

STACK

Motu River

*A description of its catchment, channel,
waters and sediments*



National Water and Soil
Conservation Authority

NIWA Library



J010952

ISSN 0110-4705

WATER & SOIL MISCELLANEOUS PUBLICATIONS

- | | |
|--|----------|
| 4. Synthetic detergents working party report. (\$1) | 1978 |
| 5. Water quality control committee report. (\$1) | 1978 |
| 8. Water rights for the Clyde Dam, Clutha hydro power development. (\$1.50) | 1979 |
| 12. Catchment register for New Zealand, Volume 1. (\$8) | 1981 |
| 13. New Zealand recreational river survey. Pt 1: Introduction. (\$5) | 1981 |
| 14. New Zealand recreational river survey. Pt 2: North Island rivers. (\$5) | 1981 |
| 15. New Zealand recreational river survey. Pt 3: South Island rivers. (\$12) | 1981 |
| 17. Hawke's Bay area planning study: Urban capability assessment. (\$4) | 1980 |
| 19. Rakaia water use and irrigation development. (\$3) | 1980 |
| 22. Baseline water quality of the Manawatu water region 1977-78. (\$3) | 1980 |
| 23. Effects of land use on water quality—a review. (\$5) | 1981 |
| 24. Summaries of water quality and mass transport for Lake Taupo catchment, New Zealand. (\$5) | 1981 |
| 25. The report of the water quality criteria working party. (\$3) | 1981 |
| 26. Handbook on mixing in rivers. (\$8) | 1981 |
| 28. Bibliography of oceanography and sedimentology for the Northland-Auckland coast. (\$3) | 1981 |
| 29. Aquatic oxygen seminar proceedings. Hamilton, November 1980. (\$10) | 1982 |
| 30. Future groundwater research and survey in New Zealand. (\$3) | 1982 |
| 31. Land and water resource surveys of New Zealand: map coverage and reference lists. (\$10) | 1982 |
| 32. A procedure for characterising river channels. (\$8) | 1982 |
| 33. The USEPA 1980 ambient water quality criteria: a compilation for use in New Zealand. (\$5) | 1982 |
| 36. New Zealand river temperature regimes. (\$8) | 1982 |
| 37. Landslip and flooding hazards in Eastbourne Borough—a guide for planning. (\$8) | 1982 |
| 38. Physical and chemical methods for water quality analysis. (\$5) | 1982 |
| 39. A guide to the common freshwater algae in New Zealand. (\$5) | 1982 |
| 40. Peatlands policy study; reports and recommendations. (\$5) | 1982 |
| 42. A draft for a national inventory of wild and scenic rivers: Part 1, nationally important rivers. (\$2) | 1982 |
| 43. A review of land potential in the Bay of Plenty—Volcanic Plateau region. (\$10) | 1982 |
| 44. An approach to stormwater management planning. (\$5) | 1982 |
| 45. Catchment management: an ESCAP seminar. Part 1—Introductory and country statements. (\$10) | 1982 |
| 46. Catchment management: an ESCAP seminar. Part 2—New Zealand contributions. (\$10) | 1982 |
| 48. Catchment control in New Zealand. (\$15) | 1982 |
| 49. River and estuary mixing workshop; Hamilton. (\$8) | 1983 |
| 50. Directory of activities at the Water and Soil Science Centres: 1983. (\$3) | 1983 |
| 51. Handbook on estimating dissolved oxygen depletion in polluted rivers. (\$8) | 1983 |
| 52. Remote sensing for soil conservation. (\$12) | 1983 |
| 53. Review of water and soil conservation research 1981. (\$8) | 1983 |
| 54. Biological methods for water quality surveys. (\$5) | 1983 |
| 56. Deepwater waves off Hicks Bay and the North-east Coast, North Island (\$5) | 1983 |
| 57. Regional flood estimation—a design procedure (\$3) | 1983 |
| 59. Shelter research needs in relation to primary production. (\$10) | 1984 |
| 60. Nutrient processing and biomass production in New Zealand estuaries. (\$5) | 1984 |
| 61. Commissioning and maintaining a water well in New Zealand. (\$3) | 1984 |
| 62. Plant materials and management options for soil conservation on the Port Hills, Chch. (\$4) | 1984 |
| 63. Design of water quality surveys. (\$8) | 1984 |
| 64. Hydrologists safety handbook. (\$8) | 1984 |
| 65. Directory of water quality and liquid and waterborne wastes research in New Zealand, 1983. (\$6) | 1984 |
| 66. Construction and operation of a sea sled for seabed surveying. (\$2) | 1984 |
| 68. A national inventory of wild and scenic rivers. (\$2) | 1984 |
| 69. Land treatment of wastes: Proceedings of seminar. Part 1. (\$8) | 1985 |
| 70. Land treatment of wastes: Proceedings of seminar. Part 2. (\$8) | 1985 |
| 71. Bibliography of hydrological and sedimentological studies in Manukau and Waitemata Harbours, Auckland. (\$3) | 1984 |
| 72. The New Zealand Land Resource Inventory rock type classification. Part I: North Island. (\$8) | 1985 |
| 73. The New Zealand Land Resource Inventory rock type classification. Part II: South Island. (\$8) | 1985 |
| 74. Land use capability classification of the Southern Hawke's Bay-Wairarapa Region. (\$10) | 1985 |
| 75. Correlation of North Island regional LUC units from the NZLRI. (\$6) | 1985 |
| 76. Ocean Outfall Handbook. (\$15) | 1985 |
| 77. Urban flood hazard. | in press |
| 78. Research requirements for the design and operation of community irrigation schemes. (\$4) | 1985 |
| 79. Green Island Borough Urban Land Use Capability Study | in press |
| 80. Inventory of NZ lakes. Part I North Island | in press |
| 81. Inventory of NZ lakes. Part II South Island | in press |
| 82. Seminar: Biological monitoring in freshwaters. | in press |
| 83. Seminar: Biological monitoring in freshwaters. | in press |
| 84. Review of water and soil conservation research 1982/83. (\$15) | 1985 |
| 85. The NZLRI erosion classification. | in press |
| 86. The law relating to watercourses. | in press |
| 87. A macroinvertebrate community index of water quality for stony streams. (\$8) | 1985 |
| 88. Index to hydrological recording sites in NZ 1985. (\$10) | 1985 |

**MOTU RIVER: A DESCRIPTION OF ITS
CATCHMENT, CHANNEL,
WATERS AND SEDIMENTS**





FRONTISPIECE One of the members of the October 1982 raft expedition was cartoonist Murray Ball. He has kindly given permission to use a selection of his drawings from the trip. These were first published in a variety of New Zealand and Australian newspapers.

**MOTU RIVER: A DESCRIPTION OF ITS
CATCHMENT, CHANNEL,
WATERS AND SEDIMENTS**

Edited by
R.H.S. McColl
Water and Soil Directorate
Ministry of Works and Development
Wellington

WELLINGTON 1986

Motu River: A Description of its Catchment, Channel, Waters and Sediments

Edited by R.H.S. McColl, Water and Soil Directorate,
Ministry of Works and Development, Wellington.
Water & Soil Miscellaneous Publication No. 92, 1986,
00 p., ISSN 0110-4705

This publication consists of five reports describing the Motu River and its catchment. Information is presented on: geology, soils, topography, erosion, vegetation, rainfall, water levels and flow, scenic quality of the river channel, the rapids, river navigability, water quality, river sediment yields and characteristics, and coastline and coastal sediment characteristics. The effects that development of the river and its catchment for various uses might have on land, water, sediment and recreational resources are discussed.

National Library of New Zealand
Cataloguing-in-Publication data

MOTU River : a description of its
catchment, channel, waters and
sediments / edited by R.H.S. McColl. -
Wellington, N.Z. : Water and Soil
Directorate, Ministry of Works and
Development for the National Water
and Soil Conservation Authority,
1986. - 1 v. - (Water & soil
miscellaneous publication,
ISSN 0110-4705 ; no. 92)
333.91620993116

1. Water resources development--
New Zealand--Motu River Watershed.
2. Motu River (N.Z.). I. McColl,
R. H. S., 1942- . II. New
Zealand. Water and Soil Directorate.
- III. National Water and Soil
Conservation Authority (N.Z.).
- IV. Series.

COVER Bullivants Cascade, Upper Gorge, Motu River.

J.C. Horne, photo

©Crown Copyright 1986

Published for the National Water and Soil Conservation Authority by the Water and Soil
Directorate, Ministry of Works and Development, P.O. Box 12-041, Wellington North,
New Zealand.

CONTENTS

	<i>Page</i>
Foreword	vii
Section 1: Description of the Motu River Catchment, by D.E.K. Miller ..	1
Introduction	1
Geology	1
Soils	3
Topography	3
Erosion Under Indigenous Forest	3
The Effect of Logging and Roothing on Erosion	9
Vegetation	9
Vegetation and Erosion Characteristics of the Motu River Channel	10
Erosion and Sediment Transport in the Motu River	11
The Effect of Landslips on the River Channel	12
The Effect of Different Use Options	12
Summary	12
Acknowledgements	13
References	13
Section 2: Motu River Hydrology, by J.M. Riddell and M.P. Mosley	15
Introduction	15
Rainfall	15
Water Level and Flow Data	15
Low Flows	18
Flood Flows	19
Flow Variability	20
Potential Effects of Man-Induced Changes	22
Summary	25
Acknowledgement	26
References	26
Section 3: Scenery and Recreation Along the Motu River, by M.P. Mosley ..	27
Introduction	27
General Description of River	27
The Scenic Quality of the Motu River	31
Rapids of the Motu River	32
Navigability of the Motu River	32
Impact of Water Resource Development on the Motu River	36
Summary	39
References	40
Section 4: Water Quality of the Motu River and its Tributaries, by D.G. Smith and G.B. McBride	41
Introduction	41
Sampling and Analysis	41
Description of Water Quality	42
Effects of Development	45
Summary	48
Acknowledgements	48
References	48

	<i>Page</i>
Section 5: Motu River Sediments: A Source of Eastern Bay of Plenty Beach Material, by R.K. Smith	51
Introduction	51
River Sediment Yields and Characteristics	51
Coastline Changes and Sediment Characteristics	53
Discussion	55
Implications of Development	56
Summary	57
References	57

FOREWORD

This report documents information collected during hydro-electric power development investigations and during investigations leading up to the Motu River water conservation order hearings. The report describes water, soil and sediment characteristics of the river and its catchment and some of the recreational and scenic qualities of the river. The granting of a national water conservation order has for the time being removed the possibility of any development of the water resource of the Motu River. However, the order does not permanently foreclose the development option. The possible effects on the river and the coastline of previous development proposals are examined in this report.

SECTION 1: DESCRIPTION OF THE MOTU RIVER CATCHMENT

D.E.K. Miller,
Land Stability Group,
Water and Soil Directorate,
Ministry of Works and Development, Gisborne

INTRODUCTION

This section summarises existing knowledge on the geology, soils, erosion and vegetation of the Motu River catchment with special reference to the area north of Motu township. It attempts to relate those aspects to landscape, water quality and river channel characteristics, and considers their relationships to river uses and possible river developments. To supplement available information the river was traversed by raft in October 1982, aerial photographs from a number of dates were examined, and colour oblique photographs were taken from a fixed wing aircraft immediately after the October 1982 raft traverse. The locations of features referred to in this section are marked on Fig. 1.1.

GEOLOGY

Detailed geological mapping has been carried out on only the upper part of the catchment down to a point about 3 km below the Motu Falls. A study by Ongley and MacPherson (1928) provides some information on the east side of the river down to the Mangaotane Stream.

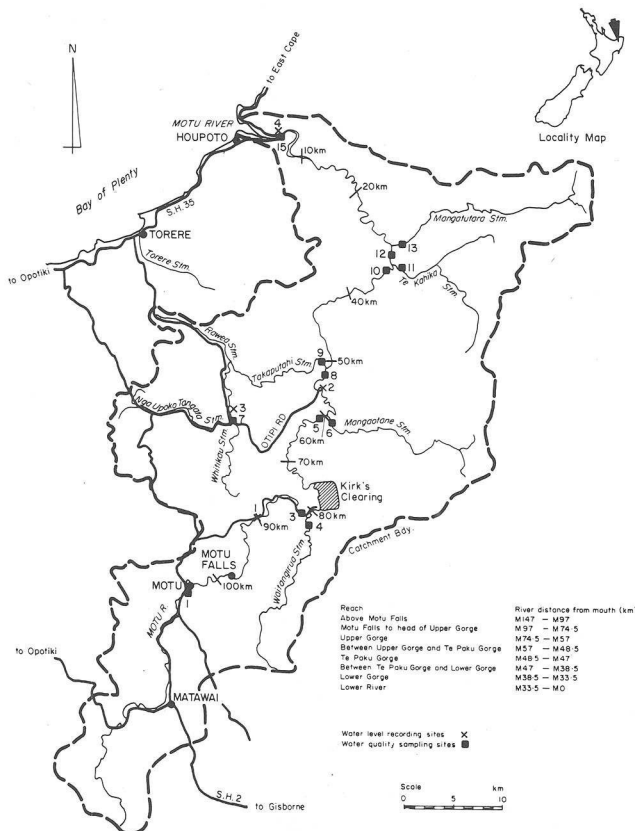


Fig 1.1 Motu River catchment map showing river distances (km), water quality sampling sites, and water level recording sites.

Two raft traverses (1959, 1960) provided reconnaissance knowledge of the remainder of the river and detailed investigations have been carried out at proposed dam locations. The lower part of the catchment below approximately Otipi Road end (M56) and to the west is underlain by greywackes of the upper Jurassic-lower Cretaceous age. They are highly deformed and dip steeply at angles near to vertical. Being well indurated they have high strength, except in crush zones. The rocks of the southern and eastern upper catchment are of younger Cretaceous period, dominantly Clarence series moderately hard sandstones and softer mudstones. These dip steeply and are moderately weathered. Remnants of river terraces consisting of coarse gravels and boulders exist in the main valley and major tributaries. High rates of river downcutting in response to tectonic uplift are indicated by the generally incised nature of the Motu River and the presence of almost vertically-sided gorges (O'Loughlin 1982).

Faulting

The evidence on faults is summarised in Fig. 1.2. This has come from observations during the 1959 raft traverse (Fyfe 1959), field evidence in Kingma (1965), remote sensing (DSIR 1978), and 1977-78 1: 50 000 aerial photographs.

Lineation 1 and 3, Fig. 1.2, appear as crush zones in the river channel and may be the cause of deep-seated earth movements (Plate 1b). In the greywacke area the river has "adjusted to structure" and eroded chiefly along weak zones (Fyfe 1959).

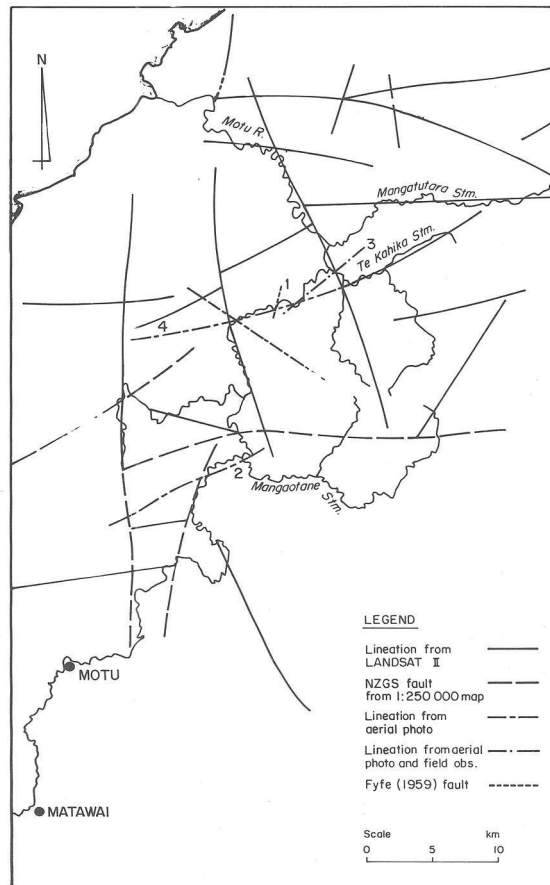


Fig 1.2 Faults and lineations that have been observed in the Motu catchment.

Seismic Activity

There are no well substantiated reports of recent seismic activity in the area.

SOILS

These are described by O'Loughlin (1982) as being steepland skeletal variates of the Raukumara yellow brown pumice soils. They have a high tephra content and on the steeper slopes are very shallow, stony and friable. On lower and mid slopes the soils are underlain by coarse colluvium or talus materials but on steeper slopes a thin organic soil mantle is generally perched directly on bedrock. He considered the most important features of the soils, from the viewpoint of stability, to be their high permeability, shallowness (the soils and colluvial parent material are usually less than 2 m deep and often less than 1 m deep), and the dense network of tree roots which permeates most of the soil mantle down to about 1 m.

TOPOGRAPHY

This is steep and rugged. The mean of 63 measurements of basal and mid slope regions in the middle Motu catchment was $41^\circ \pm 19^\circ$ (standard error). The highest peak, in the headwaters of the Mangaotane Stream, is 1455 m asl. Above 1000 m the peaks are very steep and rugged. "The topographical features reflect a youthful dynamic landscape actively eroding and regrading in response to continuing uplift." (O'Loughlin 1982).

EROSION UNDER INDIGENOUS FOREST

Erosion Forms

O'Loughlin (1982) indicates that the common erosion forms are shallow debris slides, debris avalanches, combination debris slide-avalanches, and rockfalls. Less common are deep-seated rock avalanches, debris flows, debris falls and rock slides.

Most shallow debris slides and debris avalanches originate on forested hill slopes steeper than 30° and usually involve soil and underlying parent materials down to 1.5 m. Rockfalls are confined to near-vertical bedrock bluffs and gorge walls, the largest occurring along the narrow inner gorge walls of the Motu River itself. Debris flows occur in streambeds as the result of debris avalanches in the headwater slopes above.

Distribution and Density of Erosion Scars

Using the 1977-78 1: 50 000 aerial photographs a map of erosion scar density has been prepared (Fig. 1.3). Three densities of scarring are mapped for vegetated areas, with a fourth category for erosion arising from logging and hydro investigation access roads.

In the Mangatutara area in 1971 there were 9.8 to 14.4 scars/km², a high density compared to other intact forest covered steep land in New Zealand (O'Loughlin and Pearce 1976).

The same (1971) aerial photographs used by O'Loughlin (1982) to determine these densities and also 1981 aerial photographs of the same area were analysed with line transects (approximating 125 m spacings) to estimate the area of land affected by erosion scars (Table 1.1). The results show that erosion scars increased markedly between 1971 and 1981.

A further area covered by SN 5975/G24 and 25 (1981) and located south of the Te Kahika Stream in the very severe erosion zone was also analysed, showing that 4% of the ground surface was apparently bare scar.

Factors Affecting Erosion Distribution

(a) Altitude

There is a strong relationship between altitude and scar density. O'Loughlin's (1982) study of 300 landslides around Mangatutara Stream indicate higher frequencies of failure on the mid and upper slopes than the lower slopes. However, four small areas of very severe scarring occur in the stream gorges which are affected by tectonic uplift and river downcutting.



1a. Very steep slopes at over 1000 m altitude in the eastern part of the Motu River catchment showing debris slide scars and some recent wind damage.



1b. A large deep-seated rock slide in a crush zone on the Te Kahika Stream (Plate 2). This rock slide probably occurred during a storm in late 1978.



1c. The small heap of shingle on the large rock appears to be part of the deposit on the right hand bank. The vegetation on that deposit is only 2-3 years old which implies that shingle deposits 3-4 years ago were 3.5-4.0 m above the current bed of the Te Kahika Stream. The source of the shingle may have been the deep-seated movements visible in Plate 1b.

The high altitude scars appear to be shallow debris slides, debris avalanches, debris slide-avalanches in the streambeds, and debris flows (Plate 1a). Studies by O’Loughlin and Pearce (1976) and O’Loughlin *et al.* (1982) have shown that shallow debris slides and avalanches on forested hill slopes are usually triggered by heavy rainfall, particularly when rainfall exceeds 100 mm in 24 hours.

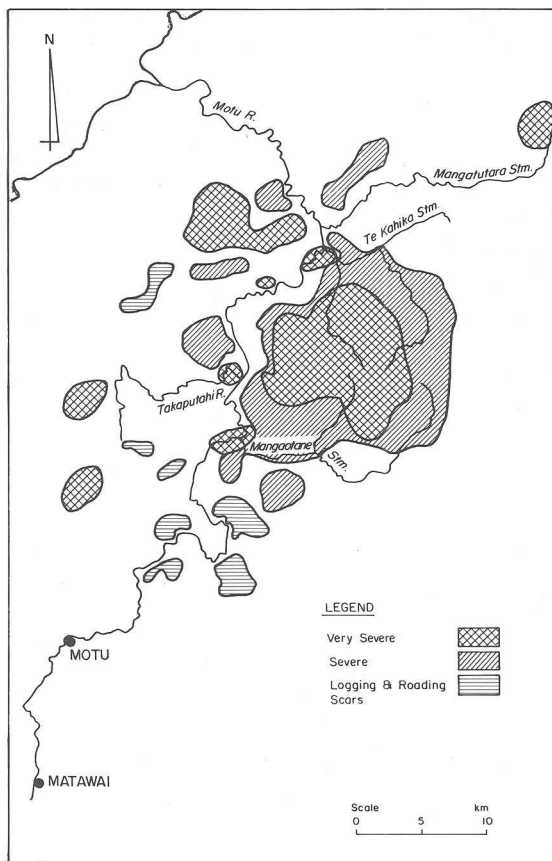


Fig 1.3 Map of erosion distribution, erosion scar density and areas affected by logging and roading scars for the Motu catchment derived from 1977–78 1: 50 000 aerial photographs. The areas of the catchment not hatched have moderate erosion.

Table 1.1 Comparison of 1971 and 1981 erosion scar densities in Mangatutara/Te Kahika region of the Motu catchment

Aerial photograph number	4431/17 (1971)	4432/34 and 35 (1971)
Scar count (from O’Loughlin 1982)	9.8 scars/km ²	14.4 scars/km ²
Area affected by erosion scars in 1971	0.7%	1.5%
Aerial photograph number	5975/E12 and 13 (1981)	5975/F23 (1981)
Area affected by erosion scars in 1981	3.1%	3.6%

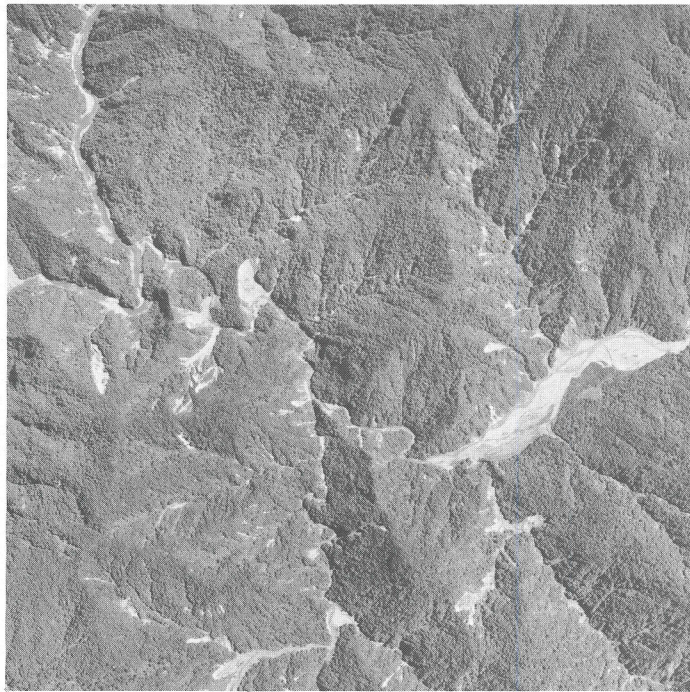
(b) Rock Type

Erosion scars on the upper Cretaceous moderately hard sandstones and softer mudstones tend to be at the base of slopes, indicating streambed downcutting (eg, in northern tributaries of the Mangaotane Stream and the Upper Gorge). Cretaceous mudstones exposed by landslide break down on drying and particles dislodge in heavy rain. Headward extension of the scar can occur under heavy rainfall with debris slides sweeping off established vegetation.

