River reach analysis of the Waiau River, Southland, from Mararoa Weir to Te Waewae Bay

Report submitted to the Erosion/Sedimentation Task Group, Waiau Working Party

by

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Brief :

1) To designate and characterize geomorphologically-defined river reaches of the Waiau River downstream of Mararoa Weir

2) To develop an understanding of controls on the character and evolution of each reach

3) To outline implications and recommendations for future study of changes to the erosion/sedimentation regime of the Waiau River induced by flow regulation

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Preface

This report to the Erosion and Sedimentation Task Group of the Waiau Working Party characterizes river reaches of the Waiau River downstream of the Mararoa Weir. Information provided in this report is supplemented by an annotated air photo inventory. Appendices detailing field methodology, the summary river reach data set, particle size data, and a preliminary vegetation survey are provided in a separate volume. This report is intended to be read in conjunction with the air photo inventory and the appendices.

This report summarizes field data collected to designate and characterize river reaches of the Waiau by the author, field assistants Sue Bennett and Clare Tipene, and Glen Lauder (DOC advisory scientist) during the last two weeks of March and first week of April, 1992. Interpretation of air photographs from the 18.12.91 flight run was undertaken by Keith Fitchett from the Department of Biogeography and Geomorphology at the Australian National University in Canberra. Keith Fitchett also drafted the figures.

The field work and time taken to write this report were undertaken while the author was employed at the Australian National University, under an informal agreement in which the scientific merit of the project warranted attention in itself. Assistance in completing this report has been considerable, especially through The Institute of Advanced Studies at the Australian National University, the Department of Conservation, Southland Regional Council, and several residents along the lower Waiau River. Opinions expressed in this document, however, are solely the responsibility of the author.

I wish to take this opportunity to extend special thanks to Glen Lauder for making this happen, to field assistants who had to put up with a particular blend of Southland weather (until the sun goddess put us right), to Trevor Tidey who helped with the row boat, to the Miller's who provided first class accommodation at Holly Burn, and to Anne McCracken who helped with arrangements in Tuatapere.

Cautionary note. While this may seem a lengthy and long-winded document, it has been produced from the perspective of an investigative scientist who is interested in channel adjustments of the Waiau River at some stage in the future (maybe 20 or 30 years hence). Information provided in a base-line inventory such as this is only valid if the the conceptual framework and field methodology are stated explicitly.

Summary statement

1) ***Landscape science :*** The role of the geomorphologist in river management issues is described. Geomorphologists study interactions among landscape form, processes and evolution, and examine controls of landscape patterns over a range of spatial and temporal scales. This report documents a geomorphic interpretation of the Waiau River, and is written from the perspective that "*Human impacts on river systems can only be reliably interpreted once controls on the character and evolution of the system are understood.*"

2) ***River reach analysis:*** Eleven "reaches" of the Waiau River downstream of Mararoa Weir are identified and characterized at *valley setting*, *channel character* and *river bar* scales.

3) ***Downstream changes in reach character :*** A *distinct pattern* in river reaches of the Waiau is discernible, with an *alternating sequence* of bedrock/terrace constrained reaches and less constrained reaches with multi-channelled planform geometries. These are transitional to a lowland reach downstream of Tuatapere, where planform adjustments are more prevalent than in any other reach along the river.

4) ***Bedrock or terrace-constrained reaches :*** These are either *single-channelled* reaches with an imposed broad sinuousity (e.g. Blackmount-Mangapiri) or are short, relatively straight reaches (e.g. Duncraigen, Motu, Clifden Suspension Bridge, Hagen Road, Orauea).

5) ***Unconfined reaches :*** These are *multi-channelled* reaches, in which channels are *laterally unstable* and of *varying sinuosity*. A distinct pattern of gravel bar assemblages and particle size trends emerges from less constrained reaches. In Wairaki, Lill Burn and Downstream o'Clifden reaches there is a distinct *within-reach* trend in gravel bar type. Bars change down-reach from lateral and bank-attached compound bars at the reach head, to mid-channel compound and diagonal bar types, to lateral and point bars at the downstream limit. These three bar styles result from differing channel behaviour.

6) ***Lowland reaches:*** The downstream reach at Tuatapere does not accord to the primary styles described for other reaches. This lowland reach has a considerably *greater proportion of active gravel surfaces* than any upstream reach. It is described as a *wandering gravel-bed river reach*, in which flow is divided into two or more laterally unstable channels which migrate across adjacent alluvial flats over intervals of tens of years. *Sedimentation zones* within this reach may gradually migrate downstream *en masse*. Although Tuatapere reach is the lowland reach of the Waiau catchment, it still maintains a *relatively steep channel bed slope*, as reflected by the pattern of riffles. Subreaches in which these riffles are more numerous may reflect the leading edge of sedimentation zones moving downstream.

7) ***Summary of reach trend :*** Because of the alternating pattern of reach types, the overall downstream sequence of planform styles, bar character, bed condition and gravel clast size on the Waiau River downstream of Mararoa Weir is complex and does not accord with simple text-book notions of river behaviour. The Waiau truly

exemplifies the notion that *each river; indeed each river reach - must be studied and understood separately* prior to relating river character to general principles.

8) ***Valley setting controls :*** This geologic factor conditions both lateral constraint placed on the channel due to structural factors, but also conditions sediment sources to the contemporary Waiau River through vast accumulations of fluvioglacial gravels in vast outwash terraces.

9) ***Channel planform controls :*** Confined reaches have little propensity for channel adjustment, and are accordingly single-channelled reaches with an imposed straight or broadly sinuous course. In contrast, the channel is able to adjust its position in less constrained reaches. Within-channel deposition resulting in channel multiplicity; channels are laterally unstable, and frequently quite sinuous. Given these conditions, a suite of gravel bar forms may develop. At the head of unconfined reaches, flow is concentrated into a high velocity filament as it exits the bedrock reach from upstream. Flow deflection associated with the removed lateral constraint results in deposition of gravels at the channel margin. As the reach widens, the ability of the flow to carry sediment is reduced as flow energy is dissipated over a broader area. This is termed the *competence limit*. In many instances large volumes of sediment are added to the river at tributary confluences (affecting the *capacity limit*). The river either has sediment which is too coarse for it to carry, or there is simply too much sediment for the river to carry, and hence within-channel sedimentation results in the formation of mid-channel bars. These are subsequently dissected by flows of differing magnitude to produce compound bar features. At the downstream limit of unconfined reaches, bedrock once more imposes a lateral constraint on the channel, and sedimentation is restricted to lateral and point bar features.

9) ***Downstream changes in gravel bar type :*** Gravel bar assemblages are determined primarily by channel planform character. Accordingly, an alternating suite of bar types is found along the Waiau, associated with constrained and unconstrained reach types. Most bars observed are compound features, made up of a suite of smaller depositional units.

10) ***Downstream gradation in particle size :*** Thirty-three samples were collected to analyse grain size variation in the lower 100 km of the Waiau. In each instance b axes were measured for 100 clasts, at 1 m interval along a tape in the coarsest gravel unit on each bar surface. The downstream gradation in clast sizes described in this study is completely counter-intuitive, as the coarsest sample was measured at the mouth of the river. Within-reach gradation in clast size is evident in laterally unconstrained reaches, but the overall pattern is quite confused. Each grain size sample must be understood in the context of local sample site character and sediment source/supply variations down-river.

11) ***Downstream variations in gravel-bed condition :*** Surfaces of sampled gravel bars are dominated by jumbled, only partly imbricated clasts. While these are generally winnowed to 20 mm, there is only a moderate degree of packing. This is partly related to sediment movement through the system, as distinct lobes of finer grained gravels have accumulated either as within-channel bars or as distinct sheets on bar surfaces. The only instance in which tightly

packed, imbricated gravels were observed was in the sample immediately downstream of Mararoa Weir. It is interpreted that flow is sediment starved at this location, so the bed condition is locally scoured.

12) ***Implications and recommendations for future study***

a) ***Relation to channel adjustment :*** Channel adjustments of the Waiau River following flow regulation have been restricted primarily to those reaches where the *river has space to adjust laterally* or reaches where there are *significant inputs of sediment* from tributary catchments. These effects operate to differing extents in 7 reaches, namely : Redcliff, Waicoe, Wairaki, Lill Burn, Downstream o'Clifden, Orauea and Tuatapere. While the Tuatapere reach has experienced considerably greater channel adjustments than all other reaches in the past 10 years, significant adjustments are also evident in the Wairaki, Lill Burn and Downstream o'Clifden reaches.

Channel adjustments that have taken place along the Waiau River since flow regulation need to be *rigorously interpreted* in the context of river reach analysis. Since air photos are available from 1946 onwards, with large numbers of photo runs in the 1980's, it is possible to assess not only the character, but also the rate of channel change, and by relating this to the hydrology records, an assessment of the character and extent of channel changes to flood events of varying magnitude and return interval can be made.

b) ***Tributary confluences :*** To be effective, any assessment of river adjustments to environmental change (advertent or inadvertent) must employ a "*total catchment*" approach. This implies that study should focus not only on the trunk stream of the Waiau, but also on the *primary subcatchments*. For example, it is evident that significant channel adjustments are associated with tributary confluences. The character and rates of inputs of both water and sediment should be assessed at these confluences.

c) ***Monitoring gravel movement in Tuatapere reach :*** An *appropriate strategy* should be emplaced to monitor of the *nature, rate and controls of sediment movement* through Tuatapere reach. The flow dynamics of the system need to be evaluated. This primarily entails assessment of relative energy required to move particular quantities of sediment through the river system of particular gravel size. Of particular concern is the *'paved' condition of the river*, and the *migration of mobile gravel sheets* of finer sized gravels atop a coarser gravel base. While this is not a problem in itself - indeed, it results in a more stable channel bed configuration - this scenario needs to be more rigorously assessed from reach to reach. To carry out such work, the surface layer of gravels needs to be compared with subsurface samples. Through assessment of bed shear stresses, or stream power, and discharges required to mobilize differing size fractions of bedload can be estimated. Among the primary data required for such analysis is *water surface slope* - this is a crucial parameter in flow hydraulic investigations, and reliable estimates are required for each river reach. Beyond this, given the enormous complexity in the gravel depositional environments of the Waiau River, *great caution* must be employed in assessing grain size characteristics.

d) ***Conceptual framework and data base management :*** A conceptual framework within which rigorous procedures for scientific investigation of channel adjustments is outlined. This focusses on a geographic approach to analysis of river landscapes, in which several scales of approach are identified in an hierarchical framework. These range from the catchment scale down to the scale of individual gravel clasts on river bars. This framework may provide a suitable genetic basis *not only for assessment of channel adjustments* of the Waiau River, but also for *inventory of base-line information* for various aspects of study in the Waiau Working Party. Data-base management structures derived on a generic or *ad hoc* basis may not provide the right kind of information in an accessible form for other users. It is imperative that an integrative approach to management concerns be addressed within the working party, as the most significant questions or concerns are often at the interface of tasks groups, and effective communication must be promoted. A scalar framework, based on physical units, may form the basis for discussion and implementation of an appropriate GIS approach to integration of information on the Waiau catchment.

Monitoring of changes within the Waiau catchment provide an *ideal opportunity for environmental auditing*, as the reliability of predicted trends and rates of change within the river system can be tested.

1.0 Introduction

The primary aim of this report is to provide a base-line inventory on the character of the Waiau River downstream of Mararoa Weir. Such data constitute an integral component of river management, as human impacts on river systems can only be reliably assessed once the initial "condition" of the river is known, and controls on river behaviour are understood. This concern with the "dynamic" properties of a river is a branch of fluvial geomorphology, and this report is written from a geomorphic perspective.

Primary goals of this report are to :

a) Provide primary base-line data on the "condition" of the Waiau River. This is applied using "river reach analysis" (modified after Kellerhals et al., 1976).

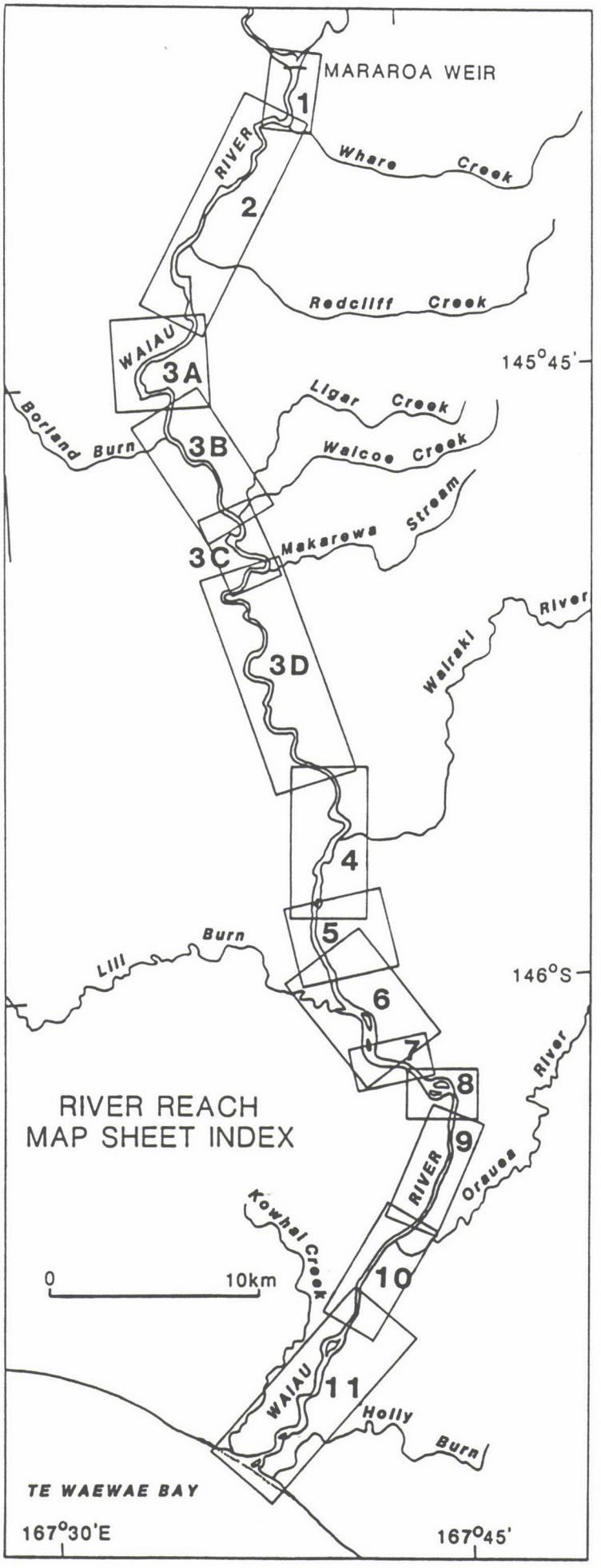
b) Evaluate controls on the character and pattern of river reaches, and

c) Use this information to design an appropriate conceptual framework with which to analyse erosion and sedimentation problems along the Waiau River following flow regulation.

