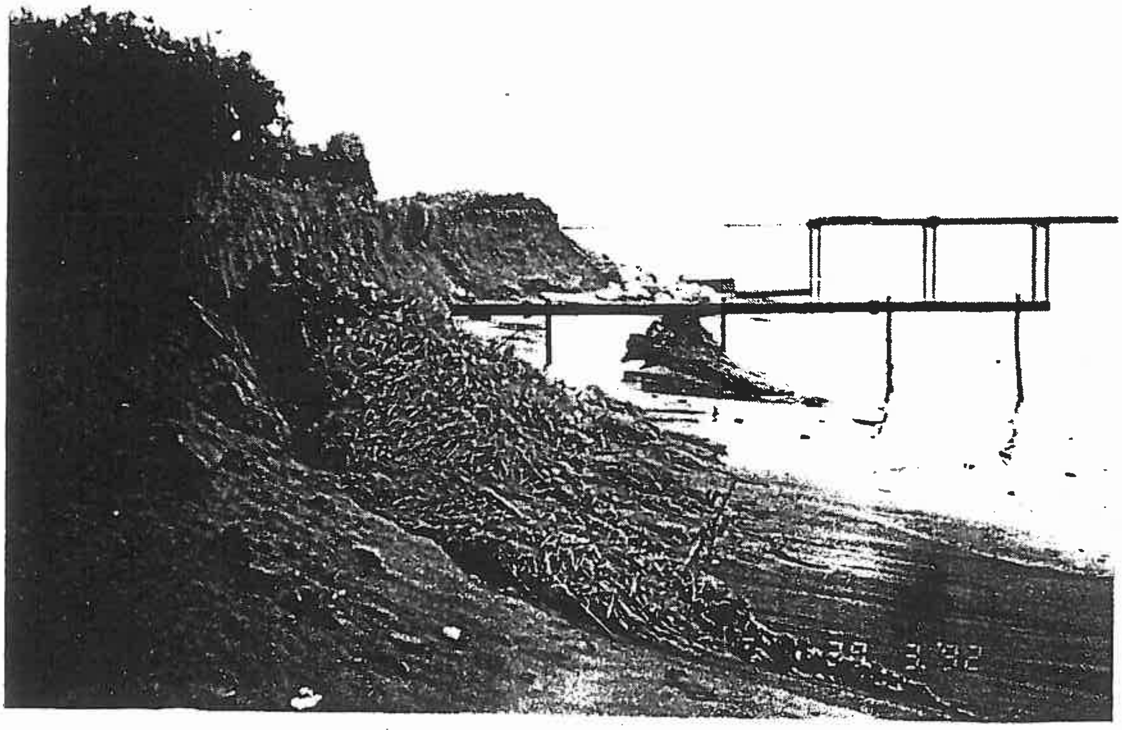
The Old Night Cart Shed, Near the Settling Ponds.

Photographs of Recent Coastal Erosion at Hokitika.
(West Coast Regional Council Photographs 20.3.1992).