On the harder greywacke rock of the lower catchment, landslides occur more frequently in the mid and upper slopes. Greywacke exposed by downcutting and undercutting in the



2a. Section of aerial photograph 4432/36 in the Te Kahika region, 1971. Only a limited amount of active erosion is visible.



2b. The same area in 1981 (aerial photograph SN 5975/F24). An increased amount of erosion is evident.

Lower Gorge is often steep in profile and does not weather as rapidly as do the upper Cretaceous mudstones and sandstones.

(c) Faulting

The effect of faulting on erosion was reported by O'Loughlin (1982) and was apparent during the October 1982 raft traverse. The larger, deep-seated bedrock avalanches and slump movements generally appear to be associated with fault crush zones (Plate 1b). A large movement immediately downstream from the Ministry of Works and Development M56 investigation camp is on the fault shown on the 1: 250 000 geological map. The various ages of vegetation surrounding this movement indicate a history of instability in this area.

(d) Slope Aspect

Over much of the catchment the slopes most affected by landsliding face north and to a lesser degree, east. In the Mangatutara and Kirk's Clearing areas studied by O'Loughlin (1982) 90% of all landslides faced north or east. This may be due to either the direction from which heavy rain events usually come or, as suggested by Grant (1963), that the vigour of the forest in the Huirau Range and other North Island ranges has been affected by severe droughts since about 1700 AD. Droughts would affect northern slopes to a greater degree.

Erosion Cycles

Aerial photographs dating back to 1945 show a distinct change in erosion status with time. There appear to be cycles of landslide activity with much more now than in 1945.

(a) Upper Gorge Area

Aerial photograph 1122/19 taken in 1945 shows only a small number of raw erosion scars. There are, however, large areas of seral vegetation of at least two distinct ages. This implies that there was severe erosion in this area, prior to the photograph being taken. Grant (1981) has presented evidence for five periods of major erosion since the 13th century. The fourth of these periods closed in approximately 1900. The revegetated scars shown may have resulted from this erosion period.

The next photograph available for this area (3058/7) was taken in 1960 and shows a marked increase in the numbers of scars visible. Most of these are reactivations of the old, revegetated landslides seen in the 1945 photograph, but at least one scar is in more mature vegetation. More recent photographs show little change in the number of scars with slight enlargement of some scars and revegetation of others.

(b) Lower Gorge—Te Kahika Stream

In this area the onset of the current erosion did not occur until after 1962 and from then until 1971 (aerial photograph 4432/36, Plate 2a) there was only a moderate increase in erosion scars. The large gravel flats which are a feature of the Te Kahika Stream were in existence before 1953 and at that time were well vegetated.

There were many revegetated slip scars in the subcatchment. These probably date back to the early part of the century and have a similar erosion history to that of the upper gorge area.

In the period from 1971 to 1981, the greatest increase in instability has been in the Te Kahika valley, particularly during the four years from November 1977 to December 1981 (aerial photograph SN 5975/F24, Plate 2b). A major flood peak was recorded at Houpoto in late 1978 (2900 m³/s) and it seems likely that the associated storm event was responsible for the damage evident between 1977 and 1981. The Mangatutara area studied by O'Loughlin (1982) shows a marked increase in percentage area eroded from between 0.7% to 1.5% in 1971 to approximately 3.3% in 1981 (Table 1.1).

Analysis of sequential aerial photographs from other parts of the catchment yields a similar history of erosion, with the general trend being toward increased instability. This is consistent with Grant's (1981) observations on erosion periods, the fifth erosion period, termed the "Waipawa" erosion period, commenced in the late 1940s and still persists with no sign of abating (Mr P.J. Grant, Ministry of Works and Development, pers. comm.).



3a. A typical view of the Motu River between Kirk's Clearing and the Upper Gorge. The vegetation is in good condition.



3b. The understorey vegetation is adversely affected where there is a high population of goats on the west bank of the river.



3c. High quality vegetation on the east bank where there are virtually no goats. The understorey vegetation is intact.

THE EFFECT OF LOGGING AND ROADING ON EROSION

Roading has been carried out in three locations. The largest area, between Waitangirua Station and the area around Kirk's Clearing, was roaded to allow logging of rimu and tawa and some hydro investigations. Otipi and Puketoetoe Roads were constructed for hydro investigation work and large scars now exist where steep slopes were crossed.

O'Loughlin (1982) investigated the short-term effects of logging and roading in the Kirk's Clearing area where road construction on 30°–40° slopes has led to large increases in landsliding. Sidecast material may have caused debris avalanching below the roads and cut slope collapses were also common above roads. Cut slope failures that are initially small can extend upslope by retrogressive failure. Of the logged areas on slopes averaging 43°, north of Kirk's Clearing, 18% were affected by tracking and its associated slope failures. The volume of failed debris so generated was 7860 m³/km of track length. This is 15 to 20 times the rate on similar adjacent forested land. He comments that future roading and tracking could pose a serious threat to short-term stability and the aesthetic appearance of forested slopes. He found no evidence of instability caused by selective logging alone in this area but reports that, based on his work in North Westland, clearfelling of slopes over 30°–35° would substantially increase landslide densities.

VEGETATION

Vegetation Type

This has been described by Nichols (1971) and Jane (1979).

Four forest classes are recognised:

- Tawa forest on good soils at low altitude.
- Hard beech forests on poor soils at low altitude.
- Coastal forests.
- Red and silver beech forests at high altitude.

Kamahi, rimu, tanekaha, miro, Hall's totara and tawari occur throughout the forests except at higher altitudes where the forest is almost pure beech. The vegetation provides a forest landscape of good quality over large areas of the Motu River catchment.

Role of Vegetation on Slope Stability

O'Loughlin (1982) emphasised the importance of forests on the stability of slopes, particularly the role of the tree roots in reinforcing the regolith mantle. The soil moisture control function of the tree by interception and transpiration is also recognised.

Animal Control

The Raukumara State Forest Park draft management plan (NZFS 1982) places some emphasis on the need for animal control in the park, through which the Motu flows for a considerable part of its length. The noxious animal population appears to be having a significant effect on the forest by removing undergrowth (by goat browsing), by causing the death of some canopy trees (by possum browsing), and by preventing regeneration on slip scars. As a consequence, erosion rates appear to have increased significantly in recent years, and will probably continue to increase unless slips are revegetated. Goat browsing has eliminated a considerable amount of understorey on the west bank of the Motu River north of its confluence with the Takaputahi Stream.

The number of relatively small scars to the west of the river (see Plate 2) appears to be increasing and, while no evidence has been found of goats actually causing landslides in the Motu catchment, it is highly likely that progressively larger numbers of natural scars are remaining in a poorly vegetated condition.

Windthrow

The storm which struck the Motu catchment during the Easter weekend 1982 was accompanied by very strong southerly winds. Extremely severe windthrow of mature forest trees occurred on the southern faces, particularly at medium altitude. The areal extent of the damage to the forest has not been accurately determined but there is widespread damage on the lower east side of the catchment—an area that in recent times has been little affected by landsliding. The north and east facing slopes have been largely unaffected. Widespread damage is also present on the west side of the catchment.

The effect of the windthrow on future erosion patterns is open to speculation. O'Loughlin *et al.* (1982) report that in North Westland, even under intact forest, soils on slopes steeper than 30° are only marginally stable when saturated. Closer examination of windthrow areas shows considerable disruption of the regolith with roots being wrenched from the ground and debris slides already initiated. The depression left by the uprooted trees will tend to increase infiltration and thus lead to decreased stability.

Because some roots may still provide reinforcement of the ground, the full effect of the windthrow may not be seen until these severed roots rot in the period 1985–8. It is clear that the rapid revegetation of these areas before further landsliding and soil loss occur is critical and this can only take place if browsing animals are controlled. Even if revegetation is allowed to take place it is considered likely that future storm events will cause an increase in the degree of landsliding in the windthrow affected areas with a consequent increase in sediment supply.

The slopes immediately adjacent to the river have been affected by windthrow only in isolated locations covering small areas and are often associated with existing landslides.

VEGETATION AND EROSION CHARACTERISTICS OF THE MOTU RIVER CHANNEL

For the recreational user the qualities of the river channel are of great importance. This section describes the vegetation and erosion damage visible from the river, proceeding downstream from Motu Falls.

Tawa forest is the dominant vegetation from Motu Falls to Houpoto Bridge. Damage to the understorey from grazing animals is evident in many parts. The areas of severe erosion described in the earlier part of this section are not usually visible from the river because of screening by riparian vegetation, the limited vistas in the river channel, and perspectives which tend to foreshorten erosion scars when viewed from the valley bottom.

Motu Falls to Head of Upper Gorge (M98-M74.5) [numbers are river distances from the mouth, in km]

A short section (5 km) of pasture lies immediately downstream of the falls but this is largely obscured from the river user by a remnant strip of native vegetation along the riverbank. From here to Kirk's Clearing, 20 km downstream from the falls, the forest has been modified by selective logging for rimu and tawa. Riparian vegetation masks erosion damage which the aerial photographs show to be severe in this area.

Landslides from logging road construction are evident in locations where the road closely parallels the river, but the road itself is not often visible and it may be difficult for the river user to determine the cause of any roading scars.

Kirk's Clearing, once pasture, is now regenerating. The riparian vegetation that exists along much of Kirk's Clearing obscures most of the roading scars. Very few signs of logging are visible on the west bank.

Between Kirk's Clearing and the head of the Upper Gorge the riparian vegetation is described by Jane (1979) as being tawa forest in good health with good understorey vegetation, but with some possum damage to kamahi (Plate 3a). The landscape quality of this section is high.

Upper Gorge (M74.5-M57) and Lower Gorge (M48.5-M47, M38.5-M33.5)

While the vegetation quality of these sections is good and the landscape qualities are high, the gorges tend to have active erosion and show considerable scarring when viewed from the air. These scars do not have the same visual impact viewed from the river. Many scars on slopes above the river are visible only as a narrow chute and small debris fan on the riverbank. Signs of the Easter 1982 windthrow are visible on a few slopes close to the river but these do not detract significantly from the appearance of the landscape. The river user will often be more aware of navigational problems than erosion scars. In areas where the rapid river flows cause bank erosion, such as an outer bend, the rafter will be fully occupied in preventing the force of water pinning the raft against the rock face. A further characteristic that tends to camouflage erosion scars in the narrow gorges is the flood line at around 5 m, below which little vegetation survives. At eye level there is little to distinguish this from the bare rock of a landslide scar.

The river user, during a raft descent, gains an impression of the power of natural forces which have formed the river channel. The erosion observed from the river is not in conflict with that impression.

Middle and Lower Reaches

Downstream from the confluence of the Motu River with the Takaputahi Stream there is a marked difference in vegetation appearance between the west bank and the east bank of the river as a result of damage from grazing animals.

On the west bank tawa dominates, with hard beech toward the coast. Goat damage is very severe with the understorey most affected (Plate 3b). Where vegetation is regenerating on landslides, the browsing of seral vegetation is very noticeable.

On the east bank dense tawa dominates on the lower faces and river terraces. The kamahi is heavily depleted by possums; there is some cattle damage, but goats are virtually absent. Understorey vegetation is much better developed (Plate 3c) and the scenic quality of these reaches is maintained by good quality forest on the east bank.

In the lower reaches kowhai and pohutukawa add to the visual attraction and goat damage is less obvious. A tract of 50-year-old regenerating vegetation is being cleared and planted in exotics on the west bank 5 km above Houputo Bridge.

EROSION AND SEDIMENT TRANSPORT IN THE MOTU RIVER

In his report O'Loughlin (1982) calculates, from scar density and depth, an annual sediment input to the river of about 3000 tonnes/km²/year, which is in accord with Adams' (1979) estimate. Recent calculations of scar densities from 1981 photographs are presented in Table 1.1 and show that the Mangatutara area studied by O'Loughlin was comparable in erosion severity with the higher altitudes to the south of Te Kahika Stream. A comparison between 1971 and 1981 figures, however, shows a two to four-fold increase in the percentage of land with raw scars. Much of that increase has occurred since 1977 but, because only one major flood has occurred since that time, it seems possible that the sediment figures presented by Adams (1979) may not reflect the changing erosion conditions in the catchment.

It must be emphasised that the estimates (Table 1.1) for the percentage of land with raw scars have been taken from a limited number of aerial photographs using an unsophisticated technique. A detailed study of air photographs is required to provide reliable information on the major sediment sources. For the southern part of the catchment more recent aerial photographs may be needed to estimate the effect of recent storms.

Some evidence was found, particularly in the Te Kahika Stream, of the movement of large volumes of gravel. Plate 1c shows a small pile of gravel perched on a large boulder near the mouth of the Te Kahika Stream. According to regular river users the amount of shingle in the lower reaches has increased greatly since the Easter 1982 storm.

The geology of the Waitangirua and Mangaotane stream catchments and of part of the upper Te Kahika Stream catchment includes Clarence series moderately hard sandstones

and softer mudstones. The mudstone in this area tends to break down to smaller sized particles on drying and is likely to be a source of the colloidal size particles found in river sediments below the Waitangirua Confluence (see Section 4).

THE EFFECT OF LANDSLIPS ON THE RIVER CHANNEL

Most of the material derived from debris slides and avalanches is small in particle size and can be removed by the river, although sizeable debris fans can form and exist for some time. There is a definite possibility that the character of the river channel can be modified by increased sediment inputs. The prime results would be:

- (a) greater mobility of bedforms, particularly the gravel riffles;
- (b) an increase in the area of exposed gravel bars and gravel terraces constructed during flood events, aggradation of the bed, and possible infilling of deep pools;
- (c) increased lateral instability of the river, undercutting of side slopes, and erosion of alluvial banks;
- (d) creation of new rapids at the foot of active slips;
- (e) an increase in the number of logs, stumps and other organic debris in the river channel.

These effects would be particularly marked in tributary valleys. In gorges, where the flow is fast, only large boulders can remain in place, but it is here that the major rockslides and rockfalls occur and large boulders may remain in a location nearby for considerable lengths of time. Floods can alter the form of even the largest rapids, and minor changes were commented on by the raft guides during the October 1982 trip.

The risk to human life of rockfalls is not considered to be high by regular river users because the gorges will not normally be run when rainfall is heavy. In 88 trips the only active instability seen by one river user was a small debris slide-avalanche which ran for over one hour.

THE EFFECT OF DIFFERENT USE OPTIONS

Impoundment of the river or its tributaries could influence the land stability in the vicinity of the impoundments, but could reduce bank erosion in the remaining sections of river. Impoundment will cause the death, through drowning or clearfelling, of vegetation below and possibly just above the new water level. Forest removal on slopes greater than 30°-35° would substantially increase landslide densities (O'Loughlin 1982). Drainage from the materials above an impoundment could be impeded, causing an increased landslide risk during heavy rainfall. Soils and materials in or near the zone of water level fluctuation would become unstable as roots die and decay and because of the rapid fluctuation of water levels which are likely to occur. Slips starting at water level could retrogress upslope to the ridge, as commonly occurs in this area. Impoundment might reduce surface erosion of some existing scars near the current river level by reducing drying out and reducing the rate of river scouring and undercutting.

The period taken for the land near an impoundment to achieve a reasonable level of stability would be several decades and would depend on the degree of control of grazing animals. Changes of agricultural or forestry land use could increase erosion and increase sediment load in the river.

SUMMARY

The part of the catchment mainly considered in this report consists of highly deformed greywacke of high strength to the north and moderately hard sandstones and softer mudstones to the south. The terrain rises to over 1400 m and is steep and rugged. The soils are often less than 1 m deep, have a high volcanic ash content and are stony. The soil mantle is permeated by a dense network of tree roots.

Erosion is widespread with the most common forms being shallow debris slides and debris avalanches on the mid to upper slopes and rockfalls and debris falls on the lower slopes. Deep-seated rockslides or rock avalanches usually occur in the crush zones associated with faults.

Aerial photographs dating back to 1945 suggest that the intensity of erosion undergoes considerable variation with time. The wind damage to vegetation that occurred during the Easter 1982 storm may significantly affect future erosion patterns and it is considered that export of sediment from the catchment will increase above estimates currently available. Rooding associated with access or logging causes instability on steep slopes with 15–20 times the normal volume of debris being produced.

The predominantly tawa vegetation visible from the river is largely undamaged except for erosion or logging scars. Where goats have become established on the lower western bank the understorey vegetation is modified and revegetation of erosion scars is prevented by browsing.

ACKNOWLEDGEMENTS

Valuable discussions were held with Colin O'Loughlin, Forest Research Institute, Christchurch; staff of the East Cape Catchment Board; Brian Blewett, White Water Adventure Tours; Forest Service staff, Gisborne; Ian Speden and Colin Mazengarb, Geological Survey, Department of Scientific and Industrial Research.

REFERENCES

- Adams, J. 1979: Sediment loads of North Island Rivers, New Zealand—a reconnaissance. *Journal of Hydrology (NZ)* 18(1): 36–48.
- DSIR 1978: Landsat II over New Zealand 1978 (Edited by P.J. Ellis, I.L. Thomas and M.J. McDonnell). *Department of Scientific and Industrial Research Bulletin 221*. DSIR, Wellington.
- Fyfe, H.E. 1959: Reconnaissance survey—Motu River. New Zealand Geological Survey Internal Report.
- Grant, P.J. 1963: Forests and recent climatic history of the Huirau Range, Urewera region, North Island. *Transactions of the Royal Society of New Zealand Botany* 2(12): 144–72.
- Grant, P.J. 1981: Major periods of erosion and sedimentation in the North Island, New Zealand, since the 13th century. In, "Erosion and Sediment Transport in Pacific Rim Steeplands". *IAHS Publication No. 132*. pp. 287–304.
- Jane, G.T. 1979: Impact of wild animals on the forests of the Raukumara Ranges. New Zealand Forest Service Internal Report.
- Kingma, J.T. 1965: Geological map of New Zealand, 1: 250 000. Sheet 6 East Cape. New Zealand Geological Survey, Wellington.
- NZFS 1982: Raukumara State Forest Park Draft Management Plan 1982. New Zealand Forest Service, Wellington.
- Nichols, J. 1971: Forest type map, Sheet 6 Raukumara. 1: 250 000 New Zealand Forest Service Mapping Series.
- O'Loughlin, C.L. 1982: A preliminary investigation of slope stability in the Motu catchment. New Zealand Forest Service, Forest Research Institute. Unpublished report. Prepared for the Working Party on Forest, Land and Wildlife Values.
- O'Loughlin, C.L.; Pearce, A.J. 1976: Influence of Cenozoic geology on mass movement and sediment yield response to forest removal, North Westland, New Zealand. *Bulletin International Association, Engineers Geology* 14.
- O'Loughlin, C.L.; Rowe, L.K.; Pearce, A.J. 1982: Exceptional storm influences on slope erosion and sediment yield in small forest catchments, North Westland, New Zealand. In "Proceedings of Australian First National Forest Hydrology Symposium 1982". Australian Institute of Engineers. pp. 84–91.
- Ongley, M.; MacPherson, E.O. 1928: The geology of the Waipau Subdivision, Raukumara Division. *NZ Geological Survey Bulletin* 30.

SECTION 2: MOTU RIVER HYDROLOGY

J.M. Riddell^{1*} and M.P. Mosley²
¹Water and Soil Directorate, Ministry
of Works and Development, Wellington
²Hydrology Centre, Ministry of Works
and Development, Christchurch

INTRODUCTION

This section describes the hydrology of the Motu River and its tributaries and examines how this may influence river uses such as recreation, abstraction and impoundment. The locations of features referred to in this section are marked on Fig. 1.1 (Section 1).

RAINFALL

Mandeno *et al.* (1979) and Riddell (1980a) estimated that long-term annual rainfall varies from 1400 mm at the coast to 4000 mm at the top of the ranges. Riddell presents an analysis of storm durations and finds that the majority of storms are of less than three days' duration. Two-day duration storm rainfalls of between 150–250 mm can be expected once every two years.

WATER LEVEL AND FLOW DATA

Four water level recorder sites are operational on the Motu River system. Details of names, locations, catchment areas and record length are given in Table 2.1. Mean annual flow estimates are presented in Table 2.2.

For the Takaputahi and the present Mangaotane sites, water level records only are available, because their rating curves have yet to be derived. Ratings are available for the Mangaotane site when it operated from 12 September 1961 to 14 June 1963.

Table 2.1 TIDEDA: Number in brackets after site name is recording site on Fig. 1.1

TIDEDA Site No	River Name	Site Name	Catchment Area (km ²)	Location	Record Length
16502	Motu	Waitangirua (1)		295 N79: 032946	1960-
16503	Motu	Mangaotane (2)	646	N79: 098080	1961-63 1978-
16501	Motu	Houpoto (4)	1381	N70: 057358	1957-
16511	Takaputahi	Ngawhakatatara (3)	142	N79: 003060	1978-

Table 2.2 Summary of mean annual flow estimates for the Houpoto, Waitangirua and Mangaotane water level recorder sites (m³/sec)

Site Name	Riddell (1980a)	Mandeno <i>et al.</i> (1979)	TIDEDA
Waitangirua	13.6	13.6 (1961-78)	13.1 (1961-81)
Mangaotane	36.3		
Houpoto	89.3	92.5 (1958-78)	92.2 (1958-81)

*Present address: Kennington, No. 1 RD, Invercargill.

Rating curves at all sites are dynamic and constantly under review. Differences between data in the reports of Mandeno *et al.* (1979) and Riddell (1980a) often arise because of this, and because Mandeno *et al.* used Water and Soil Directorate, MWD, TIDEDA files and Riddell used Power Directorate, MWD, TIDEDA files.

Both Mandeno *et al.* (1979) and Riddell (1980a) give estimates of mean annual flows for ungauged catchments (Table 2.3) based on a water balance approach in which catchment mean rainfall is corrected for evapotranspiration.

Table 2.3 Estimates of a mean annual flow at ungauged sites in the Motu catchment

Site Name	Location	Location Details	Catchment Area (km ²)	Mean Flow Estimate (m ³ /sec)
Motu River ⁺	N88: 007887	Motu Falls	250	11.5
Motu River *	N70: 168239	30 km from river mouth	1251	80.5
Motu River ⁺		River mouth	1310	93.0
Waitangirua Stream *	N79: 084947	Confluence with Motu	70	2.7
Mangaotane Stream ⁺	N79: 103055	Confluence with Motu	185	9.4
Takaputahi Stream *	N79: 004048		138	7.8
Takaputahi Stream ⁺	N79: 006105	Downstream of Rawea Stream Confluence	216	12.6
Takaputahi Stream ⁺	N79: 104107	Confluence with Motu	260	13.5
Te Kahika Stream ⁺		Confluence with Motu	240	19.8
Mangatutara Stream ⁺		Confluence with Motu		

* Riddell (1980a) + Mandeno *et al.* (1979)

Water balances are available for gauged catchments (Table 2.4). The estimate by Mandeno *et al.* (1979) for evaporation of 500 mm at Houpoto was considered too low, so they adjusted the evaporation loss to 650 mm, in line with the Waitangirua value, saying the inaccuracy of their isohyetal map was the cause.