This report is designed to be read in conjunction with an annotated photographic inventory of the Waiau River submitted to the Erosion/Sedimentation Group, Waiau Working Party. The report is structured as follows. In section 2 a brief statement is made on the philosophical background to this study. This outlines a geomorphologic perspective on investigations of channel change, and provides a brief introduction to some methodological considerations. The methodology employed integrates information from air photographs and topographic maps with field observations and measurements. This information is used to define river reaches (i.e. lengths of river of similar character). Analysis is undertaken at valley-setting, channel, and gravel bar scales, such that the controls on channel character in each reach can be unravelled. In section 3, river reaches are designated and characterized for the Waiau River downstream of Mararoa Weir. These reaches are located on Figure 1. Geomorphic controls on the character and pattern of reaches are assessed in section 4. Insights from river reach analysis are then used to develop a conceptual framework with which to assess the impact of flow regulation on the Waiau River (Section 5). Recommendations for future study are suggested. Brief conclusions are presented in section 6.

Appendices constitute an extremely significant proportion of this report and are presented in a separate volume. References and a glossary of technical terms are provided at the end of the report.

FIGURE 1


MARAROA WEIR
1
RIVER
2
Whare Creek
Redcliff Creek
WAIAU
3A
145°45'
Borland Burn
3B
Liger Creek
Waicoe Creek
3C
Makarewa Stream
3D
Wairaki River
4
5
Burn
Lill
146°S
6
7
8
RIVER REACH
MAP SHEET INDEX
RIVER
9
Orauea River
Kowhai Creek
0
10km
10
WAIAU
11
Holly Burn
TE WAEWAE BAY
167°30'E
167°45'

2.0 Philosophical perspective : The role of the geomorphologist in river management

The way we look at the landscape determines what we see. As such, the framework through which we examine the environment is critical to any analysis undertaken on the character, processes and controls of landscape features. Equally important is the ability to fit together the different pieces of the environmental jigsaw, so as to interpret how these aspects change and evolve over space and time. Implicit to this is an understanding of the scale at which differing types of interaction take place. For these and other reasons, the conceptual framework adopted in any study of environmental change is crucial for the reliability, replicability and credibility of results produced. Unless any scientific exercise is applied *rigorously*, the results *cannot* be trusted, and are prone to gross misrepresentation. Interpretation of results is refutable; under optimal circumstances, the data themselves are not.

One of the most significant issues in any assessment of the "condition" of the landscape is the *timeframe* over which changes are assessed. This report is written from the perspective of a *geomorphologist*, and relates changes to river systems over timeframes extending from the role of individual events which may occur over a matter of seconds (such as bank collapse) to longer-term aspects of landscape evolution which occur over tens to hundreds to thousands of years, and provide the context or boundary conditions within which the present river operates. A primary example of the latter is the role played by terrace features adjacent to rivers. Analysis of terraces may provide insight into former river behaviour, yet the terraces themselves may affect the contemporary river through their impact on sediment supply from eroding banks, or they may impose lateral constraints on movement of the river channel.

A geomorphic approach differs to that adopted from a engineering perspective, as the timeframe of reference is generally longer, and concern is with system *dynamics* rather than design solutions to site-specific problems. Hickin (1983) proposed a three-scale framework for research on river channel changes :

a) *Geologic scale*

This entails study of river development at the catchment scale over thousands to millions of years. Among environmental controls considered at this scale are the regional tectonic history, glaciation etc. These factors condition landscape configuration and the nature of the materials over which rivers flow.

b) *Geomorphic scale*

A geomorphic approach to river channel changes endeavours to understand controls on form/process associations in river systems, over timescales ranging from individual events which may last a matter of seconds, to lagged adjustments which may occur over tens, hundreds or thousands of years. Only with these insights can river evolution and response to altered environmental conditions be interpreted. Examples of such controls include lateral constrictions placed on the river, variations in sediment input to the river, or flow regulation.

c) *Engineering scale*

Engineering concerns relate primarily to design solutions to river management problems, and are characteristically framed over timeframes determined by the "design-flood regime", typically the 100 year flood. Such effects are typically brought about by changes to the hydrologic and/or sedimentation regime of a river.

Controls on channel changes are complex, and require *interdisciplinary* research by geologists, geomorphologists and engineers. From a geomorphic perspective, it is necessary to comprehend *present day processes* in the context of *longer term change*. This is important for at least three reasons :

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

ii) System adjustments to infrequent, *high magnitude events* can only be evaluated from longer-term records.

iii) Some processes *operate over longer timeframes* than those evident from direct human observation. For example, sediment wedges may gradually migrate down a river over timeframes of hundreds or thousands of years.

One of the recent lessons from the study of river character is that each river must be studied as an individual entity. There is great danger in interpreting any river, or river reach, as symptomatic of a particular "style". We must move away from traditional, oversimplistic text-book notions of river behaviour, as they do not necessarily relate to site-specific situations. If river management is to be effectively emplaced, engineering solutions to site-specific problems must be integrated with geographic and geomorphic insights into system behaviour.

It is implicit that "total catchment management" must adopt an holistic perspective, in which effective communication is promoted among all relevant parties. This can only be attained if processes guiding system evolution are reliably understood, such that spatial patterns in the landscape can be explained. This report focusses on one aspect of the spectrum of concerns in total catchment management - namely "understanding the behaviour of the river itself". The river serves to integrate all aspects of catchment management; hence the designation "*Waiau* Working Party". Human impacts on the river can only be assessed once the character and behaviour of the river can be reliably interpreted. This is the primary focus of *geomorphology*, namely assessment of *form/process associations* and their variation as systems *evolve*.

In this report, primary *base-line data* are collected and collated in a comprehensive, hands-on manner, to describe the present "condition" of the Waiau River downstream of Mararoa Weir. The essential core of the adopted perspective is guided by the desire to compile relevant information which can be readily and reliably applied in subsequent comparative

and other analytical studies (such as time-sequence analysis). Prior to outlining the approach adopted in this study, a few background principles of river geomorphology are described.

2.1 Some background principles of fluvial geomorphology relevant to this report

Rivers are differentiated into two types, those which flow on their own deposits (i.e. *alluvial* channels), and those which are constrained by either *bedrock* or boulders. While the latter are doubtless very prevalant in Southland, they are typically restricted to particular reaches in which channel changes are not significant, as channel condition is imposed. Conversely, alluvial channels are able to adjust their form, by adapting their channel geometry, migrating across their floodplain (either laterally or downstream), or adjusting their erosion/sedimentation regime.

Alluvial channels in Southland are of three primary styles. *Braided* rivers are highly dynamic, multichannelled systems, which switch their channel position frequently. In contrast, *meandering* rivers are single-channelled, but sinuous. If freely meandering, the channel is laterally unstable, with erosion on the outside of bends and concomitant deposition on the inside bank. An intermediary river type, termed a *wandering gravel-bed* river, is characterized by fewer channels than a braided river, yet many of its channels may meander. Once more, this is a laterally unstable channel style. In this simple breakdown, channel style is described by three different terms : *channel sinuosity*, the *number of channels*, and the *lateral stability of the channel(s)*. Any one river is usually made up of a combination of these different styles.

The two primary controls on channel planform type are the *channel bed slope* and the *particle size* of the channel bed material. Braided rivers are typically associated with steeper slopes, and more abundant supply of coarser materials than are meandering styles. A further significant control, however, is the nature of the *flow regime*, as braided rivers are characteristically associated with more fluctuating discharges than are meandering rivers. In essence, a multichannelled channel condition arises for one of two reasons : the sediment load is either too coarse for the river (termed the *competence* limit) or there is simply too much sediment for the river to carry (the *capacity* limit).

Any change in these controls (particle size or quantity, slope, or flow regime) may bring about adjustment in channel style. This is referred to as *channel metamorphosis*. Geomorphic assessment of controls on the character, rate and permanance of channel metamorphosis has enormous implications for river management and designs of appropriate engineering responses.

River reach analysis provides an appropriate basis for base-line inventory of channel 'condition', as it directly links longer-term controls on channel development (a geologic approach), with local-scale considerations essential for engineering design structures.

2.2 Introduction to river reach analysis

Just as individual rivers must be treated as individual entities, within-catchment variability in channel character determines that each river cannot be summarized as a single feature, and river reaches must be designated. Controls operating at the river reach scale determine local river character. To understand the 'big picture', however, each reach must be placed in the context of its upstream and downstream counterparts. Questions arise as to how to define and to characterize reaches. This report follows the suggestion of Kellerhals et al. (1976, p814-815) who state that "Classification of a river should proceed by individual 'homogenous reaches;' i.e., channel reaches (of variable length) within which hydrological, geological, and adjacent watershed surficial conditions remain sufficiently uniform so that a sufficiently uniform river morphology results."

Kellerhals et al (1976) continue (p815), "The characteristics of a river channel will change wherever a change occurs in any of the conditions that govern fluvial morphology and reasonably detailed knowledge of these conditions is therefore an essential prerequisite to the proper planning of any engineering interference to a river." The Waiau River is a perfect example of the need for such a base-line inventory; indeed, under ideal circumstances an equivalent exercise would have been undertaken prior to flow regulation!

This study cannot attempt to represent a comprehensive analysis of changes in the past. Careful analysis of pre-regulation air photographs, along with appropriate field analytical techniques, can provide information not only on the current (March, 1992) condition of the river, but also make an informed assessment of some of the adjustments which have taken place since regulation. This is not the primary goal of this study, however, as a prerequisite for understanding any past or future changes in channel character must be reliable understanding of the *present-day configuration* of the river.

2.3 Framework for the base-line inventory of river reach analysis employed in this study

River reach analysis undertaken in this study uses the framework proposed by Kellerhals et al (1976) as a starting point for investigation. Field work was applied at three scales of analysis. Specifics of the field strategy and sampling procedure are detailed in Appendix I. In the first instance, *valley characteristics* are analysed by field observation. These include features such as 'terrain' which describes the valley setting, character of terrace features, and nature and extent of constrictions on the channel. This scale of analysis is important as it describes the context or boundary conditions within which the channel is able to adjust. For example, the number and morphology of terraces can be used to infer past migration patterns of the channel, while acting presently as a significant sediment source in certain areas.

The second scale of field analysis entails study of *channel characteristics*. This refers primarily to channel planform, which describes the configuration of the channel in plan view. This is measured using three parameters, namely the

number of channels, their sinuosity, and their lateral stability. Types of river bar are described, as these can be used to determine the character of channel change, while the character of the flow and bank materials are also described. These features are especially significant as they provide indicators of the migration pattern of the river (either downstream or laterally), and can be used as predictors of likely future channel changes.

The final scale of field analysis describes *gravel bar characteristics*. Features such as grain size and sorting, the packing arrangement of gravels, and variations in particle shape and lithology are recorded. These characteristics record the ease with which the river is able to move materials on the channel bed, and are highly sensitive indicators of sediment transport within the channel. Of particular significance is the paving or armoring of gravels on the bed of a river, as this is a major indicator of the 'stability' of the channel bed.

The primary characteristic used to designate river reaches of the Waiau River downstream of Mararoa Weir is the *planform geometry* of the channel. Distinct reaches can be determined along the Waiau based on lateral constrictions of the channel, whether imposed by bedrock or proximity to terraces. Laterally unconstrained reaches demonstrate variable channel patterns in terms of channel multiplicity and sinuosity. River reaches of the Waiau are described in subsequent sections.

3.0 Designation and characterization of river reaches of the Waiau River downstream of Mararoa Weir

Information described in this section has been summarized from the base-line data inventory presented in Appendix II. Other than primary field data, air photo runs from 1984, 1989 and 1991 have been utilized, as well as relevant 1:50,000 and 1:63,360 topographic maps.

3.1 DUNCRAIGEN REACH

This reach extends for 2.2 km downstream of Mararoa Weir (Photo 1), to a point immediately upstream of the confluence of the Waiau with Whare Creek. Mararoa Weir is roughly 100 river kilometres from Te Waewae Bay.

Duncraigen reach is a single-channelled, almost straight river reach. This channel condition is imposed by channel-marginal fluvioglacial terraces (Photo 2) and there are virtually no alluvial or valley flats. Gravel bars are restricted to small alternating lateral bars, with no within-channel deposits. Sample Point 1 is located on one of these lateral bars (Photos 3 and 4). Although gravels are poorly sorted, the bed condition is well-imbricated and winnowed, indicating that the bed may be paved. Gravels are quite coarse, with almost 50% of particles coarser than 100 mm.

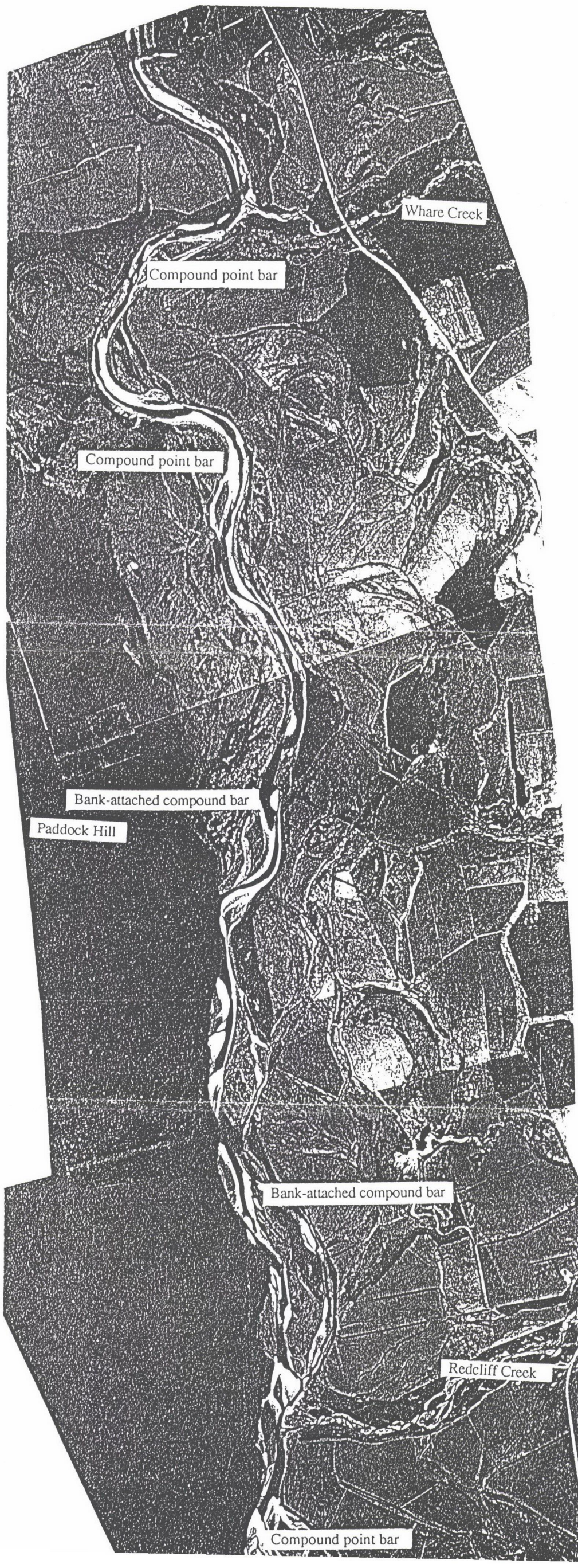
3.2 REDCLIFF REACH

This reach extends for 14.3 km, from just upstream of the Whare Creek confluence to about 4 km downstream of Redcliff Creek confluence, adjacent to Blackmount Forest. A recent air photo strip of this reach is shown in Figure 2.

