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Coastal hazard mapping
as a planning technique for Waiapu County

He ripoata whakature mo nga whenua papa-a-tai
o te rohe o te kaunihera o Waiapu–Tairawhiti

Jeremy G. Gibb

Coastal hazard mapping as a planning technique for Waiapu County, East Coast, North Island, New Zealand

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by Jeremy G. Gibb

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National Water and Soil Conservation Organisation
Wellington 1981

NOTE

Although the fourteen coastal hazard photomaps (Figures 21–34) were prepared with great care, they must not be used for accurate definition of the coastal hazard zones. The photomaps are based on aerial photographs taken in 1971–72 and for most areas the shore line has either advanced or retreated since then. To accurately define the widths of the hazard zones, the descriptions given in the text for each area should be used and related to the present-day shore line positions.

Gibb, J.G. 1981: Coastal hazard mapping as a planning technique for Waiapu County, East Coast, North Island, New Zealand. He ripoata whakature mo nga whenua papa-a-tai o te rohe o te kaunihera o Waiapu–Tairawhiti. *Water & Soil Technical Publication 21.* 63 p.

ABSTRACT

Coastal erosion, migrating river mouths, flooding from the sea, and landslides are natural geologic hazards that are identified and quantified along the Waiapu County coastline. Movement of 50–60 mm/yr along the Pacific–Indian Plate boundary have resulted in extensive rock deformation, fault movements, and tectonic uplift at 0.4–2.6 mm/yr along the coast. The movements have triggered gravity slides up to 520 km² in surface area that are being reactivated by coastal erosion.

Sediment supply sources for all major beaches are determined and coastal erosion/accretion measurements made from field work and historic data. Of the county's 147 km-long coastline, about 47% is eroding, 33% accreting, and 20% is 'static' (erosion rate less than 0.02 m/yr). With respect to downcutting rates on the shore-platform plane, erosion rates are higher by one order of magnitude for platform ramps and by two orders of magnitude for sea cliffs. Volcanic sea cliffs are eroding at 0.01–0.03 m/yr, sandstone–siltstone cliffs at 0.05–0.92 m/yr, and Holocene dunes and beach ridges at 0.29–1.24 m/yr. Deforestation (1880–1930) and afforestation (since 1969) of the hinterland have had a measurable effect on river aggradation and coastal accretion.

Techniques are developed for calculating hazard zone widths for coastal lands highly vulnerable to natural geologic processes over the next 100 years. Photomaps show coastal hazard zones (widths varying from 35 m to 780 m) for 14 localities in Waiapu County, and there are some recommendations for zone management.

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Contents

Title page Looking north-west at the Te Hekawa Point, with the Last Interglacial wave-cut platform above and the present-day shore platform seaward of the road and the postglacial sea cliff. Haupara Point, in the middle distance, separates Kawakawa Bay from Hicks Bay. The terraces on Matakaoa Point, in the background, are flights of wave-cut platforms cut in the volcanic rocks during previous interglacial high stillstands of the sea. [10 August 1980]

Front cover Te Araroa township in Kawakawa Bay, looking west from the edge of the Last Interglacial marine terrace, the Awatere River in the foreground. Although the gravel beach ridges in the background (seen clearly beyond the school) are evident of accretion over the last few years, the shoreline adjacent to the township has reversed to erosion of 17 to 40 metres since 1951. The Kawakawa Bay coastline is now realigning. [10 August 1980]

Figures

All photographs were taken by the author except figures 21–34.

Tables

Te Kaupapa

Naku na te kai tuhituhi o tenei ripoata i whakaaro me tangi atu au ki a koutou te iwi Maori o te rohe o te Tairawhiti - no te mea ko o koutou whenua - heke iho i o koutou tipuna - nga whenua kua rarangitia i roto i te ripoata nei, a me nga whenua hoki o etahi atu.

Te kaupapa o te ripoata e whai ake nei —

1. Kua tuhia e au he maka i runga i nga mapi o nga whenua papa-a-tai o te rohe o te kaunihera o Waiapu. Te tikanga o taua maka - Ka herea nga wawata - tumanako a te tangata, (i raro i nga ture) mo aua whenua papa-a-tai-mai i te hiku o te tai whaka-uta ki te maka kua oti nei i a au te maka i runga i nga mapi.
2. Te tikanga i herea ai, i roto i taku mahi ara wananga i nga nuku o te whenua mai i nehera ki aianei, nga ngau a te moana i te whenua, te waipuke o nga awa (ara geologist) ka kitea e au - ki te kore tatau e aro ki te tiaki i o tatau whenua papa-a-tai tena te wa - i etahi wahi - ka riro i te moana te kai - ka hinapouri te iwi kainga. No reira ka mau taku maka ki runga i nga mapi - he whakatupato i a koutou - te iwi kainga.
3. Ehara taku i te whakakore mo ake tonu atu nga moemoea a tena a tena mo tona whenua kei tatahi - engari he whakamarama noa iho, kia tupato me ata titiro tonu nga korero mehemea tou whenua kei raro i tenei kaupapa.
4. Nga mahi hanga whare, mau kirikiri pohatu ahakoa he aha te hiahia - mehemea he mahi e pa ana ki nga whenua papa-a-tai - kia tupato tirohia nga mapi - nga ture - kia nohopai ai koutou me a koutou uri i runga i o koutou whenua mo ake tonu atu.

Tena koutou katoa - Hurinoa

Na Dr J. Gibb

Geologist

Theme of this paper

[TRANSLATION]

It is my desire as author of this paper to greet you in humility, the people of Ngati Porou. It is those lands passed on to you from your ancestors, together with other lands owned by other people, that are the subject of this paper.

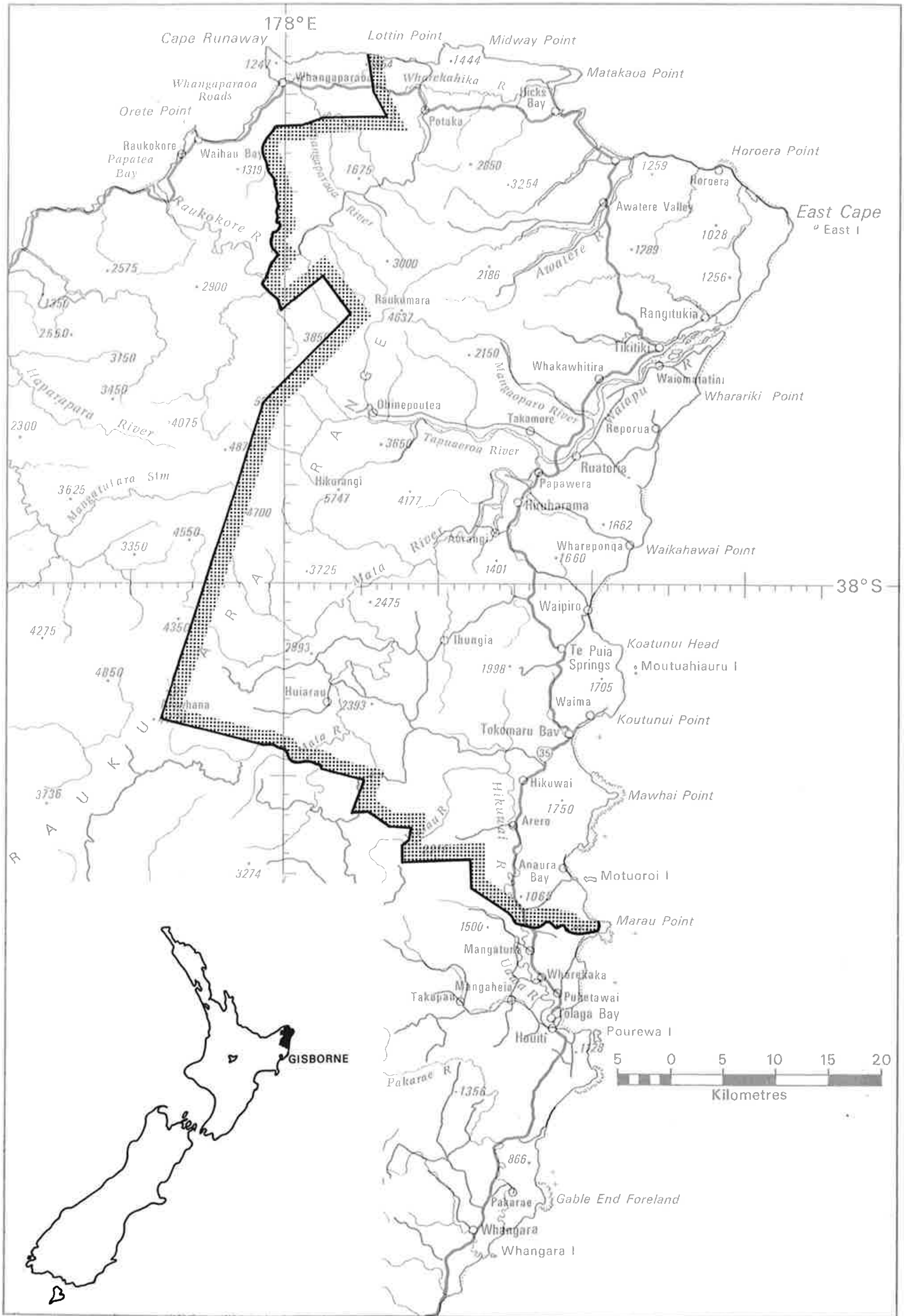
The main items covered in the paper are:

1. I have drawn a line on maps of the coastline within the Waiapu County. The significance of this line is to deter (under legislation) those landowners desiring to develop that part of their properties which lie in the coastal hazard zone. That is, the lands which lie from the edge of the sea inland to the line on the map, here designated the coastal hazard zone.
2. The reason I have declared this area a hazard zone, is that during my studies of land movement, sea erosion, and the effects of widespread flooding from the rivers, I concluded as a geologist that these hazards have all had a serious effect on our coastline. If we ignore this knowledge and persist in developing lands that lie in the hazard zone, then it is my considered opinion that those landowners and their children will one day have cause for regret.
3. It is not my intention to deny you any wish you may have for the use of your properties, it is simply to make you aware of the risks involved should you decide to proceed with any development.
4. The erection of buildings, the removal of sand and shingle; any works or activities which affect the natural topography of the land lying in the hazard zone, must be carefully assessed. Please study the maps and the recommendations before proceeding with such activities.

I wish only for you and the generations that follow you to live in peace and well-being on your lands, your heritage.

Dr J. Gibb

Geologist



Cartography by Cartographic Branch. Department of Lands and Survey.

Figure 1 Location map of Waiapu County.

Introduction

Waiapu County is located on the North Island East Coast (Figure 1). The county has about 147 km of coastline of which 69% is held in Maori tenure. Apart from small towns in Tokomaru Bay, Waipiro Bay, and Te Araroa, the coastline is mostly undeveloped. Pressures for residential development and recreational use are likely to increase over the next twenty years owing to predicted increases in the population (Ministry of Works and Development 1977).

Following the findings of the Taylor Report in 1967 (NWASCO 1970), a programme of exotic forest planting commenced in the county primarily within the headwaters of the Waiapu, Awatere, and Karakatuwhero rivers. First production from the Ruatoria Forest is expected in 1995 and will support a large pulp and paper mill and/or sawmills and veneer mills. By 1998 it is estimated that over 1.5 million tonnes of timber will be produced annually and that an increased population of 9500 could be supported around Ruatoria, Tikitiki, Te Araroa, and Hicks Bay. The construction of a breakwater harbour at Hicks Bay, capable of handling overseas shipping for the export of forest products, is thought likely (Ministry of Works and Development 1977).

Although Waiapu County is in a fairly remote part of New Zealand, there is an abundance of published and unpublished data available for the coastline. Such data have provided the basis for the present study, sources of which are listed either under References or Acknowledgements at the back of the text. A limited amount of additional information was collected by the writer between May 1979 and June 1980 during four field trips totalling 27 days.

This paper is an expanded version of a report prepared by the writer for the Waiapu County Council (Gibb 1979c), which was unanimously adopted by the council at its 26 June 1980 meeting at Te Puia Springs.

Statutory functions

Waiapu County lies within the East Cape Catchment District. The East Cape Catchment Board (previously Poverty Bay Catchment Board) was established under the Soil Conservation and Rivers Control Act 1941, and deemed to be a regional water board under Section 19 of the Water and Soil Conservation Act 1967. As such, the statutory functions of the Board, as delegated to it by the National Water and Soil Conservation Authority (NWASCA) under Section 20(5a) of the 1967 Act, extend from the coast to the outer limits of the territorial sea, presently 19.5 km (12 miles).

Under both the 1941 and 1967 Acts the Board has a statutory function towards the prevention and mitigation of coastal erosion and damage by floods. Both acts give the Board a number of discretionary powers in dealing with such matters.

Under Section 30 of the Soil Conservation and Rivers Control Act 1941, the Soil Conservation and Rivers Control Council (SCRCC) is empowered to make grants or loans towards the cost of coastal erosion control works, either directly to any person or body, or through the catchment board. However, under the National Water and Soil Conservation Organisation's (NWASCO) policy certain claims, such as those for the protection of urban development initiated after 18 November 1971 and for the resettlement of persons affected by marine erosion or flooding, are ineligible for grants and loans.

Between 1953 and 1978, about 85 erosion control works around New Zealand were considered by NWASCO for the protection of public and private assets from wind and sea erosion and from flooding by the sea. Over the last 26 years the total present-day cost of coastal protection works within NWASCO's policy was $4.8 million (Bagnall 1978).

Combatting any particular beach erosion problem is usually very expensive and, in the case of future development, can be avoided simply by the provision and management of an adequate width of land between the development and the beach. Such a width of land is here termed a *coastal hazard zone* as it is highly vulnerable to coastal erosion processes.

The Town and Country Planning Act 1977 allows for identification of areas vulnerable to natural hazards in Regional Planning Schemes (First Schedule, clause 4c) and for appropriate provisions to be made for such areas in District Planning Schemes (Second Schedule, clause 8a). In particular, clause 8a states that the District Scheme must provide for:

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

Coastal erosion, flooding from the sea, landslides, and wind erosion of sand dunes are natural hazards that occur along the Waiapu County coastline. Such hazards are recognised in the Waiaipu County District Planning Scheme through appropriate policies and ordinances and the delineation of the *coastal hazard zones* on the District Scheme planning maps.

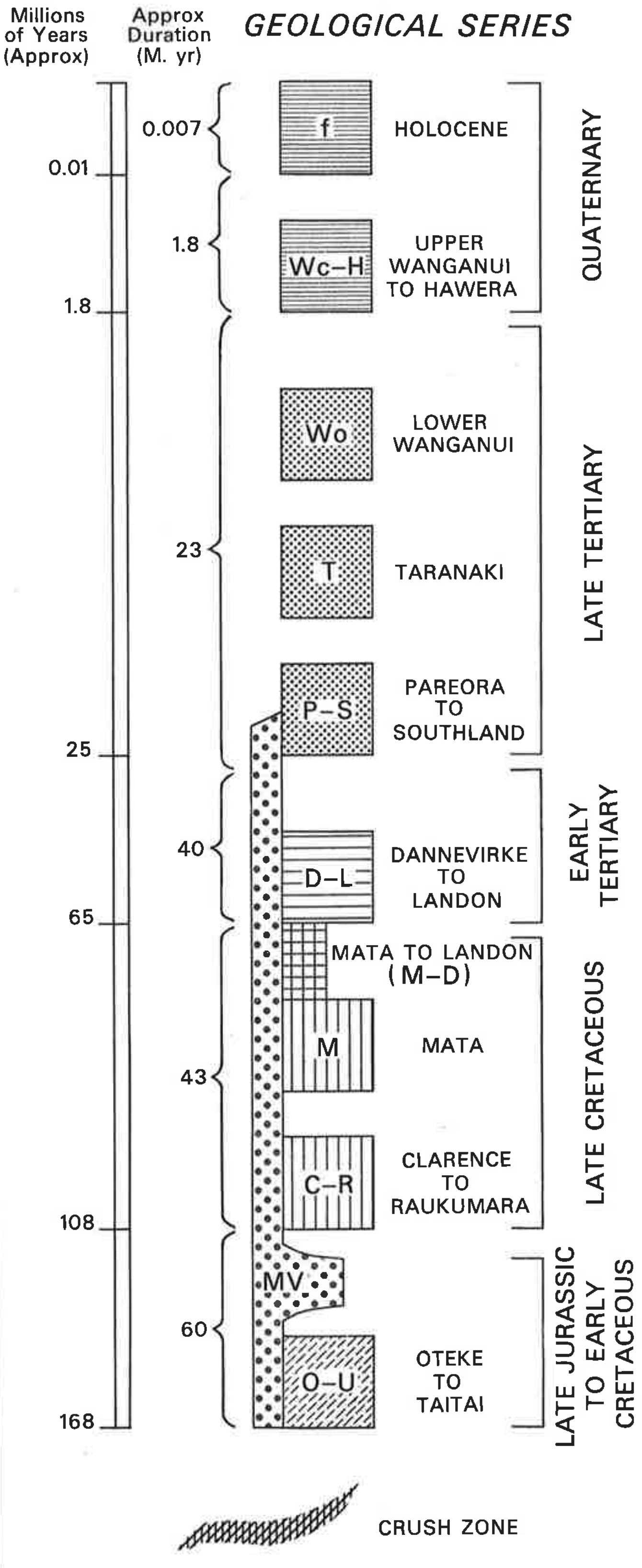
Further, urban development within the hazard zones may be controlled under Section 641 of the Local Government Amendment Act 1979, which empowers the territorial authority to refuse a building permit when:

> *The land, or any part of it, is subject to erosion or subsidence or slippage, or inundations by the sea or by a river, stream or lake or by any other source . . . unless the council is satisfied that provision has been made or is to be made for the protection of the land from erosion or subsidence or slippage or inundation.*

Clearly the legislation as it stands provides adequate scope for wise coastal planning and management.

Study objectives

The main objective is to identify and quantify the coastal hazards that occur along the Waiapu County coastline and to delineate *coastal hazard zones* from such information. A second objective is to provide basic information for wise management of the coast and to develop and standardise a technique for calculating the width of the hazard zones.



Millions of Years (Approx)	Approx Duration (M. yr)	GEOLOGICAL SERIES			LITHOLOGY
0.01	0.007	f	HOLOCENE	QUATERNARY	Unconsolidated mud sand and gravel, swamp deposits, dunes and beach ridges forming flood plains and coastal terraces.
1.8	1.8	Wc-H	UPPER WANGANUI TO HAWERA		Soft sandstone-siltstone, minor conglomerate, carbonaceous and tuff beds.
	23	Wo	LOWER WANGANUI	LATE TERTIARY	Soft sandstone-siltstone with tuff beds.
		T	TARANAKI		Quartz sandstone-siltstone, minor comglomerate and pumiceous tuff beds.
25		P-S	PAREORA TO SOUTHLAND		Siltstone, alternating sandstone-siltstone, minor sandstone, conglomerate, limestone tuff beds and breccia.
65	40	D-L	DANNEVIRKE TO LANDON	EARLY TERTIARY	Sandstone, siltstone, conglomerate, greensand, bentonitic mudstone and limestone.
	43	(M-D)	MATA TO LANDON	LATE CRETACEOUS	
		M	MATA		Light grey hard siltstone locally calcareous or siliceous (Whangai siltstone) grading down to alternating sandstone-siltstone variable bed thickness and minor conglomerate.
108		C-R	CLARENCE TO RAUKUMARA		Fine grained siltstone grading down to alternating sandstone-siltstone and minor sandstone.
	60	MV		LATE JURASSIC TO EARLY CRETACEOUS	Matakaoa Volcanics, gabbro, basalt dolerite, breccia and tuffs.
168		O-U	OTEKE TO TAITAI		Hard indurated siltstone grading down into alternating sandstone-siltstone, sandstone and minor siltstone units, minor conglomerate, breccia and tuff beds.

Cartography by Cartographic Branch, Department of Lands and Survey.

Figure 2 Geological map of the East Cape Region, adapted from Kingma (1965), Stoneley (1968), and Speden (1977).

Sig. 2

Geology

A plate boundary has passed through the continental mass of New Zealand for the last 40 million years, the boundary surface lying about 100–200 km offshore parallel to the North Island East Coast (Lewis, in press), along an elongate depression known as the Hikurangi Trough. The boundary passes beneath the entire Raukumara Peninsula, the subducting Pacific Plate to the east, dipping at 12° west for some 250 km beneath the Indian Plate, before diving at about 45° beneath the Taupo Volcanic Zone (Walcott 1978b). According to Walcott (1978a,b) the Pacific Plate is moving at 50–60 mm/yr in the East Coast region, relative to the Indian Plate, and over the last 10 million years the movement at the plate boundary has tended more and more towards oblique compression. In the East Coast region the relative motion of the two plates over the last 40 million years has been taken up by rock deformation, fault movements, and tectonic uplift of the entire region.

A simplified geological map of Waiapu County, based largely on Kingma (1965) is shown in Figure 2. Owing to the small scale of the map, the complexity of faults, folds, and décollement sheets (large-scale gravity slides; Stoneley 1968) are not shown. The following brief description of the geology is based largely on a general statement supplied by Dr I.G. Speden, Regional Geologist, New Zealand Geological Survey. The statement is based on detailed mapping of the region north and west of the Tapuaeroa and Waiapu rivers by I.G. Speden and P.R. Moore. Both geologists agree that the stratigraphy and structure of the area are more complex than was previously known and that further detailed field mapping is required south of the Waiapu River.

Alternating sandstone-siltstone sequences, ranging in age from the Late Jurassic (Speden 1977) to present-day, are the dominant rocks. Although sand and silt grades are the dominant textures, the rocks contain minor limestone, breccia, and conglomerate units. Pumiceous ash beds are common in the Taranaki–Hawera Series sequences, while bentonitic siltstone-claystone and glauconitic sandstone sequences and igneous conglomerates are characteristic of the Dannevirke–Landon Series sequences. Basic igneous rocks of the Matakaoa Volcanic Group outcrop west of Te Araroa.

The rocks range in hardness from very hard to very soft. Rock hardness depends on composition, cementation, and age, hardness generally increasing with age. The Matakaoa Volcanics are hard to very hard. Mata series and older rocks are mostly moderately hard to very hard. Rocks of the Dannevirke–Landon Series sequences range from hard limestones and calcareous cemented siltstones to very soft bentonitic claystones and siltstones which become plastic when wet. The Pareora–Taranaki Series rocks are, except where cemented by calcite, very soft to moderately soft, while the Quaternary sequences are unconsolidated to very soft.

The strength of the rocks is influenced by weathering and structure (faults, joints, shear-planes). The more intense the weathering, the weaker the rock. Similarly, the more closely jointed, sheared or faulted the rock, the weaker it is and the greater its tendency to crumble away.

Rocks older than the Pareora Series, especially the Mata–Landon Series sequences, have been intensely deformed by a major deformation event that occurred 40–25 million years ago. The deformation, lubricated by the interbedded bentonitic mudstones, was probably triggered by tectonic movements (Stoneley 1968) related in turn to plate boundary movements. Large and small-scale gravity sliding of sheets of rock, which slid over and ploughed into other sheets, caused extensive faulting, folding, crushing, and disruption. The margins of the sheets were severely deformed producing zones of crushed and sheared rock (mélange) containing various sized blocks of more coherent rocks of diverse lithology and age. A massive slide (decollement) south-west of Mt Hikurangi, described by Stoneley, has a surface area of 520 km^2.

Continued mild deformation during early Pareora Series time caused minor faulting and folding, slightly weakening the rocks. Late Pareora and younger rocks have a simple structure of open folds, mostly striking north-south or east-west, and near vertical faults.