Table 2.4 Estimated water balances for gauged catchments from Riddell* (1980a) and Mandeno *et al.* + (1979)

Site Name	Rainfall (mm)	Discharge (mm)	Evapotranspiration (mm)
Waitangirua *	1960	1435	525
Waitangirua +	2100	1450	650
Mangaotane *	2360	1770	590
Houpoto *	2690	2040	650
Houpoto +	2600	2100	500

Riddell (1980a) thoroughly revised the New Zealand meteorological service isohyetal map, giving a more sound basis for his water balance calculations. The evaporation losses increase with increasing catchment area. This corresponds with the larger catchment rainfall and an increase in the ratio of forested area to pasture, which implies larger transpiration losses from forest. The estimates for evaporation are in agreement with the distribution pattern defined by Finkelstein (1973).

Annual flow duration curves at the Houpoto and Waitangirua sites are presented in Figs. 2.1 and 2.2. At Houpoto, mean flow (92.2 m³/sec) is equalled or exceeded 27% of the time, 30 m³/sec 76% of the time, and 20 m³/sec 90% of the time. At Waitangirua, mean flow (31.1 m³/sec) is equalled or exceeded 26% of the time, 4 m³/sec 69% of the time, and 2 m³/sec 89% of the time. Seasonal flow patterns have been summarised by Mandeno *et al.* (1979) and Riddell (1980a), e.g., Fig. 2.3. Mean monthly flows are higher in winter with minimum flows in February-March, and maximum flows in July-September for Waitangirua and in June-August for Houpoto.

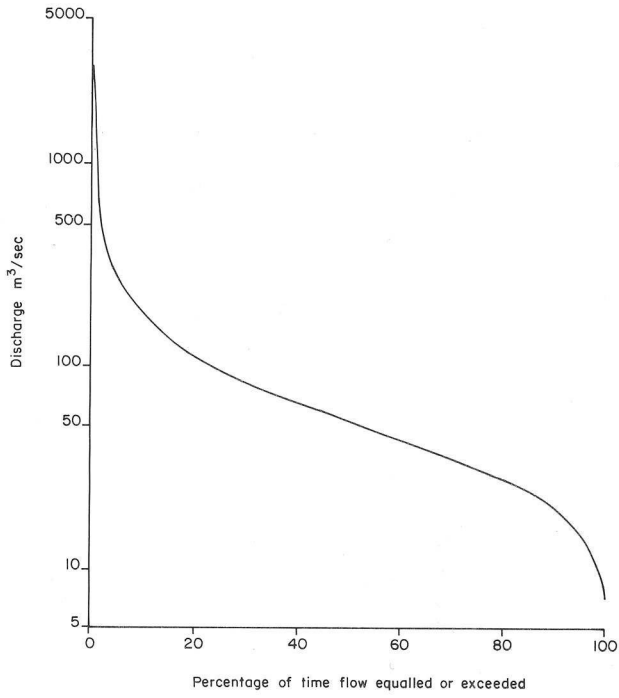


Fig 2.1 Flow duration curve for Houpoto water level recorder.

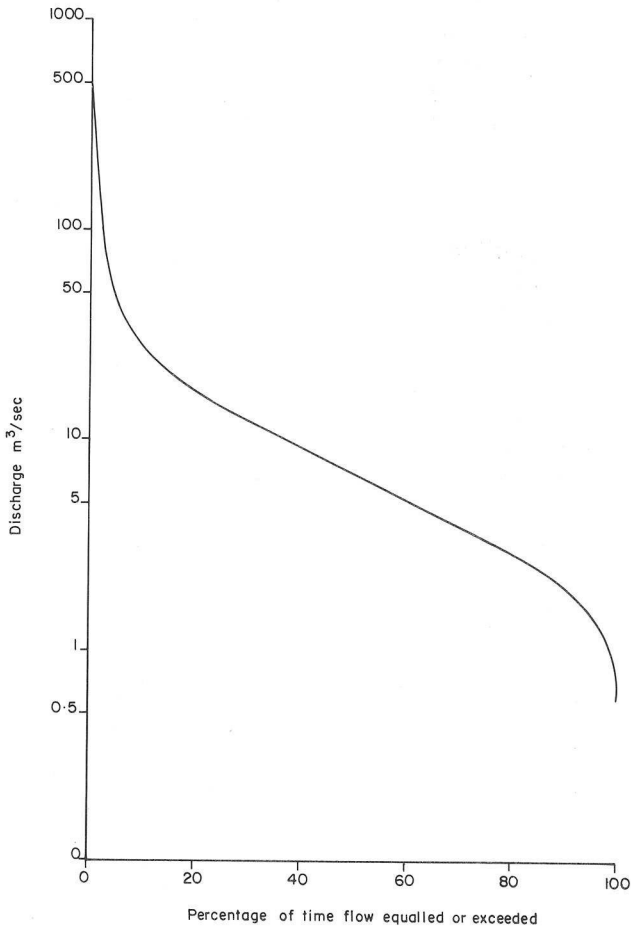


Fig 2.2 Flow duration curve for Waitangirua water level recorder.

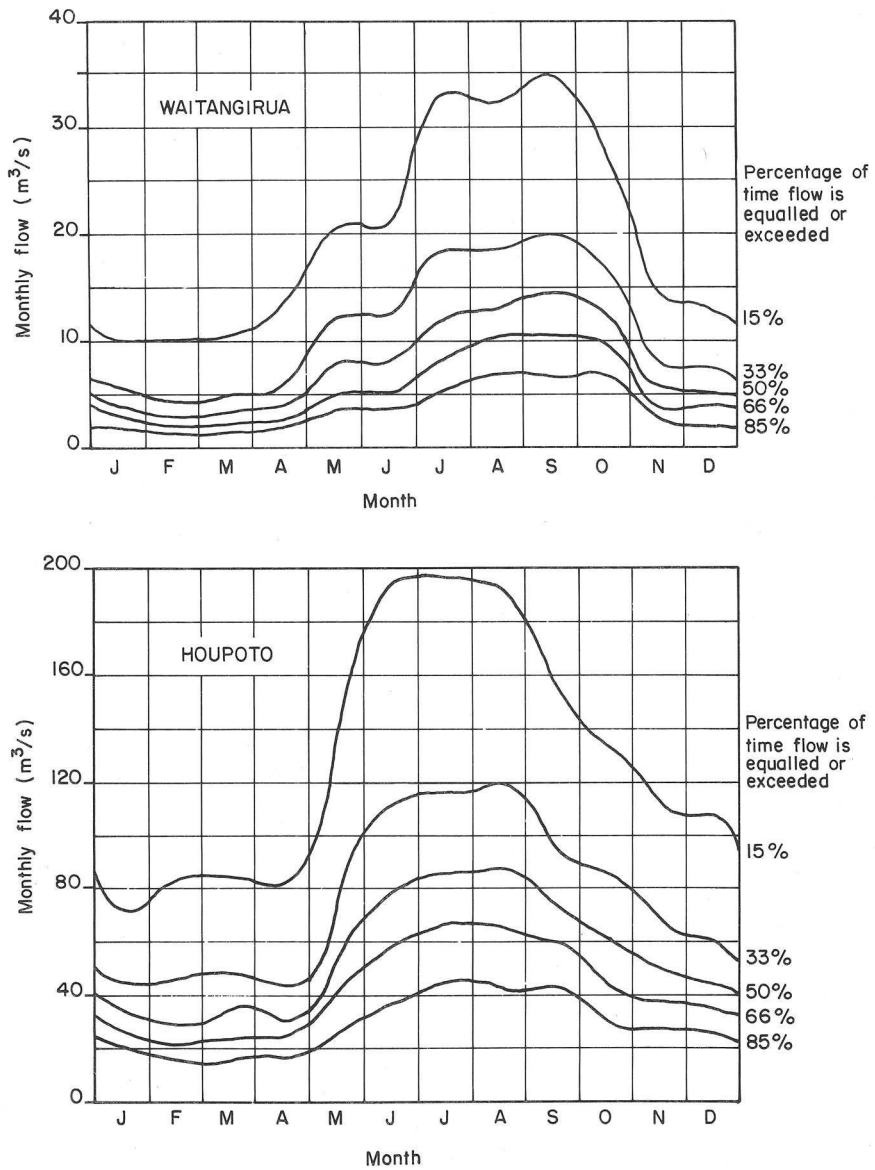


Fig 2.3 Seasonal variation in monthly mean flow at Waitangirua and Houputo (from Riddell 1980).

LOW FLOWS

Riddell (1980a) presents low flow data (Table 2.5).

Table 2.5 Minimum flows at Waitangirua and Houputo

Site Name	Return Period (Years)	Minimum 24-Hour Flow (m^3/sec)	Minimum 30-Day Flow (m^3/sec)
Waitangirua	2	1.07	2.02
	10	0.60	1.10
	100	0.40	0.69
Houputo	2	13.40	22.10
	10	7.85	12.90
	100	5.30	8.70

In 1978, very low flows were recorded at both the Houpoto and Waitangirua sites. At Waitangirua the 1978 30-day minimum flow was 0.522 m³/sec, which has a return period of greater than 100 years. At Houpoto the 30-day minimum flow was 7.79 m³/sec, which also has a return period of greater than 100 years. The lowest recorded one-day minimum flows also occurred in 1978 and had return periods of 85 years at Waitangirua and 25 years at Houpoto.

To supplement the low flow information, an analysis of the Houpoto flow record was undertaken to identify from the 23 year record the number of periods when daily mean flows fell below selected low flow values (30 m³/sec and 20 m³/sec). The durations (length in days) of low flow periods were recorded for selected months. Tables 2.6 and 2.7 present the results for January, April, July and November. Where a low flow period overlapped into the previous or following month it was included. Table 2.6 documents the number of periods when flows fell below 20 m³/sec. There were 16 Januaries in the 23 year record when flow never fell below 20 m³/sec, but for the remaining seven, there were 15 periods of flows below 20 m³/sec, eight of up to seven days' duration, six of 8–14 days' duration, and one of 20 days' duration.

Similarly, for 11 of the 23 years of record, April flows did not fall below 20 m³/sec. For the remaining 12 Aprils there were 19 periods with flows below 20 m³/sec, 10 of up to seven days' duration, eight of between 8–14 days' duration, and one of 17 days' duration.

The consequences of low flows at Houpoto on river navigability for recreational rafting/canoeing interests are discussed in Section 3 of this report. The optimum conditions for rafting are described to be above 55–75 m³/sec at Houpoto; from the above analysis of flow values of 20 and 30 m³/sec, it is obvious that quite long periods of low flows that are less than optimum for navigation by raft can occur during the main rafting season.

Table 2.6 Number of occurrences of periods with mean daily flows less than 20 m³/sec at Houpoto during 23 years of record

Number of With Flows Always Greater Than 20 m ³ /sec	Number of Periods With Less Than 20 m ³ /sec for:			
	1–7 Days Duration	8–14 Days Duration	15–21 Days Duration	Greater Than 21 Days Duration
January 16	8	6	1	0
April 11	10	8	1	0
July 23	0	0	0	0
November 18	8	1	0	0

Table 2.7 Number of occurrences of periods with mean daily flows less than 30 m³/sec at Houpoto during 23 years of record

Number of With Flows Always Greater Than 30 m ³ /sec	Number of Periods With Less Than 30 m ³ /sec for:			
	1–7 Days Duration	8–14 Days Duration	15–21 Days Duration	Greater Than 21 Days Duration
January 3	17	11	5	7
April 2	17	19	5	3
July 20	4	1	0	0
November 12	16	4	2	0

FLOOD FLOWS

Flood flow analysis has been carried out by Riddell (1980a) based on Gumbel analysis, unit hydrograph techniques and probable maximum flood theory, while Mandeno *et al.* (1979) used regional flood envelopes and TM61 methods. Some of these results are published in

Riddell (1980b). Results of the analyses are in good agreement (Tables 2.8 and 2.9). Riddell (1980a) presented details of maximum flows for specified durations with assigned return period (Table 2.10).

Based on these estimates the records used by Riddell were examined to find 2-year and 15-year return period floods. Details on maximum two-hourly peak flows, flood duration (duration of direct runoff as defined by Riddell), time to peak and mean and maximum two-hourly rates of hydrograph rise were extracted. These details are documented in Table 2.11.

FLOW VARIABILITY

Flow in the Motu River is highly variable and this has relevance to navigability (see Section 3). A plot of discharges at Houputo water level recorder during 1981 exemplifies the highly variable flows (Fig. 2.4). The rates of rise during flood events are very rapid. At Houputo water level recorder, discharge during the rising stage of a flood event with a two-yearly recurrence interval may increase by up to 680 m³/sec in only two hours, and at Waitangirua

Table 2.8 Summary of flood flow estimates (from Riddell 1980a)

Site	Mean Flow (m ³ /sec)	Peak Discharge (m ³ /sec)				Probable Maximum Flood
		2 Years	15 Years	500 Years	1000 Years	
Waitangirua WLR *	13.6	250	450	740	800	1350
Mangaotane WLR	36.5	710	1240	2040	2200	3550
Motu River, 30 km from mouth	80.5	1590	2760	4550	4900	7550
Houputo WLR	89.3	1800	3100	5100	5500	8300
Takaputahi Stream at N79: 004048	7.8	150	265	440	470	760

*WLR = Water Level Recorder

Table 2.9 Summary of flood flow estimates for a 1000-year return period (m³/sec) (Mandeno *et al.* 1979)

Site	Regional Flood Envelope Method	TM61 Method
Motu at Waitangirua	830	857
Motu at Houputo	5230	5580

Table 2.10 Maximum flows (m³/sec) for different flood return periods at Waitangirua and Houputo (from Riddell 1980a, Table 3.1)

Site	Maximum Flow (m ³ /sec) for the Duration Specified					
	Return Period (y)	Instant- aneous	2 hr	6 hr	12 hr	24 hr
Waitangirua WLR	2	236	230	227	215	187
	15	437	432	417	392	348
	500	747	743	708	662	595
	1000	808	804	765	715	
Houputo WLR	2	1560	1513	1409	1283	1079
	15	3040	2907	2719	2459	2019
	500	5290	5046	4728	4262	3463
	1000	5730	5465	5121	4615	3745

Table 2.11 Statistics on selected flood of approximate return times of 2 or 15 years

Date	Approx Return Period (yrs)	Storm Rainfall (mm)	Maximum 2-Hourly Flow (m ³ /sec)	Duration (hours)	Time to Peak (hrs)	2-Hourly Rate of Rise (m ³ /sec)	
						mean	max
<i>Waitangirua</i>							
5/7/60	2	119	231	88	16	28	42
4/5/62	2	100	235	94	32	14	40
26/4/66	2	176	236	76	22	21	63
19/11/60	15	350	465	146	36	24	52
19/11/60	2	290	1481	128	36	77	255
23/6/62	2	132	1484	84	20	145	680
10/1/63	2	166	1540	76	24	116	284
13/2/65	15	228	2725	102	32	224	780

water level recorder by up to 63 m³/sec in only two hours (Table 2.11). The peak discharge during a flood may be many times greater than the baseflow discharge immediately beforehand; Table 2.12 summarises the ratio between peak discharge and preceding baseflow for all flood events during the period 1960–81 (April 1962–June 1963 excepted because of an unreliable record). During the 20.6 year period, eight floods exceeded more than fifty-fold the baseflow discharge immediately beforehand, and 50 exceeded the preceding baseflow by more than twenty-fold.

As Fig. 2.4 indicates, flood events are a very frequent occurrence on the Motu; Table 2.13 summarises their frequency and interval for the full period 1960–81. The mean interval between floods (exceeding 1.5 times the preceding baseflow) was 9.6 days, ranging from eight days in July to 11.3 days in February. The greatest interval without a significant flood was 46 days, in April 1964 and in April 1978.

Table 2.14 shows the number of flood peaks with specified peak discharges that occurred during the same period on average, there were 11.6 per year exceeding 350 m³/sec at Houpototo water level recorder, mostly during the months of May–September.

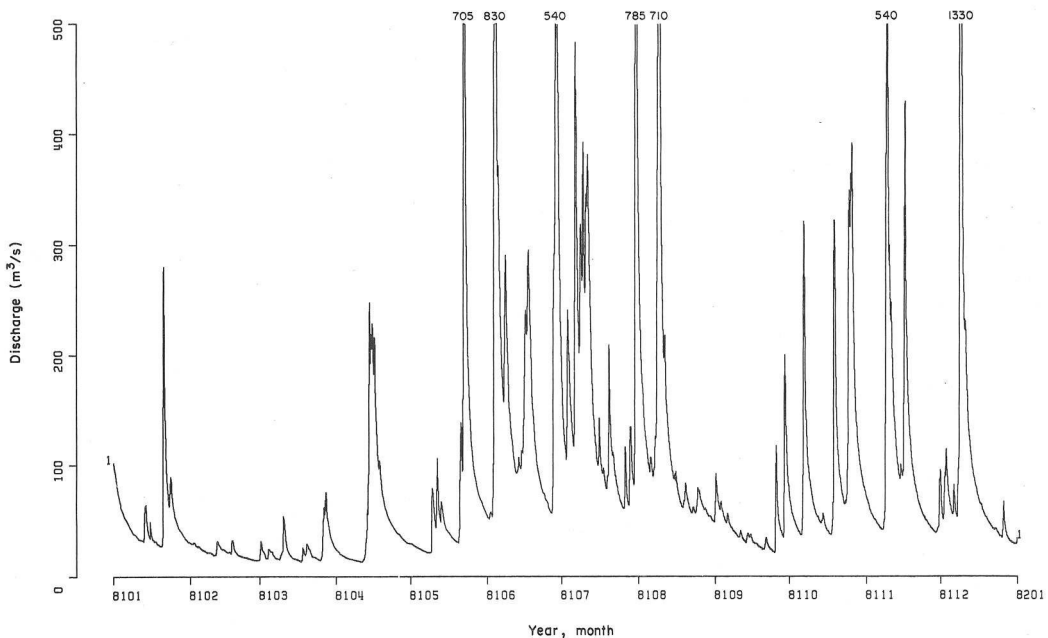
**Fig 2.4** Hydrograph for 1981 at Houpototo water level recorder (Motu Bridge).

Table 2.12 Number of floods having specified ratios of peak discharge to preceding baseflow, 1960-1981*, at Houpoto water level recorder

Ratio Peak discharge Baseflow discharge	Ratio											
	J	F	M	A	M	J	J	A	S	O	N	D
0-2.49	22	15	19	9	17	17	21	26	25	20	20	20
2.5-4.99	24	15	17	18	20	26	31	20	22	14	14	17
5.0-7.49	4	7	9	7	9	8	17	7	8	10	7	3
7.5-9.99	2	2	5	4	2	8	5	7	8	5	6	1
10.0-14.99	8	3	4	3	7	6	3	10	5	5	7	6
15.0-19.99	1	1	0	6	5	1	1	2	3	2	4	3
20.0-29.9	1	2	2	5	1	1	3	3	2	3	2	3
30.0-39.9	0	2	2	0	1	0	2	1	1	0	0	1
40.0-49.9	0	0	0	0	0	2	0	0	0	0	0	2
> 50.0	1	1	2	0	0	0	0	0	0	0	2	2

*April 1962—June 1963 excepted because of unreliable record; missing record 18/4/77-31/5/77 and 28/7/77-1/9/77. Only floods whose peak exceeded 1.5 times the preceding baseflow included.

Table 2.13 Frequency of flood peaks** having a specified interval since the preceding flood, 1960-1981*, at Houpoto water level recorder

Interval (days)	TOTAL NUMBER, 1960-1981												Average per year	
	J	F	M	A	M	J	J	A	S	O	N	D		Year
1-2	8	7	7	4	9	10	8	11	6	8	6	4	88	4.0
3-4	11	7	16	9	18	13	11	12	13	12	9	10	141	6.5
5-6	7	1	7	5	11	15	11	15	18	5	6	9	110	5.1
7-8	6	7	5	6	9	11	22	13	13	9	14	7	122	5.6
9-10	5	7	9	4	7	8	11	9	5	5	3	12	85	3.9
11-12	6	5	1	10	5	6	8	6	4	5	5	2	63	2.9
13-14	4	5	5	2	3	4	6	3	4	3	6	6	51	2.3
15-16	4	3	1	7	2	3	2	7	2	5	2	2	40	1.8
17-18	4	1	3	5	3	1	6	1	3	4	5	6	42	1.9
19-20	1	0	2	3	2	2	0	1	1	5	4	1	22	1.0
21-22	0	5	1	1	1	2	0	1	1	1	0	2	16	0.7
23-24	2	0	0	2	4	2	0	0	3	0	1	1	15	0.7
25-26	1	0	0	0	0	0	0	0	0	0	2	0	3	0.1
27-28	1	1	2	0	1	0	0	0	0	0	2	1	8	0.4
29-30	0	1	1	2	0	2	0	0	0	1	0	0	7	0.3
> 30	3	3	2	3	0	0	0	1	0	1	1	0	14	0.6
Total, 21.8 year	63	54	62	63	75	79	85	80	3	64	66	63	827	
Average per year	2.89	2.48	2.84	2.89	3.44	3.62	3.90	3.67	3.35	2.94	3.00	2.89	37.94	
Mean interval (days)	10.7	11.3	10.9	10.4	9.0	8.3	8.0	8.5	9.0	10.5	9.9	10.7	9.6	

*Missing record, 18/4/77-31/5/77 and 28/7/77-1/9/77.

**Only peaks exceeding 1.5 times the preceding baseflow are included.

POTENTIAL EFFECTS OF MAN-INDUCED CHANGES

At present, the Motu River is virtually unaffected by abstraction and there are no diversions or impoundments. The river offers significant hydro-electric generation potential and, for example, could act as a water supply for Gisborne. However, because of its wild and scenic, recreational, and other qualities the river is presently subject to a national water conservation order which prevents abstraction, diversion or impoundment of the lower reaches.

Table 2.14 Number of flood peaks of specified size, 1960-1981*, at Houpoto water level recorder

Peak Flow m ³ /sec													Average per year	
	J	F	M	A	M	J	J	A	S	O	N	D		Total
100-149	10	7	11	8	5	5	11	8	12	11	17	5	110	5.3
150-199	5	5	1	6	5	5	12	9	9	5	5	4	71	3.6
200-249	3	3	4	2	6	9	11	6	7	8	3	2	64	3.1
250-299	6	1	6	3	3	7	8	4	2	1	5	1	47	2.3
300-349	2	0	2	7	5	8	2	5	4	3	1	1	40	1.9
350-399	1	2	1	1	5	5	5	6	7	3	3	3	42	2.1
400-449	2	0	0	1	2	2	4	3	6	2	2	2	26	1.3
450-499	1	2	1	2	4	1	2	6	8	0	0	1	28	1.4
500-999	3	4	6	2	8	17	18	11	12	5	7	7	100	4.9
1000-1999	2	1	1	4	1	0	4	7	0	3	3	4	30	1.5
> 2000	0	1	1	1	0	1	1	0	2	0	2	0	9	0.4

*Missing record, 18/4/77-31/5/77 and 28/7/77-1/9/77; April 1962-June 1963 omitted because of unreliable record.

The likely effects on the hydrological regime of some speculative man-made manipulations of the river are discussed below.

(a) Abstractions and Diversions

Abstractions (or diversions) of 1, 5, 10 and 15 m³/sec were chosen and their effects on mean annual flows, and one-day and 30-day minimum flows were estimated for selected sites (Tables 2.15, 2.16, 2.17). Abstractions of this order would have negligible effects on flood flows.