The valley setting in this reach differs notably from Duncraigen reach in that the valley opens up, with extensive valley flats (Photos 5 and 6). This is clearly evident in the valley cross-section (see Appendix II). The channel migrates laterally some distance downstream from its laterally confined condition in Duncraigen reach. As the extent of alluvial flats increases downstream in Redcliff Reach, so does the extent of active gravel surfaces, and the channel divides from a single channel at the head of the reach to four or five channels downstream of Redcliff Creek. This may also be related to distinct sediment inputs from Redcliff Creek. These inputs result in the capacity limit of the Waiau being exceeded, with concomitant within-channel sedimentation. The terraces are exceedingly prominent on the left bank of the Waiau, while the right bank is pinned against the foothills of Paddock Hill (Photo 9).

Since both lateral constraints and channel multiplicity vary downstream in Redcliff Reach, there is an according change in bar types. The reach is broadly sinuous at its upstream end, with compound point bar features. These are transitional downstream to a sequence of alternating lateral bars. Many large, dissected islands are noted adjacent to the contemporary channel. Depositional units on these islands are typically aligned down-island. Islands appear to be non-

REDCLIFF REACH



formative, in that adjacent areas of floodplain have been dissected by side channels resulting in island development. As the channel divides significantly downstream of Redcliff confluence, large complex compound bars are highly dissected with irregular accretional units (Photos 16 and 17). Several topographic levels are evident in this braided configuration, reflecting variable responses of the river to differing magnitudes of flood events.

Three gravel samples were collected in Redcliff Reach. The upstream sample, collected about 1.5 km downstream of Whare confluence on a lateral bar, is composed of loose, very mobile gravels, which possibly reflect a series of gravel sheets on the bar surface. While the modal particle size group is the same as Sample 1 in Duncraigen Reach (91-127 mm), the mean grain size is notably smaller than upstream (73 mm as opposed to 93 mm). This possibly reflects sediment input from Whare Creek. There is little evidence of a paved gravel bed at this point. Remaining sample locations in this reach are just upstream and downstream of Redcliff confluence (Photos 7 and 14 respectively). Both samples are locally highly variable, although the sample upstream of Redcliff Creek (sample 3) is generally 'overloose', while the sample downstream is partly imbricated. Coarse-particle parameters (D95 and D84) and mean grain size are both larger in the sample downstream of Redcliff confluence.

3.3 BLACKMOUNT-MANGAPIRI REACH

Blackmount-Mangapiri reach is the longest of the river reaches described in this inventory, and is made up of four subreaches. These are termed Blackmount, Monowai, Waicoe, and Mangapiri. In their summary form these subreaches extend from 46.1 to 81.5 km from the mouth of the Waiau River. This reach is characterized by a laterally constrained single channel, which flows within an imposed broadly sinuous course. Within-channel sedimentation is restricted to two large compound point bars, in mid-section of Blackmount and Waicoe subreaches. The only other forms of gravel deposition observed in this reach are occasional lateral bars associated with tributary channel confluences and small mid-channel bars associated either with bedrock steps or local valley widening.

3.3.1 BLACKMOUNT SUBREACH

Blackmount subreach extends from 74.2 to 81.5 km above the mouth of the Waiau River. It is marginal to Blackmount forest on its left bank for its entire length.

Blackmount subreach is characterized by a broadly sinuous single channel, which has little opportunity to migrate laterally due to constraints imposed by fluvioglacial outwash terraces and bedrock (Photo 18). The valley flat is fragmentary, and significantly less extensive than in Redcliff reach upstream. In the downstream half of this reach many former channel outlines and meander loops are evident on the valley flats (Photos 24-27). These attest to the great stream power of the Waiau in the past, and indicate that the present channel configuration is largely an artifact of former channel history.

Alluvial flats are very restricted in Blackmount subreach, and within-channel sedimentation is restricted to the inside of one bend, where a compound point bar has been dissected by a series of small chute channels (Photo 23). Although the upstream end of the subreach is broadly sinuous, there is no lateral accretion on the insides of bends, inferring that this is an imposed sinuosity. In the downstream half of this subreach several abrupt transitions in bar type are demonstrated, from :

a) a wide bend with a compound point bar to
b) a lateral bar to
c) a bedrock-constrained bend to
d) another bedrock-stepped lateral bar at the downstream limit of the subreach.

Both gravel bars sampled in Blackmount subreach are lateral bars, and in both cases gravels are partly imbricated with significant winnowing (Sample Points 5 and 6). Once more the gravel surfaces are somewhat loose and jumbled. While the modal grain size class at the upstream sample is consistent with those described for upstream reaches (91-127 mm), it is one class smaller at the downstream sample site (64-90 mm). This difference is especially evident in the coarsest clast size parameter (D95), which is 45 mm smaller at the downstream site (132 mm compared to 177 mm). In both instances, however, mean clast size is smaller than at sample sites upstream.

3.3.2 MONOWAI SUBREACH

Monowai subreach extends over 6.7 km from the broad bend upstream of Borland Burn to the confluence of the Waiau River with Waicoe Creek.

Monowai subreach is essentially similar to Blackmount subreach, with single-channelled, laterally constrained flow dominant. It differs in that within-channel sedimentation is even more restricted and alluvial flats are not evident. Indeed, gravel bar features are observed solely as lateral bar features adjacent to tributary confluences. These are non-alternating, and are restricted to the right bank. As observed in the Blackmount subreach, there is an imposed moderate sinuosity, but bends are anything but freely meandering. Accordingly, contemporary point bar features are not observed.

The terrace pattern in Monowai subreach is especially significant in elucidating longer-term controls on channel adjustment. Terraces are especially well-developed as perched features on the insides of the broadly sinuous bends of this subreach. As noted previously, these bends are not contemporary features, and the terrace pattern reflects lateral adjustment and downstream translation of bends at some period in the past. In the bend downstream of Monowai power station there are five or more stepped terraces around the inside of the bend, with side channels at the base of terrace risers.

The gravel bar sampled in this subreach is located immediately upstream of the Waiau confluence with Monowai River. This is a lateral bar feature, which formed as an extension of a riffle at the outside of a bend (Photo 30). The gravel surface is partly imbricated, and appears to represent a distinct pavement, although some clasts are loose and the surface has a distinctly jumbled appearance. The mean particle size is notably finer than at all upstream samples, while the modal size class is equivalent to the previous sample upstream (64-90 mm, as observed in Sample 6 from the lower Blackmount subreach). Only 11 of the 100 sampled clasts have 'b axis' measurements beyond 100 mm, compared to 25 clasts in all previous samples.

3.3.3 WAICOE SUBREACH

Waicoe subreach extends for 4.7 km from the Waiau River confluence with the Waicoe to a point immediately downstream of the confluence with Makarewa Stream.

Whereas Monowai subreach is confined laterally to a greater extent than Blackmount subreach, Waicoe subreach is less constrained, and both valley and alluvial flats are more extensive. Once more, however, this effect is discontinuous within reach, and is accentuated within bends (Photos 34 and 35), where terrace configuration outlines the former pattern of bend migration. Bends in this reach are significantly tighter than those observed upstream, but this is a condition imposed by bedrock buttresses at the outsides of both the meander loops in this subreach.

A single channel is maintained throughout most of this subreach - as noted elsewhere, the channel only subdivides on the compound point bars in the tight bends. There is an interesting sequence of gravel bars moving downstream through this subreach, probably associated with the imposed bend structure and the two primary confluences that join the Waiau. A lateral bar has formed on the opposite bank downstream of the Waicoe confluence, probably associated with flow deflection around the bend. A large gravel point bar has developed at the apex of this bend (Photos 31 and 32). The tightness of this bend (i.e. its small radius of curvature), has induced distinct secondary flow circulation cells at the outside of the bend (Photo 33). This bar is especially poorly sorted, and is composed of poorly packed and jumbled gravels (Sample 8; Photo 31). The D95 at this sample site is 250 mm - over 70 mm coarser than at any sample point upstream.

The bend immediately downstream of Sample Point 8 contains a highly dissected compound point bar (Photo 34), in which a series of chute channels have short-circuited the main flow around the outside of the bend. Extensive low-lying alluvial flats are found on the left bank downstream of this bend (Photo 36). Downstream of these flats the Waiau is eroding a perched outwash terrace upstream of another tight bend - this bend is coincident with the Makarewa confluence (Photo 37). A bedrock step in this bend, along with the tightness of the bend and tributary sediment supply, have resulted in a complex riffle and point bar assemblage (Photo 38). Sample 9, collected in a chute channel on this point bar, exhibits a coarser modal grain size group than any sample point upstream (128-180 mm), but once more this sample is poorly sorted, although it has been selectively winnowed (with only 7 from 100 clasts smaller than 30 mm).

On the inside of the tight bend at the downstream limit of this subreach is a significant area of flat land which tapers around the bend. An equivalent unit, also less than two metres above the position of the contemporary channel, was observed on the left bank downstream of Waicoe Creek. This surface probably has its counterpart in Redcliff reach, and is considered to represent within-reach degradation following flow regulation.

3.3.4 MANGAPIRI SUBREACH

Mangapiri subreach extends for 16.7 km, from 46.1 to 62.8 km from the mouth of the Waiau River. The upstream limit of this sub reach is demarcated by the confluence with Makarewa Stream, while the downstream limit is located at the head of a large point bar 2.5 km upstream of Wairaki confluence.

This subreach of the Waiau River lies in a foothills setting, between Mangapiri Bush on the left bank and Dean Forest on the right bank (Photo 43). Throughout the subreach the river is laterally constrained by fluvioglacial terraces and bedrock, while the valley itself is relatively wide. The channel has an imposed broadly sinuous outline, in which sedimentation is restricted primarily to the insides of bends. In the downstream 2 km of this subreach the configuration of gravel bars changes somewhat, as a bedrock step with riffle atop has induced within-channel deposition and divided the flow (Photos 49 and 50). Downstream of this point the flow remains laterally constrained within bedrock capped by outwash terraces, but a series of alternating bars have developed (Photo 51).

Two gravel bars were sampled in Mangapiri subreach (Samples 10 and 11). Sample 10 was collected on a diagonal bar which has a bedrock (Papa) base adjacent to Glendearg station (Photos 46 and 47). At its upstream limit, this bar is composed of a layer of gravels a single grain thick atop the highly friable mudstone - at its downstream limit this bar is contiguous with a major riffle feature (Photo 48). Gravel organization on the bar surface is highly variable, with some imbricated sections while most gravels are jumbled and overloose. Sample Point 11 is located at the head of a lateral bar, approximately 1 km upstream of Wairaki reach (Photo 54). While gravels on this bar are locally imbricated and less jumbled than observed in other samples from upstream, they are still predominantly 'overloose' and are indicative of a mobile gravel surface (Photo 56). Coarsest clast size, mean grain size and modal group observed in samples 10 and 11 are roughly equivalent with values observed in upstream samples. Modal 0.5ø clast size interval is 91-127 mm.

3.4 WAIRAKI REACH

Wairaki reach contrasts starkly with the lengthy Blackmount-Mangapiri reach located upstream in terms of the extent of lateral constraint placed on the channel, and its subsequent response in terms of both channel multiplicity and lateral stability. Wairaki reach extends for 8.2 km, from a large point bar 2 km upstream of Wairaki confluence to a bank-

attached compound bar just downstream of Broadlands Bush. A recent (1992) air photo strip of this reach is presented in Figure 3.

The valley widens considerably in this foothills setting, adjacent to the confluence of Wairaki River and Dean Burn. Associated with the wide valley flat are extensive and complex terrace sequences. At its downstream limit, at the head of Otahu Flat, the river becomes pinned against bedrock at the western valley margin - this is adjacent to Motu Bush and is referred to as Motu reach (see section 3.5). Terraces are generally fragmentary in Wairaki reach, and reflect local circumstance (e.g. the pattern around the inside of the bend at the head of this reach) and broader regional-scale controls (reflected in the extensive upper terrace which extends back to the valley margins).

With the increased width in the valley flat is a concomitant increase in the area of alluvial flats and active channel zone (Photo 62). Although generally more than several hundreds of metres wide, the alluvial flats are fragmentary, and switch from valley side to valley side. Coincident with the increase in the width of the valley flat are discrete sediment inputs from Wairaki River and Dean Burn. These conditions have resulted in reduced flow competence and have exceeded the capacity of the channel to transport all its sediment. Within-channel sedimentation has resulted, and flow divides around a series of complex bars and riffles, with dissection of bank-attached compound bars by chute channels. In addition to this, several small lateral bars are noted in this reach. For all these reasons this reach appears to represent a "sedimentation zone" in a wandering gravel-bed river (*sensu* Desloges and Church, 1987).

Wairaki reach is characterized by pronounced lateral instability in the channel. Indeed, many recent channel adjustments have taken place in this reach, as evidenced by comparing the present channel configuration with the 1984 air photo run. This is especially true adjacent to Wairaki confluence, where a large riffle feature has translated downstream and subsequently been dissected into a series of smaller bar units. This local deposition may reflect reworking of locally eroded banks immediately upstream. At least two primary areas of erosion are evident:

a) along the left bank outwash terrace at the head of the reach (Photo 60) and

b) along the outside of a bend on the right bank just upstream of Wairaki confluence.

