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EROSION AND SEDIMENTATION ON THE WAIAU RIVER AND COAST

An interim report to the Erosion and Sedimentation Task Group of the Waiau River Working Group.

by

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Curriculum Vitae of the Authors

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Dr James Shulmeister is a Post-Doctoral Research Fellow at the Department of Geography, University of Canterbury, working with the Coastal Group. He is currently examining the geomorphic development of the coastal systems of a number of Southland Rivers including the Waiau, the Aparima, the Oreiti, and the Mataura. His interests centre on the evolution of the coast over the last 6000 years.

Dr Gary Brierley is a Post-Doctoral Research Fellow at the Department of Biogeography and Geomorphology, the Australian National University. He has worked extensively on gravel rivers in Canada, New Guinea and the Pacific Islands. He is currently working on the lower reaches of the Waiau, Aparima, Oreiti and Mataura Rivers in a co-operative project with Dr James Shulmeister.

Foreword

This document contains two independent reports on the current state of knowledge of the Waiau River and Waiau Coastal System. These reports were compiled after a preliminary visit to the Waiau in December 1991, on the request of Dr Glen Lauder, co-ordinator of the Erosion and sedimentation task group of the Waiau Working Group.

The first report by Dr G.J. Brierley provides a preliminary river reach analysis for the Waiau River. It also highlights areas where research is required and suggests a methodology for approaching these questions.

The second report by Dr J. Shulmeister and Prof. R.M. Kirk describes the Waiau coastal system in the light of current understanding of gravel river coasts. It identifies several major areas where current knowledge is incomplete, in respect of the Waiau, and outlines the research required to correct this situation. A timetable for research is also provided.

Both reports stress the absence of prior scientific work on the Waiau and the need for fundamental information on the behaviour of the river and coast to be put in place so that areas of concern and future management can be addressed. Though the river and the coast can be examined independently, the systems are interlinked and should ideally be investigated in tandem.

James Shulmeister 22-1-92
(Report Compiler)

Controls on channel changes of the Waiau River

An interim report submitted to Glen Lauder (Department of Conservation, Invercargill), Co-ordinator of the Erosion and Sedimentation Task Group in the Waiau River Working Party

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Figure 1 : The mouth of the Waiau River. Note the very confined channel at the mouth, with the pronounced gravel barrier and lagoon system. The main channel of the Waiau River is clearly divided, although it adopts a broadly sinuous course. This reach is referred to as a "wandering gravel-bed river". Note also the etched nature of the grassed floodplain, indicating that the river mouth has been considerably more dynamic in the past, with channel configurations indicative of a braided channel style.

Introduction

Before river responses to altered environmental conditions can be predicted, the character of the river and its evolution must be understood. Relationships among forms and processes in both the river channel and on its associated floodplain, along with reliable interpretation of the controls on river development, provide the primary base-line data for evaluating river response to changes in environmental controls. This base-line data must be collected and collated in a comprehensive, easily managed (i.e. hands-on) manner, such that it can be readily and reliably applied to subsequent comparative and other analytical studies (e.g. time-sequence analysis).

Critical to any research in the natural sciences is the establishment of a suitable conceptual framework within which to carry out the research. Research on environmental issues is interactive, prompting the use of integrative systems approaches. Hickin (1983) proposed a three-scale framework for research on river channel changes:

a) Geologic scale. This entails long-term (millenia) of river evolution over broad (i.e. regional) scales. Among the environmental controls at this scale are factors such as regional tectonic history, glaciation, etc. This conditions landscape configuration and the nature of the materials over which rivers flow.

b) Geomorphic scale. This entails analysis of medium-scale controls on river evolution at the range of tens to hundreds of years. Such research is typically applied with regard to the downstream sequence of channel and floodplain features, and characteristically differentiates the river into a series of reaches of similar character. This is termed "river reach analysis" (Kellerhals et al., 1976). Examples of environmental controls at this scale include lateral constrictions which impose channel character, and the role of discrete sediment inputs into a river system, such as those related to tributary effects.

c) Engineering scale. This is the scale of river design structures, which are characteristically implemented at local scales within constraints imposed by the "design-flood regime". Such small-scale effects are typically brought about or necessitated by the local hydrologic and/or erosion/sedimentation regime.

Implicit to this three-phase framework is the sense that controls on channel changes are extremely complex, necessitating interdisciplinary research over a range of timescales. For effective understanding and resolution of problems associated with river channel change, all three frames of reference must be addressed, entailing combined research by geologists, geomorphologists and engineers. Present day processes of river channel change must be understood in the context of longer term change. This is relevant in at least three issues :

a) Human impact on river systems can only be comprehended if the background (i.e. pre human interference) data is reliably interpreted,

b) Only with longer term records can system adjustments to events of differing magnitude be evaluated. This is especially critical in evaluating the effects of extreme flood events, and

c) Some processes operate over timeframes longer than those of direct human observation. For example, sediment wedges in river reaches may gradually be moving downstream, in response to either climate modifications or discrete sediment inputs.

In this brief report, rudimentary river reach analysis is applied within the three-phase framework outlined above. It is felt that this framework provides the most suitable basis for integrative study of the nature of channel changes on the Waiau River, and assessment of underlying controls on channel adjustments. Recent changes associated with discharge reduction can only be evaluated in the light of longer-term system evolution. Such insights are fundamental to any consideration of likely future scenarios for river development.