Table 2.15 The remaining mean annual flows after removal of 1, 5, 10 or 15 m³/sec from the Motu river

Site	-1 m ³ /sec	-5 m ³ /sec	-10 m ³ /sec	-15 m ³ /sec
Waitangirua	12.1	8.1	3.1	0
Mangaotane	35.3	31.3	26.3	21.3
Houpoto	91.2	87.2	82.2	77.2

Table 2.16 1-day minimum flows (m³/sec) after abstracting or diverting 1, 5, 10 or 15 m³/sec

Site	Return Period (years)				
		-1 m ³ /sec	-5 m ³ /sec	-10 m ³ /sec	-15 m ³ /sec
Waitangirua	2	0.07	0	0	0
	10	0	0	0	0
Houpoto	2	12.4	8.4	3.4	0
	10	6.9	2.9	0	0

Table 2.17 30-day minimum flows (m³/sec) after abstracting or diverting 1, 5, 10 or 15 m³/sec

Site	Return Period (years)				
		-1 m ³ /sec	-5 m ³ /sec	-10 m ³ /sec	-15 m ³ /sec
Waitangirua	2	1.02	0	0	0
	10	0.1	0	0	0
Houpoto	2	21.1	17.1	12.1	7.1
	10	11.9	7.9	2.9	0

The results show that the effects of abstraction (or diversion) would, as expected, become more pronounced further up the river system where flows are smaller (Table 2.15).

One-day and 30-day minimum flows at Waitangirua could barely sustain a 1 m³/sec abstraction or diversion at even the two-year return period frequency (Tables 2.16, 2.17).

In the case of one-day minimum flows at Houputo, 10 m³/sec abstraction could be sustained at the two-year return period (leaving a residual flow of 3.4 m³/sec) but not in a 10-year return period low flow situation. On the 30-day minimum flow basis, abstraction of 10 and even 15 m³/sec could be sustained at a two-year period, but given a 10-year return period low flow, a 10 m³/sec abstraction or diversion could barely be met.

Sustainable abstractions or diversions from points on the main channel between the two main water level recorder sites would range between the two situations presented, with sustainable quantities improving down the river system.

An analysis of the flow record was carried out to identify the number of periods when daily flows would fall below 20 m³/sec, given 5 and 15 m³/sec abstractions (Tables 2.18, 2.19).

Table 2.18 Number of periods and their durations, with mean daily flows less than 20 m³/sec, given a 5 m³/sec abstraction; Houputo site

Number of Months With No Periods With Flows Less Than 20 m ³ /sec		Number of Periods With Flows Less Than 20 m ³ /sec				
		1-7 Days Duration	8-14 Days Duration	15-21 Days Duration	22-28 Days Duration	Greater Than 28 Days Duration
January	7	19	5	2	4	1
April	15	18	12	2	2	1
July	23	1	1	0	0	0
November	17	8	2	2	0	0

Table 2.19 Number of periods and their durations, with mean daily flows less than 20 m³/sec, given a 15 m³/sec abstraction; Houputo site

Number of Months With No Periods With Flows Less Than 20 m ³ /sec		Number of Periods With Flows Less Than 20 m ³ /sec				
		1-7 Days Duration	8-14 Days Duration	15-21 Days Duration	22-28 Days Duration	Greater Than 28 Days Duration
January	1	21	6	5	3	8
April	1	14	11	6	5	3
July	19	8	3	0	0	0
November	5	23	8	4	1	1

Comparison of these estimates (Tables 2.18, 2.19) with those in Table 2.6 shows that abstraction of 5 or 15 m³/sec would cause a marked increase in the occurrence of periods with flows of less than 20 m³/sec in the January and April months, for example: Abstractions of 5 m³/sec would approximately double the chance of flows falling below 20 m³/sec in January. There would be an increase from 8 to 19 periods of up to seven days' duration with less than 20 m³/sec and an increase from one to seven periods of over 15 days' duration. It is likely that other months when flow tends to be low would be similarly affected.

(b) Structures, Impoundments

Building of control structures for power generation would create impoundments and smooth out natural flow peaks. The effects on low flows would depend on the flow regime chosen but enhancement of low flows may be possible. Because the river is extremely flashy in nature and has steep-sided, narrow valleys, impoundments would have a relatively small storage capacity and would be expected to transmit the larger flood peaks.

Considering an impoundment at Houpoto with an available operating volume of $37 \times 10^6 \text{ m}^3$, a 50% plant factor, and continuous maximum generation of $180 \text{ m}^3/\text{sec}$, the times to fill the operating volume were calculated. Table 2.20 presents the results for selected two and 15-year return period floods.

Table 2.20 Times to fill an impoundment of Houpoto, given typical 2 and 15-year return period floods

Flood Date	Return Period (years)	Natural Time to Peak (hours)	Time to Fill Operating Volume (hours)
19/11/60	2	36	22
23/6/62	2	20	12
10/1/63	2	24	15
13/2/65	15	32	17

These results show that medium to large floods would overtop the storage capacity within 24 hours and opportunity for regulation of flood outflows would be limited.

Under normal flows, and given a peak load generation regime, at times of peak electricity demand impoundment levels would drop and there would be high outflows. During periods of low demand generation would be minimal, with rising impoundment levels and low residual outflows. A daily cycle with minimum outflows at night, and a buildup of generation and outflows during the day is likely. There would also be a week/weekend cycle, with higher demand during the week than at weekends. These would be superimposed on the natural seasonal flow cycle of high winter flows and low summer flows.

SUMMARY

Mean annual rainfall of the Motu River catchment varies between 1400 mm/year at the coast and 4000 mm/year at the top of the ranges. Two-day duration storm rainfalls of between 150–250 mm can be expected once every two years.

Mean annual flow at the Waitangirua, Mangaotane and Houpoto water level recorder sites are about 13, 36 and $90 \text{ m}^3/\text{sec}$ respectively.

One-day minimum flows of $1.07 \text{ m}^3/\text{sec}$ and $13.4 \text{ m}^3/\text{sec}$ can be expected once every two years at the Waitangirua and Houpoto sites respectively. Lowest flows normally occur in February and March. At Houpoto during March, $45 \text{ m}^3/\text{sec}$ (50% of the mean flow) can be expected to be equalled or exceeded 33% of the time, while $18 \text{ m}^3/\text{sec}$ (20% of the mean flow) is equalled or exceeded 85% of the time.

A typical flood at Houpoto with about a two-year return period, records a two-hourly mean peak flow of $1\,500 \text{ m}^3/\text{sec}$ (17 times the mean flow). Rates of hydrograph rise can be very large and on average are about $120 \text{ m}^3/\text{sec}$ in two hours. In medium to large floods it typically takes 20–36 hours to reach peak flow. The rapid rates of rise, short times to reach peak and large peak flows of this large catchment are significant hydrological features. These factors reflect the steep topography, dissected landscape and shallow soils of the catchment and the lack of any hydrological storage (lake or groundwater). The Motu River is flashy in nature and potentially hazardous.

Abstractions or diversions would have the greatest effect on river flows during the dry summer/autumn months. Continuous abstractions or diversions of greater than $1 \text{ m}^3/\text{sec}$ at Waitangirua could not be readily sustained on a two-year return period 30-day minimum flow basis. At Houpoto abstraction of $5 \text{ m}^3/\text{sec}$ could be sustained on a 10-year return period basis, but abstraction or diversion of $10 \text{ m}^3/\text{sec}$ would leave a 30-day minimum flow of only $2.9 \text{ m}^3/\text{sec}$.

Any control structure and impoundment on the main Motu River would regulate flows. The relatively small storage capacity available because of the narrow valleys would mean that a typical two-year storm would be contained in a reservoir upstream, for example, of

Houputo for less than 24 hours. Regulation of medium to large floods would probably be small.

Each of the Motu's four major tributaries contributes between 10-15% of mean flow to the main channel.

ACKNOWLEDGEMENTS

The assistance of Power Directorate, Ministry of Works and Development, in providing unpublished reports is acknowledged.

REFERENCES

- Finkelstein, J. 1973: Survey of New Zealand tank evaporation. *Journal of Hydrology (NZ)* 12(2): 119-31.
- Mandeno; Chitty and Bell, 1979: Small hydro-electric, potential, West Poverty Bay region. Report to the NZ Energy Research and Development Committee.
- Riddell, D.C. 1980a: Hydrology of the Motu River. Power Directorate, Ministry of Works and Development, Wellington. Unpublished report.
- Riddell, D.C. 1980b: Flood hydrology of the Motu River. *Journal of Hydrology (NZ)* 19: 35-48.

SECTION 3: SCENERY AND RECREATION ALONG THE MOTU RIVER

M.P. Mosley,
Hydrology Centre,
Ministry of Works and Development, Christchurch

INTRODUCTION

This section describes the channel of the Motu River and relates the channel and flow characteristics to the scenic and recreational attributes of the river. There are few information sources. Topographic data are available from maps N70, N79 and N88 of the NZMSI 1: 63 360 map series, vertical aerial photographs taken at various dates between 1945 and 1981, and other special purpose maps such as Sheet 6 of the NZ Forest Service mapping series number 6, the 1: 250 000 Forest Class Map. Penny (1982, pp. 11-17) provides a brief description of a variety of features of the river. Egarr and Egarr (1981) in a recreational rivers survey rate the Motu highly for river scenery and "whitewater" recreation. A description of the rapids in narrative form with information on landscape and camp sites is provided by NZFS (1978) guide for dinghy descents. Since the time of writing, a review of recreation and landscape of the Motu has been prepared (MacMurray 1984).

In order to supplement available information, the river was traversed by raft in October 1982; flow was stable and low (approximately 45 m³/sec at Motu Bridge), and weather conditions were good.

Fig. 1.1 (Section 1) shows the location of features referred to in this section of the report.

GENERAL DESCRIPTION OF RIVER

River Reaches

The Motu River drains the western Raukumara Ranges. It falls naturally into eight reaches, each having a distinctive character. The mean width, maximum width and normal low flow water surface width of various reaches are presented in Table 3.1 along with comments on substrate type.

Above Motu Falls (M147-M97) [numbers are river distances from the mouth, in km]

The river meanders across a wide terraced floodplain which is pastoral in character (Plate 4a); erosion of the silty banks is common and the 10-15 m wide channel has a gravel bed with frequent organic debris (branches, etc) present. In places, the channel is lined with willows.

Motu Falls to Head of Upper Gorge (M97-M74.5)

Below Motu Falls, the Motu is incised below the surrounding country in a narrow commonly tree-lined trench. The river is narrow (15-20 m), shallow and generally slow-flowing, with a bed composed of gravel. Occasional rock bars, gravel riffles and sections with exposed boulders provide easy rapids. The channel slowly widens to about 30 m at Kirks Clearing; it remains shallow and slow-flowing, with occasional easy riffles which at low flow may be too shallow for a raft to pass without grounding.

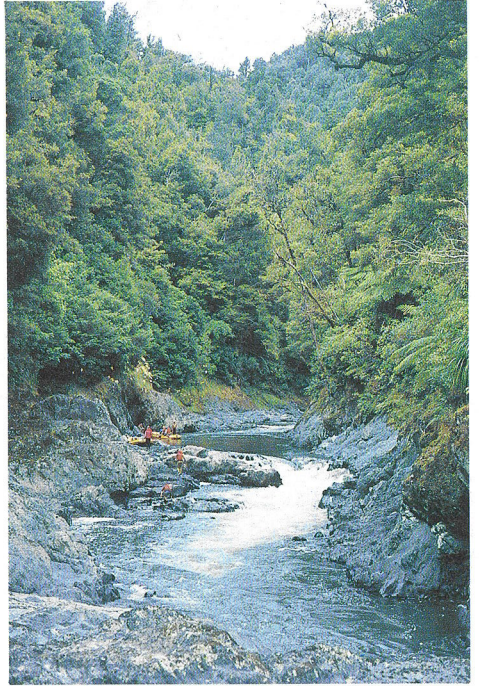
The landscape ranges from improved pasture, through reverting pasture and scrub, to selectively logged and undisturbed native forest. However, because of the entrenched nature of the channel, the pastoral nature of the surroundings is frequently not apparent from the river. Old logging roads are occasionally seen.

Upper Gorge (M74-M57)

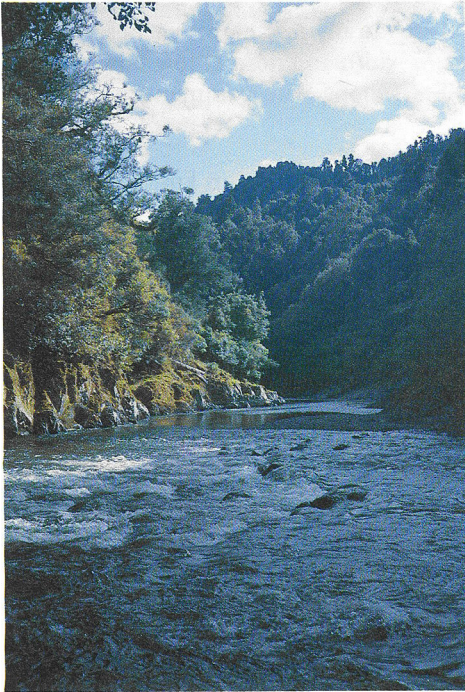
The river steepens through the Upper Gorge, becoming narrower, faster flowing and more turbulent, with larger rapids. The channel is highly variable in nature. There are steep



4a. Upper Motu River valley, from above Motu Falls, looking upstream.



4b. Grade 2+ rapid in Upper Gorge, flowing through a narrow bedrock chute. J. C. Horne, photo.



4c. Grade 1 rapid of the bouldery riffle type in the Upper Gorge, Flow runs directly into a rock bluff.



4d. Waterfall under a vertical rock bluff in the middle Motu.

Table 3.1 The main reaches of the Motu River, their widths and substrate type. River widths were measured from aerial photographs and in the field by (October 1982)

Reach	River Distance* (km)	Mean Width (m)	Maximum Width (m)	Water Surface Width Normal Low Flow (m)	Comments
1 Above Motu Falls	147-97		not measured		
2 Motu Falls to head of Upper Gorge	97-74.5				
(a) Downstream from falls		15-20	30	15-20	Commonly rock bound channel
(b) Above Waitangirua		20-25	30	20	Commonly rock bound channel
(c) Waitangirua to Upper Gorge		30	50	30	Gravel bed, and regular riffles and pools
3 Upper Gorge	74.5-57				
(a) Top end		25	35	20	Rock bound with gravel bed
(b) Bottom end		30	40	20-25	Rock bound with gravel bed
4 Between Upper Gorge and Te Paku Gorge	57-48.5	55	70	25	Gravel bed; riffles and pools
5 Te Paku Gorge	48.5-47	45	55	25	Rock bound, with gravel bed
6 Between Te Paku Gorge and Lower Gorge	47-38.5	65	120	35	Gravel bed, regular riffles and pools
7 Lower Gorge	38.5-33.5	60	90	35	Bouldery bed at rapids; gravel bed intervening
8 Lower river	33.5-0				
(a) Te Kahika to Mangatutara ⁺		60	65	30	Gravel bed; riffles and pools
(b) Mangatutara to Huaero ⁺		90	150	35	Gravel bed; riffles and pools
(c) Huaero to Manuriki ⁺		100	150	45	Gravel bed; riffles and pools
(d) Below Manuriki ⁺		130	200	50	Gravel bed; riffles and pools

*Distance from the sea

⁺Confluences

drops over bedrock sills (Plate 4b), bouldery riffles commonly flowing towards rock cliffs (Plate 4c), and long, deep and slow moving pools entrenched between steep rock walls. The river winds between steeply sloping, forested spurs and ridges. At many places the slopes are scarred by slips and the debris frequently creates bouldery rapids in the channel.

Between Upper Gorge and Te Paku Gorge (M57-M48.5)

At Otipi Road end, site of the M56 dam site investigations, the Upper Gorge widens out to about 55-70 m, with a low flow water surface width of 25 m. The channel has a gravel bed with regularly occurring small rapids, commonly of the gravel or bouldery riffle or "rock garden" type, interspersed by long, deeper and slower moving stretches. The landscape is similar to that of the Upper Gorge, with the river winding between forested ridges and spurs, but hillslopes are less steep and the valley more open (Plate 5a). The river occasionally flows under steep or vertical bluffs (Plate 4d).

Te Paku Gorge (M48.5-M47)

Te Paku Gorge has a series of gently flowing, deep pools interspersed with a few small rapids; the channel is up to 55 m wide with a low flow water surface width averaging 25 m. The channel is bordered by steep to vertical bluffs which are commonly scarred by slips; vegetation is a mosaic of ages ranging from colonising species on recent slips, through manuka to mature forest.

Te Paku Gorge to Lower Gorge (M47-M38.5)

This section is similar to the section above Te Paku Gorge. The channel winds between gravel bars and across small rapids of the gravel riffle type. The low flow water surface width averages 35 m. The valley is open, with long, steep, forested spurs and ridges stretching back to the high ground (Plate 5b).

Lower Gorge (M38.5-M33.5)

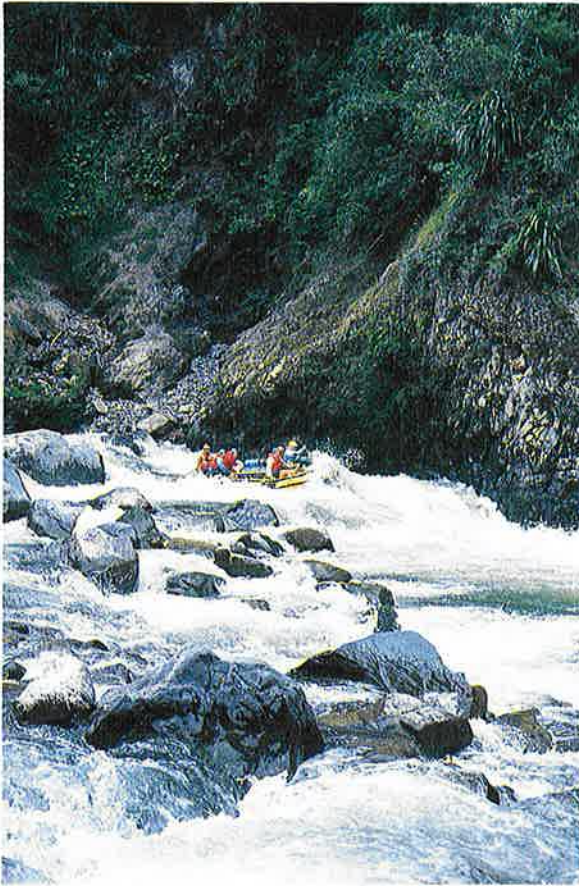
The average channel gradient steepens through the Lower Gorge, primarily because of a series of steep rapids. The channel winds between rock banks and alternating gravel bars



5a. A 'rock garden' rapid in the middle section of the Motu, looking upstream.



5b. Middle Motu River, looking downstream with Mangakirikiri confluence in the foreground.



5c. Grade 3 rapid in the Lower Gorge. J. C. Horne, photo.



5d. Lower Motu River.

and has an average low flow water width of 35 m. The larger rapids are commonly caused by major accumulations of boulders over which the river drops up to 3 m (Plate 5c). There are long placid stretches of water between steep to vertical rock bluffs.

Lower River (M33.5-M0)

Below the Lower Gorge, the valley opens out and the river winds tortuously between forested bluffs with alternating gravel riffles providing a succession of easy rapids between long, slow pools (Plate 5d). The overall channel width is up to 150 m in the lower reaches and the low flow water width is 45–50 m.

In the lower reaches, the native forest has been cleared from the left bank, and is being converted to exotic forest. Below Houpoto the now braided river meanders over a predominantly shingle deltaic deposit which extends 5 km to the sea. Vegetation here is sporadic and occasionally destroyed by migrating stream channels.

Tributary Streams

NZFS (1978) describes the country surrounding the Motu as a maze of ridges, spurs, saddles and bluffs, and states that the major tributaries (Mangatutara, Te Kahika, Mangaotane and Mangakirikiri Streams) contain difficult gorges and can be traversed only if river levels are normal. These tributaries drain some of the highest land in the catchment. The Takaputahi Stream is stated to be impossible to negotiate from the Motu, and its vertical cliffs difficult to sidle. Subsidiary streams have many waterfalls and gorges, and are choked with debris, making them impossible as escape routes.

THE SCENIC QUALITY OF THE MOTU RIVER

The grand scenery through which the Motu River flows a major feature of a river trip. An important aspect of the scenery is the depth of the riverbed below the surrounding hills, and the width of the valley. On Fig. 3.1 is drawn the generalised contour of the summits bordering the river. The depth of the valley gives an indication of the grandeur of the scenery. Maximum valley depth occurs in the vicinity of Te Paku Gorge, where the elevation difference is in the order of 650 m.

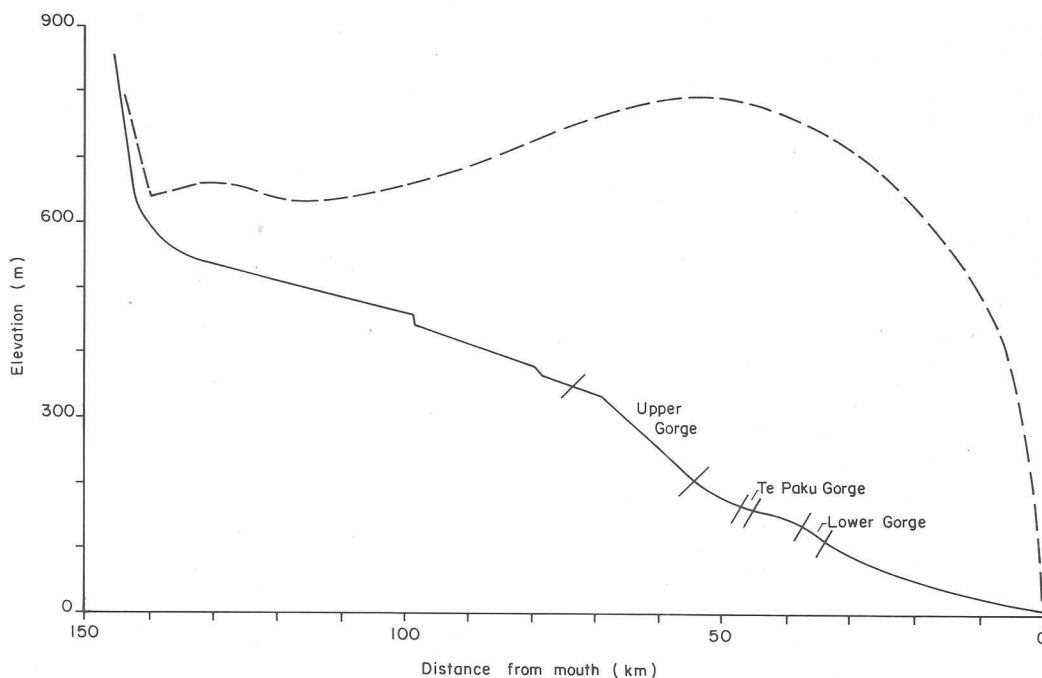


Fig 3.1 Longitudinal profile (solid line) of the Motu River (after Riddell 1980). The generalised contour of the surrounding hilltops is also included (broken line).

Table 3.2 International river classification of white water

Grade	Description
1	<i>Very easy</i> —Waves are small and regular, passages are clear. Obstacles are sand bars, bridge piers, and riffles.
2	<i>Easy</i> —Rapids of medium difficulty with clear, wide passages.
3	<i>Medium</i> —Waves are numerous, high and irregular. Passages are clear but narrow and require expertise in manoeuvring. A spraydeck on open boats is useful.
4	<i>Difficult</i> —Long rapids with powerful waves and many obstacles are present. Passages are difficult to see and powerful, precise manoeuvring is required. A spraydeck is essential on open boats.
5	<i>Very difficult</i> —Rapids are long and very violent, following each other almost without interruption. The riverbed is extremely obstructed with large drops and violent currents.
6	<i>Extraordinarily difficult</i> —The difficulties of class 5 carried to the extremes of navigability.