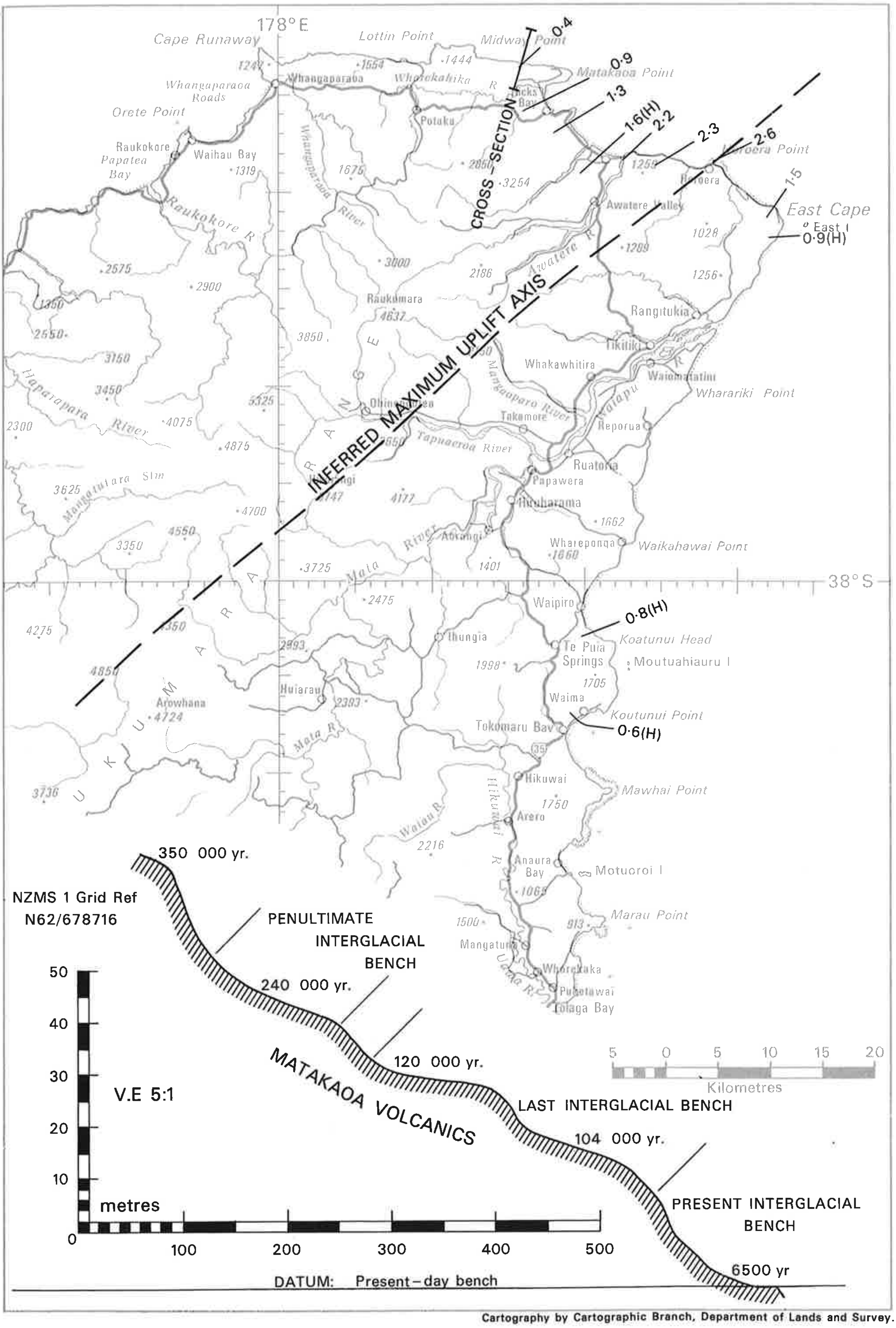
Tectonic deformation

The entire region, including the coast, has been elevated by tectonic uplift. Successions of raised marine benches, cut during interglacial high stillstands of the sea during the Late Quaternary, are well preserved in the Matakaoa Volcanics (Figure 3) and to a lesser extent in the sedimentary rocks between Te Araroa and East Cape. The Last Interglacial bench is inferred (after Chappell 1974) to have formed 120 000 years ago and is recognised by a mudstone bench capped by well-rounded beach gravels, overlain in sequence by Hamilton Ash (minus the basal member) and by Rotoehu Ash (Mr K. Berryman, New Zealand Geological Survey, pers. comm. 1979). The coast is bordered by a raised Holocene bench which is inferred (after Gibb 1979a) to have formed over the last 6500 years. The Last Interglacial bench formed at a sea level within $+5 \pm 3$ m of the present-day sea level (Chappell 1974; 1975) and the present interglacial bench at a sea level within ± 1 m (Gibb 1979a).

Rates of uplift were calculated from the emergent heights of the Last Interglacial bench and from the highest Holocene shore line at the back of the present interglacial coastal plane, as follows. About 3 km west-south-west of Te Araroa, the crest height of the earliest stranded Holocene gravel beach ridge is about 10.5 m above the present-day forming feature. Assuming that the 10.5 m ridge formed 6500 years ago, then the uplift rate is 10.5/6.5 = 1.6 mm/yr. Similarly, about 2.5 km east-south-east of Te Araroa the Last Interglacial bench is about 278 m above the present-day wave cut shore platform. Assuming that the 278 m bench formed 120 000 years ago then the uplift rate is 278/120 = 2.3 mm/yr. For Te Araroa, the uplift values estimated here are considerably higher than the 0.4 mm/yr estimated by Chappell (1975) from a terrace "at about 48 m" behind the township. During field investigations, this terrace could not be found.

The terrace behind Te Araroa (Grid Ref N63/765605) is of Last Interglacial age and has an elevation of 274 ± 5 m (Berryman, pers. comm.). On the western flank of the terrace, however, there is a large-scale relict landslide (Grid Ref N63/755605) with an uneven ponded surface over which State Highway 35 passes. As the edge of the landslide is 40–50 m above the Holocene coastal plain, it is possible that Chappell mistook this as the Last Interglacial terrace.

Rates of uplift are shown for the coast on Figure 3. The rate of uplift increases progressively eastwards from about 0.4 mm/yr west of Matakaoa Point to about 2.6 mm/yr at



Cartography by Cartographic Branch, Department of Lands and Survey.

Figure 3 Sketch map showing uplift rates for the Waiapu County coastline in millimetres per year. Values suffixed by (H) were determined from the 6500 yr bench and the remainder from the 120 000 yr bench. The cross-section was surveyed by J.G. Gibb on 10 September 1977, normal to the coastline, about 4.5 km west of Matakaoa Point. Ages of benches shown on the cross-section are inferred from Chappell (1974). A relatively uniform uplift rate of 0.4 mm/yr is indicated.

Horoera Point, decreasing to about 0.9 mm/yr at East Cape. From the Cape south to Marau Point, any evidence of the Last Interglacial raised bench has been destroyed by erosion and landslides.

Similarly, most of the early Holocene raised bench has either been destroyed by sea erosion or buried beneath landslide debris or outwash fans. However, remnants of early Holocene benches at the Waikawa Stream mouth, Waipiro Bay, and the Waitakeo Stream mouth, Tokomaru Bay, indicate uplift rates of about 0.8 mm/yr and 0.6 mm/yr respectively.

For the East Cape region, uplift rates have remained about the same for the last 120 000 years (see cross-section on Figure 3). Similar uniform uplift rates over the same period were described by Ghani (1978) for the North Island east coast, south of Hawke Bay.

The axis of maximum uplift shown on Figure 3 is inferred from the distribution of uplift rates along the coast and from the pattern of maximum elevations of the inland mountains. The position of the axis indicates a general eastward tilting of the coastline south of East Cape, which would assist large-scale gravity sliding in that direction.

Within the Waiapu County the pattern of faults is extremely complex (see Kingma 1965). According to I.G. Speden, no evidence of active faulting has been reported or is known, which suggests that earthquake uplifts are not localised but probably affect the entire region. Earthquake uplifts in the tectonically mobile Waiapu County are likely to continue to reactivate the large-scale gravity slides and trigger many smaller landslides along the coast.

Coastal landslides

According to Varnes (1958) a landslide denotes the downward movement of slope-forming materials composed of rock, soil, artificial fills, or combinations of these materials. The moving mass may proceed by falling. sliding, or flowing, or by their combinations. The distribution of coastal landslides, based on a study of aerial mosaics (1:15 840 scale) and on an aerial reconnaissance made of the coast on 21 May 1979, is shown in Figure 4.

Both old and recent coastal landslides occur mostly between Waipiro Bay and the Waiapu River mouth in the pre-Pareora Series rocks (Late Cretaceous–Early Tertiary), especially the Mata–Landon Series. These extensively deformed rocks are particularly prone to surficial and deep-seated gravity sliding and erosion, especially where the coast is intersected by mélange zones, faults, or old landslides, or where the beds and décollement sheets strike parallel to, and dip towards, the coast (Speden, pers. comm.).

Once disturbed and disrupted by gravitational sliding, the mélange zones of the Mata–Landon Series rocks have their characteristics changed. They behave like soils instead of rocks, and are therefore prone to continual landsliding (earthflows) aided by lubrication from interbedded bentonites and fault pug. Moreover, permeability differences between coherent alternating sandstone-siltstone strata, plus excessive pore-fluid pressures generated in the sandstones, can permit gravitational sliding on slopes as little as 2½° (Stoneley 1968). Widespread mud-vulcano activity reported by Ridd (1968) in the Raukumara Peninsula region is evidence of the effect of abnormally high pore-fluid pressures.

At the Waikawa Stream mouth, Waipiro Bay, a large gravity slide about 1.3 km wide extends inland for about 7 km passing through Te Puia Springs township. The slide is composed of colluvium of Late Jurassic–Early Cretaceous aged sediments that are bisected by a crush zone (see Kingma 1965). According to Mr C. Goldsmith, farmer, Waipiro Bay (pers. comm. 1980), movement of the toe of the landslide over the last eight years has made the lower reaches of the Waikawa Stream impassable and may eventually block the stream altogether. As the height of the actively moving landslide toe is 150–185 m above the stream bed (Grif Ref N81/714105) the gravity slide may exceed 200 m in depth.

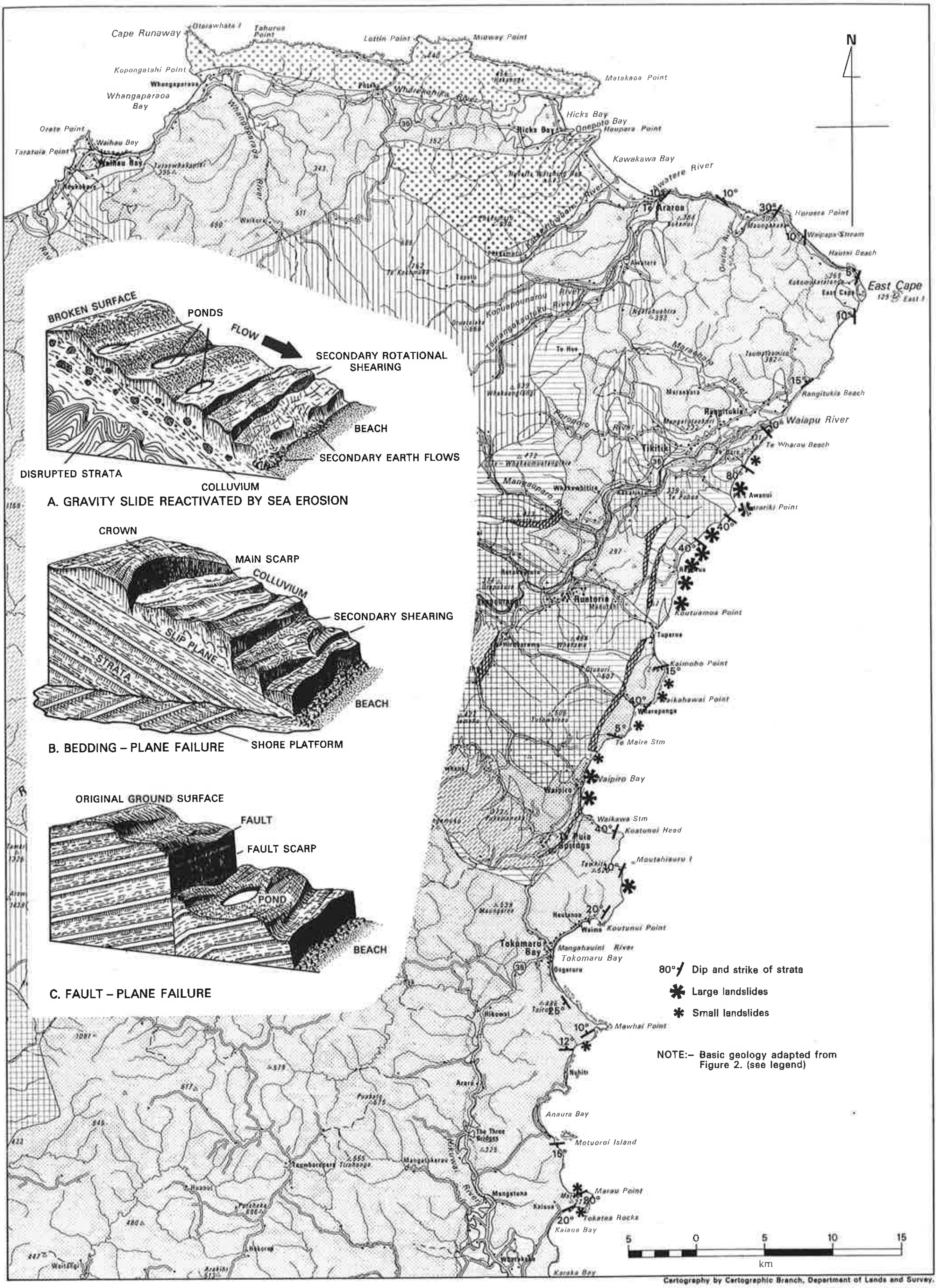
At Te Puia Springs, re-surveys by the Department of Lands and Survey show that the body of the slide is also moving. Figure 5 shows the results of a recent re-survey of the Te Puia Springs Urban Standard Traverse, the surveys and computation of results being carried out by the Gisborne District Office of the Department of Lands and Survey. The original survey was carried out in March 1973 and the re-survey in May 1980. The direction and distance of the horizontal shift of each mark over this seven-year period is shown by a vector on the diagram. The average rate of movement of the five marks (SS2–SS6) is 53 mm/yr in a north-east to east direction. The shifts are all in a down slope direction, that is, towards the Waikawa Stream, but no significant height shifts were found within the limits of accuracy of the surveys (Mr A. Radcliffe, senior surveyor, Department of Lands and Survey, pers. comm. 1980). Earth flows are common at the toe of most gravity slides, as shown in Figure 6a for the coastline about 1.5 km north of Waikawa Stream mouth.

In spite of a net rate of retreat of 0.2–0.9 m/yr (see items 26–28, Appendix 2) of the sea cliffs cut in highly deformed Late Cretaceous–Early Tertiary rocks near Reporua, one cliff section 3–4 km in length has actually advanced about 20 m between 1928 and 1975 (see items 29 and 31, Appendix 2). Taking the net rate of cliff retreat into account, it is estimated that the landslide toe is advancing at 1.4 m/yr. The slide is probably part of a large-scale gravity slide lubricated by bentonite, as the hummocky ponded surface extends several kilometres inland.

No coastal landslides were observed in the hard Matakaoa Volcanics (Jurassic–Tertiary) and few in the sandstone-dominated Taranaki Series (Late Tertiary). According to Ongley and Macpherson (1928), most of the Taranaki Series beds dip away from the coast (Figure 4). Erosion and landslides in these rocks occur mainly in siltstone or alternating sandstone–siltstone formations, due primarily to the relative hardness of the beds, steep slopes and crushing along faults (Speden, pers. comm.). An old landslide (slump) with a 1.6 km wide toe, was observed in coherent Taranaki Series beds on the headland between Waipiro and Tokomaru Bays. The landslide scarp strikes north-south as do the faults at this locality (Kingma 1965) suggesting that the landslide may be a fault-plane failure.

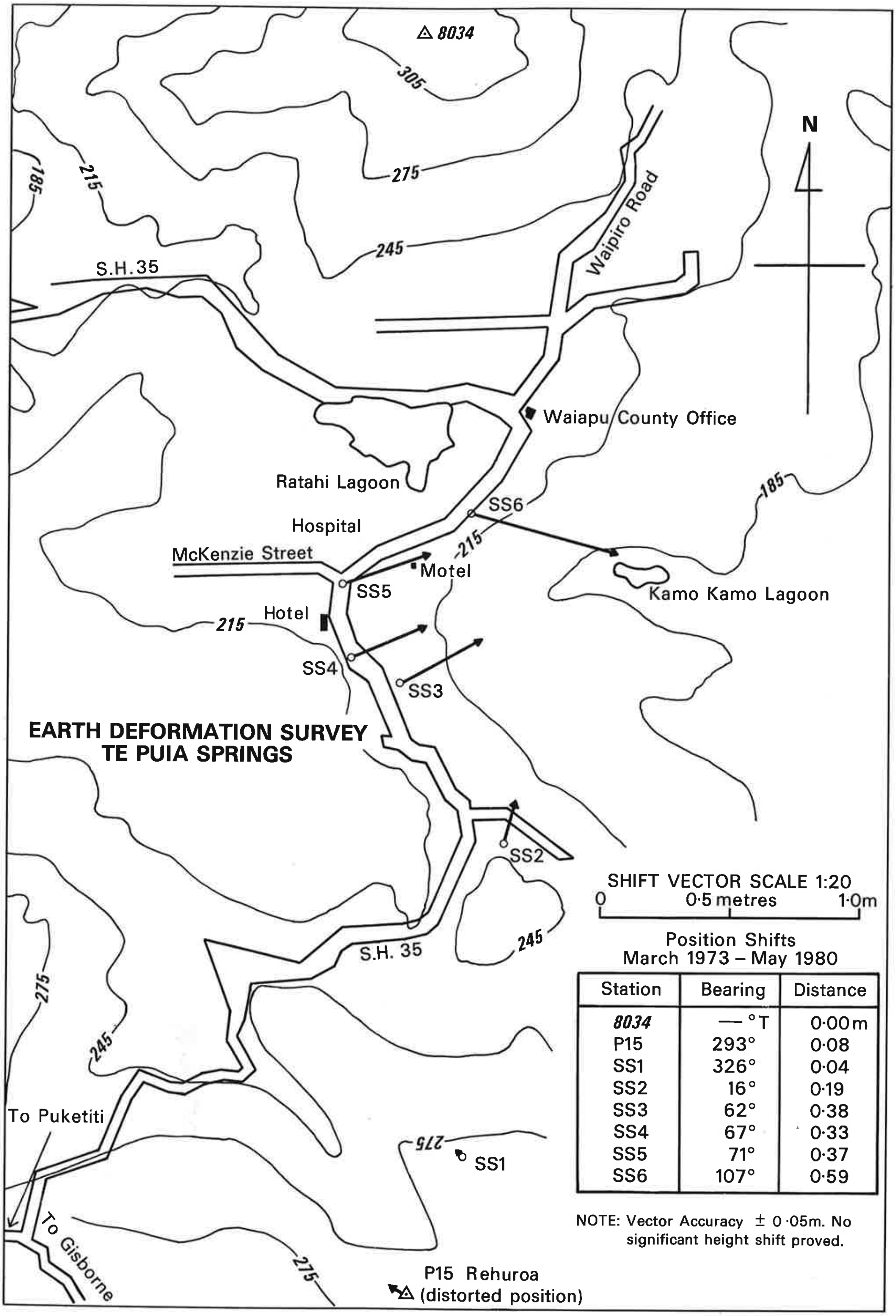
An example of a possible fault-plane failure is shown in Figure 6b. The landslide was investigated in January 1980 and a fault was observed in the same position and parallel to the main landslide scarp. The strata were observed to dip gently landwards. From field and aerial photographic investigations, it was estimated that the slide had moved about 8.4 million m^3 of material.

A landslide originating from a possible bedding-plane failure was observed on the south side of Marau Point where the cliffs are retreating from coastal erosion. Here, the coherent Taranaki Series beds dip seawards at 30° (Figure 4). According to Mr J.M. Williams (pers. comm. 1980), owner of the farm (Kaiaua Station), the slide occurred about 1910, destroying a 20 ha (50 acre) paddock, and since 1910 about 50% of the toe has been removed by the sea. During a field inspection in January 1980, it was estimated, with the aid of aerial photographs, that the slide



Cartography by Cartographic Branch, Department of Lands and Survey.

Figure 4 Sketch map showing the distribution of old and recent coastal landslides as at May 1979. Large landslides have a toe width greater than 1 km and small landslides less than 1 km. Coastal geology adapted from Ongley and Macpherson (1928) and Figure 2. Inset block diagrams represent the three main landslide types observed along the East Coast by the author.



EARTH DEFORMATION SURVEY
TE PUIA SPRINGS

Position Shifts
March 1973 – May 1980

Station	Bearing	Distance
8034	— °T	0·00m
P15	293°	0·08
SS1	326°	0·04
SS2	16°	0·19
SS3	62°	0·38
SS4	67°	0·33
SS5	71°	0·37
SS6	107°	0·59

NOTE: Vector Accuracy ± 0·05m. No significant height shift proved.

Figure 5 Department of Lands and Survey Plan No. 525A showing the results of the Earth Deformation Survey of Te Puia Springs. Arrows indicate direction and amount of horizontal shift of the ground surface relative to the line scale. Table gives the direction ('Bearing' °T) and amount ('Distance' in m) of movement from March 1973 to May 1980, at each change point along the Urban Standard Traverse. Contours in metres.

Figure 6 Landslides along the East Coast.

a Active earth flows at the toe of a gravity slide at the south end of Waipiro Bay about 45 km south of East Cape.

b Fault plane failure at the south end of Kaiaua Beach about 80 km south of East Cape.

c Bedding plane failure at Tatapouri headland about 110 km south of East Cape. The intertidal shore platform has formed over the last 6500 years and is up to 430 m wide.

had moved about 1.2 million m³ of material. A similar, very large bedding-plane failure is shown in Figure 6c.

High shear stress on the coastal rocks will continue to be induced by coastal erosion removing the lateral support of the land. This process will continually reactivate the old landslides as will continuing tectonic movements in response to the oblique compressional movements along the plate boundary. From the viewpoint of coastal landslides as natural geologic hazards, the Late Jurassic-Early Tertiary rocks shown on Figure 4 have the greatest landslide potential, followed by the Late Tertiary rocks. Rocks with a minimal landslide potential are the Matakaoa Volcanics and the Holocene sediments that form the coastal plain.

Deforestation and afforestation effects

Prior to the 1880s, small-scale logging operations were carried out in the Waiapu County, mostly by European settlers. Clearing of native bush for the purposes of establishing pasture began in earnest in the 1880s, and was virtually completed by 1930. According to Mr R.D. Black, Geologist, New Zealand Forest Service, Gisborne (pers. comm. 1979), the Tapuaeroa River catchment (major tributary of the Waiapu River) was deforested between 1891 and 1905, followed by the Awatere and Karakatuwhero river catchments between 1914 and 1925. Selby (1967) found, in the Mesozoic greywacke ranges bordering the lower and middle Waikato Basin, North Island, that deforestation increased the frequency of landslides during high intensity rainfalls.

Stream aggradation and degradation rates

Following deforestation in the Waiapu County, there was a dramatic acceleration in the erosion of stream catchments, particularly those draining the intensely deformed Late Cretaceous-Early Tertiary sedimentary rocks. River beds aggraded rapidly, the rate of aggradation generally decreasing progressively downstream towards the coast. In the Tapuaeroa River at the stock bridge (Figure 7) to the Pahikiroa homestead, the river bed rose 13.72 m at a net rate of 0.20 m/yr for the period 1912–1979. The greatest aggradation occurred between 1912 and 1921 when the river bed rose 4 m at 0.44 m/yr. In other branches of the Tapuaeroa River aggradation at 0.13 m/yr occurred over approximately the same 67 year period (Black, pers. comm.).

In the Waiapu River bed, seven cross-sections were resurveyed between 1959 and 1977 by the East Cape Catchment Board, between the Tapuaeroa River junction and the coast. The re-surveys record an average aggradation at 0.019 m/yr over the 2.4 km long stretch of river bed, with a maximum of 0.029 m/yr near the junction decreasing to 0.015 m/yr at the coast.

Few data are available for the Awatere and Karakatuwhero river beds as only one cross-section has been resurveyed across each bed by the catchment board. For the Awatere, re-surveys made between 1963 and 1976 record net aggradation at 0.026 m/yr. For the Karakatuwhero a net aggradation at 0.006 m/yr is recorded for the period 1963–1978.

Following the findings of the Taylor Report in 1967 (published as NWASCO 1970), a programme of exotic forest planting commenced in the Waiapu County, primarily within the headwaters of the Waiapu, Awatere, and Karakatuwhero rivers. Planting of the Ruatoria forest commenced in the headwaters of the Tapuaeroa in 1969 and in the Karakatuwhero and Awatere catchments in 1974 and 1976.