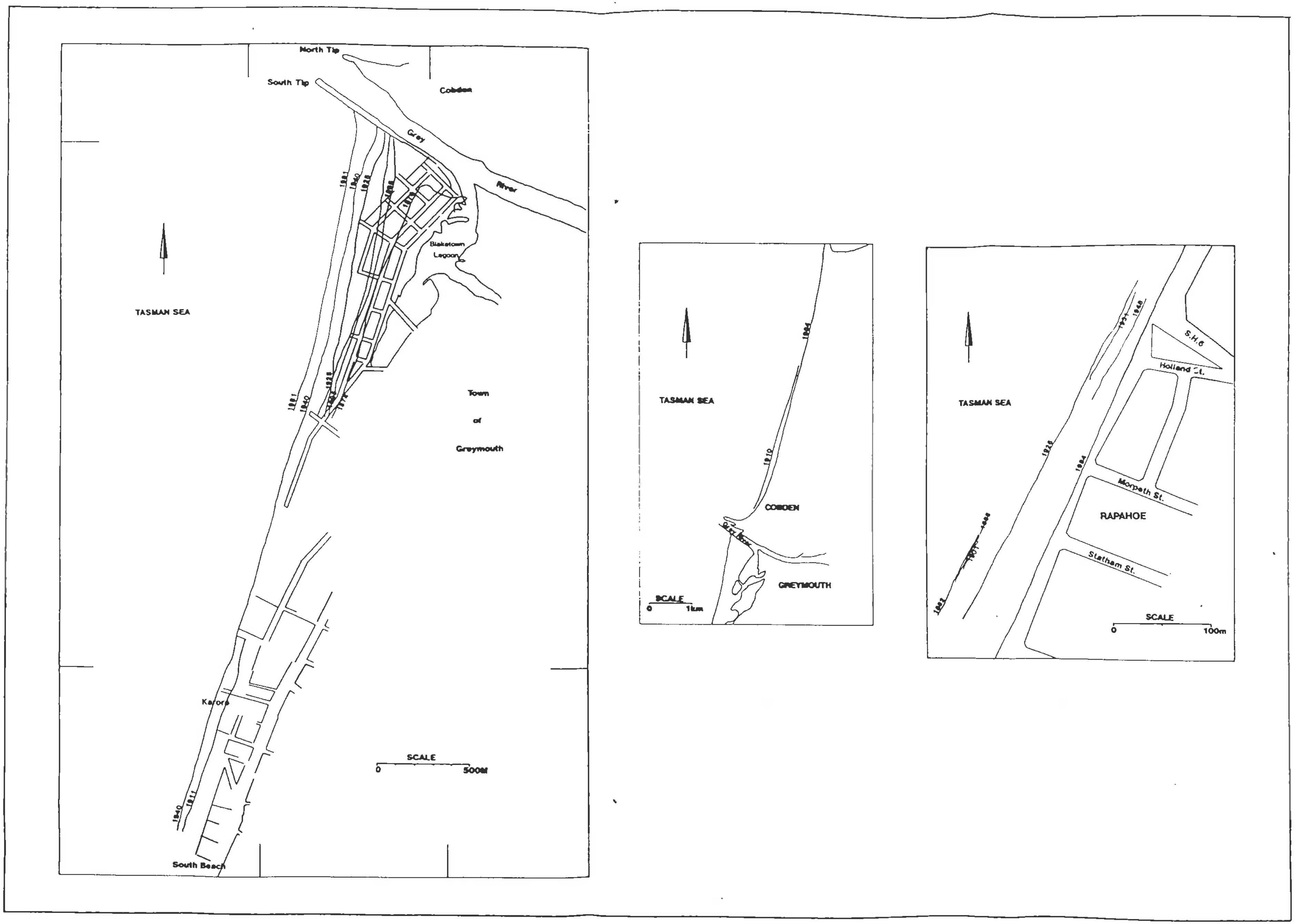
The Seaview Hospital Outfall Pipes. Note the Road - This Road went on the Seaward Side of the Night Cart Shed (Previous Page), and was Passable Two Days Prior to the Photography Date.

The Seaview Hospital Outfalls. The Short Pipe in the Foreground was Completely Exposed in Only Two Days.



Photographs of Recent Coastal Erosion at Hokitika.
(West Coast Regional Council Photographs 20.3.1992).