The other major aspect of the scenery along the river is the valley width. This is more difficult to describe quantitatively because it is highly variable, and from river level is often less apparent than the width between spurs leading down to the river. The author's assessment is that the grandest scenery is found in the Te Paku Gorge where the river flows in several places beneath high vertical rock faces, and in the Upper Gorge where the river flows within a steep-sided inner valley. Leopold (1969) suggested that the combination of valley width and depth is important and this is reinforced by the author's experience; while vertical relief is as great below the Lower Gorge as in the Lower Gorge itself, the valley is wider there and the scenery consequently less impressive. The cross-valley profiles shown on Fig. 3.1 give a far from perfect idea of the changing character of the river scenery (concealing, for instance, the scenic importance of the inner valley in the Upper and Te Paku Gorges), but indicate the "larger scale" of the scenery in the middle reaches of the river.

RAPIDS OF THE MOTU RIVER

An inventory of the rapids of the Motu River below Waitangirua Stream (the upstream limit of navigation by raft at the time) was compiled in early October 1982. Flow at the time was low, with a stage height of 1.4 m at the Mangaotane water level recorder (equivalent to a discharge of 15–20 m³/sec).

Fig. 3.1 shows the overall longitudinal profile of the river; the Upper and Lower Gorges are markedly steeper on average with a greater number of rapids and generally greater fall over each. Fig. 3.2 shows the location of rapids between Waitangirua Stream and Motu Bridge. They were located in the field and mapped in the office with the aid of vertical aerial photographs and oblique photographs taken immediately after the field visit. Each rapid was graded at the prevailing conditions using the internationally accepted convention summarised in Table 3.2. It is emphasised that the precise grade and disposition of rapids is subject to change. Because of the low flow at the time of the survey, most rapids were easier to navigate by raft than normal. At optimum flows for rafting, the difficulty of many rapids may increase by half a grade but some would become a continuous torrent constrained by rock banks (Plate 4b). The gravel riffle is not fixed but migrates as sediment and transported down river.

The number and frequency of rapids in each river reach is summarised in Table 3.3.

NAVIGABILITY OF THE MOTU RIVER

The ability to navigate the river is important to the Motu's social and recreational value; access by any other means than boat is difficult except in a few locations.

In the lower river, rapids are easy for boating (barely warranting the name rapid, rather than riffle) and are spaced on average 0.47 km apart. Rapids in the Upper Gorge are mainly in the easy category but with a few up to grade 3+ to 4 in difficulty, and are spaced on

average 0.2 km apart. In the Lower Gorge there is a lower proportion of easy rapids (Table 3.3). Overall, the Upper Gorge would be regarded as grade 2+ to 3 at normal flow, and the Lower Gorge as grade 3+ (B. Blewett, White Water Adventure Tours, pers. comm.). Description of the recreational experience afforded by some of the rapids are provided in Egarr and Egarr (1981).

Table 3.3 Rapids in Motu River

Reach	Length (km)	Mean Slope (m/km)	Total Number of Rapids of Grade					Frequency per km of Rapids of Grade					Mean Rapid Spac- ing (km)
			1+	2+	3+	1+	2+	3+					
			1	-2	-3	-4	All	1	-2	-3	-4	All	
Waitangirua Stream—Upper Gorge	10.0	4.9	23	12	0	0	35	2.30	1.20	NA	NA	3.50	0.29
Upper Gorge	17.5	6.8	4	60	22	2	88	0.23	3.43	1.26	0.11	5.03	0.20
Upper Gorge— Te Paku Gorge	8.5	4.3	16	17	1	0	34	1.88	2.00	0.12	NA	4.00	0.25
Te Paku Gorge	1.5	4.1	1	1	0	0	2	0.67	0.67	NA	NA	1.33	0.75
Te Paku Gorge—Lower Gorge	8.5	3.9	12	9	2	0	23	1.41	1.06	0.24	NA	2.71	0.37
Lower Gorge	5.0	6.7	2	7	6	2	17	0.40	1.40	1.20	0.40	3.40	0.29
Lower Gorge— Road Bridge	33.5	2.9	49	23	0	0	72	1.46	0.69	NA	NA	2.15	0.47
Totals/Means	84.5	4.4	107	129	31	4	271					3.21	0.31

NA = not applicable

Navigability is highly dependent on flow in the river, and the length of river traversed by the commercial raft operators varies with season. During the summer low flow season, they enter the river at Otipi Road end (M56) and traverse only the Lower Gorge; when flow is higher in spring, early summer and autumn they enter at the Waitangirua Stream confluence (M82) and are therefore able to traverse all three gorges. When flow is high, entry is possible 3 km downstream from Motu Falls (M97).

Commercial rafting companies consider that the optimum depth for rafting is above 1.6 m at Mangaotane water level recorder, equivalent to a discharge of 25–35 m³/sec or in the order of 12–16 m³/sec at Waitangirua and 55–75 m³/sec at Houpoto (B. Blewett, White Water Adventure Tours, pers. comm.). These conditions are expected to prevail about 20% of the time. Maximum safe depth of flow for rafting is considered to be 2.4 m at Mangaotane water level recorder, equivalent to a discharge of approximately 150 m³/sec, or about 70 m³/sec at Waitangirua and 350 m³/sec at Houpoto. Unsafe flows are expected to prevail about 3% of the time.

The features of the flow regime most important to navigation are the frequency-duration characteristics of low flows (which control the practicability of navigation) and of flood flows (which control its safety). Mean flow data are of little relevance because the flow in the Motu is highly variable. A range of hydrological statistics reported in Section 2 describes this variability and allows conclusions to be drawn on navigability. Tables 2.6 and 2.7 indicate the likelihood of low flows at different times of year, and Tables 2.8–2.14 provide a range of flood statistics.

If it is assumed that the length of time taken to traverse the river in two days from Otipi Road end and four days from Waitangirua (Ritchie *et al.* 1982), then the probabilities of a party travelling down the river experiencing a potentially hazardous flood, or having less than optimum navigability through low flows, can be estimated. During the prime recreation season October–April, the number of hazardous floods (greater than 350 m³/sec at Houpoto) averaged only 4.2 per year, so that the chance of a party travelling down the river experiencing

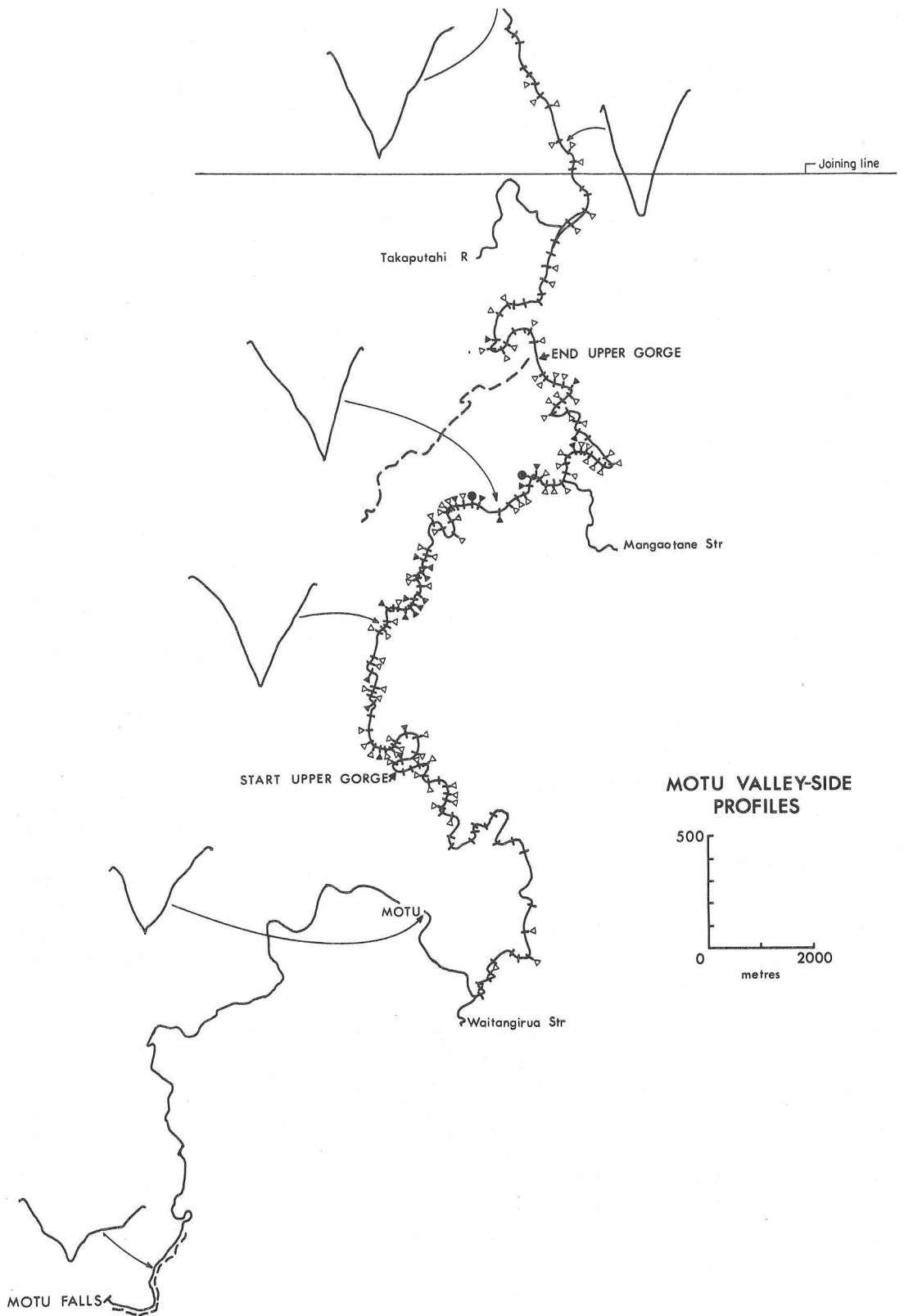
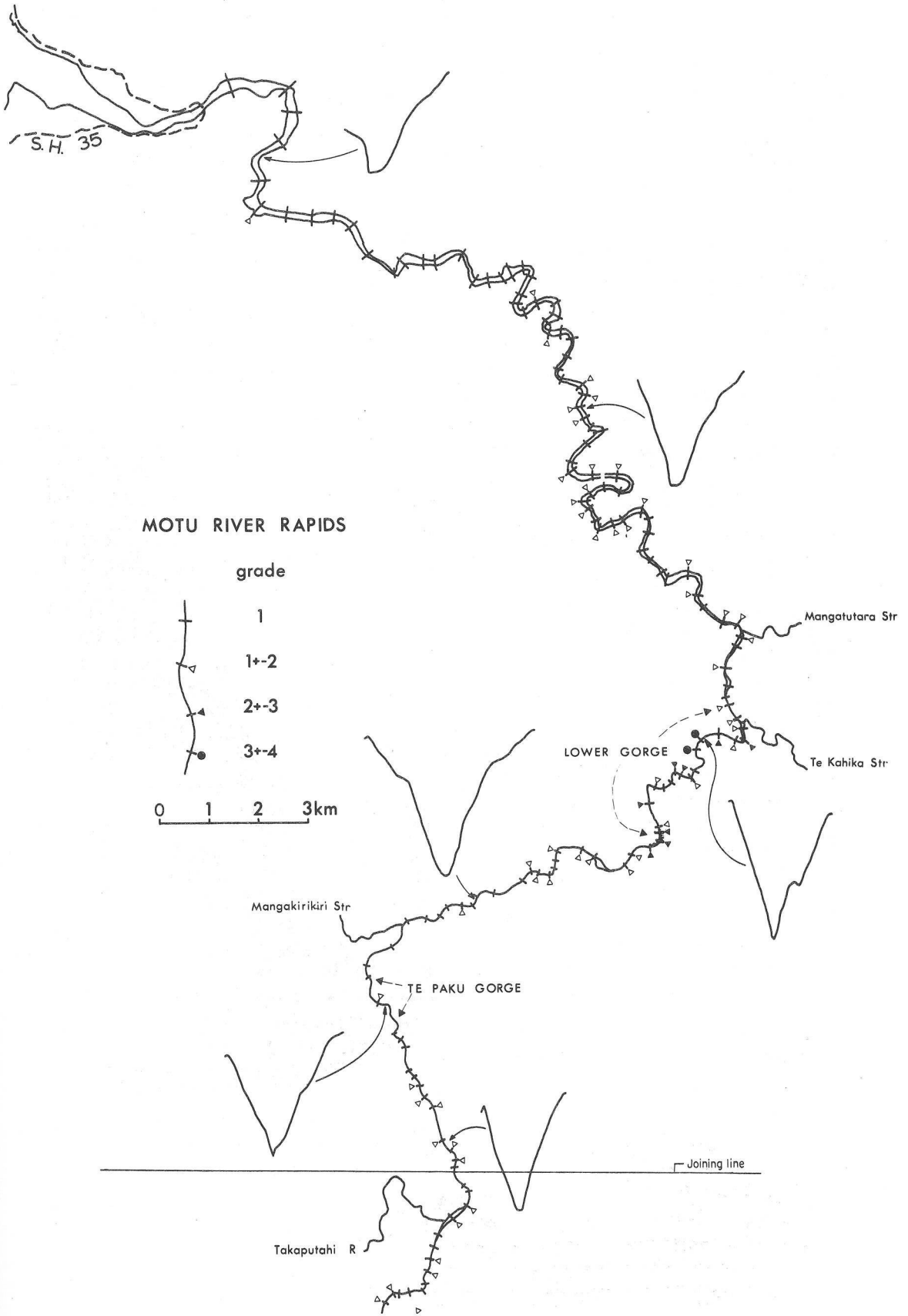


Fig 3.2 Location and grade of rapids on the Motu River between Waitangirua Stream and Motu Bridge.
 Cross-valley profiles at selected points are included (note vertical exaggeration of 4.25 times).



a potentially hazardous flood is relatively small. Furthermore, because flood peaks, particularly during the summer low flow season, are so short-lived (see Fig. 2.4), a party overtaken by a potentially hazardous flood is very unlikely to have to take refuge for more than an extra day or two. However, the chances of experiencing small floods are quite high with flows greater than 1.5 times baseflow occurring on average every 9.6 days.

One of the dangers to river users is the rapid rate at which the river flows increase during a flood (see Section 2). This can cause rapid rises in river level, especially in the gorges, and requires that camping sites are selected carefully.

IMPACT OF WATER RESOURCE DEVELOPMENT ON THE MOTU RIVER

The Motu catchment has been considered for a variety of water resource development possibilities, including small hydro scheme developments in the major tributaries, major dam construction for electricity generation at several sites on the main river, transfer of water to Gisborne City for domestic water supply, and transfer of water from the Takaputahi Stream to the Torere River for power generation.

Major Dam Construction

Major dam construction has been proposed for a number of sites; proposals are summarised most recently by Williman (1978, 1979) and Riddell (1980). Possible dam sites that have been considered are at M5 or M8; M30 or M36; M53, M56 or M59; and in the vicinity of M77. Various combinations of these are possible, but Williman (1979) recommended the combination of dams at M5 and M30 as the preferred development, and considered that the M53/56/59 and M77 options were unattractive.

The most obvious impact of major dam construction on the Motu River is inundation of the valley upstream, as far back as that point on the river with an elevation equal to that of the dam crest. A dam at M53, M56 or M59 would inundate all or most of the Upper Gorge; a dam at M30 or M38 would inundate Te Paku Gorge and the former would also inundate the Lower Gorge. The preferred option recommended by Williman (1979) would combine dams at M5 and M30; this would create two lakes reaching from Motu Bridge to just downstream of the Upper Gorge, separated by the dam at M30. Another option referred to by Williman (1979) is a single dam at M8 built as high as possible; this would inundate the lower river plus some of the Lower Gorge.

The practical impact of dam construction on river recreation would be as follows:

- (a) Single dam at M8—Use of the Upper and Te Paku Gorges and intervening river would be unaffected; some of the Lower Gorge would also be unaffected (depending on final crest elevation), but a 25 km long traverse of flat water would be necessary to reach the exit point. This would be very difficult by raft because it is unsuited to long distance paddling, and an unattractive task in a kayak. Without an exit road from an alternative point the present forms of recreational use of the river would be greatly hampered and, in the case of rafting, possibly eliminated.
- (b) Dams at M8 and M30—Te Paku and Lower Gorges and the intervening and lower river would be inundated; Upper Gorge would probably be unaffected, but exit from the Upper Gorge would be onto a 25 km long lake. Paddling this lake would be very difficult for rafters and unattractive for canoeists, so that present forms of recreational use would be in practice virtually eliminated. If Otipi Road were maintained, this could be used as an exit point and the upper river and Upper Gorge could continue to be used for rafting and canoeing.
- (c) Dams at M53, M56 or M59—A dam at one of these sites was regarded by Williman (1979) as practically independent of any other development. The effect would be to render the Upper Gorge unfit for present forms of recreational use.
- (d) A dam in the vicinity of the Waitangirua confluence supplying water to a powerhouse at M77 would inundate the upper river to Motu Falls.

Alternative forms of recreation such as powerboating, sailing and fishing would be enhanced by dam construction provided appropriate facilities were provided.

There are a variety of lesser impacts on the Motu River which could result from major dam construction.

- (a) Sedimentation would occur at the head of any system of impoundments producing a flat, marshy delta which would prograde downstream. Riddell (1980) presented data on sediment yield that are pertinent; they indicate that up to several hundred years would be required for the reservoirs to completely fill, but, since the head of a reservoir is narrow and shallow, delta advance might be initially very rapid (Table 3.4).

Sedimentation would also occur at the head of each reservoir arm. Since the steep headwaters of the tributary catchments are some of the most rapidly eroding sections of the catchment, delta growth in such locations might be initially rapid.

- (b) Riverbed degradation could occur wherever free flowing river remained downstream of any dam site. This impact could occur on the river between the sea and the first dam. No coarse and only a part of the fine sediment would pass this dam and scour of the present gravel channel might be expected. There are few data available to predict the response of a gravel bed river like the Motu to dam construction; bed level lowering of 2-3 m might be anticipated immediately below the dam, although proximity to sea level might limit this. Armouring of the bed might also occur, as finer materials are scoured, but because of the flashy nature of the river, even with a cascade of dams present, the bed would not become inactive.
- (c) Any dam would affect the flow regime downstream in any part of the river channel unaffected by impoundment, such as from M5 or M8 to the sea. Damming would tend to smooth out flood peaks but the degree of smoothing would depend on hydro station operating regimes, maximum and minimum operating water levels, and flood size. Williman (1978) indicated that any Motu development would probably be used to generate at peak loads; outside periods of flood flow, discharge would be up to four times the mean flow for short periods, with intervening periods of residual flow. Under this regime, floods would still be a dominant factor affecting the character of any remaining river channel.

Table 3.4 Sedimentation in reservoirs (assuming each is the only one construction)

Source—Riddell (1980)

Dam	Catchment Area (km ²)	Erosion Rate (m ³ /y × 10 ⁶)*	Crest Elevation (m)	Reservoir Volume (m ³ × 10 ⁶)	Years to Fill
M56	646	1.14	350	240	230
M53*	651	1.15	305	200	260
M30	1251	2.22	210	430	220
M8*	1367	2.42	150	1000	620
M5	1381	2.45	88	220	115

*Riddell (1980) estimates a total erosion rate of 3.2×10^6 t/y, or about 2×10^6 m³/y. Adams (1979) estimated suspended sediment load only at 4.1×10^6 t/y, or about 2.5×10^6 m³/y.

*From Williman (1979).

Takaputahi Stream Development

Two possible schemes for development of the Takaputahi catchment have been considered:

- (a) A diversion dam 23 km from its confluence with the Motu River and a tunnel to the reservoir behind a dam at M53 or M56.
- (b) A dam just downstream from the Rawea Stream confluence and a diversion tunnel to the Torere River.

Option (a) could be part of a full development of the Motu; River option (b) would, by taking up to 17.7 m³/sec from the Takaputahi Stream, reduce the hydro potential of any

lower Motu River development and could therefore be considered if the lower Motu River schemes were not proceeded with.

For option (a) a dam at 23 km (elevation 312 m) would have a crest level of 329 m or 353 m for dams on the Motu River at M53 and M56 respectively. Inundation of the valleys upstream for a distance of about 4.5 and 7.5 km respectively would be the direct result; the main valleys (Whitikau and Nga Upoko Tangata Streams) have been developed for pastoral use. As with the impoundments in the Motu Valley, sedimentation would occur at the head of each arm in the Takaputahi reservoir, and there would be scouring of the channel downstream by flood flows spilled past the dam. The latter effect would probably not extend below the confluence of the Rawea Stream.

The Takaputahi development associated with a dam at M56 on the Motu River would have a water utilisation of over 90% (Williman 1979) so that the Takaputahi Stream between the dam and the Rawea Stream would for much of the time contain only any residual flow stipulated. Flow through the section of native forest below the Rawea Stream confluence would be augmented, but since flow at the dam site is approximately 70% of total flow, flows in the lower Takaputahi Stream would be very much reduced. The impact of reduced flows would probably be for the river channel to become increasingly blocked by logs and other organic debris, and for debris introduced by mass movement on the valley side slopes to remain longer in the valley bottom. In combination with the reduced flows, this would render the Takaputahi Stream virtually impassable by raft, which is at present the only means of traversing the river.

For option (b), a 70 m high dam downstream of the Rawea Stream confluence would create a reservoir extending 15–20 km back up the valleys of the Rawea, Whitikau and Nga Upoko Tangata Streams; 1000 ha of predominantly farmland would be inundated (Mandeno *et al.* 1979). As with option (a), flow in the lower Takaputahi Stream would be reduced to some specified residual flow for considerable periods; flood peaks spilled past the dam would not be sufficient to prevent sedimentation and blockage of the channel by input of sediment and organic debris from the valley sides, and the river would be rendered impassable by raft.

The impact of these two options on the Motu River itself would be less severe, because the Takaputahi Stream provides only about 15% of total flow at Houpoto. Option (a) in combination with a dam at M53 or M56, would be associated in practice with full development of the Motu River; its impact on the Motu River would therefore be virtually irrelevant. Option (b) would probably only proceed in the absence of development on the Motu River; its impact could be in reducing low flows in the Motu River still further thus rendering the channel, particularly through the Lower Gorge, shallower, more obstructed by boulders, and less easily navigated. Effects due to changes in sediment yield from the Takaputahi Stream are unlikely to be perceptible.

Small Hydro Development

Mandeno *et al.* (1979) considered the possibilities for small hydro development in the other major tributaries of the Motu River. They concluded that none were attractive because of high access and construction costs, and did not present detailed proposals. Little can therefore be said about possible impacts on these tributaries and the Motu River, other than that:

- (a) small hydro development would only proceed in the absence of development on the Motu River itself; dams would probably be constructed close to the confluences with the Motu River;
- (b) reservoirs would be created whose length and area would depend on dam height, but which would inundate the lower reaches of the tributaries involved;
- (c) rapid sedimentation of the reservoirs would occur by delta construction at the head and by mass movement from the valley sides directly into the reservoirs. Because of the small size of the reservoirs and the high erosion rates in these steep sided valleys, early infilling could be expected, producing extensive alluvial plains upstream which would be periodically inundated and marshy;

- (d) because each tributary represents only about 10% of total flow in the Motu River the effect of any single development upon flow and channel morphology in the main river would be small, particularly after reservoir infilling had occurred and the scheme was operated as 'run-of-the-river';
- (e) during the period when reservoir infilling was occurring sediment load in the Motu would be somewhat reduced, but there would be few perceptible impacts upon the main channel from individual schemes because the sediment input from each tributary is a small part of the total load. After reservoir infilling had occurred, there would be no further impact on the main river, because sediment would pass the dam.