The layout of this report is as follows. Following a brief overview of background theory on channel styles and their controls, a preliminary assessment of river reach analysis is applied to the planform character of the Waiau River downstream of Te Anau. These preliminary observations are based solely on an air reconnaisance flight, a jet boat trip up the river, and initial examination of a 1982 air photo suite of the river. From this basis a proposal for further study of the Waiau River is outlined, in which primary base-line data on the "state-of-the-river" system would be described in detail, and the nature of underlying controls on this river condition would be assessed.

Background theory

Rivers are differentiated into two types, those which flow within their own deposits (i.e. alluvial channels), and those which are constrained by either bedrock or boulders. While the latter are doubtless very significant in areas of Southland, they are typically restricted to specific reaches, in which the river style can be said to be imposed. On the basis of channel planform (i.e. the configuration of river channels in plan-view), alluvial channels in Southland are of three primary styles. Braided rivers are multi-channelled, and typically laterally unstable. In contrast, meandering rivers are single-channelled, but sinuous. An intermediary river type, termed a "wandering gravel-bed river" is characterized by fewer channels than a braided river, and many of these channels may meander.

In this simple breakdown, channel style is described by three different terms - channel sinuosity, the number of channels, and the lateral stability of the

channels. Any one river is usually made up of a combination of these differing styles.

The two primary controls on channel planform type are the channel bed slope and the particle size of the channel bed material. A further significant control, however, is the nature of the flow regime, as braided rivers are characteristically associated with highly fluctuating discharges, while meandering rivers are typically associated with more uniform flow. Indeed, many rivers have been observed to change their planform style under differing flow conditions. Change in any of these environmental controls may result in adjustment in channel planform style (i.e. an adjustment in channel behaviour). This is referred to as "channel metamorphosis". Assessment of controls on the character, rate and permanence of channel metamorphosis is a primary branch of research in fluvial geomorphology, and has enormous implication for river management and design of appropriate engineering structures.

Controls operating at the scale of each individual river reach determine the planform style, yet each reach must be viewed within the context of its upstream and downstream components. As such, study of the "big picture" is critical in assessment of channel evolution and adjustments to altered environmental controls. River reach analysis provides an appropriate framework for such study, as it directly links longer term controls on channel development, with local-scale considerations for design structures.

Preliminary River Reach Analysis of the Waiau River

On the basis of channel planform characteristics interpreted from a 1982 air photo run, the Waiau River can be divided into the following reaches :

a) Lake Te Anau to Lake Manapouri

In this reach the Waiau River is laterally unconstrained, and has adopted a meandering pattern with tightly curved bends (Figure 2). Air photo evidence indicates that the river has migrated significantly in the relatively recent past, as there are a significant number of meander scars and some of the bends appear close to being cut-off.

b) Lake Manapouri (Te Anau 1:50,000 sheet, GR: 944164) to Mararoa Weir (Takitimu 1:50,000 sheet, GR: 960969)

In the upstream end of this reach the Waiau River is almost straight. This channel configuration is probably imposed by the nature of the materials into which the channel has incised. While the channel is more sinuous in the lower end of this reach, evidence of active channel migration is negligible (Figure 3).

Figure 2 and 3 : River reaches a and b. The Waiau River in the Lake Te Anau to Mararoa Weir reach. Note the laterally constrained nature of the channel, which has been adopted a single channel, low sinuosity thread.





c) Mararoa Weir to 3km downstream of Redcliff Creek (Takitimu 1:50,000 sheet, GR: 918 850)

The upstream end of this reach is characterized by a series of alternating bars and occasional point bars in a reach of low to moderate sinuosity. This appears to be a relatively stable channel congifuration, wih little evidence of either lateral migration or downstream translation of depositional units. As such, these bars represent passive sedimentation zones rather than constructive macroforms which subsequently alter channel morphology.
Bar style changes in the lower half of this reach to a mid- channel, compound bar style. In many instances, these bars appear to have become bank-attached. The dissected nature of flow in this sub-reach may be attributed to the less constrained nature of flow. A large number of abandoned braid channels are observed on the adjacent floodplain. The observed downstream transition in planform style in this reach may be attributed to:
(i) Change in the character of channel boundary materials,
(ii) Input of additional, possibly coarser, sediments, or
(iii) A combination of other factors which would reduce flow competence thereby resulting in greater within-channel sedimentation.

d) 3km downstream of Redcliff Creek to Taylors Bush (Takitimu 1:50,000 sheet, GR: 938724)

A series of prominent terraces and terrace rises are evident in this reach, extending down to the contemporary channel position. These indicate that this has been a reach of significant channel adjustment in the past. At present, however, incision of the Waiau into these terrace materials (likely fluvioglacial outwash) and underlying bedrock (as evidenced at Manowai; see figure) has restricted sedimentation to the insides of bends in a series of relatively small point bars.

e) Taylors Bush to 2km upstream of Wairaki confluence (Ohai 1:50,000 sheet, GR: 983636)

This is a much more narrowly incised reach adjacent to Dean Forest and Mangapiri Bush, with very little within-channel sedimentation. Once more, a multitude of complex braid channels are evident on the terrace surface, with three or more terraces perched above the contemporary channel.

f) 2km upstream of Wairaki confluence to Otahu Flat (Ohai 1:50,000 sheet, GR: 972580)

This is a broader zone of recent within-channel alluviation, with development of complex point bar assemblages which are dissected at higher flow stages. A complex pattern of bar units is observed at the Wairaki confluence associated with additional sediment input into the Waiau.

g) Otahu Flat to 1km upstream of Lill Burn confluence (Ohai 1:50,000 sheet, GR 982 553)

The Waiau River is highly constrained in this reach between a bedrock cliff on the right-hand bank and terrace sequences on the left-hand bank. The latter have a series of former channel outlined on their surface. There is virtually no within-channel bar formation in this reach.