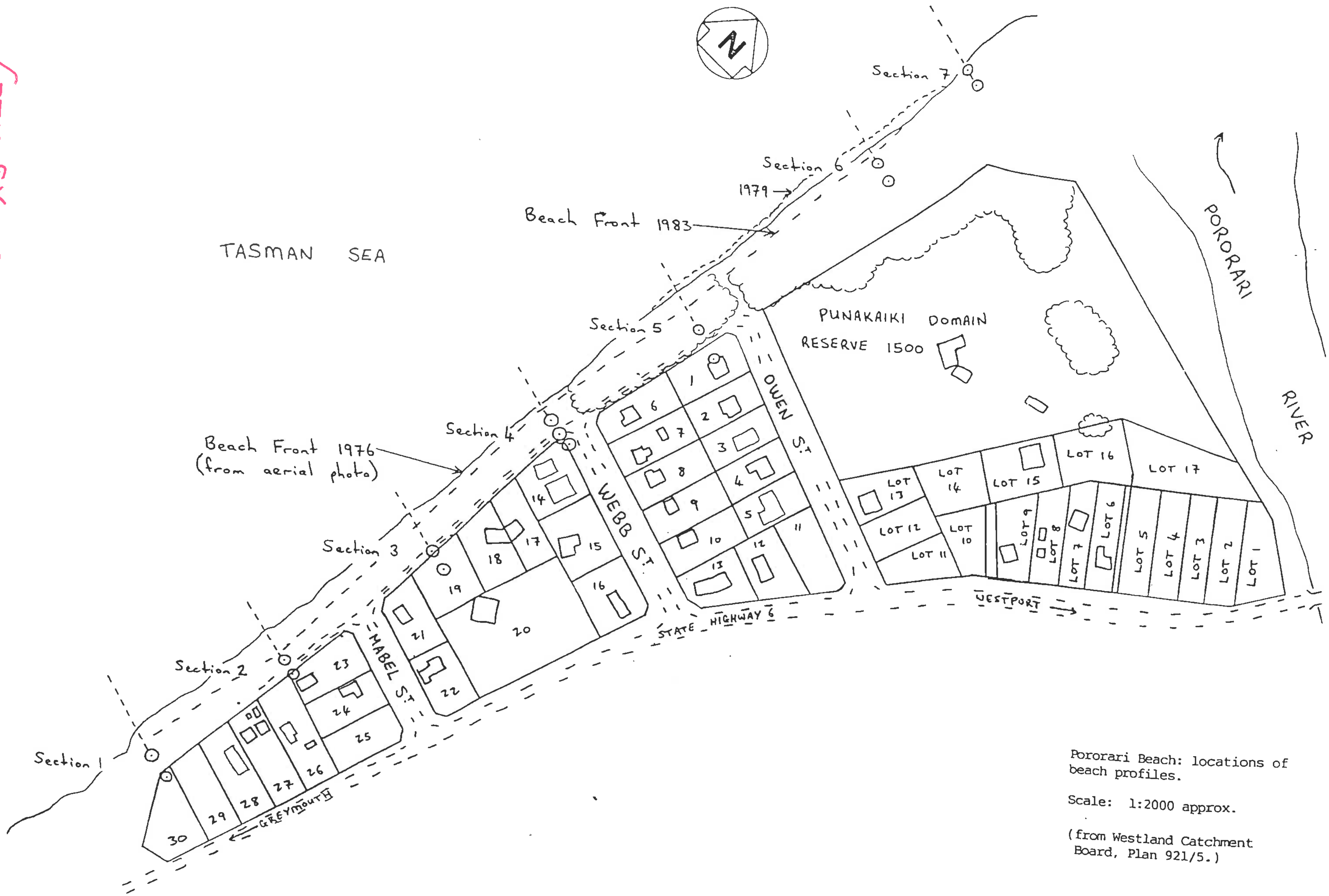
APPENDIX 6.



Coastal Changes in the Greymouth Area (Pfahlert 1984).

[SEE SEPARATE pdf FOR THIS DIAGRAM IN A3 SIZE]

[SEE SEPARATE Pdf FOR THIS DIAGRAM IN A3 SIZE]