Water Abstraction from the Motu Headwaters

There is a possibility that water could be abstracted from the headwaters to augment the domestic water supply of Gisborne. The prime impact of abstraction would be to reduce flows in the Motu River, and consequently to reduce flow depth and velocity, increase the area of exposed rock and gravel bars and the number of boulders exposed in the channel, and to make navigation more difficult. Impacts would be greatest on the river between the abstraction point and the Waitangirua Stream confluence. This section is already marginal for passage because of shallow depths; as Fig. 2.3 shows, during January-March, the mean flow of the Waitangirua Stream exceeds 5 m³/sec only one year in three, and exceeds 3 m³/sec in one year in two. Removal of 1-2 m³/sec would significantly reduce the length of the period during November-April in particular that passage is possible, and removal of 5 m³/sec would render the section impassable for much of the time, except during floods when parties would be unlikely to set out in any case. Flow is augmented by the Waitangirua Stream, and many parties now enter the Motu River at this point. Abstraction of 1-2 m³/sec would make passage downstream from Waitangirua Stream more difficult during low flow periods, particularly down to the Mangaotane Stream confluence, and might extend the period (presently Christmas to March) when the upper river is marginal for rafting. Removal of 5 m³/sec would significantly extend this period, possibly so that the section above Otipi Road end was marginal during the whole November-April period, except during freshes and floods (cf. Figs. 2.17 to 2.19).

SUMMARY

The Motu River may be divided into a number of reaches each having a distinctive character:

- (a) Above Motu Falls (M147-M97).
- (b) Motu Falls to head of Upper Gorge (M97-M74.5).
- (c) Upper Gorge (M74.5-M57).
- (d) Between Upper Gorge and Te Paku Gorge (M57-M48.5).
- (e) Te Paku Gorge (M48.5-M47).
- (f) Between Te Paku Gorge and Lower Gorge (M47-M38.5).
- (g) Lower Gorge (M38.5-M33.5).
- (h) Lower River (M33.5-M0).

The scenery for much of the river's course, as seen from the river, could be described as imposing and grand. The river valley is in many places deep and narrow, and the river winds between steep interlocking spurs. Maximum relief between riverbed and surrounding ridgetops is up to 500 m around Te Paku Gorge. The native forest has been cleared in the lower reaches near Motu Bridge and along the upper course almost down to the head of Upper Gorge, but elsewhere the forest is intact, though regeneration of naturally occurring slips is being retarded by browsing by introduced mammals, especially goats. A major attraction of the Motu River is the white-water boating experience that it affords, particularly through the Upper and Lower Gorges.

Below Motu Falls, the river has for much of its length, a channel flowing over a gravel or cobble bed, with frequent easy rapids of the "skewed riffle" type. In the Upper and Lower

Gorges, there are more frequent and more severe rapids where the river drops by up to 3 m over bedrock outcrops in the channel or through bouldery areas known as "rock gardens". A few of these rapids are classified as "difficult on the international river classification scale", but overall the river would be classified as easy to medium. In many places the channel is composed of deep, slow-moving pools entrenched in narrow bedrock gorges.

A major constraint on boating is low flows; during the summer months the commercial rafting companies normally enter the river below the Upper Gorge because of inadequate flows upstream. On the other hand, flood events impose a constraint by affecting safety of river travel; optimum flow is above 55–75 m³/sec at Motu Bridge, and maximum safe flow is about 350 m³/sec. Flood flows are large, and flood peaks are rapidly reached, but also are generally short-lived, so that parties caught by an unexpected flood will normally have to take refuge for only one or two days. The mean interval between flood events (defined as a peak on the flow hydrograph at least 50% greater than the preceding low flow) is 9.6 days, but there are on average only 11.6 floods each year greater than 350 m³/sec, and only 4.2 during the October–April recreation season. Hence, the chance of experiencing a potentially hazardous flood on a 2–4 day trip down the river is small.

A number of water resource developments have been proposed for the Motu River, although granting of a national water conservation order has for the time being removed the possibility of development. The greatest impact would result from dam construction on the main river, which would inundate much of the best recreational water and/or create serious access problems for any remaining. Small hydro developments in the tributary catchments might have little impact on the main river, except during an initial period of reservoir filling, but would create flat, marshy alluvial plains upstream of any dams constructed. Diversion of water from the Takaputahi Stream to the Torere Stream has also been proposed; the consequent reduction in flow in the lower Takaputahi Stream would probably encourage its blockage by sediment and organic debris from neighbouring hillsides, and would render it inaccessible. Diversion of water from the upper Motu River to Gisborne City would similarly have an impact upon navigability of the upper river and Upper Gorge, to the extent that they could become unusable during the summer low flow season; in the absence of continued access by Otipi Road to the foot of Upper Gorge, such diversion could eliminate white-water boating from the whole river.

REFERENCES

- Adams, J. 1979: Sediment loads of North Island Rivers, New Zealand—a reconnaissance. *Journal of Hydrology (NZ)* 18(1): 36–48.
- Egarr, G.D., Egarr, J.H., 1981: New Zealand recreational rivers survey—part II North Island rivers: *Water and Soil Miscellaneous Publication No. 14* Ministry of Works and Development. pp. 90–92.
- Leopold, L.B., 1969: Quantitative comparison of some aesthetic factors among rivers. *US Geological Survey Circular* 620.
- MacMurray, C. 1984: *The Motu Dialogue*. NZ Forest Service, Lincoln.
- Mandeno Chitty and Bell 1979: Small hydro-electric potential, West Poverty Bay region. Report to the NZ Energy Research and Development Committee.
- NZFS 1978: *Motu River, a guide for dinghy descents*. NZ Forest Service, Wellington.
- Penny, S.F., 1982: *Motu, a wild and scenic river*. Environmental Defence Society, Auckland.
- Riddell, D.C. 1980: *Hydrology of the Motu River*. Power Directorate, Ministry of Works and Development, Wellington. Unpublished report.
- Ritchie, J.E.; Shaw, P.G.; Weir, P.L., 1982: *Motu River recreation survey*. Environmental Studies Unit, University of Waikato.
- Williman, B. 1978: *Motu River power investigations, preliminary simulation study (draft)*. Power Directorate, Ministry of Works and Development, Wellington. Unpublished internal report (file 92/11/30/1).
- Williman, B. 1979: *Motu River power investigations, internal interim report*. Power Directorate, Ministry of Works and Development, Wellington. Unpublished internal report (file 92/11/30/1).

SECTION 4: WATER QUALITY OF THE MOTU RIVER AND ITS TRIBUTARIES

D.G. Smith and G.B. McBride,
Water Quality Centre,
Ministry of Works and Development, Hamilton

INTRODUCTION

This section describes the water quality characteristics of the Motu River and its tributaries, and how this would be affected by impoundment for hydro-electric power generation.

Prior to this study, no water quality data on the Motu River and its tributaries had been published. Although the present work was designed and carried out as part of the Motu River power investigations by Ministry of Works and Development, it also has contributed to information gathered for the national water conservation order hearing.

Sampling of the river was carried out monthly at Motu Township and SH35 bridge at Houpoto (see Fig. 1.1, Section 1) between January 1981 and February 1983. In addition, three longitudinal sampling surveys were made by helicopter in April 1981, January 1983 and February 1983.

Measurements were made of the concentrations of major cations and anions, plant nutrients, oxygen, suspended solids, alkalinity, pH, electrical conductivity, factors related to appearance and organic content, and temperature. The dominant planktonic algae in the waters were identified. The results are discussed in relation to present and proposed uses of the river.

SAMPLING AND ANALYSIS

The locations of water quality sampling sites are given in Table 4.1 and marked on Fig. 1.1 (Section 1). Sites 1 (at Motu Township) and 15 (Houpoto) are readily accessible by road. All other sites were reached by helicopter. Sites 1 and 15 were used to assess the water characteristics over a two year period; the others were used to examine water quality between these two sites. Altogether 13 sites were sampled.

The monthly fieldwork was carried out by staff of the East Cape Regional Water Board; the first longitudinal survey fieldwork was carried out by Water Quality Centre staff and the others by regional water board staff.

Table 4.1 Water quality sampling sites

Number on Fig. 1.1 (Section 1)	Station Name	Approximate Map Reference
1	Motu River at Motu Township	N88: 960879 (N88: 980977)*
3	Motu River upstream of Waitangirua confluence	N79: 082950
4	Waitangirua Stream	N79: 081945
5	Motu River upstream of Mangaotane confluence	N79: 102052
6	Mangaotane Stream	N79: 105054
7	Takaputahi Stream (Whitikau Branch at Ngawehenga cableway)	N79: 004046
8	Motu River upstream of Takaputahi confluence	N79: 103106
9	Takaputahi Stream	N79: 101108
10	Motu River upstream of Te Kahika Stream	N70: 170215
11	Te Kahika Stream	N70: 171217
12	Motu River upstream of Mangatutara confluence	N70: 170237
13	Mangatutara Stream	N70: 172238
15	Motu River at SH35 (Houpoto)	N70: 053355

*For the longitudinal survey (April 1981).

Temperature and dissolved oxygen were measured in the field.

Two 1 litre samples of water were collected in polyethylene bottles at each site and immediately chilled. At the Water Quality Centre laboratory (within 24 hours of collection), a subsample was taken from one of the paired samples and immediately analysed for pH, conductivity, alkalinity, turbidity and light absorbance. Further subsamples (approximately 100 ml) were frozen prior to subsequent analysis for nutrients and other determinands. The other paired 1 litre sample was used for determination of suspended solids.

As a check on the analysis of ion concentrations, sums of anions and cations were determined and the APHA (1975, p. 34) quality control check applied.

The analytical methods used are given in Table 4.2.

Table 4.2 Analytical methods used for water quality determinations

Determinand	Method
<i>Filtered Samples (0.45 µm Membrane Filter)</i>	
Calcium (Ca), magnesium (Mg), potassium (K), Sodium (Na)	Goguel (1972)
Total hardness (as CaCO ₃)	Calculated from calcium and magnesium concentrations
Chloride (Cl), sulphate (SO ₄), silicate (as Si)	APHA (1975)
Ammonium nitrogen (NH ₄ -N)	Technicon (1978)
Nitrate nitrogen (NO ₃ -N)	Downes (1978a)
Dissolved reactive phosphorus (DRP)	Downes (1978b)
Total dissolved phosphorus (TDP)	NWASCO (1982)
Dissolved total Kjeldahl nitrogen (DTKN)	Nicholls (1975)
Absorbances at 270 and 400 nm (270F; 400F)*	1 cm cell
<i>Unfiltered Samples</i>	
Alkalinity (as CaCO ₃)	APHA (1975)
Turbidity, conductivity (corrected to 25°C)	Meter instructions
Chemical oxygen demand (COD), dissolved oxygen	NWASCO (1982)
pH	NWASCO (1982)
Absorbances at 270 and 400 nm (270U; 400U)*	1 cm cell
Total Kjeldahl nitrogen (TKN)	Nicholls (1975)
Total phosphorus (TP)	NWASCO (1982)
Suspended solids (SS)	NWASCO (1982)

*F = filtered

U = unfiltered

Water samples for examination of planktonic algae were taken at sites 1 (Motu Township) and 15 (Houpoto) at 1–3 month intervals from April 1981 to December 1982 and on the longitudinal survey of 23 April 1981. Water samples (200 ml) were taken in polyethylene bottles and preserved immediately by adding Lugol's iodine solution. On return to the laboratory, samples for dominant genera were identified and an approximate cell count made (NWASCO 1983).

The annual mean discharges over the period of study tend to be considerably lower than the long-term means, and mean discharges for the monthly sampling runs are also low. This may bias the water quality towards lower suspended solids and improved appearance.

DESCRIPTION OF WATER QUALITY

A summary of the results obtained from monthly surveys for sites 1 (Motu Township) and 15 (Houpoto) is given in Table 4.3.

The river waters are about neutral pH and of low salinity. The concentrations of major ions (sodium, potassium, calcium, magnesium, chloride, sulphate and bicarbonate (as measured by alkalinity)) in the Motu River are typical of New Zealand freshwaters and about half the "world freshwater average" reported by Livingstone (1963). The water is always well oxygenated.

Table 4.3 Summary of water quality data for Motu River and Motu Township (Site 1) and Houpoto (Site 15)

Determinand	Mean		Median		Minimum		Maximum		Standard Deviation		n
	1	15	1	15	1	15	1	15	1	15	
Inst discharge (m ³ /s)	8.8	53.9	5.5	38.3	0.7	9.6	36.8	150.0	8.6	41.4	24
Temperature (°C)	12.6	13.6	12.6	14.1	6.1	8.3	20.2	19.9	4.4	3.9	24
pH	7.4	7.7	7.4	7.7	7.0	7.4	8.2	8.2	0.3	0.2	24
Conductivity (mS/m) at 25°C	7.8	9.8	7.8	9.6	5.4	7.7	9.8	13.1	0.9	1.6	24
Dissolved oxygen (g/m ³)	11.0	11.1	10.9	11.2	7.3	7.7	15.3	15.2	1.7	1.6	22
Alkalinity (g/m ³ CaCO ₃)	23.0	29.5	23.5	29.3	1.5	22.5	30.0	39.0	4.4	4.9	24
Total Hardness (g/m ³ CaCO ₃)	22.8	33.1	23.4	34.0	13.2	24.8	28.3	42.2	3.5	5.7	24
NH ₄ -N (mg/m ³)	15	13	14	11	4	3	44	35	8	8	24
NO ₃ -N (mg/m ³)	267	121	244	126	20	6	634	259	176	87	24
TKN (mg/m ³)	211	134	153	80	100	35	1340	920	251	192	24
DTKN (mg/m ³)	126	46	110	45	65	20	385	70	65	12	20
DRP (mg/m ³)	9	9	9	10	6	2	19	15	3	4	24
TDP (mg/m ³)	18	14	18	13	12	4	33	25.0	6	5	21
TP (mg/m ³)	55	115	30	40	16	14	382	1255	83	252	24
SO ₄ (g/m ³)	5.7	8.0	5.6	7.8	3.9	4.5	8.0	13.5	1.1	2.4	24
Cl (g/m ³)	5.2	5.6	5.0	5.3	4.2	4.4	6.9	9.5	0.8	1.1	24
Ca (g/m ³)	6.8	10.6	7.1	11.0	3.8	7.8	8.7	14.8	1.2	1.9	24
Mg (g/m ³)	1.4	1.6	1.4	1.6	0.8	1.2	2.0	2.2	0.3	0.3	24
Na (g/m ³)	5.4	5.5	5.3	5.4	3.7	4.6	6.9	6.8	0.7	0.7	24
K (g/m ³)	1.1	0.9	1.1	0.9	0.8	0.6	2.1	1.2	0.3	0.1	24
Si (g/m ³)	8.7	6.4	9.0	6.6	5.2	4.2	10.4	8.1	1.2	0.8	23
COD (g/m ³ O ₂)	9.2	6.3	5.3	5.0	2.9	0.8	43.0	27.0	10.7	6.5	15
270F (Absorbance x 1000)	70	34	60	30	29	19	259	129	45	24	24
270U (Absorbance x 1000)	115	295	75	96	47	21	615	2470	133	558	24
400F (Absorbance x 1000)	10	5	8	3	5	2	40	22	8	6	19
400U (Absorbance x 1000)	50	251	20	80	11	3	322	1870	88	476	19
Turbidity (FTU)	8.3	47	2.2	16	0.6	0.3	70	350	18	86	24
Suspended solids (g/m ³)	20.2	87	5.2	20.8	1.1	0.6	205	870	49	193	22

The concentrations of plant nutrients (phosphorus and nitrogen) are low and typical of those expected in forested catchments with some agricultural development (Cooke 1980). The concentration of dissolved organic material and suspended particulate material is low except during flood flows.

The waters of the Motu River and its tributaries can be regarded as of high quality at flows other than flood flows.

The dominant planktonic algae were diatoms (Table 4.4). Algal counts were low and always less than 100 counts/ml. *Navicula* was the most common genus. The algal community is typical of that of other rivers in the region and indicative of oligotrophic (nutrient poor) waters (R.D. Pridmore, Water Quality Centre, pers. comm.).

Table 4.4 Dominant algal genera in the Motu River at sites 1 (Motu Township) and 15 (Houpoto) (approximate total cell counts/ml in parentheses)

Survey Date	Site 1 Motu Township	Site 15 Houpoto
23.4.81	<i>Navicula</i> (< 100)	<i>Navicula</i> ; <i>Gomphonema</i> ; <i>Rhoicosphenia</i> (< 100)
23.6.81	<i>Navicula</i> (< 50)	<i>Cocconeis</i> (but *) (< 20)
20.7.81	<i>Navicula</i> (< 20)	*
18.8.81	<i>Navicula</i> (< 20)	<i>Navicula</i> (but *) (< 20)
21.12.81	<i>Navicula</i> (< 20)	<i>Navicula</i> (< 20)
30.3.82	<i>Navicula</i> ; <i>Cocconeis</i> (ca 20)	<i>Navicula</i> ; <i>Cymbella</i> ; <i>Fragilaria</i> (< 20)
22.6.82	<i>Navicula</i> ; <i>Gomphonema</i> (ca 20)	<i>Navicula</i> (< 20)
30.9.82	<i>Navicula</i> ; <i>Gomphonema</i> (ca 50)	*
15.12.82	<i>Navicula</i> (< 100)	<i>Navicula</i> ; <i>Gomphonema</i> (< 20)

*Particulate material masked algal identification/counting.

Water Quality Changes Downstream

The results of the longitudinal surveys are tabulated in Appendix 1a-c. Tributary inflows to the Motu River between Motu Township and Houpoto tend to cause a small increase in concentration of major ions (as indicated by electrical conductivity) (Fig. 4.1), the largest change being caused by the Waitangirua tributary. This tributary in particular causes significant rises in alkalinity, calcium, sulphate and suspended solids. The Waitangirua tributary drains a calcareous mudstone region.

Nitrate concentrations at Motu Township tend to be higher than at Houpoto, reflecting the agricultural use of the catchment upstream of the township (Plate 4a) and the largely forested catchment downriver from the township. Total phosphorus increases downriver as a result of suspended solids entering the river from tributaries (Fig. 4.1).

Water appearance changes downriver. Under flows other than flood flows the river is green coloured and non-turbid at Motu Township. This is due to the presence of dissolved organic material as evidenced by the light absorbance of filtered samples at a wavelength of 270 nm. In the lower reaches the river tends to become bluer and milkier in appearance suggesting progressive dilution of the coloured organic substances arising in the developed upper catchment and increasing contributions of suspended material (Fig. 4.1).

The dominant algae at the various sampling sites are given in Table 4.5.

Table 4.5 Dominant algal genera in the Motu River and its tributaries (results obtained from the longitudinal survey of 23 April 1981—all cell counts < 100/ml)

Site	Dominant genera
1 Motu R (Motu Township)	<i>Navicula</i>
3 Motu R (above Waitangirua confluence)	<i>Navicula</i> ; <i>Cocconeis</i>
4 Waitangirua Stream	<i>Navicula</i> ; <i>Cocconeis</i>
5 Motu R (above Mangaotane confluence)	<i>Cocconeis</i>
6 Mangaotane Stream	(Identification masked by particulate material)
7 Takaputahi Stream (Ngawehenga)	<i>Cocconeis</i> (husks only); <i>Mallomonas</i>
8 Motu R (above Takaputahi confluence)	<i>Rhoicosphenia</i>
9 Takaputahi Stream	<i>Gomphonema</i> ; <i>Rhoicosphenia</i>
12 Motu R (above Mangatutara confluence)	<i>Rhoicosphenia</i>
13 Mangatutara Stream	<i>Navicula</i> ; <i>Rhoicosphenia</i>
15 Motu R (Houpoto)	<i>Navicula</i> ; <i>Gomphonema</i> ; <i>Rhoicosphenia</i>

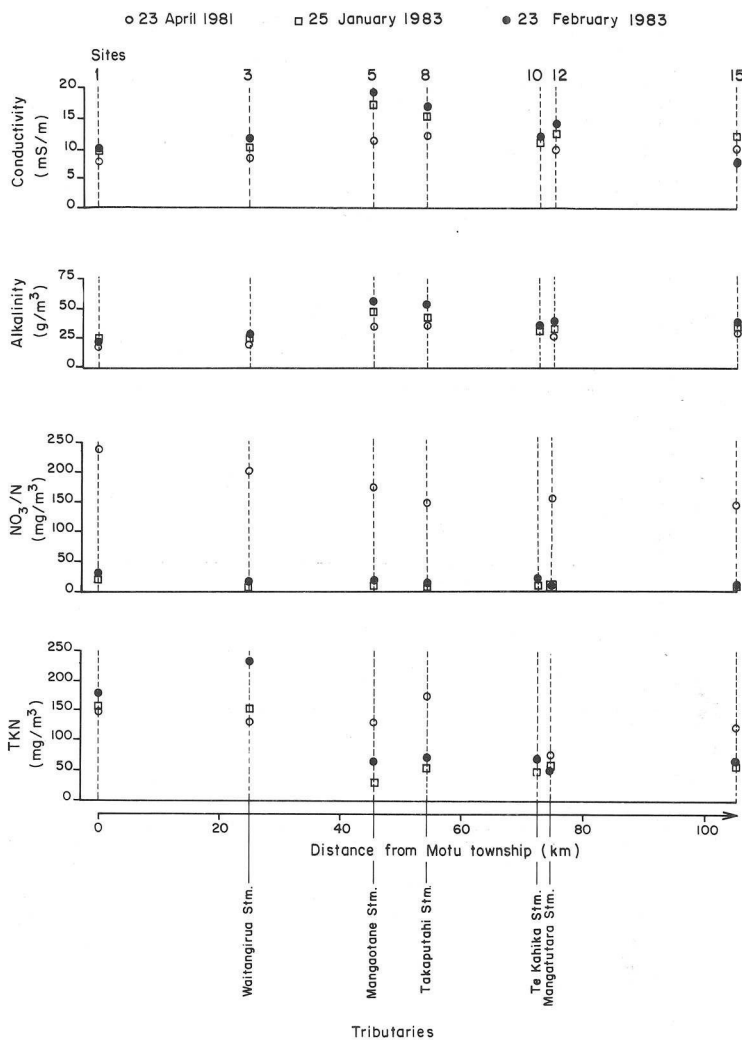


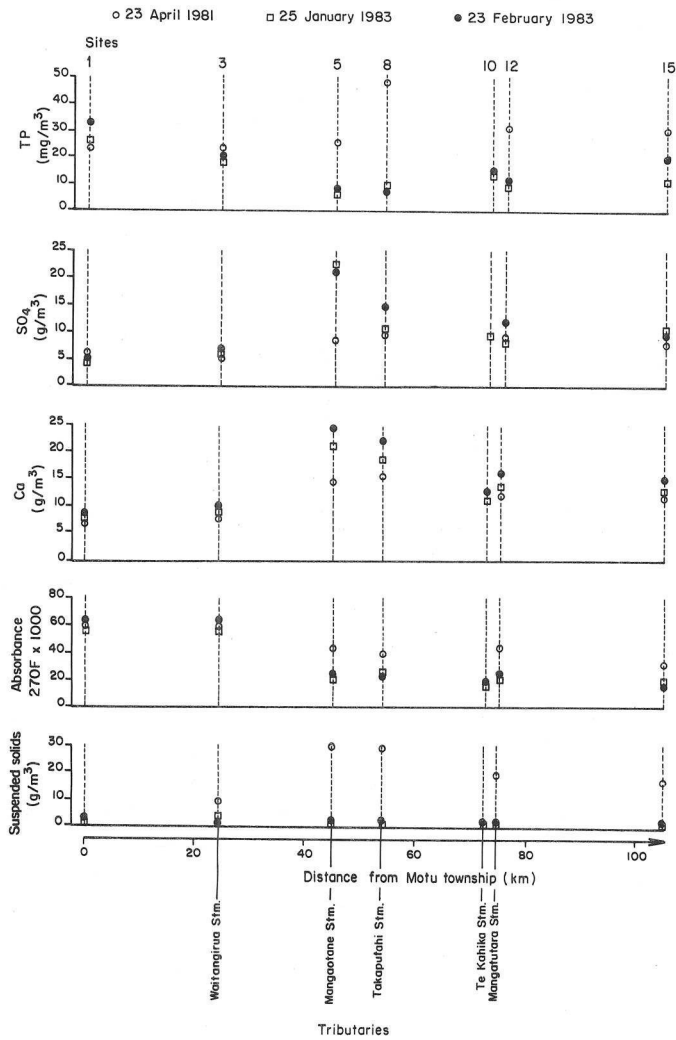
Fig 4.1 Concentration profiles for physico-chemical species in water samples collected from the Motu River during three longitudinal surveys. Sampling sites were above the tributary confluences.