h) 1km upstream of Lill Burn confluence to bend 2km downstream of Clifden (Ohai 1:50,000 sheet, GR: 038496)

The alluvial flats widen in this reach to up to 1km. With this widening, active channel sedimentation has resulted in complex compound bar development, with evidence of both lateral accretion and downstream translation of bend deposits. These bars become highly dissected at higher discharge stages in a braided/wandering gravel-bed river style.

i) Bend 2km downstream of Clifden to 1km upstream of Orauea River confluence (Ohai 1:50,000 sheet, GR: 025439)

This is a nearly-straight river reach in which the river is laterally constrained by bedrock as it has incised into adjacent and underlying mudstone (Papa).

j) 1km upstream of Orauea River confluence to just downstream of Tuatapere (Riverton 1:50,000 sheet, GR: 994 396)

This reach is characterized by a series of alternating bars in a moderately constrained reach. This is the downstream limit of bedrock constraint on the Waiau channel.

k) Just downstream of Tuatapere to the river mouth (Riverton 1:50,000 sheet, GR: 944323)

This is the least laterally constrained reach of the Waiau River. It demonstrates a characteristic wandering gravel-bed river/meandering system, with distinct pool and riffle spacing (Figures 1 and 4). Channel configuration is markedly dependent on flow stage. Bank-attached compound point bars are migrating to a limited degree laterally, yet they are much more able to translate downstream (Figure 5).

The downstream reach of the Waiau River is probably the most sensitive reach to change, given associated adjustments in the morphology and character of the barrier and lagoonal system at the river mouth (Figure 6). Given the particular importance of this zone, this reach is the focus of a separate preliminary report by James Shulmeister.

Figure 4 : The broadly sinuous lower reach of the Waiau River downstream of Tuatapere. Note the high proportion of unvegetated gravels in the active channel zone, and the highly dissected nature of the bar surface. The floodplain surface in the foreground indicates a myriad of former channel positions, from a river course which has been significantly more active in the past.



Figure 5 : A dissected compound bar in the downstream reach of the Waiau River. Note from the vegetation patterns that this bar would be dissected by a series of diagonally aligned channels at higher flow stages. The sedimentation pattern on this bar indicates that the bar is accreting in a downstream manner, and that the broadly sinuous bend is translating in a downstream direction rather than laterally migrating.



Figure 6 : The mouth of the Waiau River, with the lagoon behind, and a tributary feeder channel developing a small delta in the lagoon.



Summary of river reach analysis

The above sequence is not a typical pattern of downstream change for a gravel-bed river (*sensu* Church and Jones, 1982), as there is considerable complexity in the Waiau system. In geomorphic and geologic terms this can be attributed to two primary causes. First, in only a few reaches is the Waiau River truly "alluvial" (i.e. flowing within its own deposits). As a consequence, bedrock and fluvio-glacial outwash terraces impose constraints on channel adjustment, such that these reaches act almost as flumes, while reaches immediately downstream of constrained reaches are subjected to highly dispersed and sediment charged flows which have resulted in multi-channeled channel configurations. In some reaches there is evidence to suggest that the latter reaches may have become less active with discharge reduction, and have accordingly adjusted from a braided to a wandering gravel-bed channel configuration. Second, and directly related to the first point, two large lakes (Te Anau and Manapouri) within the Waiau catchment act as severe constraints on downstream channel and floodplain adjustments, thereby negating the possibility of a text-book downstream sequence of planform and bar types.

Proposal for future research on channel changes of the Waiau River

From this preliminary inventory of downstream river reaches of the Waiau River, the following issues need to be addressed:

a) A detailed inventory of the character of each reaches outlined above is required. This would take the form of the inventory sheets attached (Appendix 1). Such primary base-line data is essential if geomorphic controls on channel changes are to be reliably assessed, and such integrative data provides an essential time-line for the "state-of-the-system" at the time of measurement. This information is a major prerequisite for effective long-term catchment management and planning.

b) Those reaches where significant channel change has occurred need to be identified. Can the nature of these changes be predicted? What is controlling such adjustments?

c) Is the balance between erosion and sedimentation changing over time from reach to reach? Can distinct pulses or wedges of sediments be isolated? Over what timeframe are sediment pulses moving downstream? Is the channel bed becoming increasingly paved over time? Given channel changes outlined in point (b) above, can any changes in sediment sources be predicted? Observations such as these guide the more specific issues of engineering scale investigations of change in the erosion/sedimentation regime, and determines the underlying cause of any adjustments in lateral erosion by the channel and within-channel sedimentation.

Two primary data requirements seem especially significant to the channel change issues being faced on the Waiau River:

1) An appropriate framework within which to place all aspect of channel change is essential. This should be broad ranging and adaptive in scope, entailing a comprehensive and interactive manner, such that catchment-scale implications can be reliably addressed for the broadest range of environmental management and planning issues.

2) To provide the most reliable assessment of the "state-of-the-system" in its present condition, detailed river reach analysis needs to be applied, entailing on-site measurement of variables such as particle size etc. Only with such information in-hand can a meaningful and reliable framework be imposed for monitoring the character and rates of erosion/sedimentation at key locations within the Waiau River system.