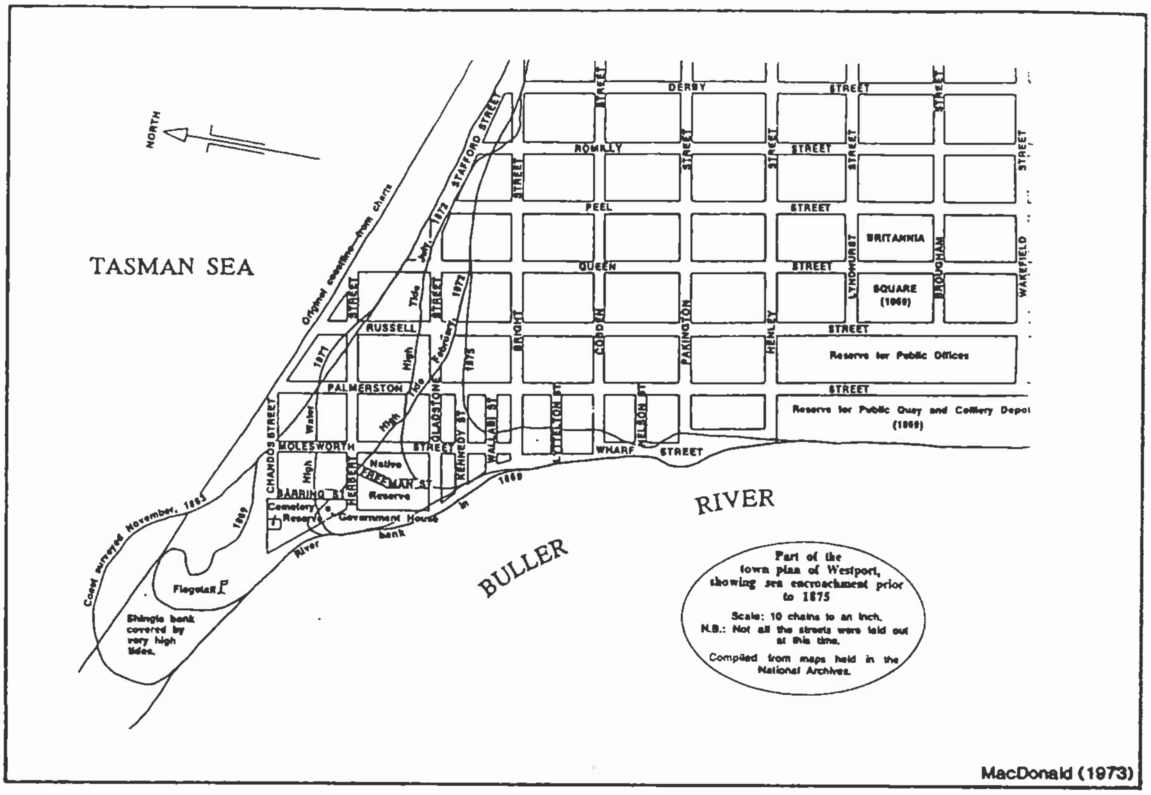
Pororari Beach: locations of beach profiles.

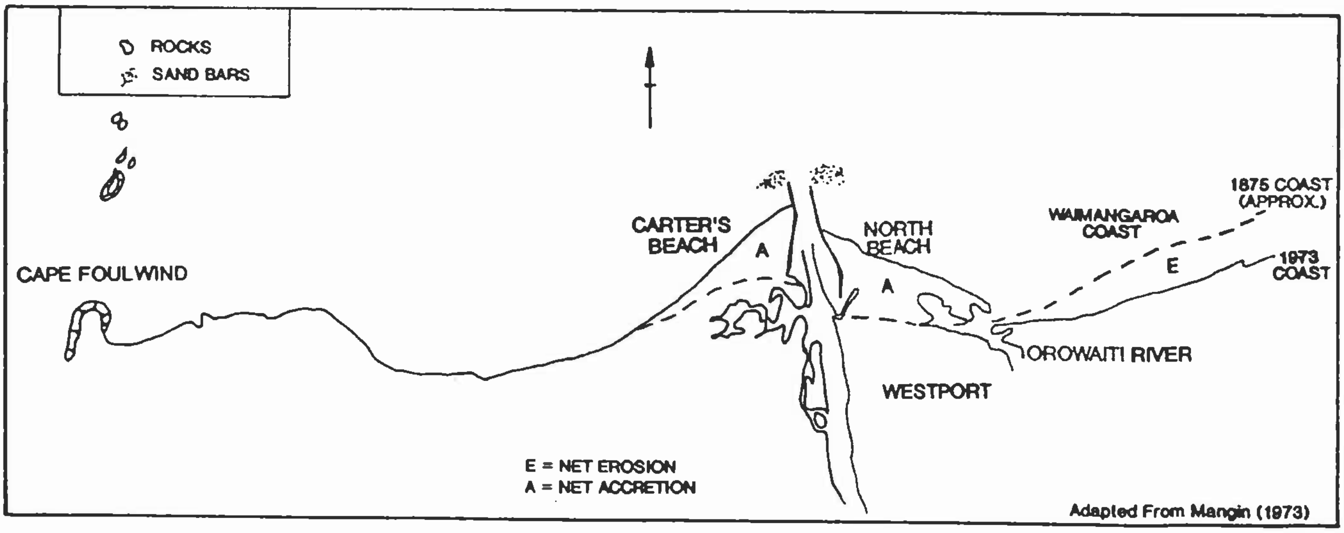
Scale: 1:2000 approx.