Figure 7 The bridge over Tapuaeroa River bed, looking downstream. Pahikiroa Station is on the right. From 1912 to 1979 the river bed has aggraded 13.72 m under the bridge. [25 June 1980]

In most if not all the stream catchments, the change of land use from pastoral farming to afforestation has significantly reduced the amount of erosion, thus reducing sediment supply to the streams, resulting in stream channels in the upper catchments degrading at about 0.3 m/yr (Black, pers. comm.). According to Mr Black, the planting of trees is not the sole cause of the degradation, as many channels rapidly cut down within two years of planting. In general, however, most streams draining small catchments appear to have degraded their beds within four years of planting, and those draining larger catchments within ten years of planting (Mr I.E. Jones, Chief Engineer, East Cape Catchment Board, pers. comm. 1979).

On the basis of the above observations, it would be unwise to suggest that tree planting alone is the sole cause of the reversal from channel aggradation to degradation. The planting programme may well have coincided with the natural waning of an erosion cycle influenced largely by climatic changes. Then again, the change in land use from farming to forestry and the resultant destocking of the land would also have an effect. Destocking alone would allow the regeneration of native plants which would reduce both run-off and soil erosion rates.

Coastal effects

The very high rates of aggradation directly following the clearance of native forest between 1880 and 1930 have resulted in a massive increase in the amount of river bedload delivered to the coast. Some stretches of coastline, dependent almost solely on rivers as a source of supply, have advanced rapidly as a result.

The most spectacular changes have taken place either side of the Waiapu River mouth and to a lesser extent at Tuparoa and in Kawakawa Bay. Up to about 1910 these shore lines were either static or advancing slowly from accretion. Historical surveys of the coast show that the rapid advances commenced some time after 1910-1915 which coincides with the period following deforestation. According to Selby (1967), the maximum effect of deforestation reaches a peak some years after initial clearance owing to changes of soil structure.

At the Waiapu River mouth, Te Wharau Beach to the south and Rangitukia Beach to the north essentially remained static between 1884 and 1915 (see items 35-38, Appendix 2). A localised advance of 120 m is recorded over this period at the north side of the mouth, probably owing to a southward migration of the mouth. From 1915 to 1975, however, Te Wharau Beach (Figure 8) has advanced 85-140 m (1.42-2.33 m/yr), the rates decreasing progressively southward from the Waiapu River mouth, and at Rangitukia Beach the shore line has advanced 108-380 m (1.71-6.03 m/yr), the rates decreasing progressively northward from the mouth.

The 3.5 km long stretch of beach at Tuparoa is fed mainly from sediments supplied from the Tohoratea River and Waitekaha Stream (Figure 9). Deforestation of both catchments in the late 1870s-early 1880s (Black, pers. comm.) resulted in rapid catchment erosion followed by aggradation in the lower channel reaches. The rapidly accumulated sediments must have taken a few years to make their effect felt on the Tuparoa Beach because photographs taken between 1900 and 1910 of Tuparoa Settlement show a stable beach lying along the base of the cliffs. From 1910 to 1976, however, the over-supply of sediments has caused an advance of about 50 m at 0.74-0.77 m/yr (see items 22-24, Appendix 2).

At Kawakawa Bay, sets of well-defined gravel beach ridges extend inland for about 2.2 km. The ridges have accumulated over the last 6500 years, since postglacial sea level rise stabilised at the present-day sea level. Beach shells from ridges 168 m and 320 m inland from the present-day ridge gave radiocarbon ages of 349 ± 74 years BP (NZ 1204A) and 671 ± 74 years BP (NZ 1205A) respectively (Garrick 1979).

Historic surveys at the same site allow a comparison of long-term (1280 AD to 1900 AD) with historic (1900-1975) accretion rates (see item 49, Appendix 2). Results show a low rate of accretion for the two early periods of 1280-1600 AD (0.48 m/yr) and 1600-1900 AD (0.31 m/yr), compared with a three-fold increase for the period 1900-1975 (1.0 m/yr). As the predominant supply source for the beaches is the Awatere and Karakatuwhero rivers, the most likely explanation for the increase in rates is a net increase in bedload output from the rivers following deforestation of both catchments between 1914 and 1925.

Finally, although deforestation has had a devastating effect inland, it has indirectly benefitted the coast through the gain of land from accretion. As the shore line is delicately balanced between advance and retreat in response to fluctuations in sediment supply, the likely effects of afforestation since 1969 with respect to the long-term stability of the coast must be carefully assessed.

Over the last decade we know that stream channels draining afforested catchments have rapidly degraded. As the input of sediments from these catchments continues to fall, one might expect the degradation process to work its way downstream, eventually "flushing out" all the stored bed-

Figure 8 Oblique aerial view of Te Wharau Beach south of the Waiapu River mouth. The 1915 shore line is shown and indicates over 200 m of accretion from Waiapu-derived bedload. Note the extensive aggradation in the lower river bed. [21 May 1979]

Figure 9 Oblique aerial view of Tuparoa looking south. The 1910 shore line position is shown and indicates about 50 m of accretion from bedload supplied by the Tohoratea River, Waitekaha Stream, and two unnamed streams about 1 km south. Note the extensive aggradation in the Waitekaha Stream bed, foreground. [21 May 1979]

load that has accumulated since the 1930s.

We also know there is a massive volume of bedload stored in the lower reaches of rivers such as the Waiapu and Awatere and that the channels 2–3 km up from the coast are presently aggrading. The critical unknown factor, however, is how long the stored plus the transported bedload will continue to over-supply the coast to sustain the present accretion. Such factors as the rate of gravel movement down each river bed, the bedload output at the coast, and the volume of bedload stored in the lower 10 km or so of each major river channel should be established. Determining these factors is vital, as a major reduction in the bedload output at the coast will effect a reversal from net shore line advance to net retreat, thus promoting a coastal erosion hazard along previously accreting sections of coastline that depend upon the rivers as their major source of supply.

Sea conditions

In general, all the study area beaches are exposed to high energy sea conditions. The east coast wave environment is made up of waves from two directions, north-east and south, the persistent southerly swells being generated by westerly trade winds in the southern storm belt between latitudes 40°S and 60°S and the less persistent north-easterly waves from depressions passing eastwards across the North Island.

Pickrill and Mitchell (1979) have summarised the ocean wave characteristics around New Zealand, including the East Cape region, from available wave records. For the East Cape region data were collected by Ministry of Works and Development between July 1977 and December 1979 from two Datawell Wave-rider buoys off Hicks Bay in water depths of 12 m and 65 m (Dr E. Valentine, Central Laboratories, Ministry of Works and Development, pers. comm. 1980). Pickrill and Mitchell analysed three-hourly summaries of significant wave height (the average height of the one-third highest waves – $H_{1/3}$), zero up-crossing period (the average period of all waves that cross the mean water level – T_z) for a 225-day period between 6 July 1977 and 3 March 1978.

Both wave recorder sites are sheltered from the full effects of the prevailing southerly swells along the east coast (Gibb 1979a) and therefore record only the refracted waves from the south. For this reason the analyses by Pickrill and Mitchell of the deep water records (65 m) show the predominant wave approach to be from the north-east quadrant. On 11 September 1977, during 15–20 kn southerly winds, the writer observed 2–3 m high swells approaching from the south at Rangitukia Beach about 11 km south of East Cape. In Kawakawa Bay, 21 km north-east of the Cape, the refracted southerly swells were observed to be approaching from the north-east (Figure 10), supporting the above contention. The deep water wave characteristics off Hicks Bay from these seas were: $H_{1/3}$ = 1.4 m and T_z

Figure 10 Kawakawa Bay looking east, showing refracted southerly swells approaching from the northeast generating a north-westerly longshore drift towards the observer. [11 September 1977]

= 8.7 s, and the shallow water characteristics were $H_{1/3}$ = 0.44 m and T_z = 8.8 s (Valentine, pers. comm. from wave-rider data).

Over the 255-day period of record analysed by Pickrill and Mitchell, the range of wave heights ($H_{1/3}$) in deep water was 0.5–6.0 m, with a mean height of 1.4 m. The range of wave periods (T_z) was 3–12 s in deep water with a mean period of 6.5 s. An indication of the highest waves over the 255-day period may be obtained by assuming a Rayleigh distribution for the waves analysed by Pickrill and Mitchell. For a maximum significant wave height of 6 m, the 1% highest wave would be 1.51 × 6 = 9.1 m (30 ft).

Storms

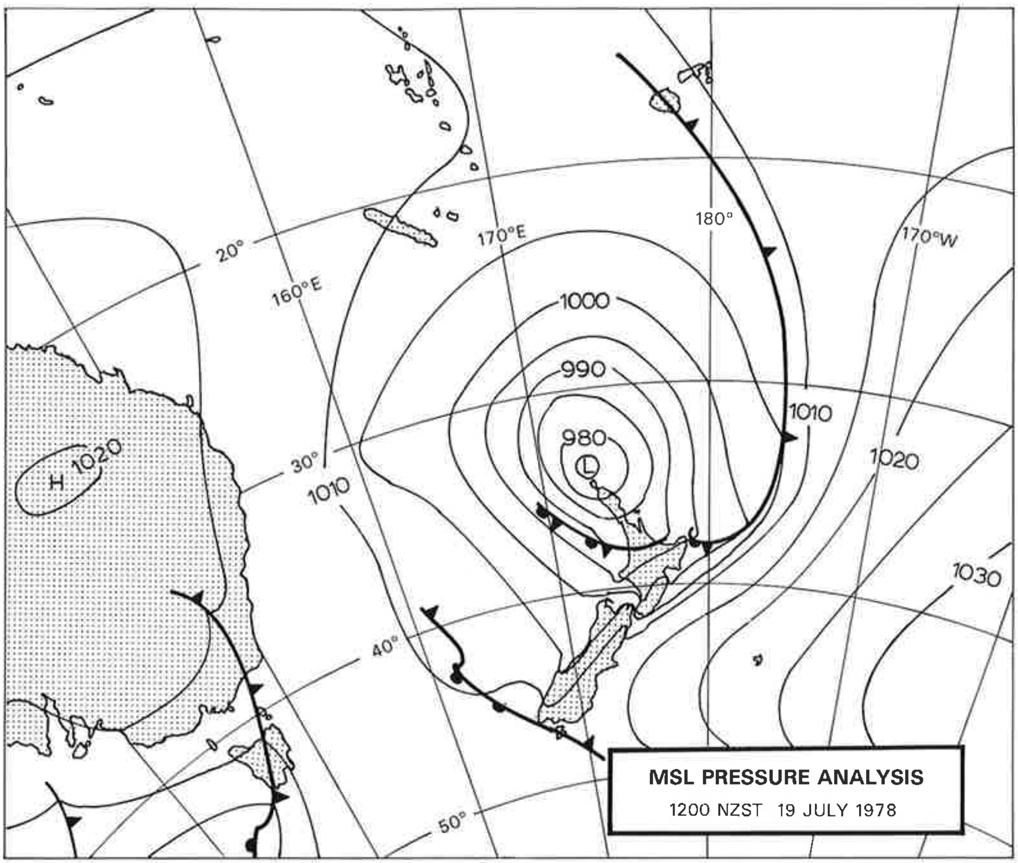
Between July 1977 and December 1979 the deepwater wave-rider buoy recorded storm-generated significant wave heights in excess of 5.0 m on 20 July 1977 (5.5 m), 23 August 1977 (5.6 m), and 19 July 1978 (7.06 m) (Valentine, pers. comm.). Assuming a Rayleigh distribution for the 7.06 m waves, then the 1% highest wave would be 1.51 × 7.06 = 10.7 m (35 ft). According to Reid (1979), the return period of a similar storm to the 18–21 July 1978 event is 30–50 years, though he notes that the return period of sea waves of the order of 10–15 m "is expected to be less than 30 years". Figure 11 shows the synoptic situation and track taken by the July 1978 storm. Wave characteristics during the storm are given in Table 5, Appendix 3.

At sea, the July 1978 storm was severe along the entire east coast of New Zealand. According to Reid, waves up to 15 m were reported by the cargo ship *Iron York* off the Northland coast, which had its forecastle flooded when high seas stove in some steel doors. Easterly swells ranging from 10 m to 15 m were reported between Cape Turnagain and North Cape by other ships and lives were lost on two ships approaching New Zealand. At Hicks Bay a local fisherman, Don Corlett, was caught at sea by the storm (pers. comm. 1979). He reported swells 15–18 m high off Cape Runaway and a change of swell direction from the north-east to the north-west during the passage of the depression. His estimates, made from a fishing vessel, are somewhat higher than the 10.7 m highest wave estimated here from the actual wave records.

Coastal effects from the July 1978 storm

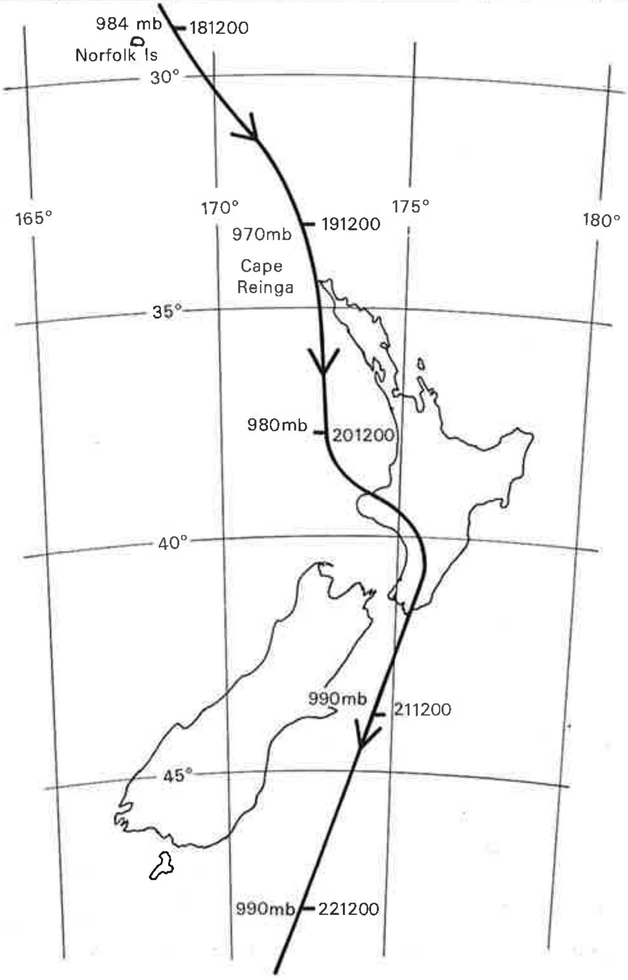
The July 1978 storm caused widespread coastal erosion and flooding along the east coast of New Zealand. At Te Araroa local informants reported large logs and debris being rafted by heavy seas across the airstrip adjacent to the beach for some 70–80 m inland. Both the driftwood and the sea reached the Kawa Kawa Hotel and the Salvation Army Hall at Te Araroa. At Onepoto Bay, the sea advanced some 30–40 m inland leaving a line of driftwood evidenced by the writer in December 1979. Local residents described how surges during the storm drove up the small stream outlets draining into the bay, overtopping and flooding the road parallel to the beach.

Although the July 1978 storm has a return period of 30–50 years, the 10.7 m maximum estimated waves for such a storm are largely a function of wind fetch, velocity, and duration. Should a storm of similar magnitude take a track closer to the Bay of Plenty, then the waves in the East Cape region will be considerably larger — possibly of the order of 15 m. Such waves would cause extensive flooding of low-lying areas such as Onepoto Bay and townships such as Te Araroa. For Onepoto Bay, a study of wave run-up levels that would result from 15 m high waves is presented in Appendix 3.



a Synoptic situation at mid-day on 19 July 1978.

Figure 11 The storm which moved over New Zealand during 18–21 July 1978. Adapted from Reid (1979, figures 1 and 2).



b Track taken by depression 18–22 July 1978. The date and the central pressure at 1200 hrs (NZST) are shown on the track.

Beaches

In terms of incident wave energy, the beaches in the study area range from steep, coarse-grained reflective types to low gradient, fine-grained dissipative types. Depending on the source of supply, the beach sediments vary widely in texture and in composition.

Along the smoothed sections of coastline, there is a strong net northerly longshore drift set up by the persistent southerly swell (Gibb 1979a), whereas for the embayed sections like Tokomaru and Anaura bays the drift is oscillatory owing to localised wave refraction around prominent headlands, islands, and offshore reefs.

Sediment sampling and analyses

To determine the sediment supply sources, ten representative beaches were sampled and the bulk densities, textures, and mineral compositions studied. Distinctive gravel tracers were identified in the major rivers supplying sections of the coast and their distribution alongshore mapped.

Bulk samples of approximately 400 g were collected at each station by channel sampling across the foreshore, using a technique described by Gibb (1977a). The samples were washed to remove salt and mechanically split into workable volumes for analysis. All ten sediment samples are lodged with the Petrographic Section, New Zealand Geological Survey, Lower Hutt.

Bulk densities and grain sizes were determined by Central Laboratories, Ministry of Works and Development, Gracefield. Grain sizes were obtained by passing the dry sand through a nest of BS 410 test sieves at 0.25 phi sieve intervals. Parameters were calculated using the MWD IBM 370/168 computer and a program developed by Adams (1977). Results are given in Table 1. Relative abundances of detrital minerals in the sands were determined by Dr W.A. Watters, Chief Petrologist, New Zealand Geological Survey. Minerals were identified and counted with a petrographic microscope. The results are presented in Table 2.

Sediment supply sources

Of the minerals listed in Table 2, pumice, volcanic glass, andesine, hypersthene, augite, hornblende, magnetite, and a small proportion of quartz are volcanic-derived; and mudstone fragments, glauconite, K-feldspar, zircon, and most of the quartz are sedimentary-derived. The most likely source for the volcanic-derived minerals is the rhyolitic tephra beds (air-fall ash deposits) that mantle the hills. The highly erodible ashes were erupted from the Central Volcanic Region over approximately the last 150 000 years. Soil erosion in the stream catchments has resulted in the volcanic-derived minerals being washed into the rivers and thence transported to the coast. Air-fall ashes erupted over the last 20 500 years are known to extend onto the sea bed (Lewis, in press); hence this area may also be a source of volcanic-derived minerals.

Other sources for some of the volcanic-derived minerals are the Matakaoa Volcanics and pumiceous ash beds which commonly occur in the sedimentary rocks of the Taranaki Series possibly originating from great eruptions in the Coromandel region. The erosion-resistant rocks of the former, however, suggest a very low contribution.

TABLE 1

Textures (phi units) and bulk densities (g/cm³) of beach sands collected between high and low tide marks at selected beaches in the Waiapu County.

phi, $\phi = -\log_2$ diameter in mm; F.S. = fine sand; Med.S. = medium sand; C.S. = coarse sand.

STATION NUMBER	COLLECTION DATE	LOCALITY	N.Z.M.S. 1 GRID REFERENCE	BULK DENSITY	MEAN GRAIN SIZE	SORTING	SKEWNESS	KURTOSIS	WENTWORTH DESCRIPTION
				(g/cm³)	ϕ	ϕ	ϕ	ϕ	
EC-1	22/5/79	Hicks Bay	N62/699693	2.79	2.71	0.35	0.02	1.14	F.S.
EC-2	23/5/79	Kawakawa Bay	N63/723654	2.67	2.64	0.29	-0.02	1.31	F.S.
EC-3	23/5/79	East Cape	N63/937532	2.68	2.63	0.22	0.04	1.24	F.S.
EC-4	23/5/79	Hautai Beach	N63/899577	2.67	2.49	0.25	-0.03	1.03	F.S.
EC-5	23/5/79	Tuparoa	N72/777263	2.66	0.95	0.68	-0.03	0.98	C.S.
EC-6	23/5/79	Reporua	N72/795320	2.66	1.70	0.57	-0.15	1.19	Med.S.
EC-7	24/5/79	Waipiro Bay	N81/727162	2.69	2.03	0.49	-0.24	0.99	F.S.
EC-8	24/5/79	Tokomaru Bay	N81/702996	2.71	2.11	0.35	-0.09	0.91	F.S.
EC-9	24/5/79	Nuhiti Beach	N81/714914	2.76	1.96	0.39	0.15	0.94	Med.S.
EC-10	24/5/79	Anaura Bay	N89/697872	2.67	2.30	0.56	-0.04	0.89	F.S.

TABLE 2

Relative abundances from grain counts of minerals in the Waiapu County beach sands.
d = dominant (> 50%); a = abundant (30–50%); c = common (15–30%); s = subordinate (2–15%); r = rare (0.3–2%); vr = vary rare (< 0.3%).

STATION NUMBER	PUMICEOUS & NON-PUMICEOUS Volcanic Glass	PLAGIOCLASE FELDSPAR Andesine	FERROMAGNESIAN MINERALS Hypersthene Augite, Rare Hornblende	Magnetite	MUDSTONE FRAGMENTS	Quartz	SHELL FRAGMENTS Modern Shells	OTHERS Glauconite K-Feldspar Zircon
EC-1	vr	s	c	s	c	c	-	vr
EC-2	r	r - s	vr	r	a - d	s	r	vr
EC-3	-	r	vr	r	a	a	r	vr
EC-4	-	r - s	vr	r	a	s	r	r
EC-5	-	r - s	r	r	a - d	s	r	vr
EC-6	vr	r - s	vr - r	r	c	c	s	vr
EC-7	-	s	vr - r	r	c	s	a	vr
EC-8	-	a	vr - r	r	r	r	a	vr
EC-9	-	a	vr - r	r	-	vr - r	a	vr
EC-10	c	c	vr	r	s	r	a	-

TABLE 3

Sediment supply sources for the Waiapu County beaches, ranked in order of predominance from A (dominant) to D.

BEACHES	ERODING SEA-CLIFFS AND SHORE-PLATFORMS	RIVERS AND STREAMS	NEARSHORE SEABED	LONGSHORE DRIFT	NOTES
Hicks Bay	C	B	D	A	Wharekahika River minor source
Kawakawa Bay	B	A	D	C	Awatere & Karakatuwhero Rivers major sources
Te Araroa to Waiapu River Mouth	B	A	D	C	Waiapu River major source
Waiapu River Mouth to Port Awanui	C	A	D	B	Waiapu River major source
Reporua	A	D	B	C	Coastal landslides major source
Tuparoa	B	A	D	C	Tohoratea River & Waitekaha Stream major sources
Whareponga	B	A	D	C	Whareponga Stream major source
Waipiro Bay	C	A	B	D	Te Maire & Waikawa Streams major sources
Tokomaru Bay	C	B	A	D	Mangahauini River minor source
Anaura Bay	B	C	A	D	

The mudstone fragments are derived from landslides, either on the coast or within stream catchments, and are therefore mostly erosion products from the pre-Pareora Series rocks, especially the Mata-Landon Series. The other sedimentary-derived minerals are common in most of the sandstone beds in the Late Jurassic to present-day sequences.

For the shell fragments (Table 2), minor carbonate may be derived from fossiliferous sedimentary rocks but most, if not all, are fragments of present-day shells derived from the nearshore sea bed and to a lesser degree from the intertidal shore platform. The carbonate mineral is almost totally calcite.

Four major sediment supply sources are, therefore, recognised for the beaches in the Waiapu County. They are:

- Eroding seacliffs and shore platforms via landslides and downcutting of shore platforms.
- Rivers and streams discharging onto the coast supplying bedload during peak flows.
- Nearshore sea bed via mass transport shoreward by wave and current action.

- Longshore drift set up by oblique wave attack along the coast, supplying down-drift beaches from updrift sources such as those listed above.

Based on data in Tables 1 and 2 plus field observations, the four sediment supply sources are tentatively ranked in order of predominance (Table 3) for particular sections of coastline. Table 3 shows that, except for Hicks Bay and Reporua, rivers and streams are the predominant supply sources to the coast north of Tokomaru Bay. The Waiapu River is by far the most dominant supplier, Waiapu-derived sediments forming about 35 km of beach north and south of the mouth.

Hicks Bay acts as the final trap for the net northerly longshore drift of fine sand, and at Reporua coastal landslides being trimmed back by the sea are the predominant source of the medium sand. From Tokomaru Bay south to Marau Point, the nearshore sea bed becomes the predominant supply source (Table 3). Based on data presented in Tables 1-3, descriptions of beach sediments and their supply sources are given in Appendix 1 for nine localities along the Waiapu County coastline.