Given the timeframes of observation on channel change outlined above, and the specific skills entailed in implementing a reliable inventory of 'river reach analysis', I would suggest that these issues be addressed by a fluvial geomorphologist. To complete such work in a comprehensive manner would

require about three weeks in the field, with an additional week for air photo work and report writing. It would be exceptionally helpful if an assistant could be employed to pull together the air photo record (i.e. have relevant photos in hand) and work out all logistical hassles (such as vehicle rental, access to field sites, etc.) prior to commencement of field work. Advisory comments on development of an appropriate framework within which to assess controls on channel change, and hence erosion/sedimentation of the Waiau River, would take a matter of a few days, but I would strongly suggest that this integrative framework alone be produced as a separate report, as it guides all other observations of concern to the wide-ranging task groups concerned with river modification.

References cited :

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Hickin, E. J., 1983, River channel changes: retrospect and prospect, in : Collinson, J. D and J. Lewin, Eds., *Modern and Ancient Fluvial Systems*, Special Publication Number 6 of the International Association of Sedimentologists, Blackwell, Oxford, 61-83.

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Appendix 1

Excerpts from Kellerhals et al (1976, pages 818-819) outlining the classification of river valley and valley flat/channel features utilized in river reach analysis

TABLE 1.—Classification of River Valley Features

Reach Name: RED DEER RIVER, nr. Sundre Reach No: _____ Date of Analysis: Feb. 1976 Analysis By: RK/MC

Scale of Air Photos: 4 in. to 1 mi. (1:15,840) Scale of Map: 1:50,000, NTS 82-O/10

NOTE: Complete codes by circling the appropriate number (s). Use '-1' for 'unknown' and '0' for 'not applicable'.

General Description of the Terrain in the Vicinity of the Surveyed Reach, above Valley

Terrain:
1 mountainous
(2) foothills
3 uplands
4 hills
5 plains
6 lowlands

Vegetation:
0 0 0 not applicable
1 1 1 almost none
2 2 2 grass
3 3 3 shrubs
4 4 4 sparsely forested, 0-25%
(5) 5 5 moderately forested, 25-75%
6 6 6 heavily forested, 75-100%
7 7 7 swamp or muskeg

Forest type:
0 0 0 not applicable
(1) 1 1 deciduous
2 (2) 2 coniferous
Comments: _____

Land use:
(0) 0 no cultivation or built-up area
1 1 partly cultivated
2 2 mainly cultivated
3 3 partly built-up
4 4 urbanized

Surficial geology:
1 1 1 bedrock
(2) 2 2 ground moraine
3 3 3 hummocky moraine
4 4 4 lacustrine deposits
5 (5) 5 glacio-fluvial dep.
6 6 6 fluvial deposits
7 7 7 aeolian deposits

Valley Characteristics above Valley Flat

Valley measurements:
____ within reach
✓ within reach and immediate vicinity
depth: 0 ft.
top width: 0 mi.
bottom width: 0.5 mi.

Slumping of valley walls:
(0) none
1 occasional
2 frequent

Length of reach with slumping valley walls (contact length in percent of total length of banks): _____

Vegetation on valley wall:
0 0 not applicable
1 1 almost none
2 2 grass
3 3 shrubs
(4) 4 sparsely forested
5 (5) moderately forested
6 6 heavily forested

Forest type on valley wall:
0 0 not applicable
(1) 1 deciduous
2 (2) coniferous

Comments: south side forested, north side mostly in grass

Terraces

Terrace presence:
0 none
1 indefinite
2 fragmentary
(3) continuous

Number of levels:
0 not applicable
1 one level
2 two levels
___ ___ levels
(9) several levels

Comments (in particular land use and vegetation): 1 prominent, high terrace, 30 ft above river, partly cleared; several low terrace levels

Relation of Channel to Valley

Valley type:
0 not applicable
1 stream cut valley
2 stream cut valley in wide valley
(3) wide mountainous valley

If no valley:
(0) valley present
1 on alluvial fan
2 on alluvial plain
3 in delta
4 in old lake

Underfit:
(0) not applicable or not obviously underfit
1 obviously underfit

Local lateral constriction:
(0) none
1 one
2 two
9 ____ cases
9 several cases

Relation of channel to valley bottom (vertical):
0 not applicable
(1) not obviously degrading or aggrading
2 partly entrenched
3 entrenched
4 aggrading

Relation of channel to valley walls or to high, resistant terraces (lateral):
0 not applicable (no valley or free)
1 occasionally confined
(2) frequently confined
3 confined
4 entrenched

Comments: could be "partly entrenched"; confined mainly by high terrace but occasionally by valley wall (beyond stereo view)

TABLE 2.—Classification of Valley Flat and Channel Features

Reach Name: RED DEER RIVER, nr. Sundre, Alberta Reach No: _____

Description of Valley Flat

Presence:
0 none
1 indefinite
2 fragmentary
(3) continuous

Extent:
0 none
1 narrow (< 1 Ws)
(2) moderate (1-5 Ws)
3 wide (> 5 Ws)

Average width 0.1 mi.
Maximum width 0.15
Channel length with valley flat on left 100 %
on right 60 %

Vegetation:
0 0 not applicable
1 1 almost none or bare
(2) 2 grass
3 3 shrubs
4 (4) sparsely forested
5 5 moderately forested
6 6 heavily forested
7 7 swamp or muskeg

Forest type:
0 0 not applicable
(1) 1 deciduous
2 (2) coniferous

Land use:
(0) 0 not cultivated, not built-up
1 1 partly cultivated
2 2 mainly cultivated
3 3 partly built-up
4 4 mainly built-up

Comments: valley flat consists of small genetic flood plains and at least 2 low terrace levels

Channel Description (near long-term mean)

Channel pattern:
1 straight
2 sinuous
3 irregular
4 regular meanders
(5) irregular meanders
6 tortuous meanders