Within-reach complexity of Wairaki reach may be explained as follows. As flow emerges from Mangapiri subreach it is concentrated in a single high velocity filament. As flow erodes the outside of the bend 2 km upstream of Wairaki confluence there is concomitant deposition on the inside of the bend, and a large point bar has developed (Photo 61). There is even deposition in the form of a lateral bar on the outside of the bend - this is considered to reflect local reworking of deposits derived from the eroding outwash terrace on the concave bank (Photo 60). An extensive area of alluvial flats behind this bar indicates that this was previously part of an active channel reach. However, flow is presently concentrated into a single channel downstream of this bend, and is deflected back towards the western valley flat, where it is presently eroding a thick sequence of outwash gravels. The compound point bar on the inside of this bend is highly dissected, with three chute channels evident.

WAIRAKI REACH



Channel configuration changes markedly downstream of Wairaki confluence. Flow divides around a complex of riffles and mid-channel bars, while relatively recent meander loops and scour features on the alluvial flats indicate that the channel is far from being laterally stable. Indeed, active gravel surfaces adjacent to the margins of the alluvial flats attest to recent channel erosion and subsequent deposition (Photos 65 and 66). The active gravel surface in this area is considered to be more extensive than at any point observed upstream. At the bedrock constriction adjacent to Broadlands Bush, however, flow configuration changes once more, as flow is concentrated into a single channel. Immediately downstream of this point two alternating bank-attached compound bars are observed (Photo 67). These bars probably reflect reduced flow competence downstream of the bedrock constriction. They are made up of several depositional units aligned down-valley, and have subsequently been dissected by both chute and side channels (Photo 68).

In summary, moving downstream through the reach, flow is initially concentrated into a moderately sinuous channel. This becomes concentrated into a fairly tight bend upstream of Wairaki confluence. Immediately downstream of this confluence, flow is aligned virtually straight down-valley, but is divided into a series of smaller channels with valley-marginal side channels. At Broadlands Bush, flow becomes concentrated into a single bedrock-constrained channel. Downstream of this subreach flow is deflected in a broadly sinuous pattern around alternating bank-attached compound bars. Beyond here the channel adopts a single-channelled, virtually straight course in Motu reach.

Three gravel samples were collected in this complex assemblage of gravel bar features. The upstream sample (Sample 12) was collected on the large point bar at the head of the reach, Sample 13 was collected on a small lateral bar just downstream of Wairaki confluence, and Sample 14 was collected on a large bank-attached compound bar downstream of Broadlands Bush. In all three instances the gravel surfaces were made up of loose, only moderately imbricated gravels, with little or no evidence of paving. Indeed, all three surfaces appeared to be highly mobile. Mean grain size diminishes downstream in the three samples collected, and all samples are finer than those recorded in Blackmount-Mangapiri reach. Indeed, in these three samples the modal group decreases from 91-127 to 64-90 to 45-63 mm from Samples 12 to 14. One feature of note on the lower two samples, downstream of Wairaki confluence, was the preponderance of fist-sized gravel sheets washed over the bar surface. These are generally more angular than the coarser clasts sampled, and may represent local sediment sources within the Wairaki catchment.

3.5 MOTU REACH

Motu reach is a short, single-channelled, almost straight reach which is pinned between extensive terraces of Otahu Flat on its eastern edge, and Motu Bush on its western margin. This 2.4 km reach extends from 35.5 to 37.9 km upstream of the Waiau mouth. While valley flats are extensive in Motu reach (up to 4.5 km wide), there are no evident alluvial flats and no within-channel sedimentation. The channel appears to be highly stable; indeed, sandy mudstone is evident in both banks at the downstream end of the reach. Thick, horizontally-bedded outwash gravels are located atop the bedrock base on the right bank (Photo 69).

3.6 LILL BURN REACH

Lill Burn reach extends for 7.4 km, from 28.1 to 35.5 km from the mouth of the Waiau River. This reach is constrained by bedrock-confined banks at both its upstream and downstream limits. Upstream the river exits Motu reach, with a bedrock based terrace on the left bank and Motu Bush on the right bank (Photo 70). At the downstream limit the Waiau is constrained by limestone bedrock just upstream of Clifden (Photo 83). A recent air photo strip of this reach is presented in Figure 4.

Downstream of the virtually straight, imposed channel condition of Motu reach, the valley flats remain extensive at around 4.5 km wide, but the alluvial flats also become laterally extensive, and the channel is able to adjust and modify its planform (Photos 71 and 74). This results in a similar condition to Wairaki reach, with distinct downstream variability in the character of within-channel sedimentation. Once more this is partially attributable to tributary inputs, as Lill Burn impacts on the Waiau River.

Adjacent to the contemporary channel in Lill Burn reach is a fragmentary lower alluvial flat, a few metres above the present channel. This forms a fairly rough pasture, and is highly dissected by secondary channels around Lill Burn confluence (Photo 74). Perched above this, about 4-5 m above the channel is a laterally extensive, continuous terrace on both sides of the valley (Photo 71). This extends for more than 1 km in width. Above this are unpaired flights of terraces - about 5 m above the second terrace on the right bank, and 10 m above on the left bank. Beyond this is a high terrace feature, marked as a ridge on the topographic map. Outwash materials are the predominant channel-marginal and valley-flat materials in this reach - bedrock is observed solely at the downstream limit of the reach.

The planform geometry of the Waiau changes notably in Lill Burn Reach. At its upstream limit, where the flow extends as a high velocity filament from the constrained Motu Reach, the river adopts a virtually straight single channelled configuration, in which flow is gently deflected around a couple of alternating lateral or bank-attached compound bars. Moving down-reach, side and chute channels become increasingly prominent on these bars, and by Lill Burn confluence there is active within-channel sedimentation (Photos 75-77). This may arise for a variety of reasons - the confluence may impose a local base level, reducing the slope of the Waiau resulting in lower flow competance, or this condition may simply reflect increased sediment supply and exceedance of the capacity limit of the channel.

The channel configuration around Lill Burn confluence has changed significantly during the late 1980's. Channel multiplicity increases notably downstream of the confluence, with four or five channels evident around riffles and mid-channel compound bars (Photos 79 and 80). In general, however, the flow appears to be more concentrated than it has been in the recent past, as prominent side channels at the margins of the alluvial flats appear to have been abandoned (Photo 81). This may reflect either lateral shifting of the channel, or simply reduced flow levels which cannot fill channels at the higher topographic levels (*sensu* Williams and Rust, 1969) other than at high discharge stages. Regardless of causality, the flow is laterally unstable, and eroding banks immediately downstream of the confluence (Photo 78).

LILL BURN REACH



At the downstream end of the reach, a kilometre or so upstream of the bridges at Clifden, the Waiau channel is constrained by bedrock into a single channel (Photo 83). This is a fairly tight bend, with a prominent gravel point bar (used, incidentally, for gravel extraction).

Three grain size samples were collected in Lill Burn reach. Sample 15 was collected on a bank-attached compound bar at the head of the reach, Sample 16 was collected on a complex mid-channel bar at Lill Burn confluence, and Sample 17 was collected on the point bar at the downstream end of the reach. All three samples are poorly sorted, with distinct locales of differing-sized clasts over the bar surface. Gravels on the bank-attached compound bar at the head of the reach are overloose and jumbled - they appear to represent a highly mobile gravel sheet. The modal clast-size group is 128-180 mm. This is notably coarser than samples described for Wairaki reach upstream, and possibly reflects greater flow energy associated with concentrated flow downstream of Motu reach. The coarsest grain size, however, is consistent with that found in Wairaki reach.

At Sample Point 16, large volumes of fist-sized gravels are washed onto gravel surfaces from Lill Burn. This has resulted in the smaller modal size class at this sample point (45-63 mm), and an accordingly smaller mean clast size, while the coarsest grain size parameter (D95) is not inconsistent with upstream samples. Gravels at this site are less mobile than observed at the head of the reach, with partly imbricated gravels, with less winnowing evident. The final sample in this reach, Sample 17, is also moderately imbricated, and is somewhat better packed than Samples 15 and 16. Modal clast-size group, D95, mean size and sorting value are all intermediary between those of Samples 15 and 16.

A large number of fist-sized gravels sheets have been washed onto the gravel surfaces in Lill Burn reach. Furthermore, sand lobes and vertically-accreted sand units are prominent at bar margins. These only appear in any significance downstream of Lill Burn confluence.

3.7 CLIFDEN SUSPENSION BRIDGE REACH

This is a bedrock constrained reach, with prominent limestone cliffs on both river banks. The reach is just 1 km long, extending from 27.1-28.1 km from the river mouth. Outwash terraces are notable marginal to the bedrock, yet the channel itself is confined to a single shannel with no alluvial flats (Photo 84). No within-channel sedimentation is evident.

3.8 DOWNSTREAM O'CLIFDEN REACH

Downstream o'Clifden reach is 5.4 km long, and extends from just downstream of the limestone cliffs at Clifden to the single-channelled, confined reach adjacent to bush at the base of the ridge with Hagen Road atop. This reach is 21.7-27.1 river kilometres upstream of Te Waewae Bay. This is a lowland setting, with gentler valley-marginal slopes.

Fewer high terraces are observed downstream of Clifden compared to reaches upstream. A recent (April, 1992) air photo strip of this reach is presented in Figure 5.

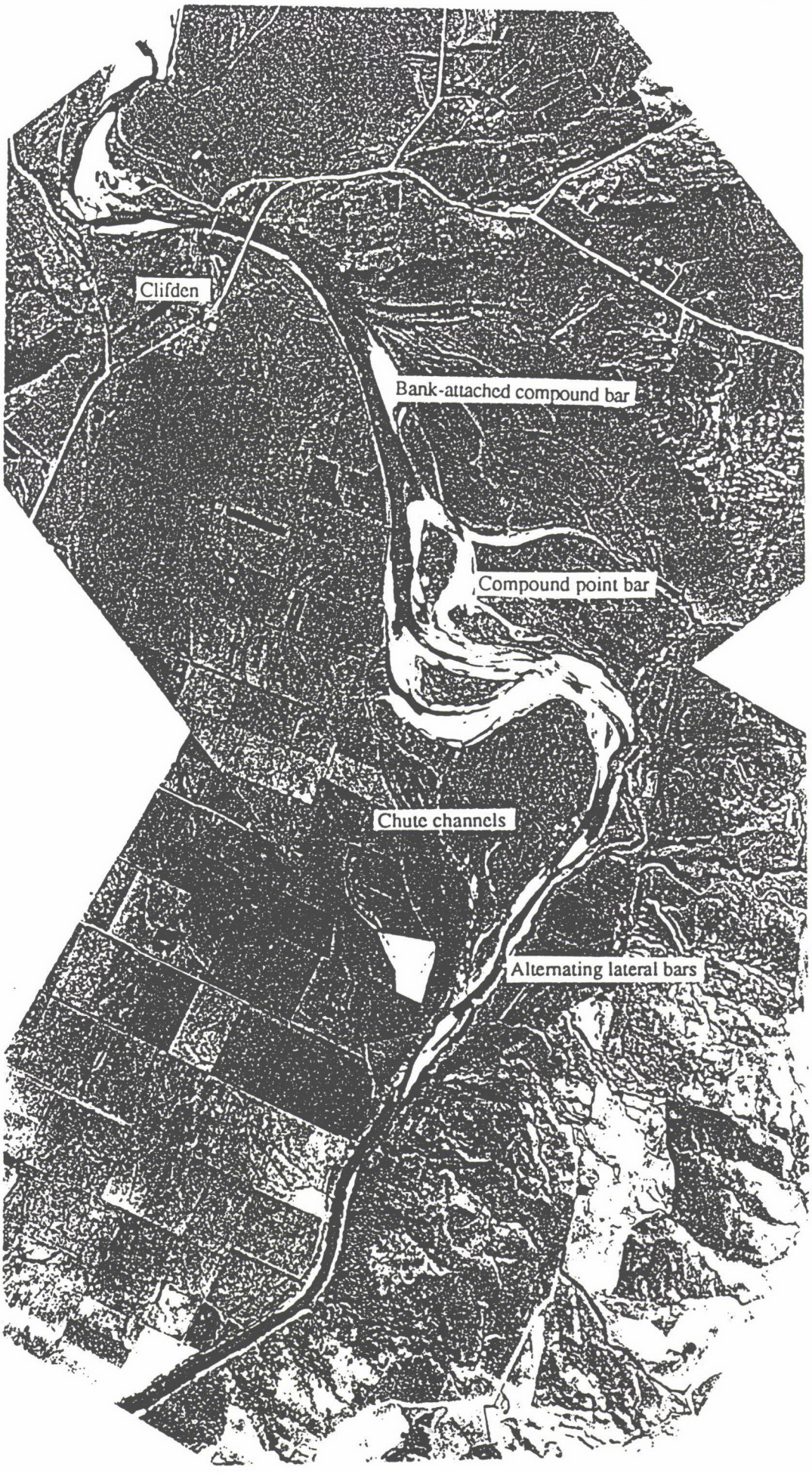
The pattern of gravel bars in Downstream o'Clifden reach is remarkably similar to that demonstrated in Redcliff, Wairaki and Lill Burn reaches, reflecting the transition from a laterally constrained single channel reach to a situation where the lateral constraint is removed, and flow divides around mid-channel bars. Downstream o'Clifden reach, however, has the tightest freely-migrating channel in the study area (Photo 89).

Lateral and bank-attached compound bars are found at the head of the reach. These are located immediately downstream of the confined Clifden Suspension Bridge reach (Photo 86). Lateral and bank-attached compound bars are transitional downstream to longitudinal and mid-channel compound bars, with dissected point bars on the inside of tight bends (Photo 89). The downstream section of the reach is characterized by within-channel sedimentation on bedrock bars associated with harder sandy beds in Papa sequences. A large gravel bar has also developed recently with the accumulation of deposits at the downstream end of side channels. These deposits appear to be directly associated with the bedrock step upstream, as the lateral bar appears to be an extension of a major riffle downstream of the bedrock step (Photo 92). Beyond this bar flow becomes concentrated into a single channel once more, with bedrock forming the base of both banks.

Four gravel samples were collected in Downstream o'Clifden reach (Samples 18-21 in downstream sequence). The gravel surface from which Sample 18 was collected is a bank-attached compound bar at the downstream end of a riffle. This has a distinct valley-marginal side channel which is in the process of becoming abandoned, with a relatively thick sand drape over the channel fill. Sample 18 is a moderately packed, moderately imbricated bar supraplatform, which has been winnowed to about 30 mm. However, gravels are poorly sorted, and a diffuse, one or two-clast thick sheet appears to have been deposited over the bar surface. Gravel clasts are distinctly coarser than observed in Lill Burn reach, with D95 values 50 mm greater (215 mm at sample 18). The mean particle size is also notably coarser than observed in both Lill Burn and Wairaki reaches.