Coastal erosion/accretion

Coastal erosion is the *process of removal* of material at the shore line, leading to a loss of land as the shore line retreats landward. Accretion is the *product of deposition* of material at the shore line, leading to a gain of land as the shore line advances seaward (Gibb 1978b).

Rates of coastal erosion and accretion for the Waiapu coast are given for 57 items in Appendix 2. Item localities are shown on Figure 12. Rates are calculated, based on methods described in Gibb (1978b), from cadastral plans, survey plans, vertical aerial photographs, field measurements, radiocarbon-dated shore lines (Garrick 1979), and from coastal surveys made by staff of the Gisborne Residency, Ministry of Works and Development, in 1975.

Comparative studies were made of cadastral plans dating from 1884 at the Department of Lands and Survey, District Office, Gisborne; aerial photographs dating from 1939 at Lands and Survey, Head Office, Wellington; and survey plans of Tokomaru Bay at the office of the Waiapu County, Te Puia Springs. Field measurements were made at Tokomaru Bay, Hautai Beach, and Te Araroa from a reference point or line dating a past shore line, to the present-day shore line.

Re-surveys of ten sections of coastline were made by Ministry of Works and Development staff in 1975, preliminary results being reported by Smith and Brown (1976) and Smith (1977). According to Smith (pers. comm. 1979) the surveys were made by commencing from the same trig station origin used during early surveys made between 1895 and 1928 (Appendix 2). The reference 'shore lines' used to fix the position of the coast varied from place to place, ranging from the seaward limit of land vegetation (e.g., Anaura Bay), cliff-base (Reporua), the berm crest of the present-day beach ridge (e.g., Tuparoa), to the line of driftwood (Hicks Bay).

Although the re-surveys were made with a high degree of accuracy (Smith and Brown 1976), the fixing of the position of the shore line is subjective and is based largely on the assumption that the early surveyors adopted the same reference shore line. Further, Smith and Brown (1976) and Smith (1977) do not give any proof of origin of the heights and positions of their reference trig stations. It is possible that some of the trigs re-occupied by them have been displaced some metres by landslides since they were occupied by the earlier surveyors, especially between Tuparoa and the Waiapu River mouth (see Figures 4 and 5). Such displacements would make the data unreliable.

For all but one locality (Appendix 2) the writer's erosion-accretion rates agree well with those obtained by Smith and Brown (1976), Smith (1977), and by staff of the Gisborne Residency. However, there are significant differences for Tuparoa (items 23-25, Appendix 2) due to the choice of a different reference 'shore line'.

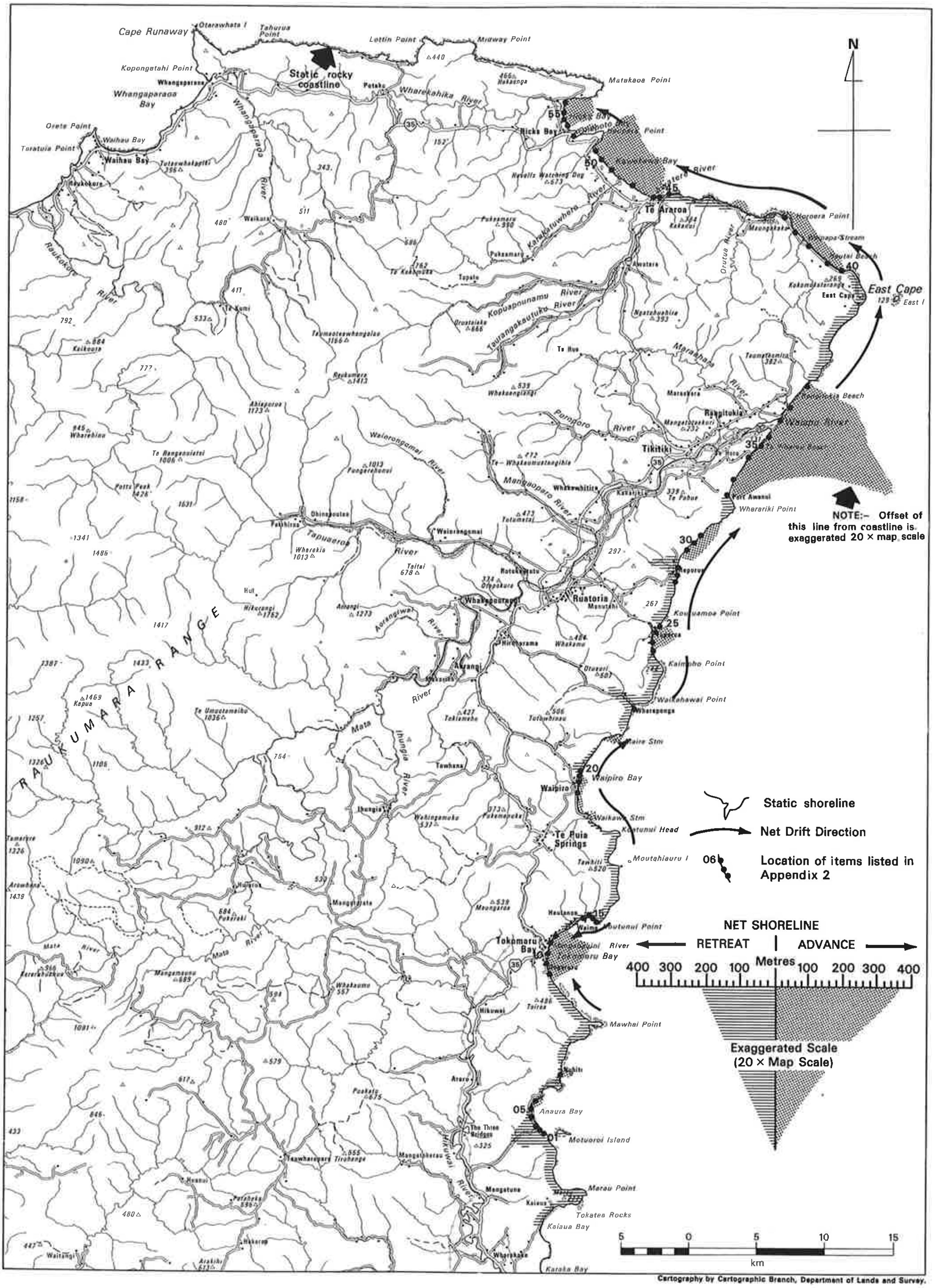
At Tuparoa, early photographs held by Mr John Whangapirita of Ruatoria (pers. comm. 1979) confirm that the vegetation line has advanced only about 50 m between 1910 and 1979, whereas a Gisborne Residency unpublished survey plan shows a 90 m advance for the same period. The distance of 50 m was verified by the writer from cadastral survey plans and from aerial photographs using the vegetation line as the reference 'shore line'. Further, the photographic record shows that the beach has maintained a constant width of 40-50 m since 1910.

For their 1975 survey, Gisborne Residency staff adopted the berm crest (Brown, pers. comm. 1979), which lies near the centre of the active beach, as their reference 'shore line'. The berm is subject to rapid and considerable horizontal displacements in very short periods (Gibb 1978a). The writer cannot, therefore, accept the 90 m advance shown on the unpublished plan. The most likely explanation for the difference of 40 m (90 m minus 50 m) is that the 1910 survey adopted the vegetation line as the shore line, whereas the 1975 survey adopted the berm crest (Figure 13).

Coastal erosion/accretion patterns

The extent and amount of coastal erosion and accretion that has occurred during the last century (1878–1978) is shown on Figure 12. The map is constructed from data in column J, Appendix 2, and from both aerial and ground inspections of the coast made by the writer in May 1979. For sections of coast where there are no erosion/accretion rate data, the amount of erosion or accretion over the last century is interpolated between the data points (column A, Appendix 2).

Of the 147 km length of coastline, Figure 12 shows that about 47% is eroding, 33% is accreting, and 20% is static. The static shore lines (erosion rate less than 0.02 m/yr) are confined only to the very hard basic igneous rocks of the Matakaoa Volcanic Group in the north-west of the county (Figure 14). By contrast all the Tertiary sandstone-siltstone seacliffs and localised sections of Holocene sand dunes and beach ridges are retreating from coastal erosion. Compared



Cartography by Cartographic Branch, Department of Lands and Survey.

Figure 12 Sketch map showing the extent and amount of coastal erosion and accretion along the Waiapu County coastline that has occurred from about 1878 to 1978. The amount of erosion/accretion is exaggerated relative to the map scale. For example, at Anaura Bay there has been about 100 m of erosion and at the Waiapu River mouth about 380 m of accretion. Every fifth item (column A, Appendix 2) is numbered.

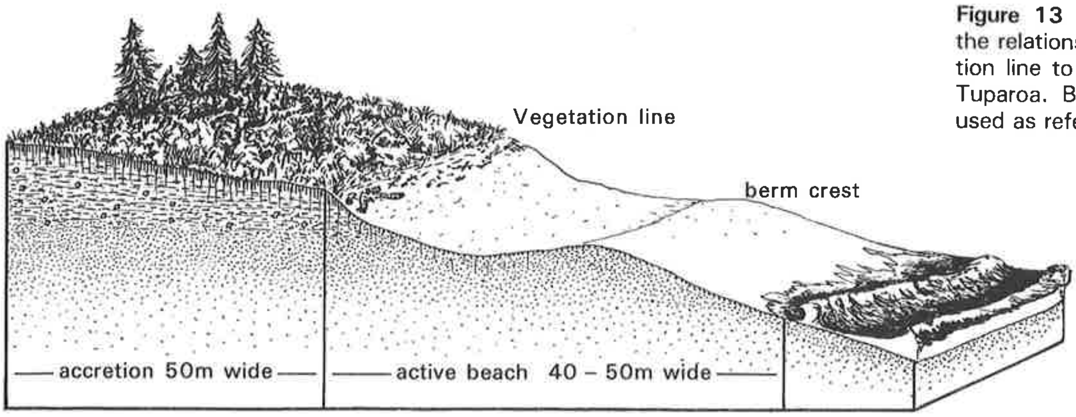


Figure 13 Diagram showing the relationship of the vegetation line to the berm crest at Tuparoa. Both features were used as reference shore lines.

with the 11 000 km long New Zealand coastline of which 25% is eroding (Gibb 1979b), the 147 km long Waiapu coastline has almost twice as much erosion.

Seacliffs cut in the moderately-deformed Late Tertiary rocks are retreating from coastal erosion at 0.05–0.34 m/yr (column J, Appendix 2). For cliffs cut in the intensely deformed Late Cretaceous–Early Tertiary rocks, the rates are higher, ranging up to 0.92 m/yr at Reporua (item 28, Appendix 2). The difference in rates reflects the relative strength of the rocks, the Late Cretaceous–Early Tertiary sequences having a higher erosion susceptibility. At Waipiro Bay and Reporua the net retreat of the cliffs from erosion is counteracted by coastal landslides which in some cases, such as Reporua, have actually resulted in net advance.

Sections of coast with a previous history of accretion have, over the last century, reversed to erosion at an average of 0.8 m/yr, a maximum of 1.2 m/yr being recorded at the south end of Anaura Bay (item 03, Appendix 2). Here, the eroded sand appears to be transported northward resulting in localised accretion of 0.2–0.3 m/yr (items 05, 06, Appendix 2), at the north end of the bay.

At Tokomaru Bay, convergence of the longshore drift at the head of the bay, supplemented by sediment supplied from the Mangahauini River, are resulting in a net accretion of 0.4–1.3 m/yr (items 08–12, Appendix 2). Further north, the southern section of Waipiro Bay is accreting at about 0.3 m/yr (items 18, 19, Appendix 2), largely due to sediment supplied by the Waikawa Stream which drains the massive landslide extending inland to Te Puia Springs.

The highest rates of accretion, however, occur along the coast adjacent to the Waiapu River mouth. Net rates range from 1.4 m/yr up to 7.6 m/yr (items 33–39, Appendix 2), the highest rates occurring next to the river mouth. Like Tuparoa, most of the accretion has taken place after about 1910 in response to deforestation of the stream catchments. The net northerly drift of Waiapu-derived sand has resulted in net accretion at 0.3–1.0 m/yr (items 40–44, Appendix 2) at Hautai Beach.

In Kawakawa Bay, an adequate supply of sediment from the Awatere and Karakatuwhero rivers has resulted in net accretion at 1.11 m/yr from 1900 to 1975 (Smith and Brown 1976). Assuming a depth of 8 m for the accretion along the 6.5 km-long shore line, then at an accretion rate of 1.11 m/yr about 60 000 m^3/yr of sand and gravel have been added to the Kawakawa Bay shore line since 1900 from the two rivers. The net northerly drift has resulted in most of the sediment accumulating against Haupara Point.

At Te Araroa township, Smith and Brown (1976) show a shore line advance of 75 m from 1900 to 1975. The advance was confirmed by the writer from an examination of early photographs held by Mrs Vivienne McConnell of Te Araroa. The earliest photographs taken in 1912 show the vegetation line lying along what is now the seaward road parallelling the beach. Other photographs of the township taken in 1928, 1939, and 1947, show a progressively advancing shore line.

Vertical aerial photographs taken between 1951 and 1977, and field measurements made by the writer in 1980, show that accretion reached a maximum of 61–96 m from the seaward road in 1951. From 1951 onwards, however, measurements show a significant reversal from accretion to

Figure 14 Oblique aerial view of Matakaoa Station, showing a 'static' shore line cut in the very hard Matakaoa Volcanics. The intertidal shore platform has formed over the last 6500 years and is about 80 m wide. The paddocks are on the Last Interglacial terrace that formed 80–120 000 years ago. [21 May 1979]

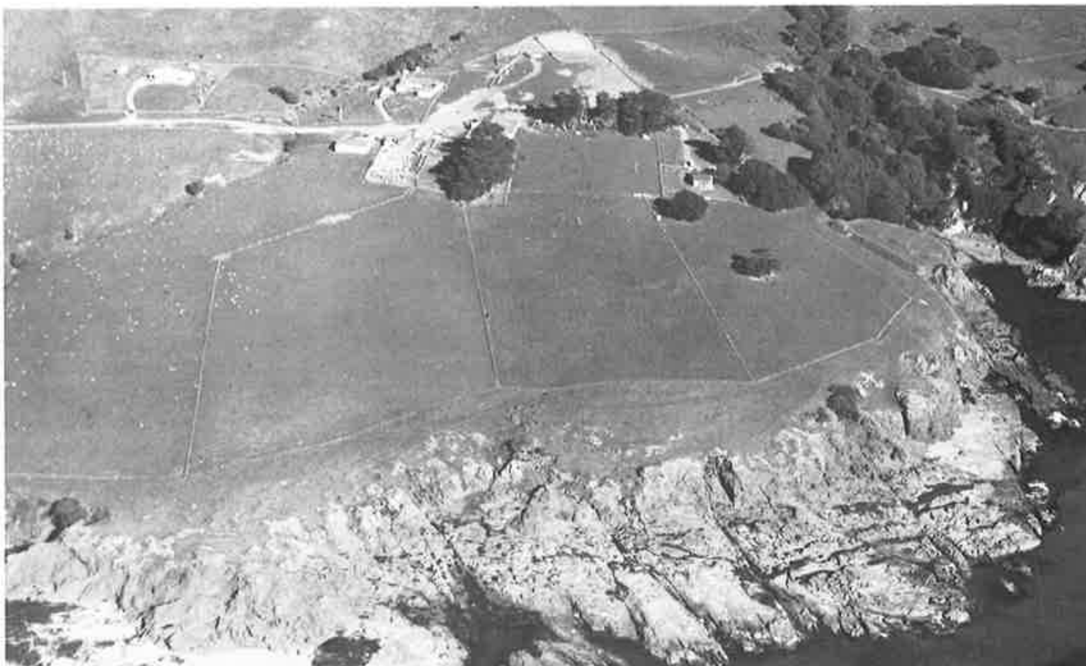


Figure 15 Looking west across Kawakawa Bay towards Matakaoa Point, showing decapitated wooden wharf piles exposed at low tide on the shore platform plane cut in Late Tertiary rocks 400 m east of Te Araroa. In 1914 the platform plane was level with the concrete around the piles in the foreground. Gravels on the lower plane are from the Awatere River. Plastic rule against the righthand pile is 0.4 m long. [23 May 1979]

erosion along the 1.2 km-long coastline adjacent to Te Araroa and the Awatere River mouth (items 46, 47, Appendix 2). Detailed measurements made by the writer show that erosion rates ranged from 0.6 m/yr to 1.4 m/yr opposite the township, averaging 0.9 m/yr over the period 1951–1980. Over the same period, however, the remaining 5.3 km of Kawakawa Bay coastline has continued to accrete, the rates increasing progressively to the north-west (items 48–51, Appendix 2). The results clearly indicate that the Kawakawa Bay shore line is in the process of realigning.

The realignment of the coastline may be caused by one or a combination of the following factors: possible reduction in bedload output from the Awatere River since 1950; localised concentration of wave energy at Te Araroa from shallowing of the nearshore sea bed at the river mouth (Corlett, pers. comm. 1979); localised adjustment of the shore line in response to the long-term retreat of the sandstone–siltstone headland to the east; possible increase in the number of severe north-easterly storms over the last 30 years.

Further north-west, Hicks Bay and Onepoto Bay trap most if not all of the net northerly drift of fine sand that bypasses Haupara Point, resulting in net accretion at 0.3–1.3 m/yr (items 53–57, Appendix 2). In spite of net accretion, the shore line of Hicks Bay is notoriously unstable owing to the migration of the Wharekahika River mouth from one side of the bay to the other in periods as short as one year. A study of aerial photographs showed that in 1971 the mouth lay hard against the southern headland of the bay and there was a lagoon behind a 2 km long spit. By 1973 the spit was breached opposite the bridge over the Wharekahika River. During a severe storm in March 1974 a coastal subdivision at the north end of the bay was destroyed by the migrating river mouth (Anon. 1974). Over a 28-month period from 1977 to 1979 the mouth has migrated 1.2 km south at 514.3 m/yr.

Shore platform erosion rates

Retreating seacliffs bordered by extensive intertidal wave-cut shore platforms comprise most of the eroding 70 km or so of the 147 km long Waiapu County coastline. According to Robinson (1977) shore platforms are common land forms on eroded coastlines. They have three main morphological elements: the *plane, ramp,* and *seacliff.* The seacliff retreats by *backcutting* and the plane and ramp are lowered by *downcutting.*

The *plane* is the near horizontal part of the platform that has reached an equilibrium level between mean sea level (MSL) and mean low water mark (MLWM). At most localities, it is either flat (see Figure 6c) or slopes very gently seawards. On many platforms erosion-resistant strata form ramparts that are higher in elevation than the plane, but are generally covered at high tide.

At the landward edge of the plane there is a marked steepening of gradient between the plane and the seacliff. This area is termed the *ramp* and is generally covered by mobile beach sediment ranging from sand to gravel. For the present study, both long-term and historic data provide downcutting and backcutting rates.

Downcutting rates

Using a micro-erosion meter, Kirk (1977) determined downcutting rates for platforms cut in Tertiary mudstones around the Kaikoura Peninsula, South Island east coast, between 1973 and 1975. Robinson (1977) used the same method over a 1.75 year period to determine downcutting rates for platforms cut in the harder Early Jurassic shales along the Yorkshire, England, coastline. Their rates are compared with those determined in the present study.

For the Kaikoura mudstone platforms, downcutting rates are only given by Kirk for the platform as a whole (see Kirk 1977, table 2). To determine erosion rates for the plane and ramp from Kirk's data, the writer averaged rates from five profile sites between 0.3 m above MSL and 0.8 m below MSL for the plane, and above +0.3 m for the ramp. For the Kaikoura platforms, downcutting of the mudstone planes averaged 1.3 mm/yr ranging from 0.8 mm/yr up to 2.2 mm/yr. For the mudstone ramps downcutting averaged 4.0 mm/yr ranging from 1.0 mm/yr up to 7.0 mm/yr.

For the Yorkshire shale platforms, downcutting rates are given by Robinson for the plane and ramp. Downcutting of the shale planes averaged 1.2 mm/yr ranging from 0.1 mm/yr up to 2.7 mm/yr (Robinson 1977, table 1). For the shale ramps, downcutting averaged 7.1 mm/yr ranging from 0.3 mm/yr up to 14.7 mm/yr (Robinson 1977, table 4). Although the Early Jurassic shale is probably harder than the Early Tertiary mudstone at Kaikoura, the rates agree well for both areas.

Many sub-aerial and marine erosive processes are important in the formation of shore platforms (see Healy 1968; Kirk 1977; Robinson 1977). Of particular relevance to the formation of those cut in the Tertiary sandstone–siltstone rocks of the Waiapu coastline is the study made by Robinson (1977). He found that different processes erode the plane and ramp.

Figure 16 Central Tokomaru Bay looking south, showing Mr B. Edgar, Waiapu County Engineer, alongside an endangered section of concrete sea wall constructed in 1965. The wall rests on a shore platform ramp cut in Late Tertiary alternating sandstone-siltstone beds dipping about 40° landward. In the boulder-filled hollow the platform ramp has been downcut 1.2 ± 0.1 m since 1965. Both increased wave turbulence at the sea wall base and the corrasive action of locally derived boulders have accelerated downcutting rates. [25 June 1980]

Figure 17 A locally derived sandstone boulder resting in a pothole cut by the boulder in a siltstone bed on the shore platform ramp, central Tokomaru Bay. [25 June 1980]

On the plane Robinson found that the most important erosive process was dessication and contraction of the shale when the platform was uncovered at low water, and hydration and expansion during high water. The movements were found to crack the shale bedding laminae into polygons which were removed by the waves. Cracking of the sandstone–siltstone bedding laminae into polygons was also observed by the writer on the Tertiary rock platforms in the study area.

On the ramp, Robinson found that the dominant process was corrasion, the abrasion of the rock surface by the movement of debris over it from wave action. Corrasion was most active during stormy periods, the rate being controlled to a large degree by beach depth and possibly grain size. A sand and pebble beach less than 50 mm thick allowed erosion at all times, whereas the rates decreased by over 65% when the beach was greater than 135 mm thick. The presence of gravel and sand on some of the planes and on most of the ramps in the study area suggests that corrasion is an active erosive process over both plane and ramp. Most of the gravels are derived *in situ* from the harder indurated sandstone beds.

Regardless of net tectonic uplift along the Waiapu coastline (Figure 13), the equilibrium level of the shore platforms at about MSL is maintained, suggesting that the net downcutting rate of the plane is equal to the net uplift rate. On this basis the net downcutting of the harder Matakaoa Volcanic rock platforms is about 0.4 mm/yr and the softer Tertiary sedimentary rock platforms about 0.6–2.6 mm/yr.

Historic downcutting rates for the plane were determined from the Late Tertiary sandstone–siltstone platform east of Te Araroa, from wooden wharf piles set in concrete in 1913 (Figure 15). When constructed, the tops of the concrete foundations were flush with the level of the shore platform. In May 1979 they were 150–300 mm above the platform level, thus indicating downcutting rates of 2.3–4.6 mm/yr over the 66-year period. The historic values agree well with the long-term net rates inferred from tectonic uplift, but are somewhat higher than those determined by Kirk (1977) and Robinson (1977). At Te Araroa, hard Awatere-derived gravels cover the lower plane; hence corrasion of the plane by the gravels has probably accelerated downcutting rates (Figure 15).

Historic downcutting rates for a Late Tertiary sandstone–siltstone ramp in northern Tokomaru Bay were determined from Waiapu County Council Plan No. 562. The plan shows differences in levels of the shore platform ramp at the base of a concrete sea wall, calculated from surveys made by Waiapu County Council staff between 1940 and 1980. The 1293 m-long survey traverse follows a gently curved promontory protected by a concrete sea wall which rests on top of the platform ramp (Figure 16). Downcutting of the ramp has resulted in sections of sea wall, constructed 15–20 years ago, collapsing from undermining.

Along most of its length, high tide reaches the base of the sea wall; hence there is considerable turbulence set up by reflecting waves at the base. Because of this the ramp at the apex of the promontory is generally bare of sand. However, there are pockets of well-rounded gravels and boulders (Figure 16) locally derived from the steeply-dipping, protruding sandstone beds on the shore platform. Many of these gravels rest in potholes (Figure 17) cut in the softer alternating beds of siltstone, suggesting that they act as corrasive agents abrading the platform ramp.