Islands:
0 none
1 occasional
2 frequent
(3) split
4 braided

Type of flow:
1 uniform water surface
2 uniform with rapid in reach
(3) irregular
4 pool and riffle sequence
5 tumbling flow

Bar type:
0 0 0 none
1 1 1 channel side bars
2 2 2 point bars
3 3 3 channel junction bars
4 4 (4) mid-channel bars
5 5 5 diamond bars
(6) 6 6 diagonal bars
7 7 7 sand waves or large dunes

Meander dimensions:
belt width 0 mi.
wave length 0 mi.
sinuosity 1.14

Natural obstructions:
(0) 0 none
1 1 logs
2 2 beaver dams
3 3 boulders (lag material)
4 4 vegetation

Degree of obstruction:
(0) 0 none
1 1 occ. minor
2 2 occ. major
3 4 frequent minor
4 4 frequent major

Comments: complete transition from well-established islands to low gravel bars

Lateral Channel Activity

Lateral activity:
0 not detectable
1 downstream progression
2 progression and cut-offs
3 mainly cut-offs
4 entrenched loop development
(5) irregular lateral activity
6 avulsion

Lateral stability:
0 stable
1 slightly unstable
(2) moderately unstable
3 highly unstable

Comments: _____

Channel Banks and Bed

Alluvial bank material:
0 0 0 no alluvial banks
1 1 1 clay and silt (cohesive)
2 2 2 silt and sand (non-cohesive)
3 3 3 sand and gravel (< 64 mm)
(4) 4 4 sand to cobbles
5 5 5 sand overlain by silt
6 6 6 gravel overlain by silt
7 7 7 cobbles overlain by silt

Non-alluvial bank material:
(0) 0 0 alluvial bank material
1 1 1 lacustrine deposits
2 2 2 till
3 3 3 easily erodible rock
4 4 4 moderately erodible rock
5 5 5 resistant rock
6 6 6 boulders

Percentage of left bank in alluvium 100%
Percentage of right bank in alluvium 100%

Bank vegetation:
0 none
(1) weak
2 good
3 very strong

Predominant bed material:
1 sand
2 sand with local gravel
3 gravel
(4) gravel with local sand
5 sand and gravel

Depth of alluvium:
0 no alluvium
1 shallow
2 moderate
(3) deep

Estimated depth of alluvium - 1 ft.

Reference or comments: bedrock banks occur beyond immediate reach

Bed Rock Below Channel

Presence of rock outcrops in channel bed:
(0) none
1 one occurrence
2 two occurrences
___ occurrences
9 several occurrences

Rock type at channel base:
(0) 0 0 not applicable (none for great depth)
1 1 1 compact clay
2 2 2 shale
3 3 3 limestone
4 4 4 sandstone
5 5 5 conglomerate
6 6 6 granite
7 7 7 ____

Erodibility:
(0) 0 0 not applicable
1 1 1 soft cohesive
2 2 2 easily erodible
3 3 3 moderately erodible
4 4 4 resistant

Comments: _____

Erratum

Figure 3 (page 5) displays the Monowai Power Station rather than Mararoa Weir. The river is still single channel and low sinuosity.

Background to the Waiau Coastal System - Areas of concern and possible research foci.

An interim report submitted to Glen Lauder (Department of Conservation), coordinator of the Erosion and Sedimentation Task Group in the Waiau River Working Group.

by

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Figure 1 : The Waiau River mouth and the entrance to the sand and gravel barrier. Note the lack of vegetation on the barrier, the position of the river channel, and the modification of the wave pattern around the barrier entrance.

Introduction

This report has been prepared for the Waiau River Working Group in response to a request for research objectives and guidelines by the Erosion and Sedimentation Task Group.

Concerns have been raised about the effects of diversion of water from the Waiau River to the Manapouri Power Scheme since 1971. These concerns extend to the coastal system of the Waiau and include, but are not limited to, issues of flooding behind the barrier, changes to the barrier, changes in temperature and salinity of the lagoon and downstream effects on biota including significant shellfish and recreational fishing resources. In the future, issues of coastal management are also likely to become significant.

These concerns must be set in the context of current knowledge of the coastal behaviour of the Waiau system. There have been no prior investigations of processes operating at the mouth of the Waiau. Some historical data exist but have not been analyzed in a systematic fashion. In our current state of knowledge, none of the apparent changes to the Waiau coastal system has actually been demonstrated, as past behaviour of the system is unknown. There is a clear need for a fundamental understanding of the dynamics and history of the system so that issues of concern and future management can be addressed.

In order to discuss problems and research objectives on the Waiau Mouth, a descriptive summary of the geomorphology of the Waiau Coastal System is provided. This description is then discussed in the context of the geomorphological /geological setting of the river and by reference to a geomorphological model of river response to flow variation. This model is based on extensive research by members of the Coastal Research Group at the University of Canterbury on the rivers of South Canterbury (e.g. Hewson,1977; Kirk et al.,1977; Kirk,1983,1987,1991; Todd,1983). It is not

presently possible to use a model derived from the coastal systems of Southland as they are remarkably poorly understood. Systematic work on the coast/river interface of Southland rivers is only beginning, largely as an effort of the authors of this report.

Description of the coastal environment

The Waiau River drains into Te Waewae Bay along a confined valley (less than 3km wide near the mouth). Terraces bound the river valley and cliffs extend behind the modern beaches both east and west of the Waiau River Valley. Figure 1 displays the mouth of the Waiau River. The river mouth is composed of five distinct components;

(i) The sand and gravel barrier
(ii) the lagoon
(iii) the river channel
(iv) the marine cut cliffs
(v) the river delta.