The coarser nature of bar deposits in Downstream o'Clifden reach is especially pronounced in Sample 19. This sample was collected in the gravel locale at the head of a mid-channel compound bar. Two-thirds of clasts sampled at this site were coarser than 100 mm, and the D95 parameter is coarser here than at any sample point upstream. The bar surface is made up of several discrete locales. Clasts are moderately packed and imbricated, but they are not well winnowed. One possible interpretation for the coarseness of the clasts at this sample point is that this is a scoured gravel surface, and it is possible that clasts sampled reflect the supraplatform. While these are definitely mobile, most of the samples previously described are bar platform samples; indeed, many reflect recent deposits from sheets washed onto bar surfaces as distinct accretionary sequences. Samples 20 and 21 are also somewhat coarser than samples collected over the previous upstream 25 river kilometres.

DOWNSTREAM O'CLIFDEN REACH



Grain-size samples collected in Downstream o'Clifden reach conform to a previously observed trend wherein grain size diminishes downstream within-reach. This is generally evident for D95, mean and modal clast-size group parameters. Samples 20 and 21 are poorly sorted, jumbled and largely unwinnowed gravel accumulations collected at the head of a point bar and lateral bar respectively.

3.9 HAGEN ROAD REACH

This lowland river reach has extensive valley flats (about 4 km wide) but very limited alluvial flats (< 300 m), as flow is confined into a roughly straight, single channelled configuration (Photo 93). At least three continuous, pronounced terraces are evident on the right bank, but the left bank is Papa bedrock. No within-channel sedimentation is evident in this 4.3 km reach which extends between 17.4-21.7 km from Te Waewae Bay.

3.10 ORAUEA REACH

Orauea reach extends for 5.5 km from about 1.5 km upstream of the Orauea confluence to immediately downstream of the bridge in Tuatapere. This is 11.9-17.4 km from the mouth of the Waiau River.

The Waiau River has a moderately straight configuration in Orauea reach, and is predominantly single-channelled (Photo 94). In this lowland setting the valley is moderately broad, with upper terraces extending over approximately 5 km width. Terraces are curved and fragmentary. These appear to be paired and non-eroding. The township of Tuatapere is located atop the third terrace level.

Within-channel sedimentation in Orauea reach is primarily associated with sediment input from Orauea confluence, which is coincident with a mid-channel bedrock step (a sandstone band in Papa bedrock; Photo 96). The channel is confined by bedrock with terraces atop throughout the reach, although alluvial flats are somewhat more extensive in the short reach upstream of Orauea confluence. In this short subreach there are a series of flood channels oriented roughly parallel to the contemporary channel. Given the lateral constraints imposed on the channel, bar types are restricted to alternating lateral bars around which the Waiau switches position between valley sides. The channel itself appears to be relatively stable.

Two sample sites are located in Orauea reach. Sample Point 22 is located on a lateral bar adjacent to reworked alluvial flats upstream of Orauea confluence. This is a poorly sorted unit of loose, but partly imbricated gravels. The D95 grain size parameter and mean particle size are consistent with trends observed in the Downstream o'Clifden reach, as both are roughly equivalent with Sample Point 21. This is a somewhat disturbed sample site, with scour evident on the grassed surface adjacent to the bar.

Particle size parameters are somewhat coarser at Sample Point 23 than observed upstream in Orauea reach. Indeed, there are seven clasts coarser than 200 mm as opposed to only one at Sample Point 22. This is clearly reflected in the histograms showing grain size distribution (see Appendix II). Sample Point 23 is located at the head of a lateral bar on the right bank of the Waiau, just upstream of Tuatapere bridge. This bar forms the extension of a major riffle unit. This is a very poorly sorted, largely unwinnowed surface, with jumbled gravels which are only locally imbricated. While these gravels appear to be relatively loose on the surface, many fine gravels are found just beneath the surface, and there are many discrete lenses of finer gravel sheets launched onto the bar surface down-bar. While D95 and mean particle size are coarser than at Sample Point 22, the modal 0.5 ø grain size class are the same at both sample points (91-127 mm).

3.11 TUATAPERE REACH

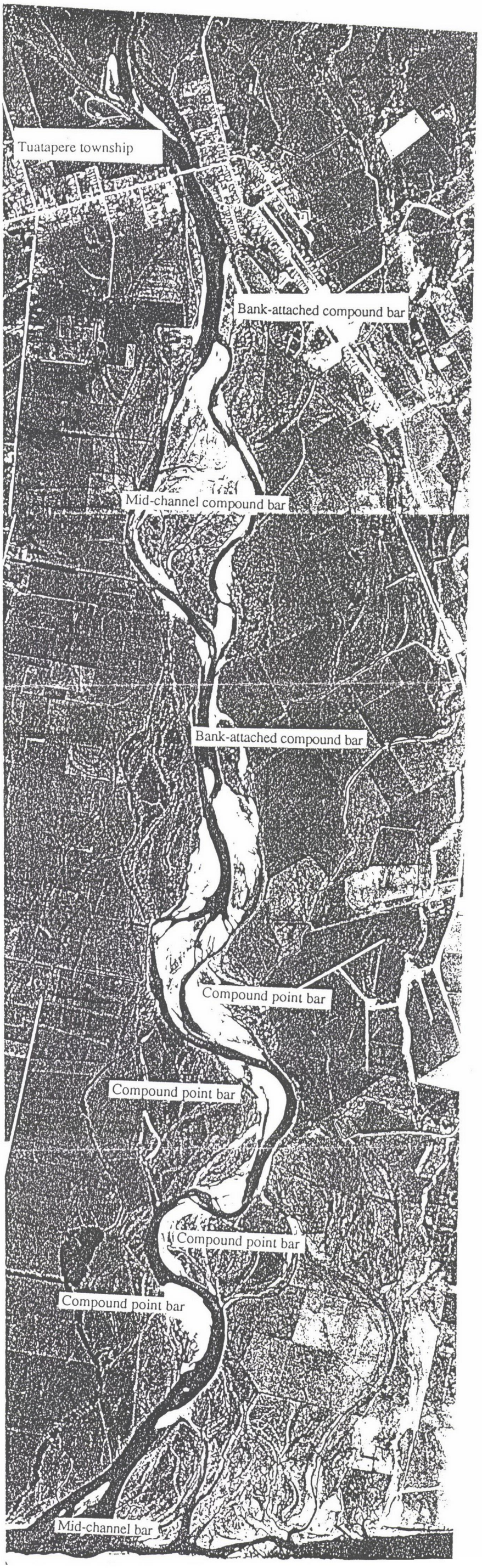
This, the downstream reach of the Waiau River, extends for 11.9 river kilometres from just downstream of the bridge in Tuatapere to Te Waewae Bay. A recent air photo strip of this reach is presented in Figure 6.

Tuatapere reach is the only truly 'lowland' reach in the study area. The alluvial and valley flats are much more extensive than elsewhere, as noted on the valley cross section in Appendix II. Terraces are set back further from the river, and do not reach anything like the heights observed upstream. It is interesting to note, however, that bedrock is observed adjacent to the channel at a couple of locations within Tuatapere reach (e.g just upstream of Sample Point 24 and just downstream of Sample Point 27; see map in Appendix II). The presence of bedrock on the channel bed is something of an enigma, as it is generally recognized that sea level was over 100 m below present levels at the height of the last glaciation (about 15,000 years ago). At this time the Waiau would have incised significantly into its bed, and it must be inferred that the channel at this time was positioned in a 'groove' adjacent to the contemporary channel position.

Associated with the greater valley and alluvial flat width in Tuatapere reach is a broad active channel zone, with active gravel bars more evident in this reach that at any point upstream (Photo 100). This a wandering gravel-bed river reach, in which flow is divided into two or more channels which are laterally unstable and migrate across the alluvial flats over intervals of tens of years. Evidence on the channel-marginal alluvial flats indicates that this reach was more multi-channelled in the past, and has modified its planform from a braided to a wandering gravel-bed regime, probably associated with flow regulation. In wandering gravel-bed rivers, sedimentation zones gradually migrate downstream *en masse* and differentiation may be made between sedimentation and transportation zones.

Although a lowland reach, the Waiau still has considerable stream power in Tuatapere reach. Indeed, the 20 m contour interval on the Riverton 1 : 50,000 topographic map is located just beyond Tuatapere bridge, giving this reach an approximate slope of 0.0017. This is exceedingly steep for a lowland basin, and clearly reflects the impression of the 'mighty Waiau'. The physical manifestation of this steep gradient is reflected in the spacing of riffles on the channel bed. Whenever riffles are closely spaced, the channel bed gradient is locally oversteepened. Riffle spacing is highly

TUATAPERE REACH



variable in the lower course of the Waiau, with distinctly oversteepened sub-reaches. These may reflect the forward face of sediment wedges (or sedimentation zones) moving through Tuatapere reach over longer time intervals (maybe tens of years). These local-scale variations in channel bed slope are reflected by within-reach variations in gravel bar style.

Immediately downstream of Tuatapere the Waiau is constrained by terraces into a single-channelled, almost straight configuration. As the effects of this constraint are removed, the channel is able to move its course laterally, and deposition occurs on the inside bank. This has resulted in the bank attached compound bar upon which Sample Point 24 was located (Photo 99). This has a prominent side channel behind it, reflecting the multi-channelled nature of flow in this reach at higher discharge stages. Immediately downstream of this bar the main channel of the Waiau divides into two courses, separated around a major mid-channel compound bar (Photo 100). Old chute channels on the surface of this bar indicate that the channel was distinctly multi-channelled in this subreach in the past. As flow has concentrated into fewer channels in this subreach, these individual channels may have greater erosive potential than the smaller branch-channels of the past. This may be reflected in erosion of the right bank of the Waiau between Sample Points 26 and 27 (Photo 102). There is considerable flow energy in this subreach, as indicated by a significant number of riffles marginal to the head of the major mid-channel compound bar.

Beyond the major mid-channel bar, the character of gravel bars in Tuatapere reach is markedly different. Flow is concentrated once more into one primary channel, and there are extensive active gravel bar surfaces around vegetated former islands. This transition reach may represent a sedimentation zone of the wandering gravel-bed river reach. Moving downstream, sample points 29, 30, 31 and 32 are all located on point bar or compound point bar features, in which flow is deflected around moderately tight bends (Photo 113). This configuration breaks down around Sample Point 32, and the main channel divides into a series of smaller channels once more, as the flow dissects former bar surfaces (Photo 112). This somewhat chaotic pattern of smaller bar features is coincident with a large number of closely-spaced riffles, reflecting local oversteepening of the channel bed.

At the mouth the Waiau channel widens considerably, with concomitant mid-channel deposition. Sample Point 33 is located on the largest of these mid-channel bars (Photo 119). The alluvial flats adjacent to this point have a large number of small channels on their surface. These are similar in outline to a braidplain configuration. While this pattern is evident on air photographs, the surface impression is less marked, as mud largely infills these surface depressions (Photo 116).

Just as channel planform and gravel bar types are highly irregular in Tuatapere reach, so are the summary grain size statistics. These seem to reflect local circumstance to a greater extent than within-reach or down-reach trends. The upstream gravel clast sample in Tuatapere reach (Sample Point 24) was sampled in a chute channel adjacent to a bank-attached compound less than 1 km downstream of the bridge in Tuatapere. This is a jumbled, moderately loose surface, which is neither winnowed nor imbricated. It is a moderately sorted sample, with a distinct peak in the 0.5ø grain size histogram at 91-127 and 128-180 mm. Indeed, 60 of the 100 clasts sampled fall into one of these size classes. Grain size parameters are consistent with those demonstrated for Orauea and Downstream o'Clifden reaches.

Sample Point 25 is located at the head of a riffle at the junction point beyond which the main channel of the Waiau separates into two distinct channels (Photo 100). This is the head of the major mid-channel compound bar described above. The D95 and mean particle size are distinctly finer than at sample point 24, just 0.5 km upstream. Conversely, the 0.5ø modal grain size class is 0.5ø coarser at 128-180 mm. This reflects the distinct tail in the particle size histogram at Sample Point 25, possibly reflecting a finer slug of materials washed onto the bar surface. Indeed, within-sample variation is noted in terms of both imbrication and packing, reflecting local-scale depositional units at the bar head.

Grain size characteristics at Sample Point 26 are very similar to those described at Sample Point 25, but their locations are markedly different. Sample Point 26 is located on a small lontitudinal bar in the right-hand channel of the Waiau. The particle size distribution has a distinct tail of finer gravels. Gravels are moderately tightly packed, but once more there is little evidence of imbrication or winnowing. This may reflect fairly rapid deposition, with little subsequent reworking. Distinct lobes of finer gravel were observed on the bar surface.

Sample Point 27 is located at the head of a point bar just downstream of Sample Point 26. This bar is the downstream extension of an eroding right bank of the Waiau. This bank appears to represent an outwash terrace feature (Photo 102). Bedrock was observed on the bed of the channel immediately upstream of this sample location. The gravel bar surface at Sample Point 27 is jumbled, and sorting is very poor. This is reflected in the 0.5ø grain size histogram (Appendix II) which shows a very diffuse peak at 91-127 mm. The D95 parameter is just over 200 mm; this is coarser than any upstream sample in Tuatapere reach, and may reflect localized scour in the chute channel adjacent to the bar head which has exposed some coarser basal platform gravels.

Sheets of fine (fist-sized) gravels were observed on the lateral bar surface on which Sample Point 28 is located (Photos 105 and 106). This is a poorly sorted and jumbled bar surface, located immediately downstream of the confluence of the two main arms of the Waiau which divided around the mid-channel compound bar. The modal 0.5ø grain size class is 64-90 mm; distinctly finer than upstream samples in Tuatapere reach. This is also reflected in the mean clast size, while the D95 parameter is consistent with upstream samples.

Sample Point 29 is located at the head of a point bar roughly mid-way down Tuatapere reach. Downstream of this point the Waiau adopts a sinuous outline, alternating around well-defined point bars. Gravels on the bar surface at Sample Point 29 are organized into distinct locales. They are not imbricated and tend to be somewhat loose. Although the 91-127 mm 0.5ø grain size class is quite distinct, this is a poorly sorted bar surface, possibly reflecting the fact that the sample tape crossed several smaller depositional locales. The D95 parameter is significantly finer at this sample point that for some distance upstream; indeed, it is the lowest D95 value in Tuatapere reach and the lowest since Lill Burn reach.

Sample Point 30 is also located on a point bar, but in this instance the sample was collected down a prominent chute channel. A distinct lens of fine gravels (between 30-70 mm diameter) has been deposited at the head of the chute channel, but the sample was collected beyond this lobe, down-chute. This is an extremely poorly sorted sample. The D95 and mean grain size are coarser than at any upstream sample location in Tuatapere reach. The notably coarser fraction (in the 256-361 mm 0.5ø grain size class) may represent a coarse basal lag, exposed by localized scour in the chute channel. This irregularity in particle size distributions is noted for all other downstream samples in Tuatapere reach.