Of the 1293 m-long section, all but 160 m along the northern flank recorded a net erosion (Table 4). For the 160 m section, there were no changes in the level of the ramp between 1965 and 1980. As this section has a sand and gravel cover in excess of 500 mm, it is thought that the depth of sediment protects the ramp from active downcutting. For the remaining 1133 m, the beach is either non-existent or less than 500 mm in depth. Here, the sandstone–siltstone ramp itself is abraded by the sweeping of sand and gravel to and fro across its surface.

Table 4 shows that, over the last 15–20 years, downcutting of the ramp has averaged 27.1 mm/yr, ranging from 12.0 mm/yr up to 50.0 mm/yr. Downcutting is greatest where the platform ramp is exposed or the beach cover is thin, and where the rock is weakened by fractures and faults. At one such site (Figure 16) at the base of the sea wall, the writer measured a maximum difference in sandstone–siltstone levels of 1.2 ± 0.1 m for the period 1965–1980, indicating a downcutting maximum of 70 ± 9 mm/yr.

For Tokomaru Bay, downcutting rates for the ramp are about seven times higher than those determined by Kirk (1977) for similar lithologies at Kaikoura and about four times higher than those determined by Robinson (1977) for

TABLE 4

Rates of downcutting for the shore platform ramp cut in coherent Late Tertiary (Taranaki Series) sandstone–siltstone rocks in northern Tokomaru Bay (NZMS1 Grid Ref. N80–81/712028–723034). Column A gives the distance apart northwards of each observation. Column B lists the survey interval. Column C tabulates the erosion as a vertical distance in millimetres for each survey interval. Column D gives the downcutting rate in millimetres per year (mm/yr).

A	B	C	D
Cumulative distance apart (metres)	Survey interval (years)	Erosion (millimetres)	Rate (mm/yr)
0	1965–1980	–750	–50.0
6	1965–1980	–180	–12.0
43	1965–1980	–259	–17.3
70	1965–1980	–290	–19.3
77	1961–1980	–470	–24.7
89	1965–1980	–491	–32.7
112	1961–1980	–610	–32.1
236	1960–1980	–521	–26.1
257	1965–1980	–290	–19.3
707	1960–1980	–750	–37.5

Late Jurassic shales in Yorkshire. Two factors are suggested to explain the differences. Firstly, turbulence created by waves reflecting off the sea wall enhances the corrasive action of the sand and gravel, especially where the beach is less than 500 mm deep. Secondly, faulting and fracturing from tectonism have weakened the Tertiary rocks in the study area so that they are much less resistant to erosive processes.

Backcutting rates

Erosive processes, that result in backcutting of the seacliffs and a net widening of the shore platform, are complex along the Waiapu coastline. Further south, McLean and Davidson (1968) found that the shore platforms near Gisborne were widened by the combination of landsliding destroying the seacliffs and wave action removing the resulting waste. Most of the Teritary rocks are landslide prone, hence these processes have application in the study area. According to Gill (1950), who also investigated the shore platforms near Gisborne, platform widths are chiefly a function of the resistance to erosion (sub-aerial and marine) of the rock from which they are cut. A comparison in the study area of the widths of the platforms cut in the hard Matakaoa Volcanics with those cut in the softer Tertiary sedimentary rocks supports this contention, and provides the means for estimating minimum long-term backcutting rates.

Figure 18 Northern Tokomaru Bay looking north, showing an outflanked sea wall. The rocks are Late Tertiary sandstone-siltstones that have retreated about 7 m since 1945. Note the polygonal cracking breaking up the cliff face. [24 May 1979]

Over the last 6500 years the continual retreat of the headlands in the study area has resulted in Tertiary sedimentary rock platforms typically exceeding 100 m in width, ranging up to 430 m at MLWM. By contrast, platforms cut in the Matakaoa Volcanics typically exceed 50 m, ranging up to 160 m at MLWM. Assuming that the seaward edge of the platforms marks the approximate position of the shore line 6500 years ago, then the horizontal distance between the seaward and landward edges divided by the period of formation (6500 yr) provides a minimum long-term backcutting rate. Based on this assumption, long-term rates of 15–66 mm/yr (0.02–0.07 m/yr) are suggested for the seacliffs cut in Tertiary rocks and 8–25 mm/yr (0.01–0.03 m/yr) for those cut in the Matakaoa Volcanics.

Historic backcutting rates for seacliffs cut in the Taranaki Series (Late Tertiary) mudstone–siltstone rocks at Waima, northern Tokomaru Bay, were determined from surveys made by Waiapu County Council staff in 1945 and in 1980. Both surveys are shown on Waiapu County Council Plan No. 28 and record the relative position of the top edge of a 11.4–13.7 m high seacliff along a 180 m long traverse.

The plan shows that all but 14 m of the 180 m-long cliff section has retreated an average of 4.2 m at 120 mm/yr (0.12 m/yr), backcutting rates ranging rrom 46 mm/yr (0.05 m/yr) up to 209 mm/yr (0.21 m/yr). For the 14 m, no change in the position of the cliff top was detected between 1945 and 1980. Maximum backcutting (0.21 m/yr) occurs where the concrete sea wall south of the Tokomaru Bay wharf has been outflanked up to 7.3 m over the last 35 years (Figure 18). The outflanking is due to increased turbulence set up by waves reflecting off the sea wall.

On the cliff face the writer observed cracking of the sandstone–siltstone bedding laminae into polygons similar to those observed on the shore platforms. Wetting and drying of the cliff face here, leading to dessication, contraction, hydration and expansion of clay layers in the siltstone is obviously a dominant erosive process causing backcutting. When the cliffs are oversteepened by this process, landsliding occurs, thus widening the shore platforms.

Backcutting rates of 0.11–0.34 m/yr listed in Appendix 2 (items 15, 16, 25), for seacliffs cut in coherent Tertiary rocks elsewhere along the Waiapu coastline, agree well with the rates above for Waima. As noted previously, backcutting rates are much higher (0.92 m/yr) where the rocks have been intensely deformed by gravity sliding and tectonism. The minimum long-term rates of 0.02–0.07 m/yr are somewhat lower than the historic rates. The reason for this is not known, but a possible explanation is that the present seaward edge of the platforms does not mark the position of the shore line 6500 years ago. The seaward edge may well be retreating from the erosive processes, like the landward edge.

Finally, with respect to erosion rates on the shore platform plane, rates are higher by one order of magnitude for the ramp and by two orders of magnitude for the seacliffs. Both downcutting and backcutting of the shore platforms and seacliffs are natural hazards that occur along the Waiapu County coastline.

Coastal hazard maps

Fourteen *coastal hazard photomaps* (Figures 21–34) are presented for selected parts of the Waiapu County coastline. Figure 19 shows the locations of the photomaps. Each area is very attractive and is likely to come under increasing pressure over the next 20 years for residential development and recreational use. They are presently either undeveloped or partly developed, so there is an excellent opportunity for the Waiapu County Council in its District Planning Scheme to allow for the provision and management of an adequate width of land between any development and the beach. Such a width of land, or *coastal hazard zone* as it is termed here, is shown on the 14 coastal hazard photomaps. The degree of hazard is indicated by the width of the zone. Where it is wide there is an extreme risk, where it is narrow, there is a low risk.

Assessment of coastal hazard zones

Criteria for assessing the width of the coastal hazard zones are different for each section of coast because of the different factors involved. Such factors to be considered are:

1. Long-term (about 100 years) erosion or accretion rate based on data in Table 4 and Appendix 2.
2. Short-term (a few tens of years) fluctuations in the position of the shore line.
3. The likelihood of a reversal from net shore line advance to net retreat in the future.
4. Extent of river mouth migration.
5. Extent of flooding from the sea.
6. Preservation of the essential elements of the natural beach system such as the protective vegetation, dunes, beach ridges, and the beach profile.
7. Susceptibility of the coastal slopes to landsliding.

The hazard zone is measured as a horizontal distance inland, either from the toe of a seacliff or sea wall, or from the seaward limit of land vegetation, whichever reference line is the most clearly defined along each section of coast.

Sand dune and gravel beach ridges

For *accreting* sections of coast that are unlikely to reverse to net erosion over the next 100 years, a **minimum hazard zone width of 50 m** is adopted to accommodate short-term shore line movements and for the protection of the essential elements of the natural beach system. The 100 year period (1980–2080) is based on the practical life of a building.

Short-term fluctuations in the position of the shore line of 15–350 m are likely to occur in periods as short as one year along depositional coasts around New Zealand (Gibb 1978b; 1979a). Data in Appendix 2 do not indicate adequately the range of short-term shore line movements that are likely to occur along the Waiapu coastline, but a minimum movement of 50 m is considered here to be possible. Further, the width of the primary beach ridge and foredune, both essential elements of the natural beach system, is of the order of 50 m in the study area.

For *eroding* sand dunes and beach ridges, the width is calculated by multiplying the **long-term erosion rate (column J, appendix 2) by 100 years and adding 50 m** to accommodate the short-term movements so that:

hazard zone width (m) = (R × 100) + S
where R = long-term erosion rate (m/yr)
100 = assessment period (in years)
S = extent of short-term movements (50 m)

Based on the above method, the landward extent of the hazard zone represents the line beyond which the shore line (seaward limit of land vegetation) is not expected to lie in the year 2080. Any development placed within the hazard zone during the next 100 years may be destroyed by coastal erosion.

Seacliffs

For eroding seacliffs of Tertiary rocks, the width is calculated by multiplying the maximum long-term erosion rate (column J, Appendix 2) at, or close to, the site by 100 years and adding a safety factor (F) of two-thirds the product [$\frac{2}{3}$ (R × 100)] so that:

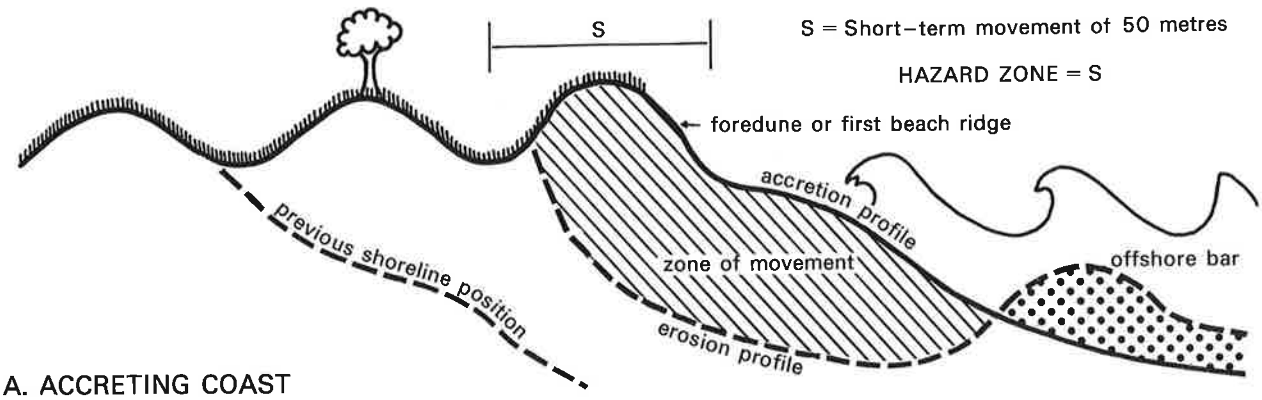
hazard zone width (m) = (R × 100) + F

The safety factor allows for landslides and unknown structural weaknesses in the rocks which will cause variations in erosion rates. Where there is evidence of past or present coastal landslides, the hazard zone is calculated from the top edge of the landslide scarp, extending inland to include the landslide-prone area between the predicted position of the top edge and the coast. Any development placed within the hazard zone may be destroyed by landsliding and coastal erosion. Figure 20 shows the method adopted here for assessing the width of the hazard zones.

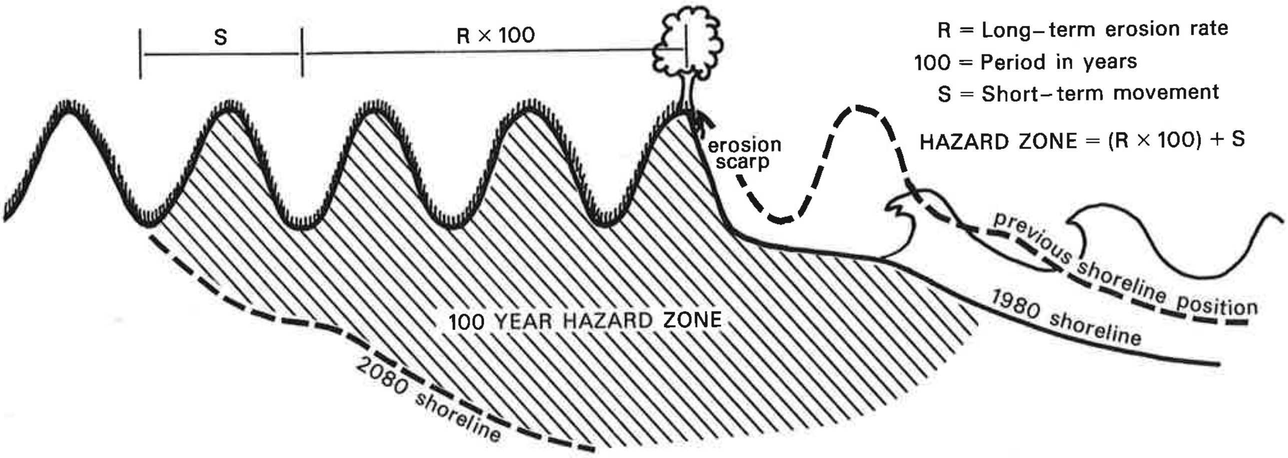
Before using the coastal hazard photomaps, see the note on page 2.

Cartography by Cartographic Branch, Department of Lands and Survey.

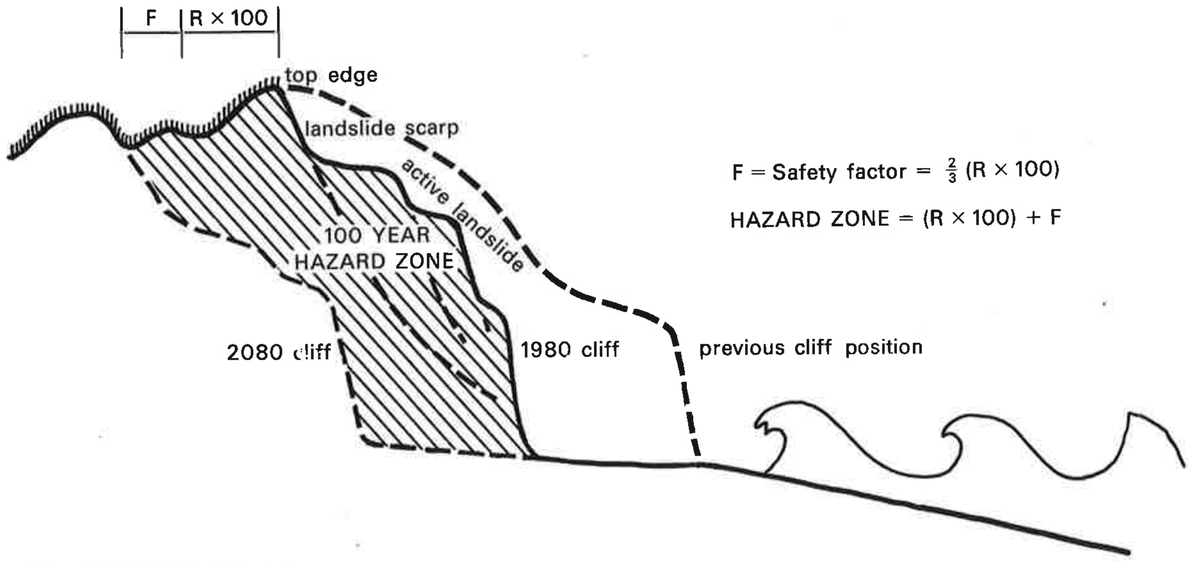
Figure 19 Location map for the 14 Coastal Hazard Photomaps (Figures 21–34).



A. ACCRETING COAST



B. ERODING DUNES OR BEACH RIDGES



C. ERODING SEA CLIFFS

Figure 20 Diagrams showing the methods used to assess coastal hazard zone widths along the Waiapu coastline for accreting coastlines (**A**); eroding sand dune andgravel beach ridges (**B**); and eroding sea cliffs (**C**).

Coastal hazard maps for Waiapu County

Figure 21 Coastal Hazard Photomap of Anaura Bay, based on aerial photograph: Survey 3566, photo A/7, 30 April 1972.

Anaura Bay (Figure 21)

The headlands and southern two-thirds of the coastline shown on the map are eroding, whereas the northern third is accreting (items 01-06, Appendix 2). The hazard zone width increases southwards to allow for the change from accretion to erosion. For the accreting section the **width is 50 m** from the vegetation line, allowing for the protection of the foredune and short-term shore line movements. The hazard zone is made wider around stream mouths and drainage points along the foredune to allow for accelerated erosion at these points.

For the eroding section the hazard zone width increases to a **maximum of 174 m** (1.24 m/yr × 100 + 50 m) by the southern stream mouth, based on maximum erosion at 1.24 m/yr (item 03, Appendix 2). As most of the coastal plain is less than 174 m wide and is backed by steep hills, the hazard zone extends only to the toe of the hills.

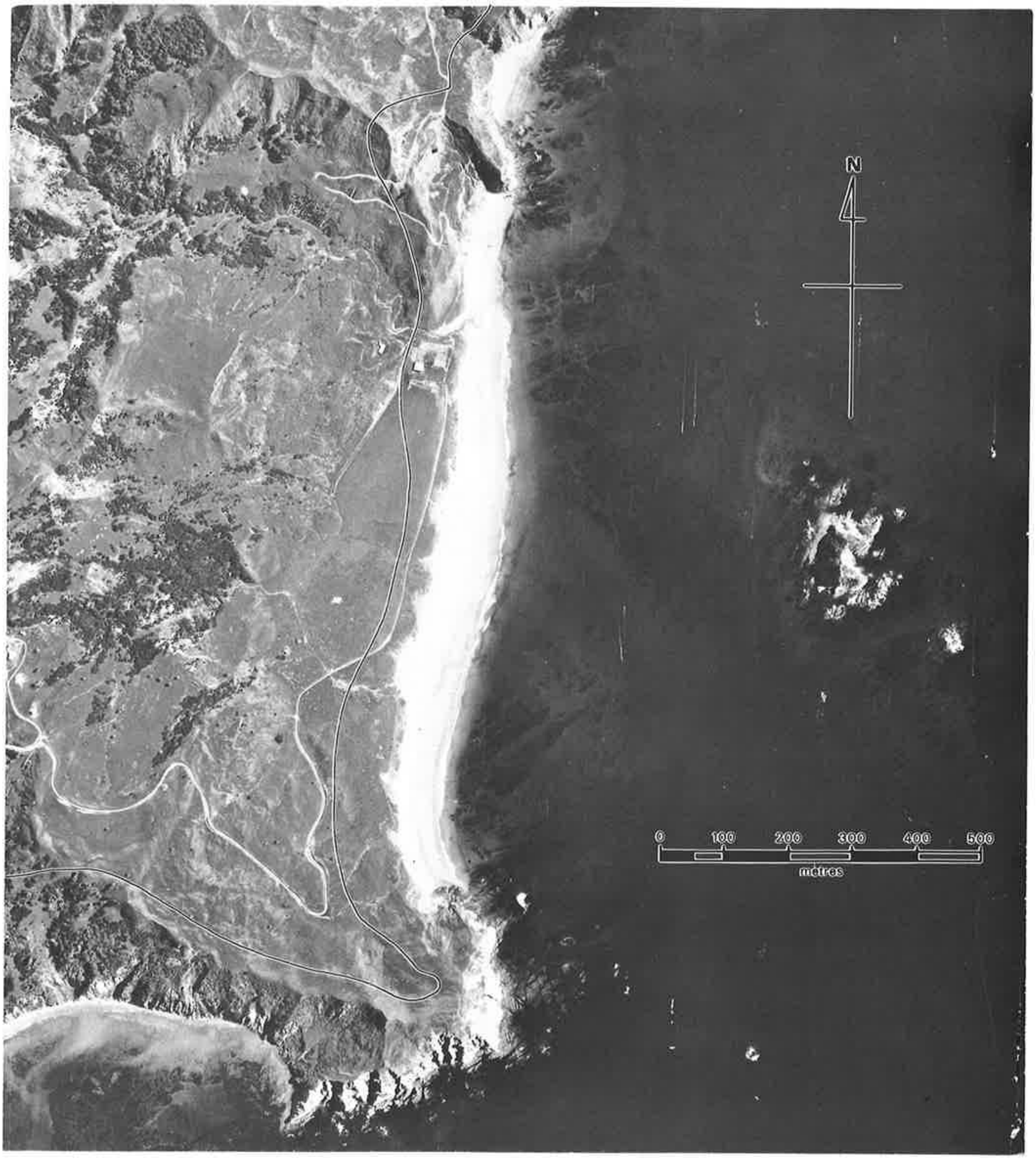


Figure 22 Coastal Hazard Photomap of Nuhiti Road Beach, based on aerial photograph: Survey 3298, photo 4460/57, 22 October 1972.

Nuhiti Road Beach (Figure 22)

The headlands and north and south depositional sections shown on the map are eroding, whereas the centre section is accreting (item 07, Appendix 2). Like Anaura Bay the hazard zone has a **minimum width of 50 m** along the accreting section, widening in relation to the eroding sections. As no rate data are available for the eroding sections of sand dunes, a **minimum width of 100 m** is adopted, based on an estimated erosion rate of 0.5 m/yr (0.5 m/yr × 100 + 50 m). For the eroding Late Tertiary mudstone headlands, a hazard zone **width of 35 m** is calculated (0.21 m/yr × 100 + 14 m), based on maximum erosion at 0.21 m/yr (item 14, Appendix 2), extending inland from the top edge of the recent or relict landslide scarps.

Figure 23 Coastal Hazard Photomap of Tokomaru Bay south, based on aerial photograph: Survey 3298, photo 4457/56, 22 October 1972.

Tokomaru Bay south (Figure 23)

With the exception of the eroding coastline south of the terminus of the southern coastal road, the entire coastline shown on the map is accreting (items 08–10, Appendix 2). According to criteria given previously, the hazard zone **width is 50 m** along the accreting section of coast, increasing in width around the mouths of the Mangahauini River (northernmost in Figure 23) and the Waiotu Stream (about 600 m further south). Both mouths migrate along the coast causing localised erosion.

Figure 24 Coastal Hazard Photomap of Tokomaru Bay centre, based on aerial photograph: Survey 3298, photo 4457/56, 22 October 1972.

Tokomaru Bay centre (Figure 24)

The southern half of the coastline shown on the map is accreting (items 11, 12, Appendix 2) and the northern half is eroding. The eroding section up to the northern promontory is Late Tertiary mudstone, and is protected by a vertical concrete sea wall that is being undermined by the downcutting of the mudstone shore platform.

Here, a hazard zone **width of 35 m** is calculated (0.21 m/yr × 100 + 14 m), based on maximum backcutting at 0.21 m/yr (item 14, Appendix 2), extending inland from the toe of the sea wall. For the southern accreting section of coast a hazard zone **extending 50 m** inland from the vegetation line is adopted.

Figure 25 Coastal Hazard Photomap of Tokomaru Bay north, based on aerial photograph: Survey 3298, photo 4456/57, 22 October 1972.

Tokomaru Bay north (Figure 25)

The entire coastline shown on the map is eroding (items 15, 16, Appendix 2). The southern section of coast is included on Figure 23, hence the hazard zone and criteria for determining the width are the same. The part of the bay shown in the middle of the map has rocks which are unconsolidated Holocene alluvial sediments that have eroded 4–7 m between 1945 and 1979 (air photographs). Here, a hazard zone **width of 35 m** is calculated (0.21 m/yr × 100 + 14 m), based on the maximum erosion rate. For the northern bay containing the wharf, a hazard zone **width of 35 m** is calculated (0.21 m/yr × 100 + 14 m), based on maximum backcutting at 0.21 m/yr, extending inland either from the toe of the Late Tertiary mudstone bank, or the top edge of the landslide scarps.

Figure 26 Coastal Hazard Photomap of Waipiro Bay, based on aerial photograph: Survey 3298, photo 4434/60 30 October 1972.