These may be characterized as follows:

(i) The Sand and Gravel Barrier. This is an eight kilometer long gravel barrier that encloses the mouth of the river and the lagoon. The barrier is characterized by a steep face on the lagoon side and a stepped seaward profile which is again, in the main, quite steep. The barrier shows the formation of cusps (small bay-like features carved into the beach (marked lowercase a on Fig. 2) on the seaward side. Similar features exist on the lagoon side of the barrier. These are small overwash fans (marked lowercase b on Fig. 2) and are formed of sediment washed over the barrier by waves.

Transport at the time of examination was directly onshore with little or no alongshore component (beach cusps do not form while longshore drift is active). Note that beach cusps are shortlived features and longshore movement may occur under different wave patterns. The height of the

barrier is related to storm wave height and the presence of the overwash fans on the lagoon side indicates that storm waves can and do overtop the current barrier. The steep profile is typical of an accreting ridge (if the barrier was being eroded, the slope on the beach face would be much lower).

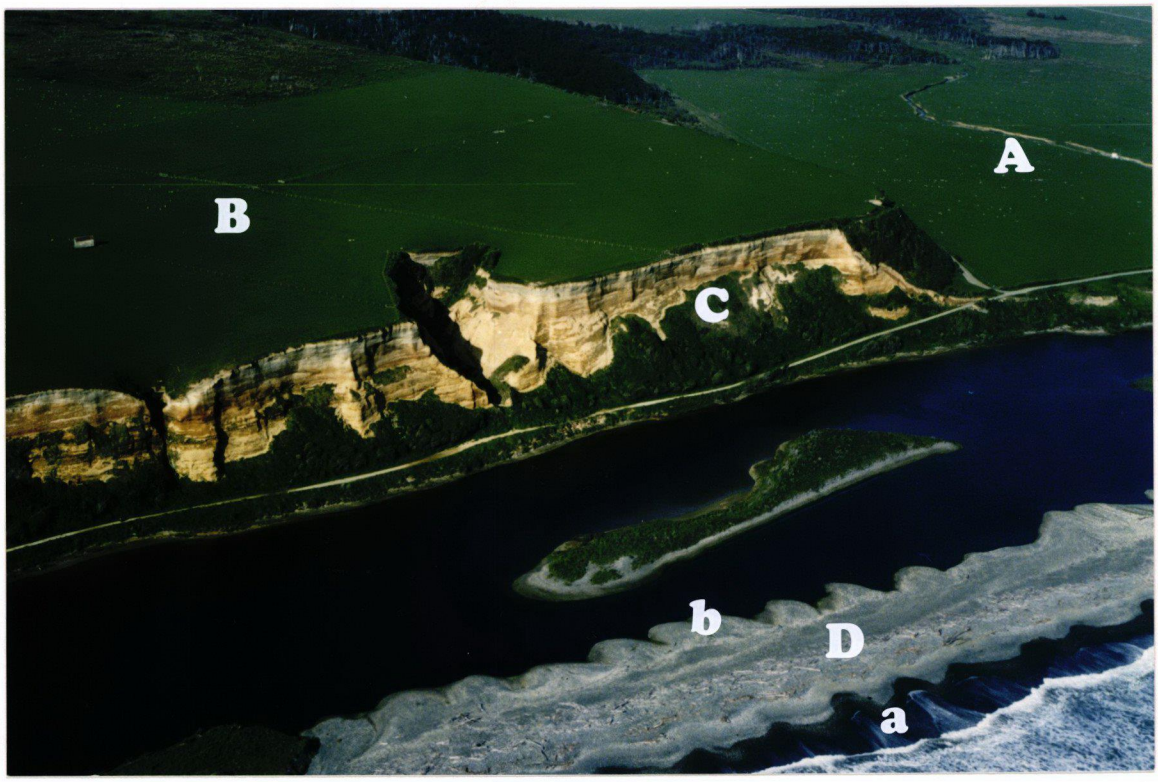


Figure 2. An aerial view of part of the western side of the Waiau Coastal System. A = The river valley of the Waiau, B = Raised terrace, west of the modern valley, C = Cliffs developed at the back of the lagoon system, D = The sand and gravel barrier, a = cusps on the marine face of the barrier, b = overwash fans on the lagoon side of the barrier.

(ii) The Lagoon. This is a narrow ribbon like band of water behind the gravel barrier. Because of the large volume of water in the Waiau, even at reduced discharge the lagoon is likely to be entirely freshwater. Saltwater incursion into the lagoon through the channel mouth is likely to be insignificant. The main source of sea-water in the lagoon will be water washing over the barrier during

storms. The lagoon is slowly being infilled by the deltas of the streams entering it (see Fig. 3).



Figure 3. The delta of a small stream infilling the lagoon. This stream is located near the eastern end of the system

(iii) The River Channel. The main channel of the Waiau River normally maintains a deep water channel to a breach in the barrier. The effects of reduced flow on the competence of the river to maintain the breach in the barrier and the consequences of this are central concerns.

(iv) Coastal Cliffs. The cliffs behind most of Te Waewae Bay including part of the Waiau Lagoon were initially cut by wave action. These cliffs are now protected by the sand and gravel barrier along the lagoon section and are not presently subject to marine erosion but may be activated by lateral movement of the river channel.

(v) The River Delta. Unlike the other components of the estuary, the delta complex is not apparent. The delta is a wedge of river derived sediment deposited just beyond the entrance channel to the lagoon. The delta occurs where water velocity declines rapidly after flowing through the entrance channel and loses its ability to carry sediment.