The 0.5ø grain size class distribution for the 100 clast sample collected at Sample Point 31 demonstrates an extremely broad spread in particle size, with 10 or more clasts measured for six 0.5ø grain size classes. The basal material in this very poorly sorted sample is moderately packed and imbricated, but a veneer of finer gravels has been laid atop. This reflects the sample location, which is oriented across the surface of a large point bar. Basal gravels on this point bar are oriented down-valley rather than around the bend. It appears that during higher flow stages this is the preferred flow orientation, and smaller-sized gravels have been draped over a coarser basal deposit. This picture is repeated at Sample Point 32, which was collected at a similar location on a compound point bar. Although only 2.5 km from the mouth of the river, the modal 0.5ø grain size class at sample point 32 is the coarsest in the entire study, at 181-255mm. This is viewed to represent the coarse basal gravels in the platform of these point bars. The mean particle size is also coarser at this sample point than at any other sample location. The winnowed nature of the surface, along with the moderate degree of imbrication, suggest that these coarse gravels may represent the pre-regulation surface. Finer gravels deposited atop this surface may have been removed subsequently.

The sample collected furthest downstream, collected on a mid-channel bar just 0.7 river kilometres above the mouth of the river, has the coarsest D95 parameter in the entire study (275 mm). The modal 0.5ø grain size class in this extremely poorly sorted sample is only 64-90 mm. This clearly demonstrates some of the problems in sampling the gravel fraction of gravel bar surfaces, as a few clasts can greatly distort the overall picture for the grain size distribution. The mean grain size at this site is 104 mm, a value not inconsistent with other values attained in Tuatapere reach. The distortion in the D95 value is attributed to scour in the chute channel from which this sample was collected. The gravels are moderately packed and partly imbricated at this location, and have a distinct mud drape atop. This is inferred to be the basal bar platform material, exposed by localized scour.

Within-reach variability in the character of Tuatapere reach is quite remarkable. While some aspects are readily explicable, such as the reduced impact of terraces associated with the lowland setting, other aspects are less so, and recourse must be taken to local circumstances to explain features which do not fit into an overall pattern. Such is the case for the ten particle size samples collected in Tuatapere reach. The broader context of the reach, describing planform variation as a wandering gravel-bed reach, with associated sedimentation zones, is also somewhat conjectural. An explanation of this ilk, however, is required to explain the within-reach distribution of gravel bar types.

4.0 Synthesis : Controls on river reach character along the Waiau River

In Section 3 the character of eleven reaches of the Waiau River downstream of Mararoa Weir were described. In this section an attempt is made to interpret some order out of the chaos of within- and between-reach variability.

4.1 Designation of reach styles

A distinct pattern in river reaches of the Waiau is discernible, with an alternating sequence of bedrock/terrace constrained reaches and less constrained reaches with multi-channelled planform geometries. Three primary styles of river reach have been discerned, namely laterally confined, laterally unconfined, and 'lowland' reaches

4.1.1 Laterally confined reaches

Six reaches of the Waiau downstream of Mararoa Weir are dominated by the role played by lateral constraint : Duncraigen, Blackmount-Mangapiri, Motu, Clifden Suspension Bridge, Hagen Road and Orauea. Bedrock or terrace-constrained reaches are either single-channelled reaches with an imposed broad sinuosity (e.g. Blackmount-Mangapiri) or are short, relatively straight reaches (e.g. Duncraigen, Motu, Clifden Suspension Bridge, Hagen Road, Orauea). In both instances, within-channel sedimentation is restricted to occasional lateral bars (typically associated with tributary confluences) or compound point bars located within occasional broad meander loops.

4.1.2 Laterally unconfined reaches

A distinct pattern of gravel bar assemblages and particle size trends has been discerned in less constrained reaches of the Waiau River. In Redcliff, Wairaki, Lill Burn and Downstream o'Clifden reaches gravel bar types change down-reach from lateral and bank-attached compound bars at the reach head, to mid-channel compound and diagonal bar types, to lateral and point bars at the downstream limit. These different types of river bar result from differing channel behaviour. At the head of laterally unconfined reaches, as flow exits the upstream bedrock-confined reach, it is concentrated into a high velocity filament. The removal of a lateral constraint allows the channel to adjust its position. This flow deflection results in channel-marginal deposition adjacent to the opposite bank. Moving down-reach the ability of the flow to carry sediment is reduced as flow energy is dissipated over a broader area. With reduced flow *competence*, within-channel deposition occurs (Leopold and Wolman, 1957), typically as longitudinal or mid-channel bars.

In three of the four laterally unconfined reaches, large volumes of sediment are added to the Waiau River at tributary confluences. This increase in sediment contributed to the river may extend beyond the *capacity limit* of the river. As such, the river either has sediment which is too coarse for it to carry, or there is simply too much sediment for the river to carry, and hence within-channel sedimentation results. These mid-channel bars are dissected by flows of differing magnitude to produce compound bar features. Bedrock constraints at the downstream limit of these reaches subsequently restricts sedimentation to lateral and point bar features.

Associated with the distinct pattern of bar types in less constrained reaches is an according within-reach downstream gradation in grain size. While flow competence diminishes down-reach, with concomitant down-reach reduction in the coarsest particle size fraction, the pattern to the downstream gradation in grain size is greatly affected by sediment inputs from tributaries. While this may increase the calibre of the bed material (e.g. Sample 4 in Redcliff Reach), a more prevalent trend in the Waiau River post-regulation appears to be the build up of finer gravel lenses which have accumulated adjacent to, and downstream of, tributary confluences. This is certainly a dominant process at Lill Burn and Wairaki confluences. These deposits appear as sheets on gravel bar surfaces downstream. Indeed, in some instances, new within-channel bars have accumulated, composed of fist-sized gravels. These are clearly finer than the coarser basal channel gravels on which they rest. Notable accumulations of these fist-sized sheets were observed in Lill Burn reach, Downstream o'Clifden reach, Orauea reach, and in Tuatapere reach.

4.1.3 Lowland reach

Observed within-reach trends in gravel bar assemblages and grain size characteristics are much more complex in Tuatapere reach than elsewhere. This is scarcely surprising, as Tuatapere reach has a considerably greater proportion of active gravel surfaces than any upstream reach. In this wandering gravel-bed river reach, flow divides into two or more laterally unstable channels which migrate downstream *en masse* as sedimentation zones over intervals of tens of years. Many channel outlines are evident on alluvial flats and bar surfaces, indicating that the reach was considerably more active in the past.

The alluvial flats within which the Waiau operates in Tuatapere reach are remarkably straight. Within this belt the active river channels have adopted a freely-migrating pattern of broadly sinuous bends. Primary movement of these bends appears to be oriented downstream, rather than laterally (a process termed downstream translation). Depositional units on bar surfaces are accordingly oriented down-valley. While many of the side channels appear to be relatively stable, and are actually infilling with fine materials, the main channels are definitely unstable, with erosion at the outside of a few bends.

Bar types in Tuatapere reach are primarily compound features, which are commonly dissected by chute channels. A within-reach trend has been discerned, with transition from bank-attached compound bars to mid-channel compound bars. Beyond the junction of the two primary channels at the downstream end of the major mid-channel compound bar, flow is concentrated into a single channel. This switches position around large compound point bars. A few kilometres from the mouth is a oversteepened zone with many riffles. This sub-reach is coincident with highly dissected bar surfaces. Downstream of this point the main channel of the Waiau broadens considerably as it enters the lagoon. Within-channel sedimentation associated with flow dispersion has resulted in deposition of mid-channel bars adjacent to the mouth of the river.

4.2 Controls on downstream variations in the Waiau River downstream of Mararoa Weir

In this section downstream variations in the character of the Waiau River are described at each of the scales used in river reach analysis.

4.2.1 Downstream variations in valley characteristics

Representative valley cross sections are shown for each river reach in Figure 7. Two primary points are evident. First, only beyond Tuatapere can the Waiau Valley be described as a 'lowland' setting. Second, the extent of lateral constraint emplaced on the river varies markedly from reach to reach. Wider, laterally unconstrained reaches with valley flat widths greater than 5 km are only evident in Wairaki, Lill Burn and Tuatapere reaches. This downstream variation in valley setting is the primary control on channel planform variation.

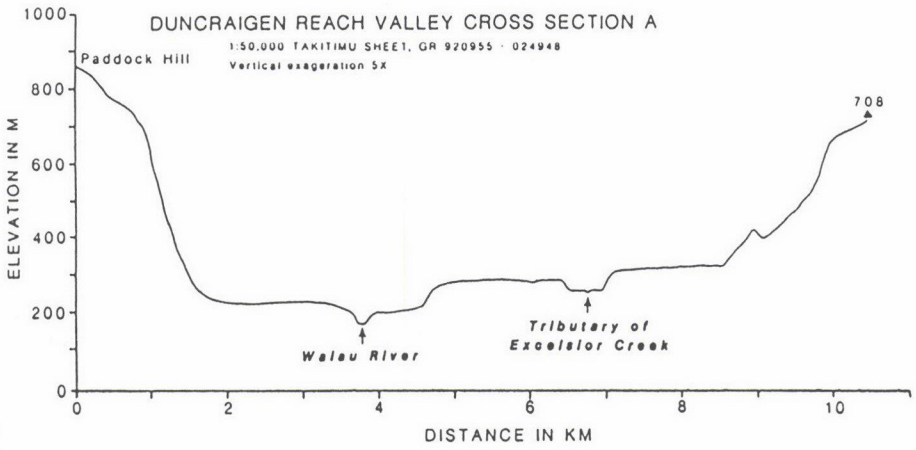
Extensive valley flats are evident well-above the present channel position in all valley cross-sections. However, terrace patterns are highly variable down-valley, in terms of their number, extent, continuity, and relationship from valley side to valley side (i.e. paired vs unpaired character). One feature of note is the apparent build-up of terraces behind bedrock ledges in the valley. Terraces are notably higher upstream of Blackmount and beyond the limestone cliffs at Clifden. This could reflect past depositional history, greater incision in upstream reaches, or greater reworking of deposits in downstream reaches.

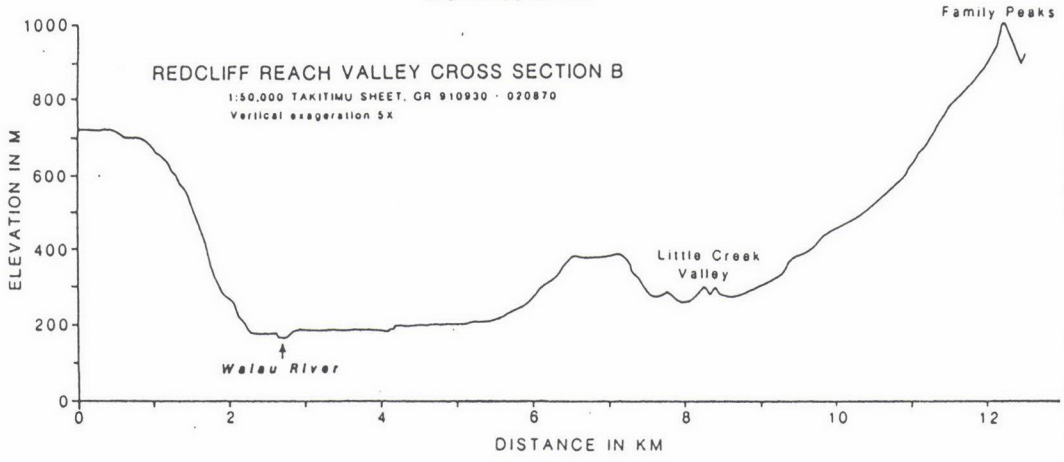
The massive terrace accumulations of fluvioglacial outwash materials throughout the Waiau Valley represent a series of former surfaces of the river. Their downstream continuity indicates that the channel was less constrained in the past. As the channel shifted from valley side to valley side, vast deposits of reworked glacial debris built up on the valley floor. This former aggradational phase represents repeated post-glacial sediment redistribution during the Quaternary (last 2 million years). This phase contrasts starkly with the subsequent incision or degradational stage(s) in which terraces are cut into the valley fill. Several extrinsic factors may account for this incision, such as tectonic uplift or isostatic rebound. Alternatively, terrace development may reflect intrinsic channel controls, wherein sediment loads in the post-glacial interval have increased the erosive potential of the river, and the river has incised into its own bed. Variations in this intrinsic control are climatically driven. The most likely 'cause' of terrace development is a combination of these factors.