Waipiro Bay (Figure 26)

The entire coastline shown on the map is affected by landslides, the largest being the bulge in the centre of the bay protected from erosion by the offshore reefs. Although a small amount of accretion has occurred adjacent to the Waipiro Bay settlement, the width of the hazard zone has to be determined by the very high susceptibility of the Late Jurassic–Early Tertiary coastal rocks to landsliding. The zone therefore, **extends 45 m** inland from the top edge of the landslide scarp which corresponds to the crest of the seaward ridge (0.27 m/yr × 100 + 18 m), based on maximum erosion in Waipiro Bay of 0.27 m/yr (item 20, Appendix 2). The zone extends inland **up to 780 m** from the vegetation line to accommodate landsliding. At the mouth of the Waipiro Stream next to the township, the zone **narrows to 50 m** from the vegetation line because the land is an uplifted river terrace with a low susceptibility to landsliding. About 1.9 km further north at the Taurapu Stream mouth the seaward ridge crests converge close to the coast, hence the zone extends **about 170 m** inland from the beach to accommodate landsliding.

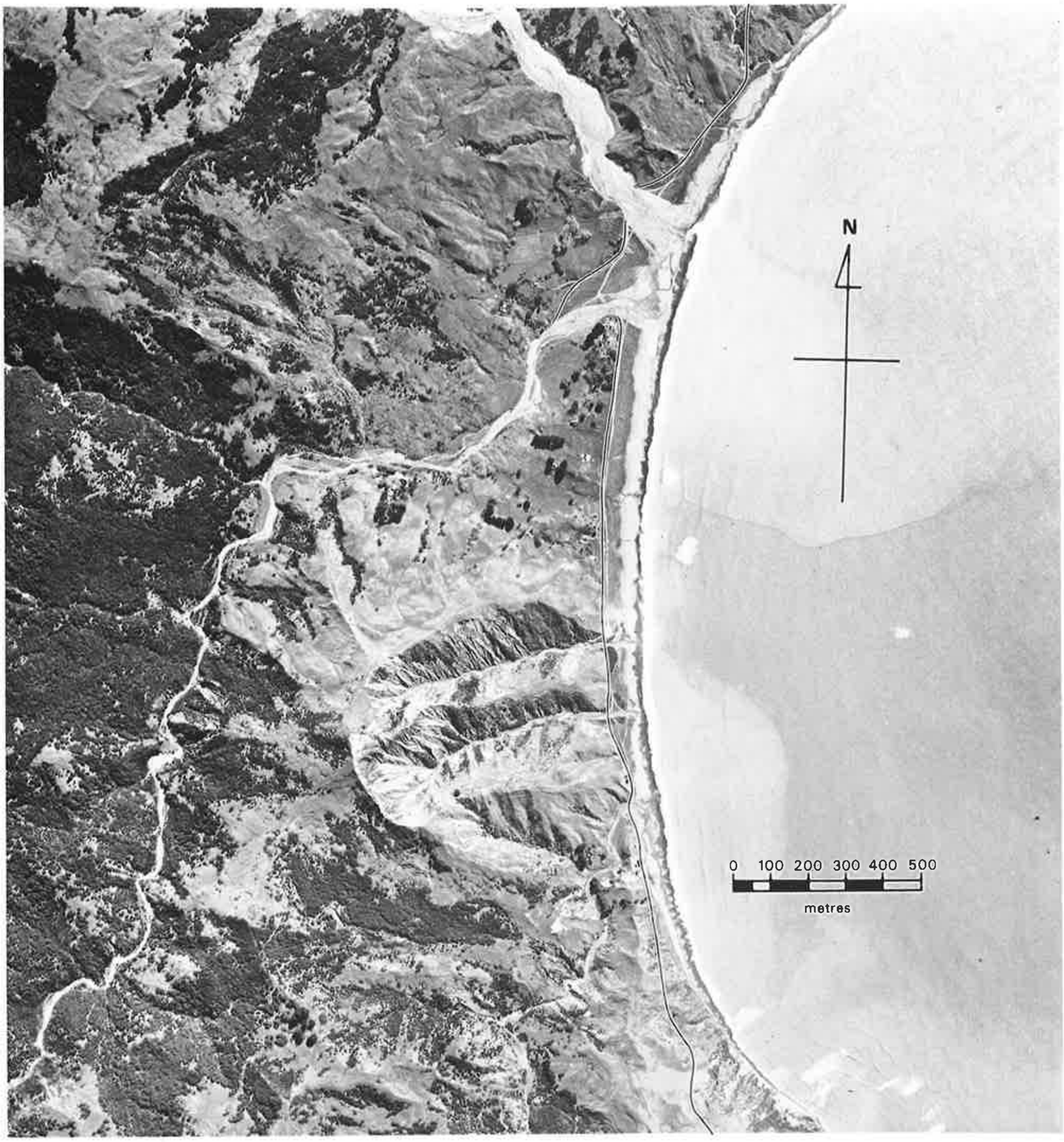


Figure 27 Coastal Hazard Photomap of Tuparoa, based on aerial photograph: Survey 3298, photo 4431/50, 10 September 1971.

Tuparoa (Figure 27)

With the exception of the eroding flanking headlands, the entire shore line shown on the map is accreting (items 22-25, Appendix 2). For the accreting section the hazard zone covers the entire coastal plain and in the centre of the bay **extends about 50 m** inland from the vegetation line to the toe of the hills.

At Tuparoa there is a likelihood in the future of a reversal from net accretion to net erosion. The supply of Tertiary sediments to the headwaters of the Waitekaha Stream (northernmost in Figure 27) and the Tohoratea River (whose mouth is 300 m further south) is being reduced by the growth of scrub. Both streams feed the beach so that reductions in bedload output must register along the coast. The coarse sand grains forming the bulk of the beach sands are soft and are readily destroyed by abrasion, forming mud in the process. The mud is washed offshore, hence abrasion from wave action will quickly reduce the volume of beach sand if the supply to the beach from the streams is significantly reduced.

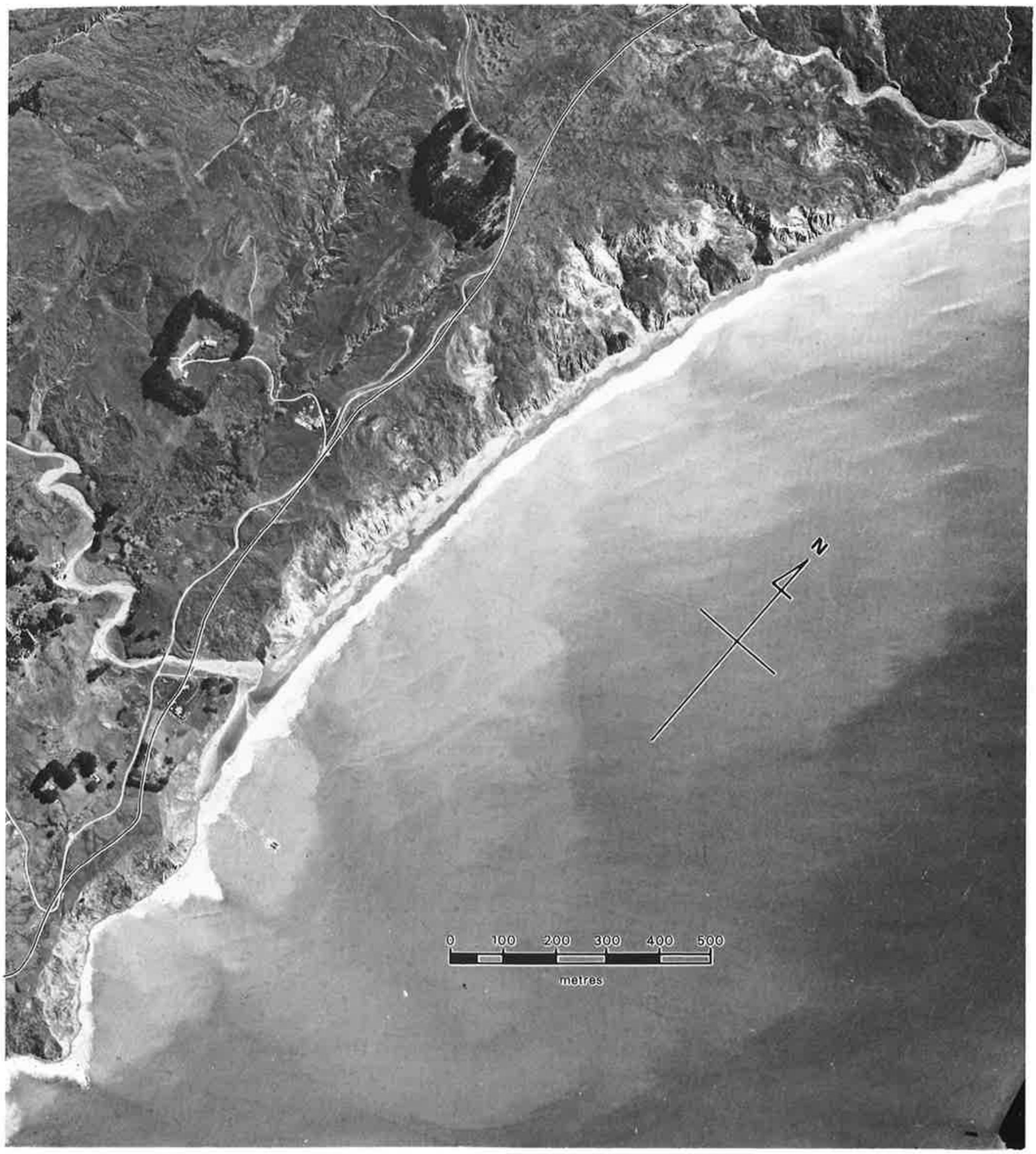


Figure 28 Coastal Hazard Photomap of Reporua, based on aerial photograph: Survey 3298, photo 4429/45, 10 September 1971.

Reporua (Figure 28)

The Early Tertiary rocks forming the coastline shown on the map are highly susceptible to landsliding and are being eroded by the sea (items 26–28, Appendix 2). The northern section of coastline adjacent to the Awatere Stream mouth (at top of Figure 28) is advancing from a massive landslide. South of the Reporua Marae the hazard zone **extends 33 m** inland from the top edge of the cliffs (0.2 m/yr × 100 + 13 m). At the marae (just south of Reporua Stream) the zone **extends 100 m** inland from the toe of the seacliffs (0.6 m/yr × 100 + 40), based on an erosion rate of 0.6 m/yr (item 27, Appendix 2) at the site. Here, the marae land is low-lying behind the seaward hill. Once the hill is breached, the rate of erosion will increase. North of the marae the hazard zone widens to accommodate the coastal hinterland highly susceptible to landsliding. Here, the cliffs are eroding up to 0.9 m/yr (item 28, Appendix 2). The zone **extends up to 500 m** inland from the toe of the seacliffs to accommodate landsliding.

Figure 29 Coastal Hazard Photomap of Te Wharau Beach, based on aerial photograph: Survey 3298, photo 4426/46, 10 September 1971.

Te Wharau Beach (Figure 29)

The entire coastline shown on the map is accreting (items 33-36, Appendix 2), but the seacliffs of Early Tertiary rocks south of the Te Wharau Beach road have a number of active landslides. For this reason the hazard zone **extends 100 m** landward of the crown of the landslides along this coastal section. North of the beach access road the line is **approximately 50 m** inland from the vegetation line. Because of the massive volume of sediment stored in the lower Waiapu River channel (top of Figure 29), the trend of accretion is likely to continue in the future.

Figure 30 Coastal Hazard Photomap of Rangitukia Beach, based on aerial photograph: Survey 3298, photo 4425/43, 10 September 1971.

Rangitukia Beach (Figure 30)

The entire coastline shown on the map is accreting (items 37–39, Appendix 2). The mouths of the Waiapu River (bottom of Figure 30) and Waikaka Stream (about 1.5 km further north) are very unstable and tend to migrate northwards. Because of the lower channel storage in the Waiapu River and the strong net northerly drift, accretion is likely to continue in the future along Rangitukia Beach. Near the river and stream mouths the hazard zone **extends 100 m** inland from the vegetation line to accommodate mouth migration. For the rest of the coast the zone **extends 50 m** inland from the vegetation line to accommodate short-term movements.

Figure 31 Coastal Hazard Photomap of Te Araroa, based on aerial photograph: Survey 3298, photo 4420/30, 10 September 1971.

Te Araroa (Figure 31)

Although the entire coastline shown on the map has a history of accretion (items 46–49, Appendix 2), a significant reversal to erosion at 0.9 m/yr since 1951 has occurred near Te Araroa township (item 46, Appendix 2). With the strong net northerly drift, there is a possibility of the erosion adjacent to the Awatere river mouth (bottom right of Figure 31) extending northwards along the coast towards the Karakatuwhero River mouth (top left). Historically, the Awatere mouth has remained in a relatively stable position against the southern headland, but the Karakatuwhero mouth is very unstable and is likely to migrate about 1.5 km either north or south of its central position. The swampy areas shown on the top of the map are old river lagoons formed during south-easterly mouth offsets and are subject to flooding when the mouth is blocked. Because of the reversal to erosion since 1951 the hazard zone **extends 140 m** inland from the vegetation line (0.9 m/yr × 100 + 50 m), to accommodate both coastal erosion and flooding from the sea, increasing to **about 700 m** by the Karakatuwhero River to allow for flooding from the river.

Figure 32 Coastal Hazard Photomap of Kawakawa Bay, based on aerial photograph: Survey 3298, photo 4419/25, 10 September 1971.

Kawakawa Bay (Figure 32)

The entire coastline shown on the map is accreting (items 50–52, Appendix 2) and is unlikely to reverse in the future to erosion. The strong net northerly longshore drift transports sediment from both the Karakatuwhero and Awatere rivers and from sources south of Te Araroa into northern Kawakawa Bay. Figure 32 (bottom) shows a lagoon formed by the northward migration of the Karakatuwhero mouth and older lagoons formed by the same process, which are now swamps. When the river mouth is blocked, the low-lying swampy area is subject to flooding, hence the hazard zone **extends up to 270 m** inland around the swampy area. For the rest of the coast the zone **extends 50 m** inland from the vegetation line.

Onepoto Bay (Figure 33)

Flanked by stable rocky headlands, Onepoto Bay is accreting (item 53, Appendix 2) at about 0.5 m/yr (1915–1977). The road parallel to the beach, servicing the residential subdivision, ranges from 14 m to 72 m from the vegetation line and is closest to the beach by the streams. Although accreting, there is no foredune, so that the low-lying land adjacent to the beach is highly susceptible to flooding from the sea. Survey cross-sections and longitudinal sections on Waiapu County Council Plans No. 546/2–4 show that the average elevation of the subdivided land between the seaward road and the beach is 2.3–2.5 m above mean high water neap tides (MHWN) and only about 1 m above the level of the back of the beach.

Based on the seaward limit of land vegetation representing the normal limit of storm wave run-up, the Waiapu County cross-sections indicate a wave run-up level 1.0–1.3 m above MHWN. During the 19 July 1978 storm, run-up extended 30–40 m inland from the vegetation line, flooding the sections between the beach and the seaward road and overtopping the same road by the west and middle streams. The cross-sections indicate that wave run-up level during the July storm was 2.5 m above MHWN and was produced by deepwater waves up to 10.7 m high (see section on 'Sea conditions').

During severe onshore storms, maximum wave run-up levels are generated by the combined effect of differences in barometric pressure, high tide, wind set-up, wave set-up, and wave run-up. These factors are explained in Appendix 3. From a study of surf and run-up processes on steep (1:5–1:10) coarse-grained beaches in the South Island, Kirk (1975) found that wave run-up level was principally controlled by breaker height and in nearly all cases the level exceeded breaker height. As the beach in Onepoto Bay is fine-grained and of low gradient (1:80–1:140), run-up level is not likely to exceed breaker height.

Storms with a return period of approximately 30 years can produce 10–15 m high waves in the study area. Also, meteorological conditions associated with such storms are likely to generate significantly higher wave run-up levels in Onepoto Bay than those generated on 19 July 1978. Therefore, wave run-up levels exceeding 2.5 m can be expected. On this basis, a minimum wave run-up level of 3 m above MHWN is thought reasonable for Onepoto Bay and is, therefore, adopted for the calculation of the hazard zone width.

Run-up levels of 2.2–3.3 m above MHWN, estimated in Appendix 3 for 10–15 m high waves, reinforces the adoption of a *minimum* level of 3 m. It should be noted, however, that the authors of Appendix 3 conclude that: "the true value will be on the higher side of the 2.2–3.3 m range or slightly above 3.3 m".

Based on the 3 m level and Waiapu County Council Plans No. 546/2–4 the hazard zone **extends a maximum distance inland of 140 m** from the vegetation line. Flooding by the sea once every 30 years or so, and several times during the 100-year planning period adopted for the present study, is the major hazard to be expected within the hazard zone in Onepoto Bay.

Figure 33 Coastal Hazard Photomap of Onepoto Bay, based on aerial photograph: Survey 5134, photo C1/6, 4 October 1977.

Figure 34 Coastal Hazard Photomap of Hicks Bay, based on aerial photograph: Survey 3298, photo 4418/20, 10 September 1971.

Hicks Bay (Figure 34)

Although Hicks Bay has a history of accretion (items 54–57, Appendix 2), the Wharekahika River mouth is notoriously unstable, migrating from one side of the bay to the other in periods of a few years. This process destroyed a small residential subdivision at the north end of the bay in 1974. The strip of coastal land along the true right bank of the river is low-lying and highly susceptible to flooding once the mouth has a pronounced offset or is blocked. The hazard zone therefore, includes the land susceptible to flooding and to erosion from the migrating river mouth and **extends inland 280–440 m** from the wetted line on the active beach shown on Figure 34.

Onepoto Bay is south of the Wharekahika River mouth.

Coastal management

The provision of adequate hazard zones, and the preservation of the natural character of the coastal environment within them by careful management, is clearly the best way of protecting both the beaches and the nearby development in the Waiapu County. Every effort should be made to incorporate such provisions in the District Planning Scheme administered by the Waiapu County Council. To assist the planning process, some recommendations are made for the management of the coastal hazard zones shown on the Coastal Hazard Photomaps (Figures 21-34). Site specific technical advice should, in the first instance, be sought from the East Cape Catchment Board.

Urban development

Urban development should be strictly controlled within the hazard zones so that disastrous consequences are avoided. Should development proceed, then property owners must be fully informed of the risks involved. The design and construction of exposed seafront structures should be such that they can be relocated at extremely short notice, as severe storms around New Zealand can erode 10–40 m of coastline in periods of a few hours. Such movements leave little time for the disconnection from the threatened houses of essential services such as electricity and waste water disposal. On such occasions, rows of houses behind the seafront dwellings present physical barriers to relocation inland and may themselves have to be moved. Land must be set aside for the relocated dwellings which would create difficulties in an intensely subdivided area enclosed by steep hills like Onepoto Bay.

Coastal erosion works will, in time, be a necessary requirement to protect the assets at risk, should development be allowed to proceed within the coastal hazard zone. Such works are very costly and require constant maintenance. The only statutory authority for giving financial assistance towards the cost of such works lies in the Water and Soil Conservation Act 1967, administered by NWASCO. In considering its policy under this statutory provision, NWASCO has resolved that urban development initiated after 18 November 1971 is *not* eligible for grants towards protection works, or for the resettlement of persons affected by marine erosion or flooding. Further, the policy has been confirmed at every review since 1971 (Mr R.K. Howard, Assistant Director, Water and Soil Division, pers. comm. 1980).

Clearly, it is better for all concerned if no urban development is allowed to proceed within the coastal hazard zone. On today's building standards, a properly maintained dwelling can be expected to last at least 100 years. Hence, if placed within the zone, both the dwelling and the occupants will be at risk.

Dune management

Vegetated foredunes occur in many localities along the Waiapu coastline, and are an essential component of the hazard zones. They function by protecting the beach in front and the land behind, acting as a natural buffer against wave attack and a source of sand for the beach during periods of erosion. Dune vegetation traps wind-blown sand, aiding dune build-up and preventing sand transgressing inland where it is lost from the beach-dune system.

If development extends onto the foredune, its natural function is impeded, often resulting in loss of housing and a need for coastal protection. If a sea wall is constructed along the foredune, the dune's function is totally impeded as wave reflection off the wall generally prevents accretion of sand on the beach. Also, a wall totally blocks input of sand to the beach system during short-term erosion episodes, resulting in steady degradation of the beach (Gibb 1979b).

The beach itself is tolerant to intensive recreational usage, but the foredune is extremely fragile. Destruction of dune vegetation results from even moderately concentrated pedestrian usage, from grazing by stock, from vehicle access, or from the exposure of inappropriate species to salt spray and blowing sand (Beach Protection Authority 1979).

Destruction of dune vegetation results initially in the development of bare areas on the dune. Strong winds complete the destruction by producing blowouts, then transverse mobile dunes, and finally a completely unstable dune system moving inland. The mobile dunes cover anything in their path, resulting in serious property damage. *Loss of sand from the foredune by wind action accelerates the retreat of the shore line* (Beach Protection Authority 1979).

To prevent damage to dune vegetation, and to give the damaged areas a chance to recover, it may be necessary to fence off the damaged or sensitive parts of the dune system and provide fenced access tracks to the beach.

Erosion control works

For some localities the coastal hazard zone may be reduced in extent by the construction of erosion control works to combat the dominant hazard. The ideal solution is one that serves the dual purposes of property protection and preservation or re-establishment of the beach and dune. In New Zealand, like in Australia, it has been the common practice to direct expenditure toward works which will only provide protection to residential development rather than contributing toward beach restoration measures.

The construction of a suitably designed, well-vegetated foredune at Onepoto Bay for example, would preserve the recreational asset of the beach and reduce the flooding hazard. Similarly, at Tokomaru Bay the undermining of the sea wall from downcutting of the shore platform ramp could be reduced significantly by maintaining a depth of beach sand greater than 0.5 m at the base of the sea wall.

Landslide-prone lands

Urban development should be avoided on coastal lands with a high susceptibility to landsliding. For such lands, the removal of the lateral support of the land by coastal erosion will ensure that landsliding continues. Hence, land use should be restricted to pastoral farming or afforestation, though it should be emphasised that the forest may be at risk at any stage from landslides. In all cases, land management practices should take into account the erosion-prone nature of the land.

Sand and gravel extraction

Because of the protective function of the beach, foredune and/or primary beach ridge, sand and gravel extraction should be strictly controlled in these areas. Where the rate of extraction is equal to or exceeds the natural rate of supply of sediment to a beach system, then coastal erosion will occur. To avoid such consequences it is best to take sand and gravel from only those areas that are over-supplied. The Awatere and Waiapu river beds are such areas.

Public involvement

Proper management of the coastal hazard zones requires public involvement. Such activities as illegal sand and shingle extraction and damage to the protective dune vegetation by stock grazing and vehicles will always occur unless there is proper on-site surveillance. As 69% of the coastline is held in Maori tenure, the writer believes that the involvement of the local Maori committees is crucial. The desire by the Maori elders to be involved has been expressed on more than one occasion to the writer in Ruatoria.

Management recommendations

The following recommendations are based on the preceding discussion on coastal management:

1 ***Coastal hazard zones*** Should be incorporated into the District Planning Schemes throughout New Zealand to satisfy the provisions of the Second Schedule, clause 8a of the Town and Country Planning Act 1977.

2 ***Urban development*** Should be strictly controlled within the Coastal Hazard Zones in accordance with the provisions of Section 641 of the Local Government Amendment Act 1979.

3 ***Dune management*** Destruction of dune vegetation from concentrated pedestrian usage, from grazing by stock, and from vehicle access, should be prevented at all costs. For intensively used areas, fencing off damaged or sensitive parts of the dune system, and provision for walkways to the beach is recommended.

4 ***Erosion control works*** Should be designed in such a way that they serve the dual purpose of preservation or re-establishment of the beach and dune, and the protection of property. Coastal hazard zones should not be reduced in extent because of erosion control works unless such works are properly maintained annually.

5 ***For landslide-prone lands*** Land use should be restricted to pastoral farming or afforestation. Urban development should be avoided on such lands.

6 ***Sand and gravel extraction*** Should be strictly controlled from the beach, foredune and/or primary beach ridge.

7 ***Public involvement*** Should be encouraged with respect to on-site surveillance and the proper management of the coastal hazard zones. It is recommended that the local Maori committees and privte landowners be requested to help in the surveillance of zones through their local riding members.