From observation of the wave pattern around the entrance channel, there appears to be a delta offset to the western side of the entrance channel. Irrespective of the mode of formation of the barrier, deltas play an important role as a primary source of new material for barriers (Orford et al.,1988).

Coastal Systems

The dynamics of a coastal system at a river mouth can be defined in terms of interaction between three elements:

1. The geological/geomorphological setting
2. River processes
3. Marine processes

For the purposes of this discussion the river and marine processes will be discussed in tandem as they are highly interlinked.

The Geological/Geomorphological setting

The Geological/Geomorphological history of the system is important for two reasons. Firstly, it provides the physical setting in which the modern processes are active. Secondly it provides information on the equilibrium of the system.

Setting : First order control of the Waiau coastal system is geological. Tectonic uplift is calculated to average about 1.1 mm/yr for the Waitutu district (Ward,1988) and presumed to be somewhat less for the Waiau Valley. This uplift has raised pre-deposited series of unconsolidated

sediments above their original datum and exposed them to erosion by the sea. The absence of bedrock near the mouth of the river defines the character of the coastline as the unconsolidated sediments are easily susceptible to marine erosion and have been eroded back as a cliff.

Equilibrium : During the last glacial period world sea-levels were substantially reduced (up to 150 m at about 17,000 years ago). The Waiau River flowed across the Foveaux Strait and at lowest sea-levels entered the sea roughly parallel with the north coast of Steward Island. The modern form of the coast is a response to sea-level rise after the last Glaciation. The modern coastline is unlikely to be more than 7000 years old (modern sea-levels were attained between 7000 and 4000 years ago) and may be substantially younger. The age and development of the coast tells us whether the coast is in equilibrium with modern marine and river processes or whether it is still controlled by and responding to changes that occurred millennia ago. This is important because it plays a significant role in determining how and whether changes to the river will be reflected at the coast.

River and Marine Processes

From observations on the Rakaia, Ashburton and other east coast rivers, Kirk (1983,1987,1991) has proposed a geomorphic model of coastal behaviour based on flow regimes in the river. This model was developed for rivers where erosion clearly exceeds deposition and its application to the Waiau, where coastal orientation is different and the coastal sediment budget is unknown, is tentative. This is the only model available for flow variation in a gravel river on a high energy coast. The large river- small river concept underlies this model.

Large river - small river concept

Zenkovich (1967) divides coastal systems of rivers into two general categories. 'Large' rivers are those where the river contributes a large volume of material to the coast such that net input of sediments equals or exceeds net erosion of the coast and the coast is either stable or prograding (advancing seaward). 'Small' rivers are ones where the input of material to the coast is less than net erosion and the coastline retreats landward through time. The scientific and technical literature is extensive for 'large' rivers, but is very limited for 'small' rivers.

In a South Island context many of the rivers including some of the largest in size, such as the Rakaia (Kirk,1983,1987) are actually 'small' rivers by Zenkovichs' classification. Despite their large discharge and sediment load, the erosional capacity of the high energy coastlines is greater than the sediment contribution from the rivers. Although detailed fieldwork is required to confirm it, the Waiau visually conforms to the general geomorphic pattern observed on the Rakaia and Ashburton rivers and elsewhere in the South Island.

A geomorphic model of lagoon barrier interaction based on flow variation

Kirk (1987) presents a three stage model for coastal response based on flow regime.

1. Class 1, High Flow (Flood) Regimes. During floods, the rivers breach their barriers opposite or nearly opposite the main river channel. As the result of the flood a temporary delta is constructed beyond the channel mouth. The lagoon may be significantly attenuated.

2. Class 2, Moderate Flow Regimes. The delta formed at flood flow alters the pattern of wave breaking near the channel entrance. The resulting longshore transport feeds sediment from the delta to the barrier. This can cause a migration of the river channel (east or west) as one side of

the barrier mouth is fed with sediment and the river channel is forced to the other side. East or westward diversion of the river continues (and it can be several kilometers) until another flood occurs and a new channel is cut, opposite the main river course.

3. Class 3, Low Flow Regimes. Under low flow regimes transport of sediment into the mouth of the channel exceeds the rate at which the river can cut into the opposing bank. The channel in the barrier will close and discharge of water from the river will dominantly occur through seepage through the barrier. This will continue until a flood large enough to breach the barrier occurs.

In the context of this model, the main question centres around whether diversion of water to Manapouri has changed the character of the river from a Class 1/2 river to one where Class 3 flows occur.

Areas of concern for long-term management and usage of the coastal system.

Kirk (1991) regards coastal interaction at the mouth of rivers as an unstable dynamic between two 'signals' (one fluvial and the other marine). These 'signals' interact and produce a response that may be fluvially or marine dominated or intermediate. Any change to an element in the system (such as a reduction in mean discharge in the river) will result in complex knock-on effects through *the entire system*. Thus, although specific problems are identified, the coastal system of the Waiau must be considered as a whole and not as a series of disconnected problems. If the model presented is applicable to the Waiau, reduction in base flow in the river may have had/be having the following consequences ;

(a) Increased Flooding in the lower Waiau.
Flooding will increase behind the barrier, especially during periods of increasing flow after a low flow period if flow is reduced to a point where the barrier closes. The

apparent increase in flooding in the lower reaches of the Waiau may be an indication that this sort of response is occurring. Freshwater floods significantly impact usages such as farming in the lower Waiau.

(b) Unknown physical changes to the barrier-lagoon system. Reduced flow will affect sediment distribution to the barrier. Less material will be provided to the marine side of the barrier and more material will be deposited in the lagoon. Starvation of sediment to the nearshore area beyond the barrier may result in net shoreward migration of the barrier as material is stripped away on the marine face. There is likely to be an increase in storage of sediment in the lagoon as material that is transported to the mouth cannot reach the sea if the barrier is closed. The long-term response of the barrier and the lagoon is unknown but is critical to future management and usage.