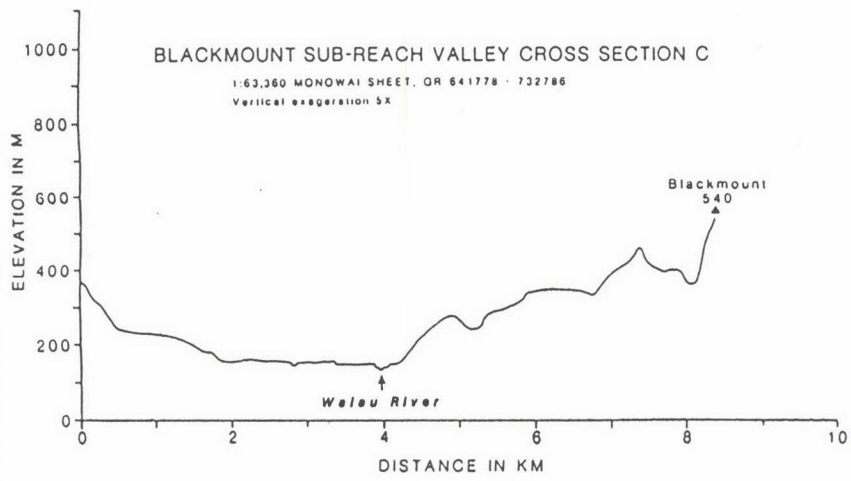
The broad valley setting, and the terrace pattern in particular, are very instructive in unravelling present river activity in the context of the past. It is evident from several locations along the Waiau Valley that the present configuration of the Waiau River is merely an extension of former behaviour, as the present channel position is entirely consistent with its location predicted by its associated flight of terraces. This is demonstrated in Photos 24, 42 and 85. In other words, the

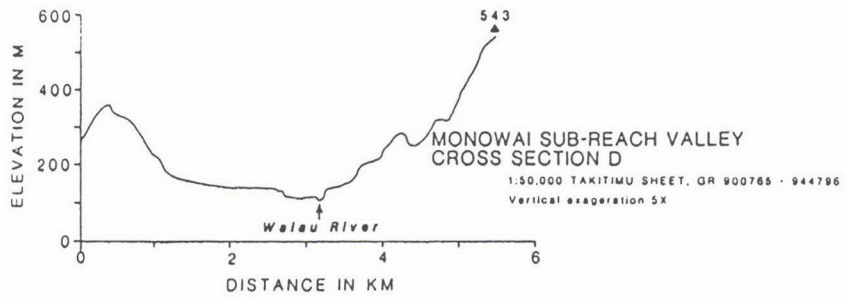
FIGURE 7

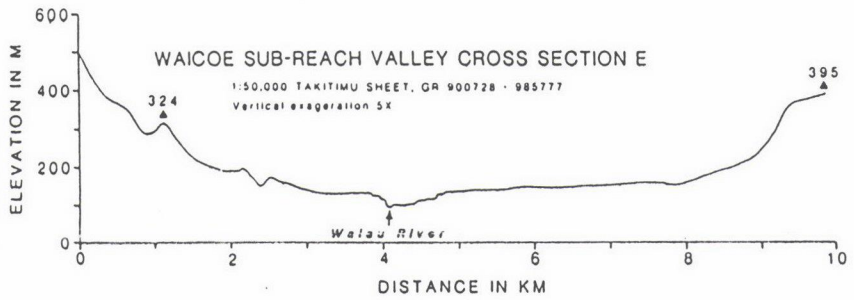
REPRESENTATIVE CROSS SECTIONS FOR EACH RIVER REACH

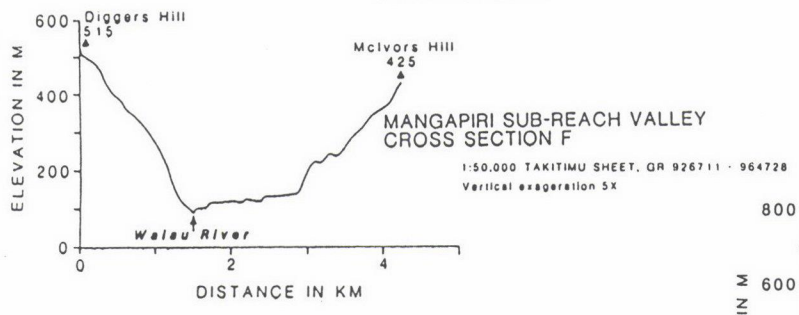


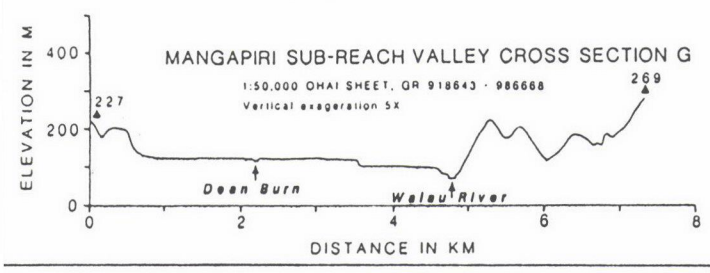


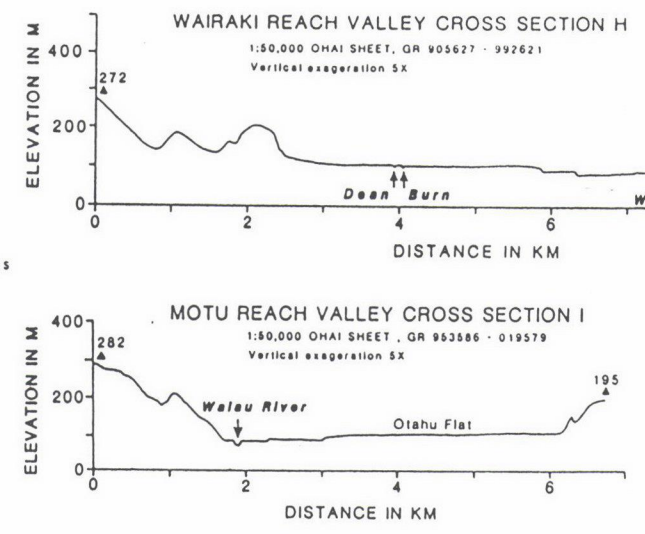


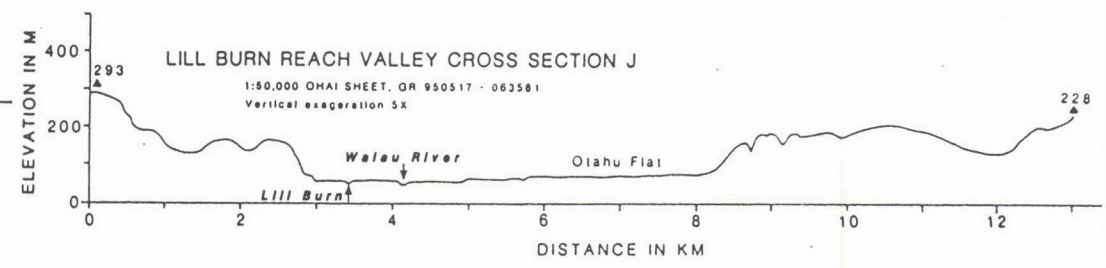


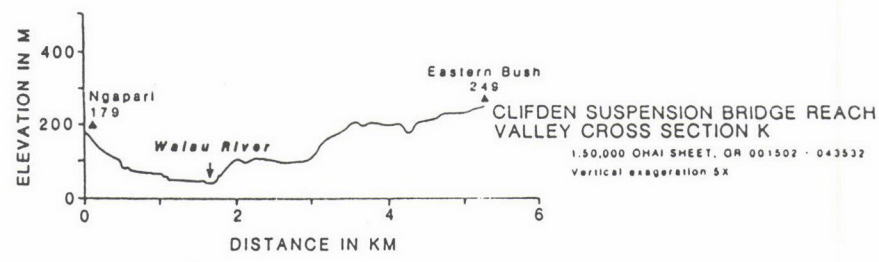


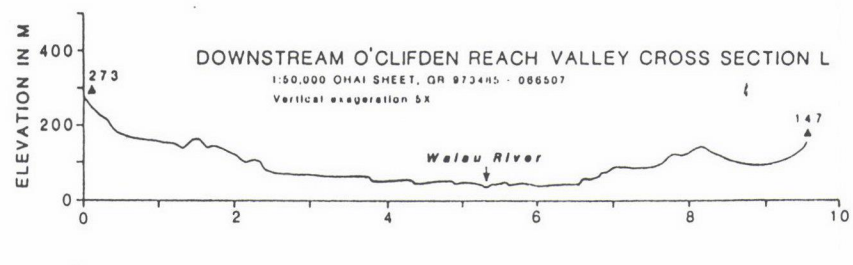


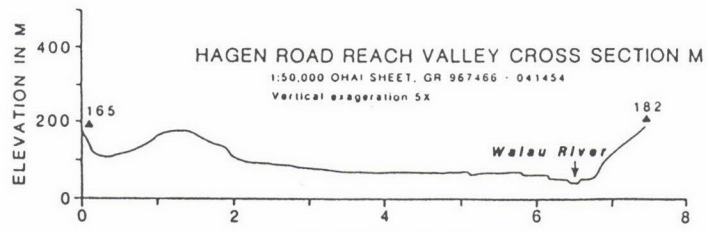


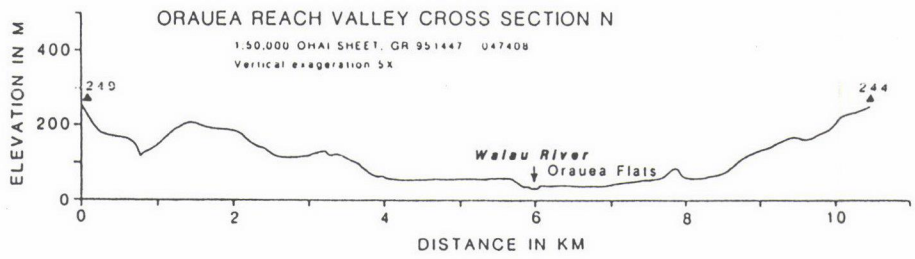


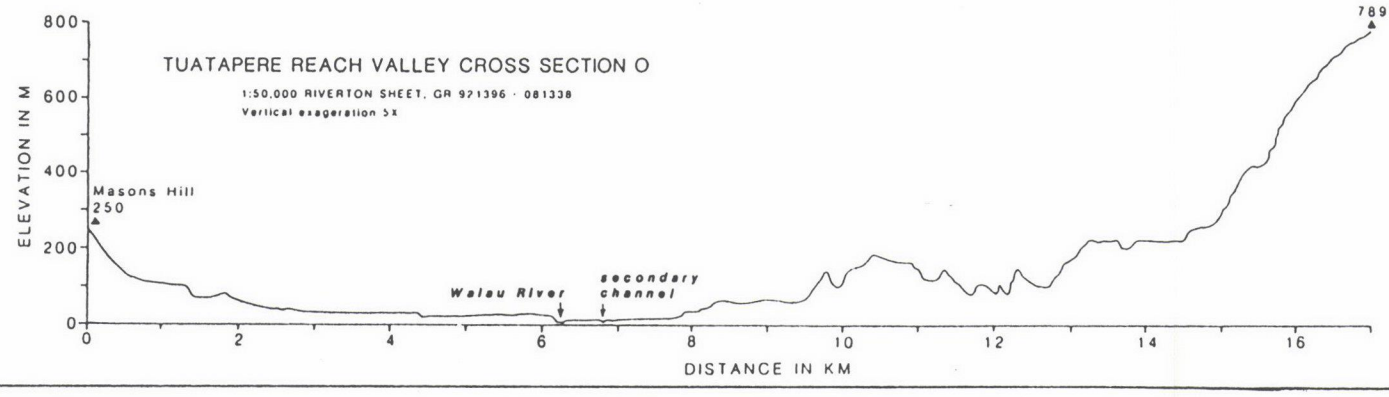












long-term Quaternary history has induced the primary control on both valley alignment and subsequent channel configuration in the Waiau Valley.

The longer-term geologic context of the valley is also critical in determining the spacing of bedrock controlled reaches, as these are probably an artifact of geological structural control in the region.

4.2.2 Downstream variations in channel planform

Downstream variations in channel planform relate directly to the pattern described for river reach analysis, as planform geometry is the primary criterion used to define reaches. This is summarized in Table 1. Because of structural controls on bedrock distribution in the valley, an alternating pattern of reach types has been determined based on lateral constraints imposed on the channel. This, in turn, controls the overall downstream sequence of planform styles, bar character, bed condition and gravel clast size on the Waiau River downstream of Mararoa Weir.

In the 100 river kilometres to Mararoa Weir the Waiau River is laterally constrained for over 50 km. While short reaches such as Duncraigen, Motu, Clifden Suspension Bridge and Hagen Road are essentially straight, remaining reaches demonstrate an imposed broad sinuosity, in which the contemporary channel alignment is typically consistent with the terrace pattern. Other than a couple of dissected bars in broad bends, the river is single-channelled throughout the laterally constrained reaches.

Of the five laterally unconstrained reaches, only Tuatapere is truly 'alluvial', as bedrock buttresses or outwash terraces are present in subreaches of Redcliff, Wairaki, Lill Burn and Downstream o'Clifden reaches. Accordingly, the number of channels, their lateral stability, and channel sinuosity are locally variable within these reaches. As these characteristics vary within-reach, so does the pattern of gravel bar types.

4.2.3 Downstream variations in gravel bar type

Just as planform geometry of the Waiau River downstream of Mararoa Weir relates directly to the pattern of river reaches described in this report, so does the downstream pattern in bar types (summarized in Table 1). Notable trends in the distribution of gravel bars are evident at the river reach scale, but do not present a well-defined 'overall' sequence.

In laterally confined reaches, gravel bar assemblages are restricted to alternating lateral bars or occasional compound point bars in broad bends. In the intervening unconfined reaches, bar types are typically transitional within-reach from bank-attached compound bars to mid-channel compound bars and islands. As flow becomes constrained at the downstream end of these reaches, lateral and point bars are found.