8 ***Extent of the coastal hazard zones*** Should be reassessed at the time of each district scheme review (every five years), using the techniques outlined in this paper.

9 ***Monitoring priority areas*** Fluctuations in the position of the shore line should be monitored in priority areas, such as Te Araroa and Tokomaru Bay, once or twice yearly to provide an adequate data base for the five-yearly assessment of the extent of the coastal hazard zones.

Summary and conclusions

1 NATURAL GEOLOGIC HAZARDS

(a) Coastal erosion, flooding, and landsliding are natural geologic hazards identified and quantified along the Waiapu County coastline. Under the provisions of the Town and Country Planning Act 1977, such hazards can easily be provided for in regional and district planning schemes.

(b) The provision of adequate *coastal hazard zones* and the preservation of the natural character of the coastal environment within them by careful management, is clearly the best way of protecting both the beaches and the nearby development in the Waiapu County.

2 COASTAL EROSION

(a) Of the 147 km Waiapu County coastline about 47% is eroding, 33% is accreting, and 20% is 'static' (erosion rate less than 0.02 m/yr).

(b) Unconsolidated Holocene sand dunes and gravel beach ridges are *extremely susceptible* to coastal erosion, maximum retreat at 1.2 m/yr occurring in Anaura Bay.

(c) Extensively deformed Late Cretaceous–Early Tertiary sedimentary rocks are *highly susceptible* to coastal erosion, maximum backcutting of the seacliffs at 0.92 m/yr occurring in Reporua. Moderately deformed Late Tertiary sedimentary rocks are *moderately susceptible*, maximum backcutting at 0.34 m/yr occurring at Tuparoa.

(d) 'Static' shore lines are the very hard basic igneous rocks of the Matakaoa Volcanic Group to the north where seacliffs are backcutting at 8–25 mm/yr (0.01–0.03 m/yr).

(e) With respect to downcutting rates of 2.3–4.6 mm/yr (sedimentary rocks) and 0.4 mm/yr (volcanic rocks) on the shore platform plane, erosion rates are higher by *one order* of magnitude for platform ramps (maximum 70 mm/yr) and by *two orders* of magnitude for seacliffs (maximum 920 mm/yr).

(f) Deforestation in 1880–1930 of the catchments of the Waiapu, Awatere, Karakatuwhero and Tohoratea rivers and the Waitekaha Stream caused a massive increase in bedload output at the coast, resulting in rapid accretion at 0.77–6.03 m/yr along those coastlines dependent almost solely on the rivers as a sedimentary supply source. Afforestation in 1969–1976 may, in time, have the reverse effect.

(g) Although deforestation has had a devastating effect inland it has indirectly benefitted the coast through the gain of land by accretion.

3 COASTAL LANDSLIDES

(a) The extensively deformed and disrupted Late Cretaceous–Early Tertiary rocks are *extremely susceptible* to landsliding, whereas the moderately deformed Late Tertiary rocks are *highly susceptible,* especially along fault planes and where strata dip seaward. The Matakaoa Volcanics and Holocene coastal plain sediments have a *very low* landslide susceptibility.

(b) Landsliding of the coastal slopes will continue to be induced by coastal erosion removing the lateral support of the land, and by earthquake uplifts in the tectonically mobile Waiapu County.

(c) Oblique compression movements of 50–60 mm/yr of the Pacific Plate relative to the Indian Plate along the plate boundary beneath the Raukumara Peninsula will continue to cause rock deformation, fault movements, tectonic uplift, and gravity slides in the Waiapu County. Although remedial measures may be taken to reduce the amount of erosion on the land, the plate boundary movement will continue to promote deep seated instability of the rocks.

4 COASTAL FLOODING

(a) Although mean wave heights of 1.4 m and wave periods of 6.5 s prevail in the East Cape region, severe storms with a return period of approximately 30 years will generate 10–15 m high waves. Such storms will produce wave run-up levels in excess of 3 m above MHWN at Onepoto Bay and cause extensive flooding of low-lying lands and widespread coastal erosion.

(b) The 18–21 July 1978 storm produced maximum deep-water waves of 10.7 m off Hicks Bay, flooding the land 80 m and 40 m inland at Te Araroa and Onepoto Bay respectively.

(c) Offsetting of the Wharekahika River mouth in Hicks Bay and the Karakatuwhero River mouth in Kawakawa Bay during low flows will lead to flooding of low-lying areas by the coast. With an offset mouth the rivers are unable to discharge their volume effectively into the sea during peak flows, so that backing up of river water occurs, flooding adjacent low-lying land.

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APPENDIX 1

Waiapu County beach sediments and their supply sources

by JEREMY G. GIBB

INTRODUCTION

Descriptions of beach sediments and their supply sources for nine localities along the Waiapu County coastline, based on data presented in Tables 1, 2 and 3 in the main text, are given below:

Anaura Bay

The beach at Nuhiti Road is medium, well-sorted sand and that in Anaura Bay is fine, moderately-sorted sand (Table 1). The higher density of sand in the former may be due to higher percentages of andesine (S.G. 2.62–2.76 g/cm^3) and shell fragments (S.G. 2.72–2.84 g/cm^3). For both beaches, the nearshore seabed is inferred to be the predominant source on the basis of abundant shell fragments. The next most important source is considered to be the eroding sea-cliffs and shore platforms, followed by negligible amounts from longshore drift.

Tokomaru Bay

The beach at either end grades from fine, very well-sorted sand (Table 1), to coarse, moderately-sorted sand in the middle. The predominant source is thought to be the nearshore seabed as the sand contains abundant shell fragments and rare mudstone fragments. The volcanic-derived andesine may also be supplied from the seabed. The coarsening of the sand in the middle of the bay is due to an influx of mudstone fragments supplied by the Mangahauini River. Although Tokomaru Bay is flanked by eroding headlands and shore platforms, the lack of mudstone fragments and quartz in the sand suggests they supply negligible sand. Insignificant amounts are contributed by longshore drift from Anaura Bay to the south.

Waipiro Bay

The beach grades north to south from gravel to fine, well-sorted sand (Table 1), to gravel. In the north, the gravel is supplied by the Te Maire Stream and in the south by the Waikawa Stream (Figure 35). Both streams have gravel deltas at their mouths and must supply large quantities of material during peak flows. The net northerly drift has transported the Waikawa-derived gravels as far as Waipiro township, and the Te Maire-derived gravels northwards out of Waipiro Bay. For much of its length the beach is fine, well-sorted sand, dominated by shell fragments, mudstone fragments, and quartz (Table 2). The predominant source for both the gravel and the sand appears to be the two streams, followed by a significant contribution from the nearshore seabed and a lesser amount from the eroding sea-cliffs to the south. Negligible amounts are contributed by longshore drift from Tokomaru Bay to the south.

Figure 35 Oblique aerial view of a delta constructed from boulders at the mouth of the Waikawa Stream, southern Waipiro Bay. The stream supplies the beach with gravel and sand. [21 May 1979]

Figure 36 Oblique aerial view of the Whareponga River mouth. Although the river supplies gravel to the beach, the coastline is eroding. [21 May 1979]

Whareponga

The beach is gravel. Although no sediment samples were taken, the similarity of the beach gravels with those in the Whareponga River suggests the river is the predominant source followed by longshore drift and the nearshore seabed. Whareponga is shown in Figure 36.

Tuparoa

The beach is moderately-sorted, coarse sand (Table 1) composed mainly of sedimentary-derived mudstone fragments and subordinate quartz (Table 2). The bulk density of 2.66 g/cm^3 for both the Tuparoa and Reporua beach sands is the lowest for all the beaches sampled and may be due to the higher percentages of mudstone fragments and quartz (S.G. 2.65 g/cm^3). The predominant sources of supply are the Waitekaha Stream, Tohoratea River, and two unnamed streams about 1 km south of the river (Figure 37) that drain rapidly eroding catchments. Eroding headlands are considered the next most important source of material. Both longshore drift and the nearshore seabed are considered to supply negligible amounts of sediment.

Reporua

The beach which is backed by eroding seacliffs, is moderately-sorted, medium sand (Table 2). Massive landslides are common along the 7 km stretch of coast and they appear to be the predominant source of beach sediment (Table 3). The common constituents of the sand are sedimentary-derived mudstone fragments and quartz, followed by shell fragments from the nearshore seabed. The seabed is probably the next most important supply source followed by longshore drift from sources to the south of Tuparoa. The Reporua stream (Figure 38) and other smaller streams are sluggish and silty at the coast, supplying negligible quantities of sand.

Port Awanui to Waiapu River Mouth

The beach grades progressively southwards from Waiapu-derived gravel at the river mouth to sand at Port Awanui. Although no sediment samples were taken, the similarity of sediments on the beach with those in the Waiapu River suggests the river is the predominant source. Waiapu-derived sediments extend along the coast for 6.6 km south and about 28 km north of the mouth, suggesting that the net northerly drift of material is about 80% of the gross drift at this locality. Longshore drift of sand supplied by coastal landslides near Reporua to the south is probably the next most important source. Sediment supply from the nearshore seabed is probably negligible, though some material is supplied from seacliff erosion to the south.

Waiapu River Mouth to Te Araroa

The beach grades northwards from gravel at the Waiapu River mouth to fine, very-well sorted sand between Te Araroa and East Cape (Table 2). Distinctive, well-rounded, Early Cretaceous-derived spilite gravel tracers from the Waiapu River were observed along the beach as far as East Cape, about 11 km north of the mouth. The similarity of beach sediments with those of the Waiapu River suggests the river is the predominant source, further material being supplied to the beach by the Orutua River and the numerous streams like the Waipapa and Waipuhaki. A net northerly drift of Waiapu-derived sediment for about 28 km north of the mouth is apparent, based on a progressive northward decrease in grain size (Smith 1977) and the occurrence of the spilite tracers. Eroding headlands and shore platforms contribute some sand, but negligible amounts are thought to be supplied from longshore drift and from nearshore seabed.

Figure 37 Oblique aerial view of Tuparoa, showing two severely eroded Late Tertiary sandstone-siltstone stream catchments. Both streams supply the beach with gravel and sand. In 1910 the beach lay against the toe of the hills. [21 May 1979]

Figure 38 Oblique aerial view of Reporua, showing severe landsliding of seacliffs cut in the intensely deformed Early Tertiary sedimentary rocks. The Reporua Stream shown on the right transports mainly mud. The settlement is the Reporua Marae. [21 May 1979]

Te Araroa and Kawakawa Bay

The beach grades from coarse gravel at Te Araroa to fine, very well-sorted sand at the north end (Table 2). The steep, swiftly flowing Karakatuwhero and Awatere rivers enter the centre and south end of Kawakawa Bay respectively. Both have gravel beds that extend to the coast. The similarity of gravels on the beach with those in the rivers indicates both rivers are the predominant source. Distinctive igneous gravels in the Karakatuwhero River bed and calcareous sandstones and marls in the Awatere bed were observed along the beach. Their distribution alongshore, the continual net northward migration of the Karakatuwhero River mouth since 1951 (from air photographs), and the northward decrease in grain size of the beach sediments, are evidence of a net northerly drift, the next most important source of beach material (Table 3). Rare amounts of shell (Table 2) indicate negligible amounts of sediments are supplied from the nearshore seabed. Some sand is supplied from the downcutting of the southern sandstone shore platform, but negligible amounts are supplied from the northern headland of volcanic rock (Haupara Point).

Hicks Bay and Onepoto Bay

Both beaches are fine, very well-sorted sand (Table 1). The bulk density of 2.79 g/cm^3 is the highest of all the beaches sampled, and is due to a higher percentage of heavy minerals (magnetite S.G. 5.20 g/cm^3; ferromagnesian minerals 2.96–3.52 g/cm^3). Some of the volcanic-derived minerals may come from the Matakaoa Volcanics, but most are derived from the tephra beds via the Wharekahika River. The net northerly drift is inferred to be the predominant source on the basis of the fine, mean grain size of the sand (2.71ϕ), characteristic of the distal end of a drift system, and the relative size and tidal lower reaches of the Wharekahika River in relation to the volume of Holocene sand in Hicks Bay. The river is inferred to be the next most important source on the basis of large concentrations of well-rounded volcanic pebbles on the beach by the mouth. The erosion-resistant headlands of Matakaoa Volcanics and the lack of shell fragments in the sand indicate that these sources supply negligible amounts of sand.

APPENDIX 2

Rates of coastal erosion and accretion in the Waiapu County

by JEREMY G. GIBB

Rates of coastal erosion and accretion around the Waiapu County coastline tabulated for 57 localities, shown on Figure 12, are tabulated below.

COLUMN A: lists 57 items numbered consecutively.

COLUMN B: gives the locality names.

COLUMN C: lists the NZMS1 yard grid reference from the latest edition of topographic maps.

COLUMN D: lists the landforms, their age of formation and lithology, as determined from Kingma (1965), I.G. Speden (unpublished data), and Gibb (1979, table B1). H_3d = Holocene sand dune; H_3r = Holocene gravel beach ridge.

COLUMN E: gives the texture of beach sediment determined from visual observations and from mechanical analysis at each locality.
S = unconsolidated sand ($M_Z < 2.0$ mm); G = unconsolidated gravel ($M_Z > 2.0$ mm); S/G = sandy gravel.

COLUMN F: defines the reference shore line used for measurements at each locality.

COLUMN G: lists the survey years and also information on advance by landslides and downcutting rates of shore platforms.

COLUMN H: tabulates as a horizontal distance in metres, land gained from accretion (+) or lost from erosion (−) for each survey interval.
(Items 17, 29, and 30 record land gained by landslides; Item 41 records land gained from tectonic uplift plus accretion; Item 45 records downcutting rates of Late Tertiary sandstone shore platforms.)

COLUMN I: gives rates of erosion or accretion in metres per year (m/yr) for each survey interval.

COLUMN J: gives the net rate (m/yr) of erosion or accretion for the entire survey period between the first and last survey.

COLUMN K: lists the numbered data sources (numbers listed correspond with those in reference list at the end of the table and refer to published and unpublished sources of information plus original observations by the writer).

A	B	C	D	E	F	G	H	I	J	K
ITEM	LOCALITY	NZMS 1 GRID REF.	LITHOLOGY AND AGE	BEACH SEDIMENT	REFERENCE SHORELINE	SURVEY INTERVAL (years)	ACCRETION (+) OR EROSION (-) (metres)	RATE (m/yr)	NET RATE (m/yr)	DATA SOURCE
01	ANAURA BAY	N89/704866	H_3d	S	veg. line	1909-1928	-10	-0.53		2
						1928-1969	-34	-0.83	-0.73	2
02	ANAURA BAY	N89/698869	H_3d	S	veg. line	1909-1975	-43	-0.65	-0.65	6
03	ANAURA BAY	N89/697872	H_3d	S	veg. line	1909-1947	-47	-1.24	-1.24	2
04	ANAURA BAY	N89/692878	H_3d	S	veg. line	1909-1975	-19	-0.29	-0.29	6
05	ANAURA BAY	N89/691885	H_3d	S	veg. line	1909-1975	+10	0.15	0.15	6
06	ANAURA BAY	N89/692890	H_3d	S	veg. line	1909-1975	+20	0.31	0.31	6
07	NUHITI RD	N81/714914	H_3d	S	veg. line	1918-1969	+20	0.31	0.31	2
08	TOKOMARU BAY	N81/702996	H_3d	S	veg. line	1895-1975	+30	0.38	0.38	6
09	TOKOMARU BAY	N81/700004	H_3d	S	veg. line	1895-1975	+84	1.05	1.05	6
10	TOKOMARU BAY	N81/702012	H_3d	S	veg. line	1895-1975	+88	1.10	1.10	6
11	TOKOMARU BAY	N81/703018	H_3d	S	veg. line	1895-1975	+103	1.29	1.29	6
12	TOKOMARU BAY	N81/705024	H_3d	S	veg. line	1895-1975	+54	0.68	0.68	6
13	TOKOMARU BAY	N81/733040	Tt (M/ST)	G	cliff top	1945-1980	-1.6	-0.05	-0.05	7
14	TOKOMARU BAY	N81/734041	Tt (M/ST)	G	cliff top	1945-1980	-7.3	-0.21	-0.21	7
15	TOKOMARU BAY	N81/737040	Tt (M/ST)	G	cliff base	1916-1972	-6	-0.11	-0.11	2
16	TOKOMARU BAY	N81/738038	Tt (M/ST)	G	cliff base	1916-1972	-8	-0.14	-0.14	2
17	WAIPIRO BAY	N81/722142	Jkl (M/ST)	S/G	cliff base	1902-1972	+4	0.06	0.06	2
					Advance by landslide					
18	WAIPIRO BAY	N81/723146	H_3r	S/G	berm crest	1902-1972	+18	0.26	0.26	2
19	WAIPIRO BAY	N81/724147	H_3r	S/G	berm crest	1902-1972	+24	0.34	0.34	2
20	WAIPIRO BAY	N81/725150	Jkl (M/ST)	S	cliff base	1902-1972	-19	-0.27	-0.27	2
21	WHAREPONGA	N72/765209	H_3r	G	veg. line	1956-1962	+9.3	1.55		1
						1962-1971	-18.3	-2.03		1
						1971-1976	-9.4	-1.88	-0.92	1
22	TUPAROA	N72/778254	H_3r	S	veg. line	1922-1979	+15	0.26	0.26	2
					berm crest	1910-1975	+48	0.74	0.74	6
23	TUPAROA	N72/777263	H_3r	S	veg. line	1922-1956	+32	0.94		2
						1956-1962	+11.4	1.90		1
						1962-1971	+7.5	0.83		1
						1971-1976	+0.8	0.16	0.96	1
					berm crest	1910-1975	+92	1.42	1.42	6
24	TUPAROA	N72/781273	H_3r	S	veg. line	1910-1956	+31	0.67		2
						1956-1962	0	0.0		1
						1962-1971	+13.7	1.52		1
						1971-1976	+6.1	1.22	0.77	1
					berm crest	1928-1975	+90	1.91	1.91	6
25	TUPAROA	N72/785277	Sw (M/ST)		cliff base	1928-1975	-16	-0.34	-0.34	6
26	REPORUA	N72/796315	Mh (M/ST)	G	cliff base	1957-1971	-2.6	-0.19	-0.19	1
27	REPORUA	N72/795320	Mh (M/ST)	S	cliff base	1957-1971	-2.6	-0.19	-0.19	1
					berm crest	1928-1975	-28	-0.60	-0.60	6
28	REPORUA	N72/797324	Mh (M/ST)	S	cliff base	1887-1928	-48	-1.17		2
						1928-1957	-25	-0.86		2
						1957-1971	-4.6	-0.33	-0.92	1

A	B	C	D	E	F	G	H	I	J	K
29	REPORUA	N72/804337	Mh (M/ST)	S	cliff base Advance by landslide	1928-1975	+20	0.43	0.43	6
30	REPORUA	N72/806341	Mh (M/ST)	S	cliff base Advance by landslide	1928-1975	+22	0.47	0.47	6
31	REPORUA	N72/812345	Mh (M/ST)	S	cliff base	1899-1928	-12	-0.41		
						1928-1975	0	0.0	-0.16	6
32	PORT AWANUI	N72/837380	H_3d	S	veg. line	1915-1975	+36	0.60	0.60	6
33	TE WHARAU BEACH	N72/842394	H_3r	S/G	berm crest	1915-1975	+85	1.42	1.42	6
34	TE WHARAU BEACH	N72/853413	H_3r	G	veg. line	1939-1957	+58	3.22		1
						1957-1960	-5	-1.67		1
						1960-1971	+33	3.00		1
						1971-1976	+13	2.6	2.68	1
					berm crest	1915-1975	+130	2.17	2.17	6
35	TE WHARAU BEACH	N72/860420	H_3r	G	berm crest	1884-1915	+10	0.32		2
						1915-1960	+100	2.22	1.45	2
36	TE WHARAU BEACH	N72/867429	H_3r	G	berm crest	1884-1915	0	0.0		2
						1915-1960	+212	4.71	2.79	2
					berm crest	1915-1975	+140	2.33	2.33	6
37	RANGITUKIA BEACH	N72/877455	H_3r	G	berm crest	1894-1914	+120	6.0		2
						1914-1972	+186	3.21	3.92	2
					wet line	1939-1957	+174	9.67		1
						1957-1971	+70	5.0	7.63	1
					berm crest	1912-1975	+380	6.03	6.03	6
38	RANGITUKIA BEACH	N72/885455	H_3r	G	berm crest	1894-1914	-10	-0.5		2
						1914-1972	+225	3.88	2.76	2
					berm crest	1939-1957	+76	4.22		1
						1957-1971	+29	2.07	3.28	1
					berm crest	1912-1975	+236	3.75	3.75	6
39	RANGITUKIA BEACH	N72/899472	H_3r	S/G	berm crest	1912-1975	+108	1.71	1.71	6
40	HAUTAI BEACH	N63/925561	H_3d	S	veg. line	1912-1975	+22	0.35	0.35	6
41	HAUTAI BEACH	N63/913566	H_3d	S	veg. line	1912-1975	+25	0.40	0.40	6
			Advance by uplift plus accretion			130-1912	+260	0.15		3
42	HAUTAI BEACH	N63/899577	H_3d	S	veg. line	1912-1969	+30	0.53	0.15	2
					veg. line	1912-1975	+60	0.95	0.95	6
43	HAUTAI BEACH	N63/886590	H_3d	S	veg. line	1912-1975	+35	0.56	0.56	6
44	HAUTAI BEACH	N63/880602	H_3d	S	veg. line	1912-1975	+18	0.29	0.29	6
45	TE ARAROA	N63/780619	Sl-Tt	G	wharf piles	1913-1979	-0.15	2.27 mm/yr		3
			(M/ST)			1913-1979	-0.30	4.55 mm/yr		3
			Downcutting rate of shore platforms							
46	TE ARAROA	N63/767616	H_3r	G	veg. line	1910-1951	+52	1.27		5
						1951-1960	-17	-1.89		1
						1960-1971	0	0.0		1
						1971-1980	-9	-1.0	0.37	3
47	TE ARAROA	N63/767616 Te-Waha-o-Rerekohu	H_3r	G	veg. line	1910-1951	+100	2.44		5
						1951-1960	-23	-2.56		1
						1960-1971	+9	0.82		1
						1971-1980	-6	-0.78	1.14	3
					berm crest	1900-1975	+75	1.0	1.0	6
48	TE ARAROA	N63/754624	H_3r	G	veg. line	1951-1966	+12.9	0.86		1
						1966-1971	+1.8	0.36		1
						1971-1977	+5.7	0.95	0.78	1

A	B	C	D	E	F	G	H	I	J	K
49	TE ARAROA	N63/754624	H_3r Radiocarbon	G years	berm crest ($T_{1/2}$ - 5568y)	130-1280	+1030	0.90		3
						1280-1600	+152	0.48		4
						1600-1900	+93	0.31		4
						1900-1975	+75	1.0	0.73	6
50	TE ARAROA	N63/737637	H_3d	S	berm crest	1900-1975	+103	1.37	1.37	6
51	TE ARAROA	N63/728645	H_3d	S	veg. line	1951-1966	+33.1	2.21		1
						1966-1971	-15	-3.0		1
						1971-1977	+25	4.17	1.66	1
52	TE ARAROA	N63/726648	H_3d	S	berm crest	1900-1975	+65	0.87	0.87	6
53	ONEPOTO BAY	N63/705664	H_3d	S	wet line	1915-1965	+21	0.42	0.42	2
					veg. line	1951-1960	+3.5	0.39		1
						1960-1966	+14.8	2.45		1
						1966-1971	-4.0	-0.80		1
						1971-1977	+11.8	1.97	1.0	1
54	HICKS BAY	N63/702668	H_3d	S	drift line	1915-1975	+65	0.87	0.87	6
55	HICKS BAY	N62/697677	H_3d	S	wet line	1951-1960	-18	-2.0		1
						1960-1967	+29	4.14		1
						1967-1971	-7	-1.75		1
						1971-1976	+3	0.6		1
						1976-1977	+3	3.0	0.38	1
					drift line	1915-1975	+40	0.67	0.67	6
56	HICKS BAY	N62/697685	H_3d	S	drift line	1915-1975	+77	1.28	1.28	4
57	HICKS BAY	N62/699693	H_3d	S	drift line	1915-1975	+20	0.33	0.33	4

COLUMN (K)
LEGEND

1. AERIAL PHOTOGRAPHS - held by Department of Lands and Survey, Head Office, Private Bag, Wellington.

2. CADASTRAL PLANS - held by Department of Lands and Survey, District Office, PO Box 1149, Gisborne.

3. FIELD MEASUREMENTS - made by Dr J G Gibb, May 1979.

4. GARRICK, R A, 1979: NZ Journal of Geology and Geophysics 22 (1): 131-39.

5. HISTORIC PHOTOGRAPHS - held by Mr J Whangapirita, Ruatoria, and Mrs R N McConnell, Te Araroa.

6. MINISTRY OF WORKS AND DEVELOPMENT - Unpublished coastal survey data held by Mr R K Smith, and lodged in the Residency Office, PO Box 1142, Gisborne.