Water Quality Changes With Flow

Suspended solids load and turbidity increase with river flow. Fine sediment is stored in the Motu channel and entrained by river water as flows increase. During flood events eroded material enters the river and the river is much more turbid in appearance. Some of the tributaries, notably the Mangaotane, become yellow-brown coloured (R.J. Davies-Colley, Water Quality Centre, pers. comm.). Forestry operations in the headwaters are believed to have caused discoloration of the Mangaotane tributary at the time of the longitudinal survey of 23 April 1981 (B.W. Turnpenny, East Cape Catchment Board, pers comm). Further information on suspended solids loading in the Motu River is given in Riddell (1980) and in Section 5.

EFFECTS OF DEVELOPMENT

Changes to the water quality of the Motu River could result from: increased intensity of agricultural or forestry land use; abstractions, diversions and impoundments; or changes in the erosion pattern in the catchment. Significant changes in erosion pattern could occur as a result of climate, changes in vegetation, or seismic activity.



Land Use Effects

The Motu River water quality is likely to be affected by large-scale land developments if such developments result in increasing of suspended materials (due to erosion) and nutrient (due to increased intensity of land-use). Pasture development of the upper catchment is largely complete but increased forestry activity is anticipated. This could result in higher suspended solids concentrations than at present and an alteration in water appearance. Increased levels of suspended material and nutrients may have a marked effect on the quality and appearance of impounded waters.

Change in Flow Regime

Flow regime changes which could affect the water quality of a river are reduction in discharge by abstraction (see Section 2), increase in discharge by inputs from other rivers and regulation by damming (see Section 3).

Reduction in discharge could increase the temperature range of residual waters and reduce their ability to dilute and absorb wastes or suspended materials, but because the valleys are steep and shaded in all but the upper catchment, temperature changes would be small.

Abstraction of Motu waters in the upper catchment would lower the river's ability to dilute suspended materials contained in tributaries (eg, Mangaotane). Attached algae (periphyton)

could increase in the riverbed under reduced flows but at present nutrient levels increases are not expected to be large.

Increase in discharge could marginally lower the temperature range of the river and increase its capacity to dilute and absorb wastes. River appearance could improve slightly if diverted waters come from a visually good source.

Impoundments would influence the water quality in the residual river. If the impoundments contained turbid waters, for example, residual river flows may tend to be less clear than at present.

Impoundment of River Waters

Impoundment could change the water appearance, water biology, and water chemistry of the Motu River. The main factors involved in these changes are retention time of water within each impoundment, growth of planktonic algae, and nutrient supply.

During flood flows, water would pass through the system too quickly for algal growths to develop. During non-flood riverflows residence times (see Table 4.6) are much longer (several weeks) and, in summer low flow periods in particular, there would be ample time for algal populations to grow. Under non-flood flows however, the relatively low nutrient levels would prevent excessive algal growths developing. It is estimated that, given the biologically available phosphorus concentrations presently in the Motu River (about 10 mg/m³), chlorophyll concentrations would increase by around 3–5 mg/m³ (perhaps with peaks of 10 mg/m³) if water were impounded for one month or more (R.D. Pridmore, Water Quality Centre, pers. comm.). If added to present water in the Motu River these amounts of chlorophyll would be scarcely noticeable. At peak concentration there might be a very slight increase in the greenness of the river waters and impoundments would likely be slightly green in colour.

Table 4.6 Possible impoundments on the Motu River: volume and retention times

Dam Site	Approximate Mean Flow (m ³ /s)	Volume ⁽¹⁾ (× 10 ⁶ m ³)	Operating Volume ⁽²⁾ (× 10 ⁶ m ³)	Resident Times (Days) at Various Flows ⁽⁵⁾		
				Mean Flow	2-Year Flood ⁽³⁾	30-Day Low Flow ⁽⁴⁾ (2-Year Return) ⁽³⁾
M5	90	220	15	28	1.7	116
M30	80	430	22	62	—	—
M56	37	240	10	75	—	—
M8	90	1000	37	129	8	526

(1) From Riddell (1980).

(2) Assuming 2 m operating range.

(3) Taken to be 1500 m³/s (see Table 2.8).

(4) Taken to be 22 m³/s (see Table 2.5).

(5) Based on total volume of the impoundment.

Considerable amounts of phosphorus and nitrogen would be transported downriver in floods but most of this would be unavailable for algal growth.

The turbidity of impounded waters in the Motu River will depend to a large extent on the size and settling characteristics of suspended solids contained, especially in floodwaters. Clay particles can produce considerable turbidity at very low concentrations because of their high surface area per unit weight and high light scattering properties, and can remain in suspension for considerable periods of time.

A particle size analysis on a single sediment sample from a backwater of the Motu River near the mouth gave a clay fraction (ie, particles of < 4 m diameter) of 2% (R.K. Smith, Water Quality Centre, pers. comm.). This suggests that there would be ample fine material available for re-suspension to cause marked effects on appearance of impounded water during floods. If however, floodwaters were cold and sediment laden (and hence more dense), they

would tend to sink and flow along the bottom of an impoundment to reappear at the dam face. Predictions on the extent of inorganic turbidity can be made only after further investigation.

Thermal stratification (warm and cold water layering) of impounded waters can take place if there is sufficient solar radiation to counteract wind and current mixing.

Stratification can result in deoxygenation of bottom waters if algal productivity in the photic zone is high. This occurs because of the decay of organic matter in the bottom waters, a process which uses up oxygen. It is not known whether stratification is likely to occur in Motu River impoundments and should it do so, whether sufficient organic matter will be produced to cause deoxygenation of bottom waters. Further research will be needed to resolve both these issues.

SUMMARY

Water quality data were obtained through a joint Water Quality Centre and East Cape Catchment Board programme of sampling and analysis carried out monthly between January 1981 and February 1983. Data include major ions, plant nutrients (forms of phosphorus and nitrogen), suspended solids, water appearance, pH, conductivity, temperature, oxygen and planktonic algae (dominant genera and cell counts). The Motu River and five of its tributaries (Waitangirua, Mangaotane, Takaputahi, Te Kahika and Mangatutara), were examined.

The waters are low in major ions and plant nutrients, and reasonably clear and well oxygenated under normal flows. The planktonic algal populations are low in numbers and diatoms dominate. Water quality changes occurring downstream reflect land use and geology. Water quality is high under flows other than flood flows and the algal community is indicative of oligotrophic conditions. During floods, water appearance deteriorates markedly because of high suspended solids loading from the channel and land surfaces.

Possible effects of abstractions, enhanced flows, impoundment and land use changes on water quality are examined. Future impoundments are unlikely to support high algal populations but water appearance problems related to suspended solids loading seem likely.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of the following people: B.W. Turnpenny and R.E. Dods (East Cape Regional Water Board) for sample collection and field analysis; G.G. Bryers and J.E. Hewitt (Water Quality Centre) for physicochemical and algal analysis respectively; J.B. Macaskill, R.D. Pridmore and R.J. Davies-Colley (Water Quality Centre) for constructive criticism during the writing of this report; I. Maze (MWD, Gisborne) for providing discharge data.

REFERENCES

- APHA, 1975: "Standard methods for the examination of water and wastewater". 14th ed. APHA-AWWA-WPCF, Washington.
- Cooke, J.G., 1980: The effect of land use on water quality in New Zealand. In "Seminar on Land Use in Relation to Water Quantity and Quality". Nelson Catchment Board and Regional Water Board. pp. 40-60.
- Downes, M.T. 1978a: An improved hydrazine reduction method for the automated determination of low nitrate levels in freshwater. *Water Research* 12: 673-6.
- Downes, M.T. 1978b: An automated determination of low reactive phosphorus concentrations in natural waters in the presence of arsenic, silicon and mercuric chloride. *Water Research* 12: 743-6.
- Goguel, R.L. 1972: Methods for the determination of some components of thermal waters by atomic absorption spectroscopy. *Chemistry Division Report No. 2151. Department of Scientific and Industrial Research.*
- Livingstone, D.A. 1963: Chemical composition of rivers and lakes. In "Data of Geochemistry". *US Geological Survey Professional Paper 440G.* US Geological Survey.

- Nicholls, K.H. 1975: A single digestion procedure for rapid manual determinations of Kjeldahl nitrogen and total phosphorus in natural waters. *Analytica Chemica Acta* 76: 208-212.
- NWASCO, 1982: Physical and chemical methods for water quality analysis. *Water and Soil Miscellaneous Publication No 38*. Ministry of Works and Development, Wellington.
- NWASCO, 1983: Biological methods for water quality surveys. *Water and Soil Miscellaneous Publication No 54*. Ministry of Works and Development, Wellington.
- Riddell, D.C. 1980: Hydrology of the Motu River. Ministry of Works and Development, Wellington. Unpublished report.
- Technicon, 1978: Ammonia in water and seawater. Industrial method No. 154-71W/B. Technicon Industrial Systems, Tarrytown New York.

SECTION 5: MOTU RIVER SEDIMENTS: A SOURCE OF EASTERN BAY OF PLENTY BEACH MATERIAL

R.K. Smith,
Water Quality Centre,
Ministry of Works and Development, Hamilton

INTRODUCTION

This section examines the sediment yield of the Motu River, the characteristics of the sediment, the role of this material in supplying eastern Bay of Plenty beaches, and the likely effects on coastal stability. The work was carried out as part of Motu River power investigations and also provided information for the Motu Water Conservation Order Hearing.

RIVER SEDIMENT YIELDS AND CHARACTERISTICS

Sediment Yield

Stream flow and suspended sediment concentrations in the Motu River have been measured by Ministry of Works and Development over a wide range of gauge heights, especially at Houpoto. Flow has been monitored since 1958 but the flow ratings at Houpoto were revised in 1977. This revision reduced the high stage discharge significantly, and consequently, affects estimates of sediment yield. Adams (1979), Riddell (1980) and Griffiths (1982) based their sediment yield estimates on the earlier ratings and report higher yields than those of the author (Table 5.1). The sediment yield from the Motu is the highest of the rivers in the region of coast under consideration (Fig. 5.1). With the exception of the Waioeka River, the Motu catchment is an order of magnitude larger than the other rivers in this region.

Table 5.2 lists the estimated average annual suspended sediment yield from the catchment in cubic metres per square kilometre and is based on sediment yield data from the Motu River at Houpoto. An even rate of erosion through the catchment has been assumed. The average annual suspended sediment yield for the period 1958-1978 is 766 m³/km² and the whole catchment yields an average of 1 067 000 m³/yr. For purposes of comparison with estimates expressed in tonnes/year, the sediment density is taken to be 2 t/m³.

Table 5.1 Estimates of mean annual sediment yield for the Motu River at Houpoto (t/year × 10⁶)

Author	Suspended	Bedload	Total	Comment
Adams (1979)	4.5	0.3	4.8	Bedload calculated using empirical formula
Riddell (1980)	2.9	0.29	3.2	Bedload assumed to be 10% of suspended load
Griffiths (1982)	2.71	0.19	2.90	Bedload estimated as 7% of suspended load
O'Loughlin (1982)			4.2	Estimate based on landslide volumes observed on aerial photographs
Smith (this study)	2.14	0.06	2.2	Bedload estimated from beach accretion, and sediment size characteristics

Sediment Characteristics

Samples of river sediment were collected from both stream channels and berm areas of the Motu delta to ascertain sediment particle size distributions and the mean volumes of each size class carried by the river annually for the period 1958-1978 (Table 5.3).

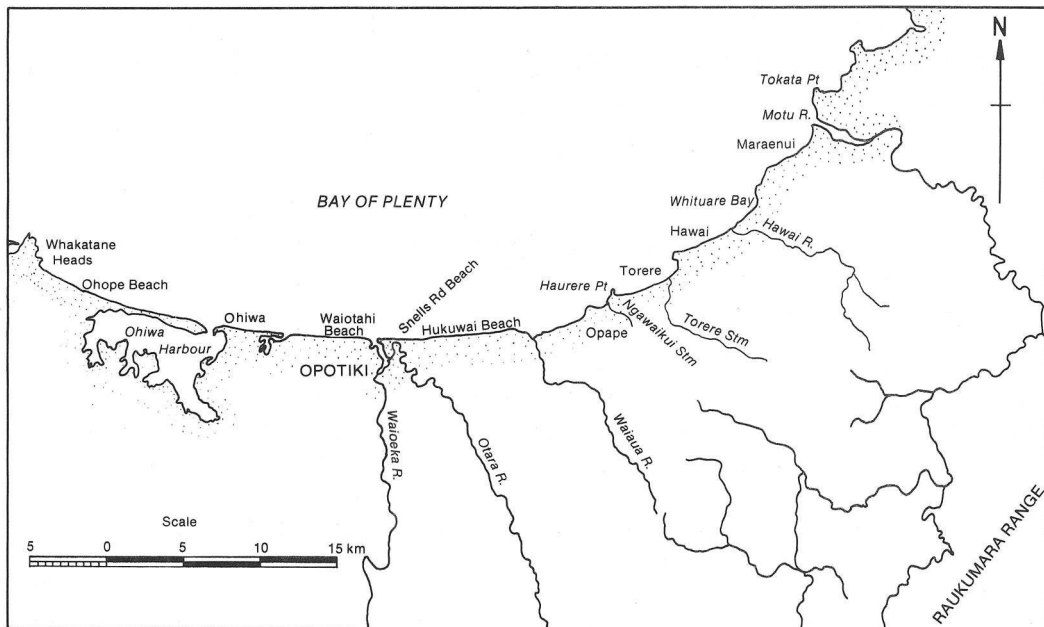


Fig 5.1 The Motu River and beaches of the eastern Bay of Plenty.

Table 5.2 Suspended sediment yields Motu River at Houpoto

Year	Yield (m^3/km^2)
1958	1241
1959	255
1960	984
1961	178
1962	1260
1963	639
1964	734
1965	1641
1966	682
1967	610
1968	427
1969	215
1970	2267
1971	1273
1972	535
1973	334
1974	656
1975	468
1976	533
1977	239
1978	916

Table 5.3 The average annual sediment yield and size grades for the Motu River 1958-1978

Size (mm)	Volume (m^3)
> 64	1 300
53-64	700
37-53	5 000
26-37	7 000
19-26	6 000
13-19	3 000
9-13	3 000
2.5-9.0	3 000
1.0-2.5	90 000
0.5-1.0	250 000
0.25-0.5	371 000
0.125-0.25	152 000
0.063-0.125	75 000
0.043-0.063	48 000
< 0-0.043	79 000

Plotting data from Table 5.3 produces a sediment distribution curve which, when examined using the technique of Visher (1969), can be separated into three basic segments (Fig. 5.2). Up to 3% of the average annual sediment yield (by volume) is indicated as being bedload (coarser than 2 mm), 77% as periodic traction load (2-0.2 mm) and 20% permanently suspended load (less than 0.2 mm). Visher's method of sediment analysis suggests that about 3% of the total sediment load of the Motu River is bedload, whereas other workers have assumed or estimated bedloads of around 7-10% of total yield (Table 5.1).

Sediment Supply to Coastal Beaches

For the purposes of estimating the amount of sediment material supplied to eastern Bay of Plenty beaches by the Motu River, it is assumed that all the bedload from the river arrives on the beaches plus a proportion of the suspended load. The estimates of mean annual bedload vary, according to author, from 3 to 10% of the total sediment yield or about 30 000 to 110 000 m³/yr.

Based on studies of the Waipaoa River (Smith 1976), which enters Poverty Bay, it is assumed that about 1% (about 11 000 m³/yr) of the suspended sediment load from the Motu River is deposited on beaches. This is sand-sized material.

Totalling and rounding off, it is thus estimated that a mean of about 40 000 to 120 000 m³ sand-size and shingle material is supplied to eastern Bay of Plenty beaches annually. This will vary up to an order of magnitude between years because of the wide annual variation in yield from the river (Table 5.2). In the author's opinion the estimate of 40 000 m³/yr is more realistic.

COASTLINE CHANGES AND SEDIMENT CHARACTERISTICS

The importance of the Motu River to coastal stability can be assessed from coastline changes and sediment characteristics between the Motu River mouth and Whakatane Heads.

Coastline Changes (1867 to Present)

Early surveys of the coastline were associated with European settlements located near the coastline (Lands and Survey Department plans). These cadastral surveys, together with aerial photographs from the 1940s, provide a long-term record of shifts in coastline position (Table 4).

Table 5.4 Coastline changes, Eastern Bay of Plenty

Beach	Change	Material
Maraenui	Stable	Shingle
Whituare	Accreting	Shingle
Hawai	Stable	Shingle
Torere	Accreting	Shingle
Opape-Waiaua	Eroding	Coarse sand
Hukuwai	Fluctuating	Sand
Waiotahi	Fluctuating	Sand
Ohiwa	Fluctuating	Sand
Ohope	Accreting	Sand

Observations from aerial photographs (Healy *et al.* 1977), from the cadastral surveys, and from Ohiwa (Smith 1976, Gibb 1977) indicate that there have been at least four distinct periods of coastline change in the Bay of Plenty, with two periods of erosion and two periods of accretion since records commenced (Table 5.5). Records are too infrequent to be certain these are the only periods of change between 1867 and present.

These periods (Table 5.5) agree with those described by Williams (1977) at Whatipu on the northern side of the Manukau Harbour entrance and it is suggested that they relate to two

Table 5.5 Periods of beach erosion and progradation in the Eastern Bay of Plenty

Period (approximate)	Characteristics
1 1867-1911	Progradation
2 1911-1930	Erosion
3 1940s-1960s	Progradation
4 1960s-1977	Erosion

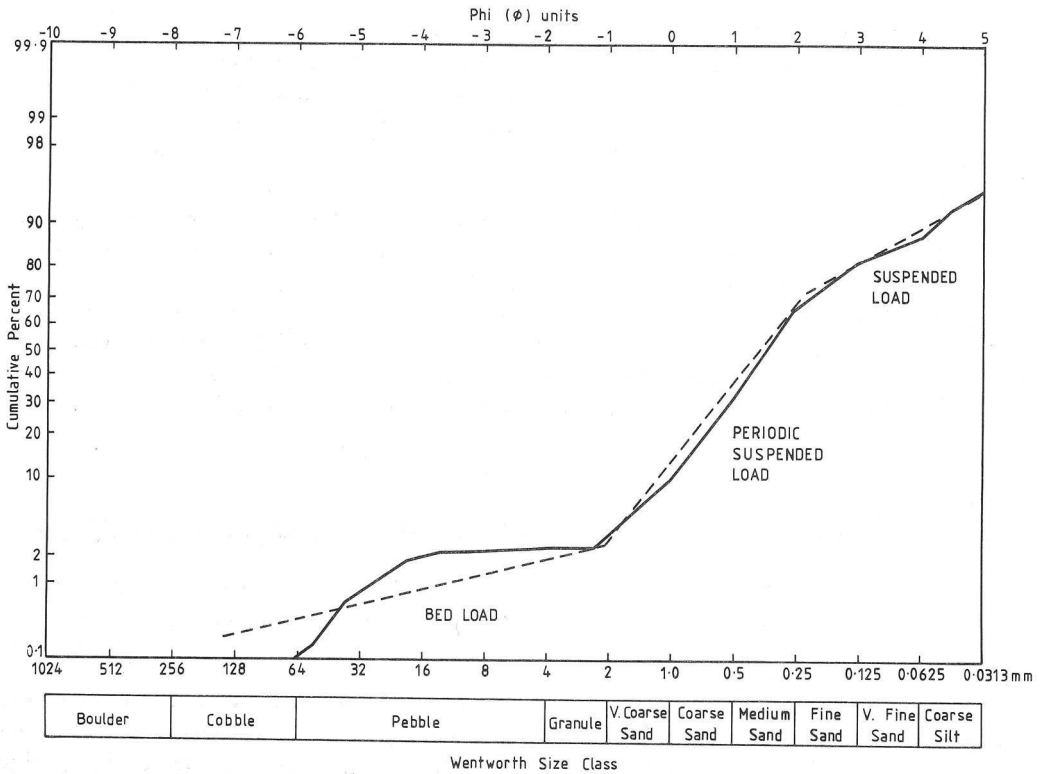


Fig 5.2 Separation of the Motu River sediment yield into transport components using the method of Visher (1969).

periods of increased storm activity in the south-west Pacific since European settlement. The survey and photographic data demonstrate that overall the shingle beaches have tended to remain stable or prograde, while the sand beaches, with the exception of Ohope, have tended to fluctuate. Ohope Beach has continued to prograde throughout the period of record.

Beach Sediment Characteristics

Beach sediments were sampled in April 1976 along the coast from the mouth of the Motu River to the western end of Ohope Beach at the base of Whakatane Heads. South-west of

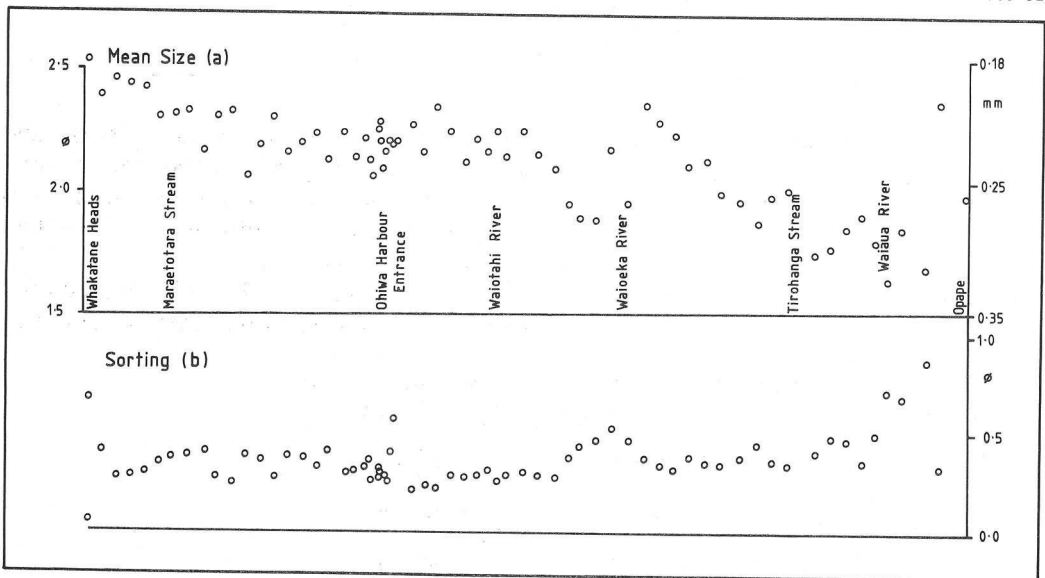


Fig 5.3 Beach sediment mean size and costing for the sandy beaches from Opape to Ohope.

the Motu River the beach is a continuous shingle feature extending to Haurere Point. Along this beach, material grain size decreases ($r = 0.640$, $P = < 0.01$) and particle roundness increases ($r = 0.587$, $P = < 0.01$) with increasing distance from the river mouth. This indicates that net longshore drift is to the south-west. Beyond Opape the beach grain size reduces further and the beach sediments become better sorted sands towards the west suggesting longshore drift continues in a westerly direction (Fig. 5.3).

North of the Motu River mouth the cliffs at Tokata Point appear to be an effective barrier to sediment movement to the north or south. There are no beach deposits along the cliff base at Tokata Point, nor do the cliffs show signs of significant erosion.