(from Westland Catchment Board, Plan 921/5.)

Coastal Changes at Punakaiki-Pororari (Kirk 1988).

APPENDIX 8





Coastal Changes in the Westport Area

APPENDIX 9

Granity Seawall, October 1988.
Note the undercutting of the structure by wave action
(Photograph - Don Neale, D.O.C. Hokitika)

APPENDIX 10

Blaketown - Karoro Beach Mining Conditions

Conditions Set By The Minister Of Energy In Terms Of Section 104(5) Mining Act 1971 For Application For A Mining Licence By ....

(Hereinafter Called The Licensee)

Conditions

1. The licensee shall not carry out mining operations by any method other than:

   a. hand methods and;
   b. methods using earthmoving machinery

2.a Mining shall be confined to the active beach area to the seaward of any dunes or vegetated areas.

b Mining shall not be undertaken within 10 metres of any dune vegetation.

3. Notwithstanding the provisions of the Mining Act 1971, the provisions of the Crown Minerals Act 1991, Quarries and Tunnels Act 1982 and Quarries Regulations 1983 shall apply to the working of this licence.

4. Removal of gravel and sand from any area must cease if so directed by the Inspector of Quarries to prevent erosion.

5.a The maximum quantity of material per annum shall not exceed x number of cubic metres.

b The quantity of material to be removed in any time period may be specified by the Inspector of Quarries in order to minimise the possibility of erosion.

6. Preventative and remedial resources for erosion control, including surveys and the placement of protection rock shall be carried out by the licensee to the satisfaction of the Inspection of Quarries, West Coast Regional Council and Department of Conservation.

7.a Existing access tracks to the beach are to be used and be maintained to the satisfaction of the Inspector of Quarries.

b No new access tracks are to be constructed unless written approval is given by the Inspector of Quarries in consultation with the landowner/occupier and/or the appropriate Local Authority.

8. The licence area shall be kept in a tidy condition, free from rubbish and scrap material.

9. The approval of the Inspector of Quarries is required for any stockpile and/or processing sites and such approval may include specified measures to control dust, erosion and other matters. Site rehabilitation measures may also be specified.

Hours of Work and Noise

10. Noise levels due to mining and ancillary work measured at any occupied residential building:

a. On normal working days during the hours of 7.00am to 6.00pm Monday to Friday and 7.00am to 12.00 noon on Saturdays, the corrected noise level (as defined in New Zealand 6802:1977) shall not exceed 55 dBA;

b. At other times on normal working days, on public holidays and on sundays, the corrected noise level (as defined in New Zealand Standard 6802:1977) shall not exceed 45 dBA.

Water

11. Unless in accordance with a water permit or other resource consent issued under the Resource Management Act 1991 mining shall be carried out so that:

a. the natural flow of any watercourse is not impeded;

Ministerial Consent

12. The licensee shall comply with all the terms and conditions imposed by the Ministers of Transport, Conservation, Agriculture and Fisheries pursuant to Section 26(6) and/or Section 27 of the Mining Act 1971.

Public Liability Insurance

13. Before starting operations, the licensee shall effect public liability insurance for an amount sufficiently adequate to safeguard licensee. The insurance shall include cover of damage caused by fire or explosion and costs of firefighting resulting from mining operations.

The licensee shall, if requested, provide the Inspector, Secretary of Commerce or the Local Authority with a copy of the insurance policy and evidence that the policy is in force.

Term

Term recommended for Mining Licence = X

Bond/Deposit

Total bond/deposit required = X