7. SURVEY PLANS - held by Waiapu County Council, PO Box 1, Te Puia Springs.

APPENDIX 3

Storm wave run-up levels at Onepoto Bay, East Coast, North Island, New Zealand

by R.B. Frisby *and* E. Goldberg

Water and Soil Division, Ministry of Works and Development, Wellington

Introduction

The study is a quantitative appraisal of the various factors that combine to determine the run-up level of storm waves on the beach at Onepoto Bay. Values used in the appraisal are based on wave and meteorological data from the July 1978 storm, and are compared with the observed run-up level at Onepoto Bay during the same event. An estimate is also made of wave run-up levels that could result from a more severe storm with a deep water 1% highest wave height ($H_{1\%}$) of 15 m and a significant wave height ($H_{1/3}$) of 10 m.

Storm wave run-up level components

For the calculation of storm wave run-up levels it is necessary to consider the following five components (see Figure 39):

(a) The predicted astronomical tide level (h_T)
(b) The barometric set-up ($h_{\triangle p}$)
(c) The wind set-up (h_w)
(d) The wave set-up (h_b)
(e) The wave run-up (h_z)

It should be noted that a storm surge results from the combined effect of barometric set-up and wind set-up (Silvester 1974).

(a) Predicted astronomical tide level

The predicted high water level is calculated using the method presented in the New Zealand Nautical Almanac and Tide Tables. The difference (h_T) between the mean high water neap (MHWN), the plan datum in the present study, and the predicted high water level, can then be found.

(b) Barometric set-up

Predicted tide levels in New Zealand are computed by assuming an average barometric pressure of 1014 mb over the region. A difference of 1 mb from the average can cause a difference in water level of 10 mm, a low barometric pressure tending to raise the sea level. The water level does not, however, adjust itself immediately to a change of pressure but responds to the average change in pressure over a considerable area.

(c) Wind set-up

Wind blowing over the sea surface induces a surface current in the water by the action of a shear stress on the water surface particles. When such a current reaches a barrier such as the coastline, water tends to pile up against the land creating a wind set-up. The magnitude of this increase in water level above that which would have occurred in the absence of wind depends primarily on the wind strength and duration, and the nature of the coast in both plan and profile.

Due to the lack of observed wind set-up data around East Cape, the calculation method in Silvester (1974) has been adopted here to quantify the expected set-up.

This method specifies that, where a storm zone has a fetch (F) in excess of the continental shelf width (L), only that portion across the relatively shallow zone is effective in producing set-up. This is likely to be the case in extratropical cyclones, such as those over New Zealand, where large areas of ocean experience winds of relatively uniform speed and direction. In the absence of detailed information on the wind field, a static wind field of uniform speed is assumed. This assumption may result in values which under-estimate the actual set-up for a moving wind field.

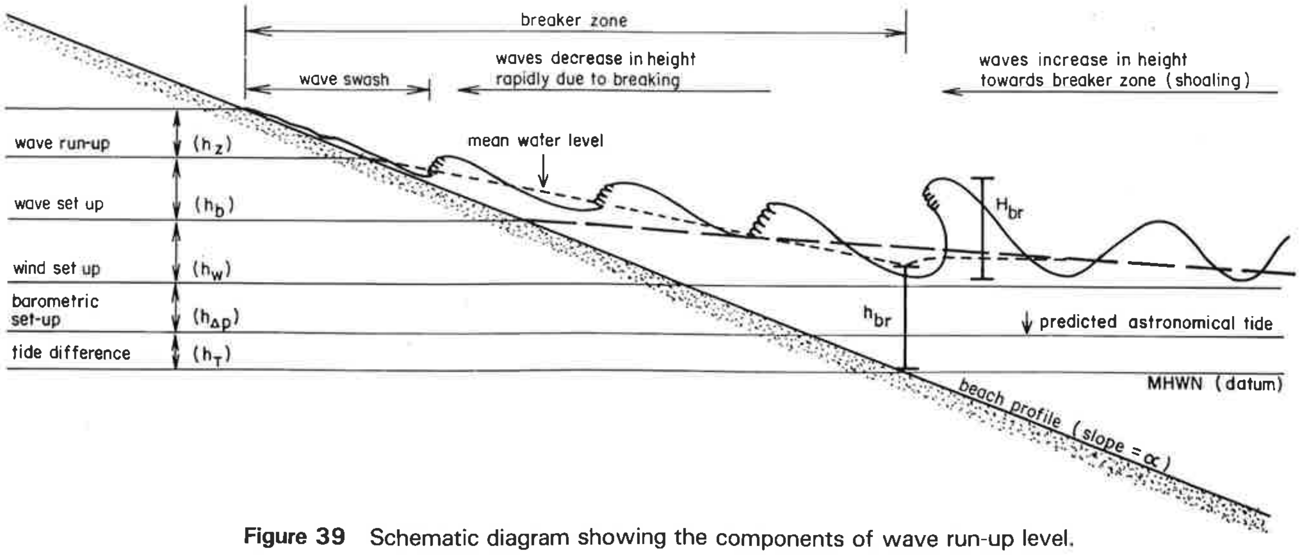

Figure 39 Schematic diagram showing the components of wave run-up level.

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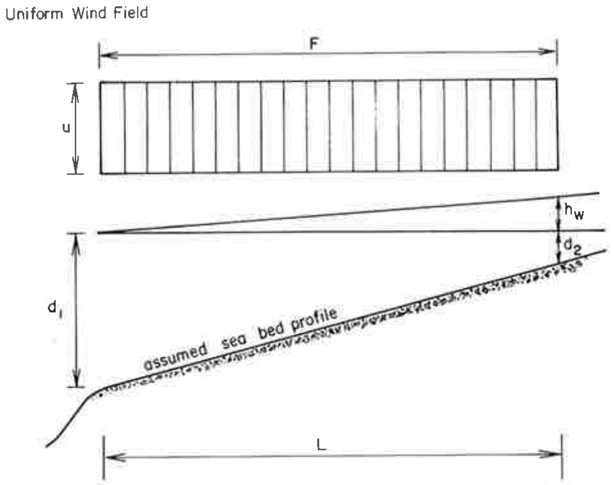

Figure 40 Diagram showing wind field parameters for the calculations of wind set-up at the coast. Adapted from Silvester (1974, figures 4–16).

For a wind field of steady and uniform speed, Silvester (1974, p. 184) gives the following formula for wind set-up (h_w) (see Figure 40):

$$\frac{h_w}{d_1} = \frac{k\ u^2\ L}{g\ d_1^2\ (1 - d_2/d_1)} \log_e \left[\frac{d_1}{d_2}\right] \qquad \ldots (1)$$

where k = a constant, which takes the value of 3×10^{-6} for oceans.
u = wind speed (m/s)
L = shelf width (m)
g = acceleration due to gravity (m/s²)
d_1 = depth at shelf edge (m)
d_2 = depth at shoreline (m)

(d) Wave set-up

As defined in the Shore Protection Manual (U.S. Army 1975), the set-up due to waves is " . . . that super-elevation of the mean water level caused by wave action alone". The amount of wave set-up is shown by Massie (1978) to be dependent on the type of breaker, the breaker height, and the breaker index as follows:

The wave set-up (h_b), for spilling breakers is:

$$h_b = \tfrac{5}{16}\,\gamma\,H_{br}$$

whereas for plunging breakers:

$$h_b = \tfrac{1}{8}\,\gamma\,H_{br}$$

where
H_{br} = height of wave at break point (m)
γ = breaker index, given by $\dfrac{H_{br}}{h_{br}}$
h_{br} = depth at break point (m)

The value of the breaker index is known to be dependent on the beach slope and hence the type of breakers. Swart (1974), defined a parameter (p) which ranges from 0 for spilling to 1.0 for plunging breakers. To determine the value of the breaker index, p is combined with the deep water wave characteristics and the beach slope to give the following equation:

$$\gamma = 0.33\,p + 0.46$$

Using an average value of 0.5 for p yields a value for $\gamma = 0.63$, which is consistent with the typical value of $\gamma = 0.6$ for gentle beach slopes ($m \cong 0.01$) such as that at Onepoto Bay. Hence, the wave set-up values fall in the range:

$$\tfrac{1}{8}\,\gamma\,H_{br} \leq h_b \leq \tfrac{5}{16}\,\gamma\,H_{br}$$

Substituting the value of $\gamma = 0.63$, we get:

$$0.1\,H_{br} \leq h_b \leq 0.2\,H_{br} \qquad \ldots (2)$$

(e) Wave run-up

The run-up level is defined as the maximum height above the mean water level reached by the wave swash on the beach. Using an empirical formula developed by Hunt (1959) for a smooth, impermeable constant slope beach we obtain the expression:

$$h_z = \sqrt{H_{br}\,L_0}\ \tan \propto \qquad \ldots (3)$$

where h_z = wave run-up (m)
H_{br} = breaker wave height (taken here as the 1% highest breaker height) (m)
L_0 = $1.56\,T_z^2$ = deep water wave length (m)
T_z = deep water wave period (s)
$\propto$ = beach slope

As determining the maximum wave run-up level is the object of this study, the 1% highest breaker height is taken here instead of the significant breaker height.

Calculation of storm wave run-up levels

Part I : 18–21 July 1978 Storm

For the July 1978 storm, Table 5 shows that a maximum significant wave height ($H_{1/3}$) of 7.06 m occurred on 19 July with a period (T_z) of 8.7 s. If a Rayleigh distribution of the wave heights is assumed, then the 1% highest wave height is given by: $H_{1\%} = 1.51\,H_{1/3}$. Hence, $H_{1\%} = 10.7$ m.

From the period (T_z) a deep water wave length of $L_0 = 1.56\,T_z^2 = 118$ m is calculated.

TABLE 5

Wave characteristics recorded by the Datawell Wave-rider Buoy in 65 m water depth off Hicks Bay, between 18–20 July 1978.

Time	Significant wave height $H_{1/3}$ (m)			Wave period T_z (s)	
(NZST)	*Tues 18*	*Wed 19*	*Thurs 20*	*Wed 19*	*Thurs 20*
0000		5.35	5.98	7.8	8.0
0300	1.91	5.69	5.48	7.6	9.0
0600		6.79	5.30	8.6	8.1
0900	1.32	7.06	5.52	8.7	7.6
1200		4.50	5.57	8.1	8.5
1500	2.54	5.08	4.66	9.5	8.2
1800		5.35	3.51	8.6	6.9
2100	3.47	6.11	3.98	8.6	7.7

(a) Tide level difference

The nearest secondary port to Onepoto Bay is Hicks Bay. For the secondary port the tide levels may be calculated from the nearest standard port, Auckland, as follows: The predicted high water spring tide at Auckland on 19 July 1978, was 3.3 m.

$$\text{Hicks Bay change} = \frac{2.2-2.0}{3.2-2.7} \times (3.3-3.2)$$
$$= 0.04 \text{ m}$$

High water at Hicks Bay $= 2.2 + 0.04$
$= 2.24$ m
Mean high water neap (MHWN) $= 2.0$ m
Hence, the tide level difference, $h_T = 0.24$ m

(b) Barometric set-up

The synoptic map for the July 1978 storm (see Figure 9, main text) indicates a barometric pressure over Onepoto Bay on 19 July of approximately 995 mb. Thus, the difference in barometric pressure $= 1014 - 995 = 19$ mb. Hence, the barometric set-up, $h_{\Delta p} = 0.01 \times 19 = 0.19$ m.

(c) Wind set-up

A bathymetric chart of the East Cape region (Cullen 1977) indicates an average sea bed profile over a distance of 11.5 km of 1:115 between the shoreline and the 100 m isobath.

With the offshore depth $d_1 = 100$ m, the shelf width $L = 11.5 \times 10^3$ m, and using the value of $\frac{d_1}{d_2} = 1000$ to approximate $d_2 = 0$ (Silvester 1974, p. 184), we find for a uniform wind field using formula (1):

$$\frac{h_w}{d_1} = \frac{(3 \times 10^{-6})(11.5 \times 10^3)\,u^2}{(9.81)(100^2)(1 - 1/1000)} \log_e(1000)$$
$$= 2.43 \times 10^{-6}\,(u^2)$$
$$h_w = 2.43 \times 10^{-4}\,(u^2) \text{ m}$$

Values of h_w are presented in Table 6 for various values of wind speed, u.

TABLE 6
Wind set-up (h_w) for various wind speeds (u)

Wind speed u (kn)	20	30	40	50	60	70	80
(m/s)	10	15	21	26	31	36	41
Wind set up h_w(m)	0.03	0.07	0.11	0.16	0.23	0.31	0.41

The mean easterly surface wind speed for the 18–21 July 1978 storm is given by Reid (1979) to be 60 kn over an extensive area east of Northland. The highest gust recorded at East Cape was 66 kn from an easterly direction, which can be equated to a mean wind speed of 45 kn (de Lisle 1975).

If we assume a surface wind speed range of 40 to 60 kn over the East Cape region, then from Table 6 the wind set-up ranges from 0.11 m to 0.23 m.

(d) Wave set-up

An iterative technique (Massie 1978) is used to determine the depth (h_{br}), and the height (H_{br}), at which a deep water wave with $H_{1/3} = 7.06$ m will break.

We find $h_{br} = 10.55$ m and $H_{br} = 6.66$ m. Thus, from (2), the wave set-up lies in the range:

$$0.67 \leq h_b \leq 1.33 \text{ m}$$

(e) Wave run-up

The beach slopes at the two surveyed cross-sections are 1:80 and 1:140, hence an average beach slope of 1:110 is used. Taking the 1% highest breaker:

$$H_{br} = 1.51 \times 6.66 = 10.06 \text{ m}$$

Then, from (3):

$$h_z = \sqrt{10.06 \times 118} \times \frac{1}{110}$$
$$= 0.32 \text{ m}$$

A summary of components (a) to (e) is presented in Table 7, from which the total storm wave run-up levels are calculated.

Part II : Design storm

The July 1978 storm had its centre to the east of Northland and the conditions at Onepoto Bay were, therefore, not as severe as if the storm had been centred near East Cape. In the following, the effect of a storm similar to that of July 1978, but with its centre near East Cape, is analysed. From meteorological data (Reid 1979) we find the following:

$$H_{1\%} = 15 \text{ m}, \; H_{1/3} = 9.9 \text{ m}, \; T_z = 9.5 \text{ s}$$

These conditions are combined with the highest predicted tide for 1980 to make up the "design" conditions.

(a) Predicted tide level difference

For the extreme case we shall consider the highest predicted tidal difference. From the 1980 tide tables the highest predicted high tide at Auckland is 3.6 m.

$$\text{Thus, Hicks Bay change} = \frac{0.2\,(3.6-3.2)}{0.5}$$
$$= 0.16 \text{ m}$$

Hence, high water at Hicks Bay $= 2.36$ m
Thus, tide difference, $h_T = 0.36$ m

(b) Barometric set-up

Taking the barometric pressure near the centre of the July 1978 storm of 979 mb, we get a barometric pressure difference of some 35 mb, giving

$$h_{\Delta p} = 0.01 \times 35$$
$$= 0.35 \text{ m}$$

(c) Wind set-up

If we assume a surface wind speed range of 50 to 70 kn then from Table 5 we can expect the wind set-up to lie in the range 0.16 m to 0.31 m.

(d) Wave set-up

Using the iterative technique, as per Part I(d), with $H_{1/3} = 9.9$ m, we find $h_{br} = 14.6$ m and $H_{br} = 9.2$ m. Thus, from (2), the wave set-up lies in the range:

$$0.92 \leq h_b \leq 1.84 \text{ m}$$

(e) Wave run-up

Taking the 1% highest breaker

$$H_{br} = 1.51 \times 9.2 = 13.9 \text{ m}$$

and the deep water wave length

$$L_0 = 1.56\,(9.5)^2$$
$$= 141 \text{ m}$$

Then, from (3)

$$h_z = \sqrt{13.9 \times 141} \; \frac{1}{110}$$
$$= 0.40 \text{ m}$$

A summary of components (a) to (e) is presented in Table 8, from which the total storm wave run-up levels are calculated.

TABLE 7:
Estimated wave run-up levels for the July 1978 storm, with wave characteristics of:
$H_{1\%} = 10.7$ m, $H_{1/3} = 7.06$ m, $T_z = 8.7$ s

Components of the run-up level	Lower limit wave set-up in metres $0.1\ H_{br} \leq h_b$		Upper limit wave set-up in metres $h_b \leq 0.2\ H_{br}$	
	(a) *Lower limit wind set-up*	(b) *Upper limit wind set-up*	(c) *Lower limit wind set-up*	(d) *Upper limit wind set-up*
Tide difference (h_T)	0.24		0.24	
Barometric set-up ($h_{\Delta p}$)	0.19		0.19	
Wind set-up (h_w)	0.11	– 0.23	0.11	– 0.23
Wave set-up (h_b)	0.67		1.33	
Wave run-up (h_z)	0.32		0.32	
Total run-up level	1.5	– 1.6m	2.2	– 2.3m

TABLE 8:
Estimated wave run-up levels for a "design" storm, with a return period of 30 years or less, having wave characteristics of:
$H_{1\%} = 15$ m, $H_{1/3} = 9.9$ m, $T_z = 9.5$ s

Components of the run-up level	Lower limit wave set-up in metres $0.1\ H_{br} \leq h_b$		Upper limit wave set-up in metres $h_b \leq 0.2\ H_{br}$	
	(a) *Lower limit wind set-up*	(b) *Upper limit wind set-up*	(c) *Lower limit wind set-up*	(d) *Upper limit wind set-up*
Tide difference (h_T)	0.36		0.36	
Barometric set-up ($h_{\Delta p}$)	0.35		0.35	
Wind set-up (h_w)	0.16	– 0.31	0.16	– 0.31
Wave set-up (h_b)	0.92		1.84	
Wave run-up (h_z)	0.4		0.4	
Total run-up level	2.2	– 2.3 m	3.1	– 3.3 m

Part III : Evaluation of wave run-up levels

On the basis of the definitions and assumptions given above, the calculated components of wave run-up are presented in Tables 7 and 8. Columns (a) and (b) of both tables relate to the lower limit of wave set-up, giving values for the lower limit (column (a)) and upper limit (column (b)) for wind set-up. By contrast, columns (c) and (d) relate to the upper limit of wave set-up, the columns giving values for the lower limit (column (c)) and upper limit (column (d)) for wind set-up. By adding together the component values in each column, a range for the prediction of a total wave run-up level is obtained.

Table 7 shows that the estimated wave run-up for the July 1978 storm ranges between 1.5 m and 2.3 m. As noted in the main text the observed value for this event was 2.5 m.

Before deciding whether the estimating procedure used here will give realistic results if extrapolated to a more severe storm, it is appropriate to recall some of the assumptions made in the calculations and consider how they affect the result:

1 To evaluate the wind set-up a static wind field has been assumed. Moving wind fields can produce a higher wind set-up. On the other hand, the position of Onepoto Bay near East Cape will allow piled-up water to escape around it, reducing the calculated value.

2 Regular waves have been assumed in the calculation of the wave set-up. In nature, wave trains are irregular and actual values for the wave set-up will oscillate around the mean value calculated.

3 For the wave run-up the phenomenon of wave grouping can be significant. This means that the run-up produced by any individual wave is dependent on the height of the preceding wave and on the time interval between them. In this way individual waves can reinforce or counteract each other in terms of the run-up they produce.

4 The run-up has been calculated for a smooth impermeable slope. A grassed surface would reduce the calculated value.

5 An average beach slope taken from two surveyed profiles was used in the calculation of the wave run-up. The actual run-up would have varied with the local slope within a range of plus or minus 0.1 m.

As we have seen, the maximum wave run-up level during a storm is produced by the very complex interaction of the wind, the sea and the bottom topography. Around the New Zealand coast, very few reliable observations have been made and calculation methods are only approximate. The upper limit of the calculated range is close to the observed value and the difference can be accounted for by the effects of some of the underlying assumptions.

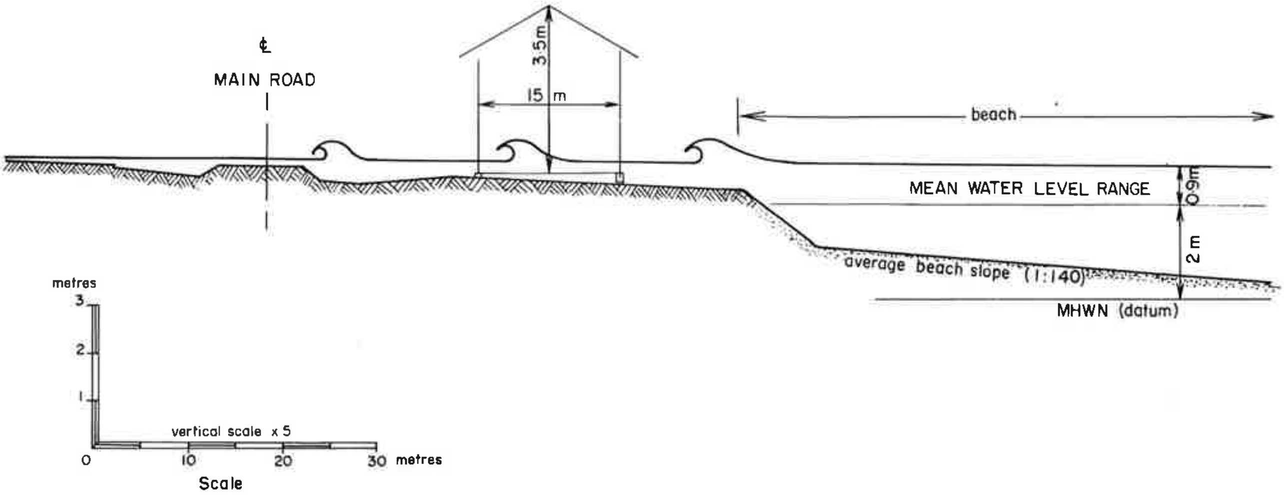

Figure 41 Diagram showing calculated mean water levels superimposed on cross-section B from Waiapu County Council Plan No. 546/3 of Onepoto Bay.

Having regard for the abovementioned qualifications, it seems justified to apply the above estimating procedure to a "design" storm with $H_{1/3}$ = 10 m which is expected to have a return period of 30 years or less (Reid 1979). This storm is combined with a high astronomical tide so that the recurrence interval of the combined event will be greater.

Table 8 shows that the estimated range of wave run-up levels is between 2.2 and 3.3 m. The July 1978 observation suggests the run-up levels will be on the higher side of the range or slightly above 3.3 m.

What this means in practical terms can be summed up as follows: During a storm, wave run-up will extend furthest inland for a period of 1–2 hours during high tide. During this period the mean water level (astronomical tide + barometric set-up + wind set-up + wave set-up), will be between 2.0 and 2.9 m above the MHWN level (Figure 41).

Figure 41 shows that at Onepoto Bay the area between the main road, parallel to the beach, and the vegetation line would be inundated up to a depth of 0.5 m (knee height) at the higher value of the mean water level. The height of the broken and reformed waves over this area would be of the same order as the depth of inundation, making a total depth of 1.0 m (i.e., wave crests could reach waist level). The waves would travel at a speed of about 2 m/s.

Conclusion

For a severe storm with deep water wave characteristics of $H_{1\%}$ = 15 m, $H_{1/3}$ = 9.9 m, and T_z = 9.5 s, a storm wave run-up level at Onepoto Bay has been calculated to lie in the range 2.2 to 3.3 m above the mean high water neap tide level. The observation of the actual storm wave run-up level at Onepoto Bay during the July 1978 storm suggests the true value will be on the higher side of this range or slightly above 3.3 m.

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Coastal hazard photomap of Te Araroa (see page 42). The front cover is a view of Te Araroa township.

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