Wave Action

Wave data for the Bay of Plenty are limited to some manual, short-term observations (Davies-Colley and Healy 1978, Harray 1977, Christopherson 1977) and wave rider buoy data from Hicks Bay (Pickrill and Mitchell 1979). All these observations show a dominant north-easterly wave approach. Forelands in the lee of the islands of Motiti and Motuhora and the Rurima Rocks indicate the dominant wave direction is 33.6° . Westerly and north-westerly wave conditions occur from time to time and cause short-term reversals in sediment drift. Westerly conditions occur for approximately 10% of the time (Pickrill and Mitchell 1979).

Amounts of Sediment Transported

Beach profile surveys carried out by Ministry of Works and Development, together with the cadastral surveys from Lands and Survey enable estimates to be made of the average amount of material being eroded or deposited annually along the coastline. It is estimated that in the shingle region (Motu River mouth to Haurere Point) around $30\,000\text{ m}^3$ is deposited each year and in the sandy region (Opape to Ohope) around 5000 to $10\,000\text{ m}^3$ is deposited each year. This totals to $35\,000$ to $40\,000\text{ m}^3/\text{yr}$ and compares closely with the lower estimated range of material supplied by the Motu River ($40\,000$ – $12\,000\text{ m}^3/\text{yr}$). Losses of material by abrasion are an unknown.

The rates of sediment transport along the coast are unknown, although for the shingle beaches the amount of transport is higher than in the sandy beaches. The angle of wave approach is apparently greater in the shingle regions than in the sandy regions and this will provide greater energy for longshore drift.

DISCUSSION

The Motu River appears to be an important source of sediment for beach material in the eastern Bay of Plenty. Grain size data and wave conditions indicate there is a net longshore drift to the south-west from the river mouth to Whakatane Heads.

The volume of shingle transported along the coast, estimated from both the beach surveys and the sediment characteristics of material from the river, indicated that Whituare Bay and Torere Beach are areas of accretion. Accretion at Torere Beach will probably continue until the shingle beach has extended around the headland. At present only coarse greywacke sand, some of which is deposited in Ngawaikui Stream Bay, pea gravel and fine sand, are transported around Haurere Point and can be found in deposits along the base of the cliffs adjacent to Opape.

Historical coastline change evidence does not indicate the destination for this greywacke sand. The beach between Opape and Waiaua has shown signs of accretion (1880–1913) followed by erosion (1913–1976). Aerial photographs from 1945 confirm a pattern of change similar to Ohiwa (Healy *et al.* 1977). At present the coastline is continuing to retreat and is slightly landward of its 1880 position. Sediment eroded from this beach and that supplied by the Motu River are apparently transported beyond the Waiaua River mouth. Healy *et al.* (1977) show that since 1945 the beach between the Waiaua and Waioeka Rivers has been accreting. However, survey data indicate little or no long-term change, the beach being in the same position at present as it was in 1867. An exception is the 2 km adjacent to the

Waioeka River mouth where up to 160 m progradation has occurred. Waiotahi Beach and the coast as far as Ohiwa has a record of erosion and accretion (Pullar 1976 and Healy *et al.* 1977). Only two surveys, 1923 and 1976, cover the eastern end of the beach and indicate overall accretion. Both the survey and the aerial photographic data indicate steady accretion of Ohope Spit. However, Pullar (1976) presents evidence of erosion in Ohiwa Harbour and short-term erosion at Ohope township associated with storm events and also with extraordinary water levels caused by the tsunamis associated with the Chilean earthquakes of 1960. Ohope Spit has had an almost continuous accretional history and appears, like Torere Beach, to be an important area of deposition. Sand-sized sediments supplied by the Motu, Waioua, and Waioeka Rivers are probably deposited on Ohope Spit. All the other beaches have histories of both accretion and erosion but in the long term show little change.

Alternative zones of deposition of new sediment are nearshore, offshore, in the river estuaries, or in river mouth bars. There are no data available on nearshore deposition rates but Kahn and Glasby (1978) have described offshore cores and rates of sedimentation to be similar to other offshore areas around the North Island despite the adjacent unconsolidated sediments of the Bay of Plenty volcanic zone. There is uncertainty over whether the estuaries act as sediment sinks for beach sands. Paul (1966) described sedimentation in Ohiwa Harbour as being mainly that of terrestrial sediments being deposited around the inland extremities. Freestone (1976) found that sediment transport in and out of the harbour on the flood and ebb tides was in balance. Gibb (1977), however, comparing a historical cross-section taken near the harbour entrance and a different cross-section measured by Freestone (1976), estimated that the harbour had infilled by one-third between 1867 and 1976. Healy *et al.* (1977) also postulated that Ohiwa Harbour was a sediment sink and that sediment for Ohope Spit was derived from further west.

Some sediment storage, albeit temporary, occurs on the bar deposits at the mouth of each estuary. The volume of material held in this way, and the period it remains as part of the bar deposit, is unknown. However, the continual supply of new sediment from the eastern Bay of Plenty catchments must be deposited in the coastal and nearshore zone. Beach sediment characteristics adjacent to the Waioua and Waioeka River mouths (Fig. 5.3) indicate a significant volume of material is being added to the beach deposits from the rivers and this material, together with sand from the Motu River, is deposited at some point.

The continued deposition at Ohope suggests that the spit is the main area of deposition in the region under discussion and that the bars and estuaries are probably temporary or short-term storage areas. There is insufficient evidence to prove conclusively that the estuaries are significant sediment sinks. The apparent net drift towards the west corresponds to the apparent dominant wave approach from the north-east. The probable destination of most of the sediments from the eastern Bay of Plenty catchments is Ohope Spit and it is suggested that Whakatane Heads forms the westward limit to this system.

IMPLICATIONS OF DEVELOPMENT

The most significant development option which could physically affect the residual river and the coast adjacent to the Motu River mouth would be the damming of the river channel resulting in a loss of sediment (ie, all of the bedload and much of the suspended load) to the coast.

It is believed that the main effects would be as follows:

- (a) The riverbed downstream of dams will erode until it either reaches bedrock or becomes armoured with interlocking cobbles and boulders.
- (b) The tide will extend further upstream thereby increasing the estuary size at the mouth.
- (c) The 19 km long stretch of gravel beaches between the Motu River and Haurere Point (ie, beaches at Maraenui, Whituare, Hawai and Torere) will start to erode in proportion to the reduced Motu River bedload output at the coast. Property and assets could be threatened within several years.
- (d) The 15 km long sandy beach between Opape and Opotiki will probably start to erode in proportion to the reduced Motu River suspended load supplied to the sea floor.

- (e) Damage to the foredunes between Opape and Opotiki would result in seawater intrusion to the low-lying land behind during storm surges.
- (f) There may be minimal effects west of Opotiki.

SUMMARY

The Motu River contributes a wide range of material to the coast and nearshore zone of the eastern Bay of Plenty. The coarser material, about 30 000 m³ annually, is deposited on the beaches between the Motu River mouth and Haurere Point. Sand-sized material is moved further west but, because of the lower angle of wave approach, the volume moved annually is likely to be small, probably between 5000 m³ and 10 000 m³. Short-term reversals of the westward drift will occur with west and northwesterly waves. However, because these are locally developed wind waves, their power to move sediment is limited by their short period and low amplitude.

The Motu River is the largest catchment discharging into the eastern Bay of Plenty and is a major source of new material supplied to the coast. Impoundments on the Motu River would reduce the supply of sediment and probably cause coastal erosion in the region between Motu River Mouth and Opotiki.

REFERENCES

- Adams, J. 1979: Sediment loads of North Island Rivers, New Zealand: A reconnaissance. *Journal of Hydrology (NZ)* 18(1): 36-48.
- Christopherson, M.J. 1977: The effect of sand mining on the erosion potential of Whiritoa Beach. Unpublished thesis, University of Waikato.
- Davies-Colley, R.J.; Healy, T.R. 1978: Sediment and hydrodynamics of the Tauranga entrance to Tauranga Harbour. *NZ Journal of Marine and Freshwater Research* 12(3): 225-236.
- Freestone, H. 1976: Report of a full cycle tide gauging carried out at Ohiwa Harbour entrance April 1976. Typescript report, Ministry of Works and Development, Rotorua.
- Gibb, J.J. 1977: Late Quaternary sedimentary processes at Ohiwa Harbour, eastern Bay of Plenty, with special reference to property less on Ohiwa Spit. *Water and Soil Technical Publication No. 5*. Ministry of Works and Development, Wellington.
- Griffiths, G.A. 1982: Spatial and temporal variability in suspended sediment yields of North Island basins, New Zealand. *Water Resources Bulletin* 18(4): 575-583.
- Harray, K.G. 1977: Beach erosion and sediments of Waihi Beach. Unpublished thesis, University of Waikato.
- Healy, T.R.; Harray, K.G.; Richmond, B. 1977: *Bay of Plenty Coastal Erosion Survey Occasional Report No. 3*. Department of Earth Sciences, University of Waikato.
- Kahn, B.P.; and Glasby, G.P. 1978: Tephra distribution and sedimentation rates in the Bay of Plenty, New Zealand. *NZ Journal of Geology and Geophysics* 21(1). 49-70.
- O'Loughlin, C.L. 1982: A preliminary investigation of slope stability in the Motu catchment. New Zealand Forest Service, Forest Research Institute. Unpublished report prepared for the working party on forest, land and wildlife values.
- Paul, L.J. 1966: Observations of past and present mollusc beds in Ohiwa Harbour, Bay of Plenty. *NZ Journal of Science* 9(1): 31-40.
- Pickrill, R.A.; Mitchell, J.S. 1979: Ocean wave characteristics around New Zealand. *NZ Journal of Marine and Freshwater Research* 13(4): 501-520.
- Pullar, W.A. 1976: Notes on coastal progradation and recession in the Gisborne and Bay of Plenty districts. In "Case studies of coastal progradation in New Zealand during the past century" (Edited by R.F. McLean). Contribution to the International Geographical Union's Working Group on the dynamics of shoreline erosion.
- Riddell, D.C. 1980: Hydrology of the Motu River. Unpublished report. Power Directorate, Ministry of Works and Development, Wellington.
- Smith, R.K. 1976: Ohiwa Spit erosion. Unpublished report. Ministry of Works and Development, Napier.
- Visher, G.S. 1969: Grain size distribution and depositional processes. *Journal of Sedimentary Petrology* 39: 1074-1106.
- Williams, P.W. 1977: Progradation at Whatipu Beach 1844-1976, Auckland, New Zealand. *NZ Geographer* 33(2): 84-89.

APPENDIX 1a Water quality data for Motu River; longitudinal survey 23 April 1981

Determinand	Site Numbers										
	1	3	4	5	6	7	8	9	12	13	15
Inst discharge (m ³ /s) ⁺	4.5 ⁽¹⁾	—	—	14.5 ⁽²⁾	—	—	—	4.4 ⁽³⁾	—	—	37 ⁽⁴⁾
Temperature (°C)	14.0	13.8	14.0	13.4	13.9	15.1	13.6	13.6	14.3	13.3	14.6
pH	7.6	7.8	8.0	8.1	8.0	7.9	7.8	7.8	7.7	7.8	7.7
Conductivity (mS/m) at 25°C	7.7	8.2	18.9	11.2	13.5	6.4	12.2	6.9	10.1	7.8	9.9
Alkalinity (g/m ³ CaCO ₃)	25	24	78	38	45	18	41	19	32	24	31
Total Hardness (g/m ³ CaCO ₃)	25	26	79	43	54	18	46	19	37	26	34
NH ₄ -N (mg/m ³)	4	4	9	5	11	9	7	20	18	11	15
NO ₃ -N (mg/m ³)	240	202	74	176	112	172	150	168	159	119	145
TKN (mg/m ³)	155	130	75	130	205	85	175	70	75	150	120
DRP (mg/m ³)	9	7	3	6	7	16	8	7	10	7	13
TDP (mg/m ³)	15	14	9	17	12	23	14	26	19	17	17
TP (mg/m ³)	25	24	12	27	78	25	47	24	32	24	32
SO ₄ (g/m ³)	6	6	9	8.6	14.5	4.5	10	5	9.5	6	8
Cl (g/m ³)	4.8	5.6	5.4	5.4	5.2	5.3	4.7	5.9	6.4	4.5	5.2
Ca (g/m ³)	7.5	7.8	29.6	14.8	18.4	4.7	15.8	5.4	12.1	7.9	11.1
Mg (g/m ³)	1.6	1.6	1.3	1.5	1.8	1.4	1.6	1.4	1.6	1.5	1.6
Na (g/m ³)	5.7	5.7	6.5	6.0	6.6	5.2	6.0	5.5	6.2	5.1	5.8
K (g/m ³)	1.0	1.1	0.7	0.9	1.1	0.7	0.9	0.7	1.1	0.5	0.8
Si (g/m ³)	9.0	9.1	5.9	7.6	4.7	8.5	6.6	8.0	7.1	5.7	4.2
270F (Absorbance x 1000)	62	62	37	45	43	14	41	19	46	19	33
270U (Absorbance x 1000)	72	71	39	54	377	18	148	24	84	35	93
Turbidity (FTU)	1.8	2.3	0.8	1.7	67	0.6	22	0.6	8.7	2.8	10.0
Suspended solids (g/m ³)	—	10	2	31	133	1	30	6	20	6	17

⁺The water level recording site numbers (see map 1.1) are given in parentheses alongside the discharge figures.

Appendix 1b Water quality data for Motu River; longitudinal survey 25 January 1983

Determinand	Site Numbers												
	1	3	4	5	6	7*	8	9	10	11	12	13	15
Inst discharge (m ³ /s) ⁺	1.5 ⁽¹⁾	—	—	7.0 ⁽²⁾	—	—	—	1.3 ⁽³⁾	—	—	—	—	10.9 ⁽⁴⁾
Temperature (°C)	15.2	16.0	12.5	13.0	16.0	16.3	15.2	15.5	14.0	16.0	15.5	15.0	16.8
pH	7.4	7.7	8.0	8.0	7.9	7.7	7.9	7.7	7.9	7.9	7.9	7.8	7.8
Conductivity (mS/m) at 25°C	9.3	10.3	21.6	17.3	14.0	7.2	15.4	7.9	11.7	12.5	12.5	10.3	12.2
Dissolved oxygen (g/m ³)	10.9	11.4	18.2	11.4	8.6	8.1	12.8	10.5	8.6	8.6	8.5	10.2	9.8
Alkalinity (g/m ³ CaCO ₃)	30	29	79	50	42	59	46	20	33	38	36	30	36
Total hardness (g/m ³ CaCO ₃)	27	29	89	63	47	19	55	21	36	41	41	32	40
NH ₄ -N (mg/m ³)	4	13	<1	9	9	4	<1	6	9	4	8	7	7
NO ₃ -N (mg/m ³)	20	9	7	10	10	39	5	17	8	5	6	7	6
TKN (mg/m ³)	155	150	40	25	70	50	55	60	45	60	55	35	55
DTKN (mg/m ³)	120	125	40	25	—	50	55	50	45	60	55	—	55
DRP (mg/m ³)	9	5	1	2	3	19	4	13	9	6	6	10	6
TDP (mg/m ³)	18	12	5	7	5	18	9	16	12	10	9	10	9
TP (mg/m ³)	27	18	5	7	7	20	10	20	14	9	10	10	12
SO ₄ (g/m ³)	4.0	6.2	14.2	22.9	11.8	3.8	10.9	3.0	9.3	8.3	8.1	8.8	10.8
Cl (g/m ³)	5.3	7.3	5.3	4.6	6.1	5.1	5.4	5.6	4.8	5.6	5.2	4.4	5.7
Ca (g/m ³)	8.0	8.7	33.2	21.7	16.1	5.2	18.7	5.9	10.9	13.6	13.3	9.7	12.7
Mg (g/m ³)	1.6	1.7	1.5	2.0	1.7	1.4	1.9	1.4	2.2	1.8	1.8	1.8	1.9
Na (g/m ³)	6.1	6.8	5.3	6.1	6.3	5.5	6.3	5.7	6.2	6.1	6.2	6.0	6.2
K (g/m ³)	1.3	1.3	0.9	1.0	1.4	0.9	1.1	1.0	1.1	1.0	1.1	1.0	1.1
Si (g/m ³)	8.8	7.8	5.9	4.6	6.3	6.9	5.5	6.8	5.0	6.0	5.7	5.1	5.5
COD (g/m ³ O ₂)	5	5	2	2	3	3	1	1	<1	3	5	4	6
270F (Absorbance x 1000)	55	56	22	21	32	13	27	18	19	24	23	16	22
270U (Absorbance x 1000)	65	61	23	22	33	14	28	19	25	25	25	19	25
400F (Absorbance x 1000)	8	7	3	2	4	1	3	2	2	3	3	2	2
400U (Absorbance x 1000)	11	10	3	3	5	2	4	3	5	4	4	4	4
Turbidity (FTU)	1.5	1.4	0.5	0.7	0.6	0.7	1.1	0.9	1.3	0.9	0.9	1.2	1.3
Suspended solids (g/m ³)	1.2	4.3	0.1	0.3	0.4	0.2	0.8	0.4	1.3	0.9	1.5	1.0	0.6

⁺The water level recording site numbers (see map 1.1) are given in parentheses alongside the discharge figures.

*For this sample there was no ion balance (APHA, 1975). It appears as though the alkalinity value is too high. This could not be verified from laboratory data sheets.

Appendix 1c Water quality data for Motu River; longitudinal survey 23 February 1983

Determinand	Site Numbers													
	1	3	4	5	6	7	8	9	10	11	12	13	15	
Inst discharge (m ³ /s)*	1.0 ⁽¹⁾	—	—	5.2 ⁽²⁾	—	—	—	0.7 ⁽³⁾	—	—	—	—	6.4 ⁽⁴⁾	
Temperature (°C)	16.0	16.0	13.5	13.0	15.5	16.5	16.0	16.0	14.0	16.0	16.0	14.0	18.5	
pH	7.4	7.7	8.0	8.0	7.9	7.8	8.0	7.7	7.9	8.0	8.0	7.9	7.7	
Conductivity (mS/m) at 25°C	9.8	11.6	22.1	18.5	15.2	7.4	17.0	8.0	12.4	13.9	13.7	11.1	7.4	
Dissolved oxygen (g/m ³)	8.0	9.0	9.8	9.8	10.0	9.5	8.8	8.2	10.1	9.7	9.6	9.5	7.7	
Alkalinity (g/m ³ CaCO ₃)	29	31	84	57	45	19	53	21	36	40	40	33	39	
Total hardness (g/m ³ CaCO ₃)	28	33	93	71	55	18	64	22	41	49	47	36	45	
NH ₄ -N (mg/m ³) ⁺	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	< 25	
NO ₃ -N (mg/m ³)	27	10	6	16	12	44	11	25	22	8	9	7	8	
TKN (mg/m ³)	180	230	75	65	165	65	70	55	70	60	50	35	65	
DTKN (mg/m ³)	155	175	55	65	110	55	70	55	70	60	50	35	45	
DRP (mg/m ³)	12	5	1	5	4	15	6	14	14	7	10	14	15	
TDP (mg/m ³)	23	11	4	7	7	16	7	16	13	9	12	16	12	
TP (mg/m ³)	34	21	5	9	20	21	9	16	14	11	12	16	21	
SO ₄ (g/m ³)	4.6	6.4	15.1	21.4	11.1	4.6	14.8	4.6	—	11.1	11.9	7.9	9.5	
Cl (g/m ³)	6.9	9.8	5.8	4.6	7.7	5.3	5.9	5.8	5.2	6.6	6.3	5.1	6.6	
Ca (g/m ³)	8.7	10.4	35.0	24.9	19.0	5.2	22.2	6.4	12.7	16.3	15.7	11.4	14.8	
Mg (g/m ³)	1.6	1.8	1.4	2.0	1.9	1.3	2.0	1.4	2.2	1.9	1.9	1.9	2.0	
Na (g/m ³)	6.4	7.6	5.6	6.4	6.7	5.2	6.6	5.6	6.3	6.2	6.2	5.9	6.3	
K (g/m ³)	1.5	1.7	1.0	1.0	1.3	1.0	1.2	1.0	1.1	1.2	1.2	1.0	1.2	
Si (g/m ³)	8.8	8.1	5.8	4.3	6.2	7.3	6.1	7.4	5.0	6.1	5.9	5.1	5.9	
COD (g/m ³ O ₂)	4	9	6	4	7	3	2	1	6	3	2	1	2	
270F (Absorbance x 1000)	63	62	21	22	34	12	26	17	18	23	22	14	19	
270U (Absorbance x 1000)	72	69	22	23	41	14	28	17	20	25	24	16	21	
400F (Absorbance x 1000)	9	8	2	2	4	1	3	2	2	2	2	1	2	
400U (Absorbance x 1000)	13	13	4	3	10	4	5	4	4	4	4	3	3	
Turbidity (FTU)	1.3	1.2	0.3	0.3	1.8	0.7	0.4	0.5	0.7	0.4	0.3	0.7	0.3	
Suspended solids (g/m ³)	1.4	1.3	0.2	0.6	17.7	20.8	0.7	0.4	2.1	0.5	0.9	1.9	1.3	

⁺Problem with background contamination. Limit of detection estimated at 25 mg/m³ N.

*The water level recording site numbers (see map 1.1) are given in parentheses alongside the discharge figures.

WATER & SOIL TECHNICAL PUBLICATIONS

1. Liquid and waterborne wastes research in New Zealand, 1976 (\$1)	1977
2. Sampling of surface waters. (\$1)	1977
3. Water quality research in New Zealand 1976. (\$1)	1977
5. Late Quaternary sedimentary processes at Ohiwa Harbour, eastern Bay of Plenty with special reference to property loss on Ohiwa. (\$1)	1978
9. Research and Survey annual review 1977. (\$2)	1978
11. The Waikato River: A water resources study. (\$12)	1979
12. A review of the habitat requirements of fish in New Zealand rivers. (\$3)	1979
13. The Ruahine Range: A situation review and proposals for integrated management of the Ruahine Range and the rivers affected by it. (\$5)	1978
14. A Survey of New Zealand peat resources. (\$10)	1978
15. Effects of urban land use on water quantity and quality: an annotated bibliography. (\$5)	1980
16. Research and Survey annual review 1978. (\$2)	1979
17. Investigations into the use of the bacterial species <i>Bacillus stearothermophilus</i> and <i>Escherichia coli</i> (H ₂ S positive) as tracers of groundwater movement. (\$1.50)	1980
18. A review of some biological methods for the assessment of water quality with special reference to New Zealand. Part 1. (\$3)	1979
19. The frequency of high intensity rainfalls in New Zealand, Part I. A. I. Tomlinson (\$5)	1980
20. Regional flood estimation in New Zealand. (\$8)	1982
21. Coastal hazard mapping as a planning technique for Waipuu County, East Coast, North Island, New Zealand. (\$5)	1981
22. A review of some biological methods for the assessment of water quality with special reference to New Zealand. Part 2. (\$4)	1981
23. Hydrology of the catchments draining to the Pauatahanui Inlet. (\$3)	1981
24. Potential for contamination of the Heretaunga Plains aquifers (\$10)	1982
25. Revised checklist of freshwater algae of New Zealand. Part 1. (\$10)	1984
26. Revised checklist of freshwater algae of New Zealand. Part 2. (\$10)	1984

WATER & SOIL MANAGEMENT PUBLICATIONS

1. Regional planning and development. (\$1)	1975
2. Wetlands. (\$1)	1975
5. Forest operations guideline. (\$2)	1978
6. A guideline for the construction of access tracks and firebreaks. (\$2)	1980
7. A guideline to skifield development. (\$2)	1980
8. A wetlands guideline. (\$5)	1982
9. A water and soil guideline for mining. (\$10)	1983
10. A water and soil guideline for pipeline easements. (\$3)	1985