(c) Possible coastal change in Te Waewae Bay.
If the Waiau is a major contributor to sediment budgets in Te Waewae Bay, as seems likely, reduction in throughput of sediments to the coast could result in the alteration or even destruction of beaches many kilometers away from the Waiau, as they in turn are starved of sediments.

(d) Biochemical and thermal changes to the lagoon.
Closure of the barrier and generally lowered flow in the river is likely to result in an increase in the temperature of the water in the lagoon. Closure of the barrier may result in an increase in the salinity of lagoon waters, as salt water washed over the barrier during storms cannot be flushed out. Changes to the temperature and salinity of the water will have profound effects on the biota in the lagoon and may result in significant changes to both the aquatic flora and fauna.

(e) Impacts on marine and freshwater fisheries.
Salmon migrating though the lagoon may also be seriously affected. In addition to the obvious problem of salmon being

unable to enter the river if the barrier is closed, salmon undergo biochemical changes when they enter rivers and have critical temperature requirements. Changes to the ambient temperature in the lagoon and river may seriously impact migrating salmon.

Barrier closures will have an effect on the marine side of the barrier also and may impinge on shellfish beds and other marine resources. The distribution of marine fauna on the barrier will be a function of the sediment supply and energy conditions along the barrier. Reduction in sediment supply will change the distribution of substrates for burrowing animals, expose previously protected areas to erosion and create new depositional environments and alter the nutrient supply from the river. The effects of these changes on species such as Toheroa are unknown.

Research required for comprehensive understanding of the coastal environment.

Four areas of fundamental research are suggested as the basis for work on the coastal complex of the Waiau. These are ;

1. Mapping and sedimentological analyses of the barrier/lagoon system. This will provide a detailed framework against which process information can be tested. Sedimentation in the lagoon will give a guide to the importance of the lagoon as a temporary sediment store. The morphology and sedimentology of the barrier will provide information on the stability of the modern barrier. Examination of the sediments in the barrier (through particle size analyses, lithology and sedimentary structure) will give an insight into whether the barrier is composed of material derived directly from the Waiau River or material reworked from the floor of Te Waewae Bay.

2. An historical study of changes both on the Barrier-Lagoon system and in the catchment of the Waiau, based on airphotos and preferably supported by oral history is highly

desirable. River mouths are very variable systems and it is important to categorize the behaviour of the river mouth (including the lagoon and barrier) before and after the diversion of water from the Waiau. The system is unlikely to have been stable at any stage but there may be a discernible change in the range of responses between the pre- and post-flow diversion eras. These changes need to be identified if the effects of flow diversion are to be understood.

It would also be useful to extend the air photograph work to the catchment of the river, as the final inputs to the coast depend on what is getting transported down the river. The Waiau may have variations in sediment input due to storms and land clearance that may compound or mitigate the effects of flow diversion. In particular, it is important to delineate the historical limits of flooding in the lagoon area. Changes in land use since flow diversion was initiated can also be identified and the contributions of these changes to changes in the coastal system can be evaluated.

These first two areas of investigation set the baseline conditions against which the modern processes of transport and erosion can be compared. Only by undertaking this historical work can it be determined whether a significant change has occurred.

3. Process studies on the marine system will allow for identification and quantification of the modern coastal environment. The areas that require investigation are the flow and sedimentation regimes in the lagoon, wave energy and direction on the barrier system and the determination of the competence of waves and currents to transport and deposit material on the barrier and offshore. These data will provide the parameters for modelling likely effects of modern sediment supply or future changes in the sediment budget in the system when data on sediment throughput from the river are also included.

4. Determination of volumetric input from the river, preferably taken from direct measurements at or near the inlet to the lagoon. This is technically difficult information to obtain and it can be alternatively extrapolated from the upstream monitoring that is already underway.

Timetable for the research

The research objectives outlined above imply a substantial commitment of time and resources. A provisional estimate of time requirements for the various elements is as follows ;

	Days
<u>Sedimentological mapping and analyses</u>	
(1) Detailed description of the Waiau Coastal System	
(a) Field Mapping	5
(b) Sediment Logging	10
(c) Surveying	5
(d) Survey Reduction	3
(2) Sediment Analyses	
(a) Sample collection	4
(b) Sample Sieving	15
(c) Other lab analyses (microscopy)	5
(d) Data plotting and Computing	2
<u>Historical Analyses</u>	
(1) Aerial Photography	
(a) Collection and collation of photographs	10
(b) Analyses of coastal change from photos	20
(2) Other Sources	
(a) Analysis of old maps and other archival material	5
(b) Collection of oral history (optional but desirable)	10
<u>Process studies on marine system</u>	
(1) Analysis of Coastal Wave Climate	
Wave refraction, runup and breaker conditions, analysis and computing	10
(2) Barrier-Beach Profile Surveys	
Regular surveys of changes on the barrier	
(a) Surveys	10
(b) Survey reduction	5
(c) Data Summaries	5
(3) Current Monitoring	10
(4) Sediment Tracing	10
Total (days)	134

The above figures do not include time for the data to be synthesized and for a report to be drawn up. The areas can be subdivided and treated as a number of projects so long as the results are synthesized.

The best available expertise in the South Island is the Coastal Group at the Geography Department, University of Canterbury. The research outlined above could be approached on either a contract basis or as a research student project. The former would provide the answers more quickly, the latter would be more exhaustive and less costly.

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