TABLE 1

Summary - River Reach Analysis - Waiau River - March/April 1992

REACH NAME	Distance from Waiau mouth (in km)	Reach length	PLANFORM CHARACTER				OTHER CHARACTERISTICS
			Number of channels	Sinuosity	Lateral stability	Bar type	
Duncraigen	95.8-98.0	2.2	Single channelled	Virtually straight	Stable, as pinned between outwash terraces	Small alternating lateral bars	Laterally confined by outwash terraces
Redcliff	81.5-95.8	14.3	One or two channels at the reach head, dividing to three or four channels at the downstream end	Imposed moderate sinuosity at head of reach, transitional to a fairly straight reach in which the river switches from side to side around alternating bars Flow becomes more freely migrating around moderately sinuous bends at the downstream end of the reach.	Distinct active-channel belt pinned against Paddock Hill to the west. Channel is laterally unstable within this belt, which is widest down- stream of Redcliff Creek.	Transitional down-reach from point and lateral bars to bank-attached compound bars with prominent side channels. Downstream of Redcliff Creek flow divides around compound point and bank- attached bars. As flow becomes constrained at the downstream limit of the reach, a sequence of alternating lateral bars is observed.	Marked downstream variation in planform character, while the extent of the valley flat is roughly constant. Two prominent channel confluences occur within this reach - Whare and Redcliff Creeks.
Blackmount-Mangapiri	46.1-81.5	35.4	Single-channelled, with occasional divided channels in bends	Imposed broad sinuosity with relatively straight sub-reaches	Highly stable - constrained by bedrock or outwash terraces	Restricted to very occasional lateral bars at tributary confluences, and compound point bars in two broad bends.	Primarily an imposed channel condition
Wairaki	37.9-46.1	8.2	Single-channelled at upstream and downstream limits of the reach, but multichannelled (with up to three or four active channels) adjacent to Wairaki confluence.	Imposed broad sinuosity at the upstream bend, while next two bends are less constrained and are moderately tight. Downstream of Wairaki confluence the broad alluvial flat is aligned roughly straight, but the channels switch position in a diagonal manner.	Laterally unstable reach, although outwash terraces at the head, and bedrock buttresses at the downstream end of the reach impose local constraints. The predominant alignment of depositional units and chute channels (or runners) is downstream	Broad, well-developed point bars upstream of Wairaki confluence transitional downstream to complex compound bars with irregular sedimentation units. As flow becomes single-channelled down-reach, alternating lateral bars are observed.	Notable within-reach variation in planform geometry associated with tributary inputs and changes in lateral constraints.
Motu	35.5-37.9	2.4	Single channelled	Virtually straight	Laterally stable as pinned between terraces and Motu Bush	No active gravel surfaces	Imposed channel condition
Lill Burn	28.1-35.5	7.4	Single-channelled at the upstream end of the reach, but divides into three or four active channels adjacent to Lill Burn. Downstream of this point are two primary channel threads. These join immediately upstream of the bedrock constraint at the downstream limit of the reach	Virtually straight at the upstream end of the reach. Beyond this, flow alternates around lateral bars in a broadly sinuous manner. Flow becomes diagonally- oriented in the multi-channelled subreach around Lill Burn confluence. Downstream of this point flow adopts a broadly sinuous outline prior to the imposed tighter bend at the downstream limit of the reach	Alluvial flats are extensive in this reach, attesting to the relative lateral instability of the channel. However, this is only relative,and flow is effectively constrained within a narrow belt of the valley. Within this belt the flow is able to switch its position freely. This effect is especially pronounced adjacent to Lill Burn confluence, but flow becomes constrained by bedrock at the downstream limit of the reach.	Distinct down-reach transition from lateral bars to bank-attached compound bars to mid-channel compound bars adjacent to Lill Burn confluence. Active gravel surfaces are prominent at this point, with many riffles evident. A large point bar has formed in the bedrock-imposed bend at the downstream limit of the reach.	Notable within-reach variations, associated with variability in lateral constraints placed on the river and tributary effects.
Clifden Suspension Bridge	27.1-28.1	1	Single channelled	Virtually straight	Laterally constrained by bedrock	No active gravel surfaces	Imposed flow condition
Downstream o'Clifden	21.7-27.1	5.4	Single channelled at the head and downstream limits of the reach, with highly dissected compound point bars in mid-reach. These have up to three active chute channels; side channels are also prominent.	While the head and downstream limits of the reach are relatively straight, the mid-section of the reach demonstrates the tightest bends observed in the study area.	The mid-section of the reach is freely migrating over a broad alluvial flat, while the channel becomes constrained by bedrock on both banks at its downstream limit.	A large lateral bar with a prominent side channel is located at the head of the reach. This is transitional downstream to two highly dissected compound point bars in tight bends. Downstream of these bends are riffles with a diagonal bar on a bedrock step. A lateral bar marks the downstream limit of the reach.	Distinct down-reach variations are related to lateral constraints at the head and downstream limits of the reach, while the alluvial flats and active gravel surfaces are laterally extensive in mid-reach.
Hagen Road	17.4-21.7	4.3	Single-channelled	Virtually straight	Stable - channel is bedrock constrained	No active gravel surfaces	Bedrock-constrained reach
Orauea	11.9-17.4	5.5	Predominantly single-channelled, although flow divides into two channels around a mid-channel bar at Orauea confluence	Virtually straight, with an imposed very gentle bend at the lower end of the reach	Primarily laterally stable - alluvial flats are virtually non-existent in this reach	Restricted to diagonal and lateral bars associated with spacing, other than mid-channel bars at Orauea confluence. This location is coincident with a bedrock step on the bed of the river.	Laterally constrained reach in which within-channel sedimentation is markedly restricted.
Tuatapere	0-11.9	11.9	While many channel outlines are evident in this reach (with up to five chute channels on individual mid-channel bars), flow is primarily restricted to one or two main channels. A distinct pattern of flow division and rejoining is evident.	The alluvial flats within which the channel is active are remarkably straight. Within this belt the river channels have adopted a freely-meandering pattern of broadly sinuous bends. The primary configuration of depositional units is decidedly downstream in orientation, rather than lateral.	Wherever flow concentrates the channel is laterally unstable - side channels appear to be stable features. Erosion is noted to be highly localized at the outside of particular bends.	Active gravel surfaces are more extensive in this reach than elsewhere. Bar surfaces are predominantly compound features, which are frequently highly dissected by chute channels. A variety of bank-attached and mid-channel forms are observed, with the lower end of the reach characterized by a series of three large compound point bars in relatively tight bends. Adjacent to the river mouth are a series of within-channel bars. These are small features which form a large composite form.	This reach has all the characteritics of a wandering gravel-bed river, in which flow separates around mid-channel bars/islands and rejoins downstream. These mid-channel features may represent sedimentation zones which gradually migrate downstream (over intervals of tens of years). Active gravel surfaces are extensive, and the channel is more able to shift in this reach than at virtually any other section along the studied river course.

Only in the lowland reach downstream of Tuatapere are a full suite of bar types observed. Bank-attached compound bars at the reach head are transitional down-reach to a major mid-channel compound bar with a range of chute channels atop. Flow is dissected around diagonal and longitudinal bars in side channels adjacent to the mid-channel compound bar. As flow rejoins at the downstream end of the mid-channel compound bar, bank-attached compound features are observed once more. These are transitional to compound point bars. A few kilometres upstream of the mouth, in an oversteepened reach demarcated by a series of riffles, compound bars are dissected into a suite of 'unit' bars. At the mouth itself, adjacent to the lagoon, mid-channel bars are observed.

Throughout its lower course, the Waiau has the energy to generate the spectrum of gravel bar assemblages. The enormous complexity of bar types observed over relatively short river distances reflects local scale conditions, induced primarily by lateral constraints, local erosion of banks or terraces, or flow and sediment inputs from tributary streams. Associated with this complexity in gravel bar type along the lower 100 km of the Waiau is an equivalent variation in grain size parameters and the character of gravel bar surfaces.

4.2.4 Downstream variations in grain size characteristics and packing condition on bar surfaces

Thirty-three grain size samples were collected in this study. In each instance, 'b axes' were measured for 100 regularly spaced clasts (at 1 m interval) in the coarsest gravel unit on each bar. Data were also recorded on the packing condition of the gravel surface. All data are summarized in Table 2. Grain size data are presented in Appendix III.

The downstream gradation in clast sizes over the lower 100 kilometres of the Waiau River is completely counter-intuitive, in that the coarsest D95 value recorded in this study was measured at the mouth of the river! Downstream trends for D95, D84 and D50 parameters (the ninety-fifth, eighty-fourth and fiftieth coarsest clasts in the 100 clast sample) are shown in Figure 8.

In general downstream grain size trends are fairly similar for D95 and D84 parameters, while some differences are evident for D50 data. In crude terms, D95 and D84 data indicate three reaches in which grain sizes diminish down-valley, prior to a complex pattern of grain sizes in the lowland reach (the lower 15 km of the Waiau). The three reaches extend from 100-70 km, 70-30 km, and 30-15 km upstream of Te Waewae Bay. The intervals at 70 km and 30 km are coincident with transitions to Waicoe and Downstream o'Clifden reaches. This may indicate tributary sediment input in the first instance, and flushing effects downstream of a bedrock-confined reach in the latter instance.

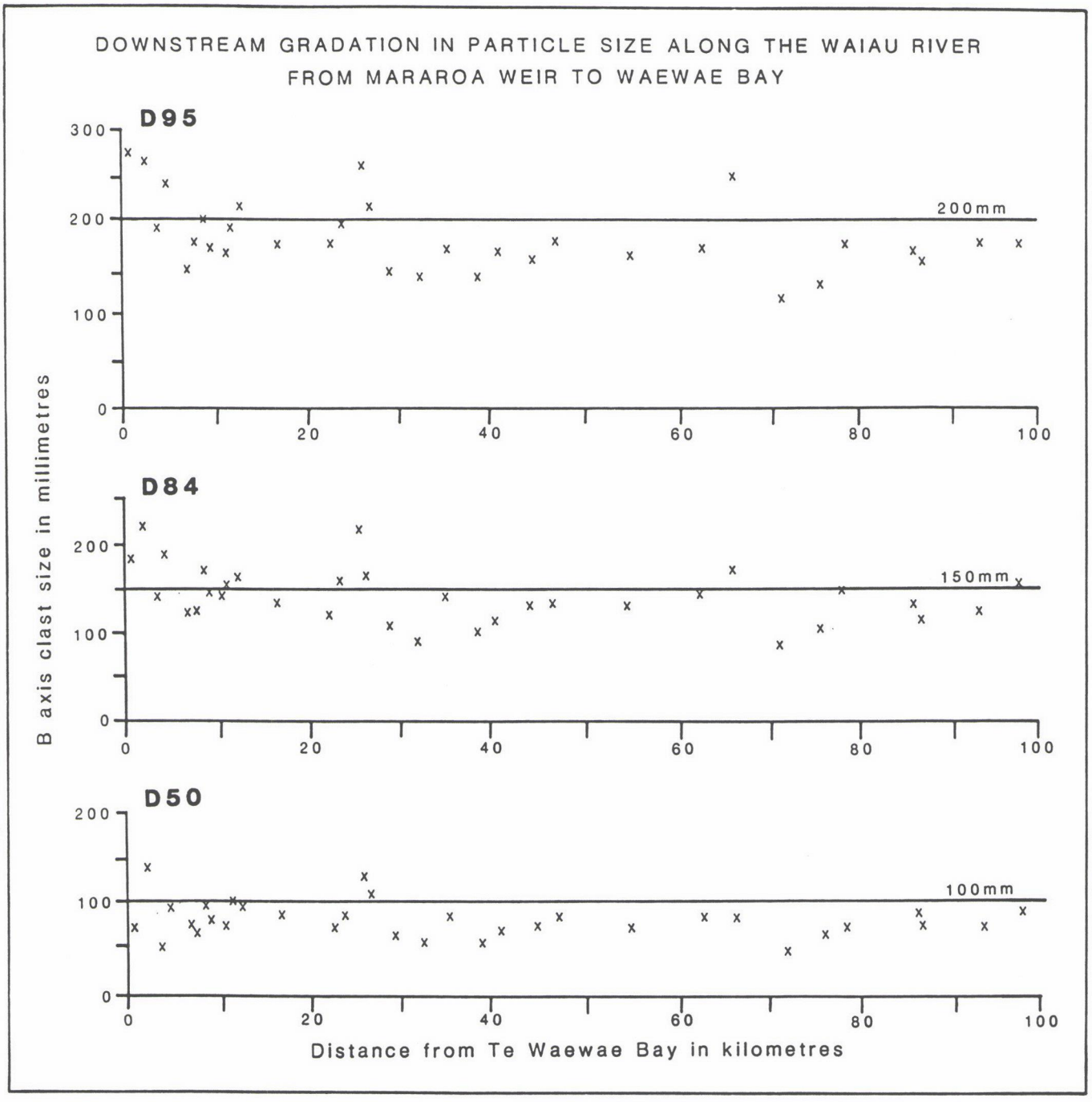
Trends described above must be viewed with some caution, however, because of local-scale impacts on the grain size measurement procedure. In focussing on the coarsest grain size unit, there is no certainty that sample sites are equivalent. For example, some samples may have been sampled from coarse basal lags exposed by recent scour on bar

TABLE 2

Summary Particle Size Parameters of Sampled Gravel Bars - Waiau River - March/April 1992

REACH NAME	Distance from Waiau mouth (in km)	Reach length	Sample number	Distance upstream from mouth (in km)	BED CHARACTER: D95 (in mm)	Mean particle size (in mm)	Standard deviation (sorting index; in mm)	Modal group (half phi interval, recorded in mm)	Packing condition
Duncraigen	95.8-98.0	2.2	1	97.7	178	93	54	91-127	Imbricated, well-packed
Redcliff	81.5-95.8	14.3	2	93.3	178	78	52	91-127	Overloose, poorly sorted
			3	86.9	157	77	43	91-127	Jumbled, overloose
			4	86	170	88	50	91-127	Locally imbricated, moderately packed
Blackmount-Mangapiri	46.1-81.5	35.4	5	78.5	177	82	54	91-127	Poorly sorted, jumbled, moderately packed
			6	75.8	132	70	37	64-90	Locally variable; partly imbricated, partly loose
			7	71.7	119	55	34	64-90	Paved but jumbled surface; partly imbricated
			8	66.4	250	103	73	64-90; 91-127	Very mixed, unsorted surface; poorly packed
			9	62.8	170	95	48	128-180	Moderately packed, selectively winnowed
			10	55.2	163	83	48	91-127	Jumbled, overloose surface; often one grain thick
			11	47.2	180	86	49	91-127	Locally imbricated, but generally overloose
Wairaki	37.9-46.1	8.2	12	44.6	159	81	46	91-127	Jumbled, loosely packed
			13	40.9	166	77	49	64-90	Loosely packed
			14	38.8	138	69	36	45-63	Jumbled, unpaved surface
Motu	35.5-37.9	2.4							
Lill Burn	28.1-35.5	7.4	15	35.4	167	89	47	128-180	Poorly sorted, unpaved, jumbled, overloose
			16	32.3	139	63	35	45-63	Moderately packed
			17	29.3	145	71	38	64-90	Fairly well packed, moderately imbricated
Clifden Suspension Bridge	27.1-28.1	1							
Downstream o'Clifden	21.7-27.1	5.4	18	27	215	114	58	91-127	Poorly sorted, moderately packed, partly imbricated
			19	26.2	262	137	74	128-180	Discrete locales; moderately packed, partly imbricated
			20	23.8	195	94	57	64-90	Jumbled, unwinnowed surface
			21	22.8	174	82	44	64-90; 91-127	Jumbled surface
Hagen Road	17.4-21.7	4.3							
Orauea	11.9-17.4	5.5	22	16.9	173	86	51	91-127	Jumbled, loose gravel surface
			23	12.5	215	106	64	91-127	Discrete locales; jumbled and only locally imbricated
Tuatapere	0-11.9	11.9	24	11.4	193	106	58	91-127	Jumbled, moderately loose surface
			25	10.9	167	88	55	128-180	Highly variable gravel surface; partly imbricated partly jumbled
			26	9.4	172	94	51	128-180	Moderately packed but somewhat jumbled surface
			27	8.7	202	107	57	91-127; 128-180	Poorly sorted and jumbled surface
			28	7.8	175	80	46	64-90	Jumbled, largely unwinnowed surface
			29	7	149	81	47	91-127	Relatively loose, unwinnowed surface, with discrete locales
			30	4.6	240	109	76	128-180	Poorly sorted; Well-packed coarse base with finer gravels atop
			31	3.9	193	80	60	45-63	Very poorly sorted, moderately packed
			32	2.4	265	149	80	181-255	Winnowed, moderately imbricated
			33	0.7	275	104	85	64-90	Very poorly sorted; moderately packed, partly imbricated

FIGURE 8


DOWNSTREAM GRADATION IN PARTICLE SIZE ALONG THE WAIAU RIVER
FROM MARAROA WEIR TO WAEWAE BAY
D95
200mm
D84
150mm
D50
100mm
B axis clast size in millimetres
Distance from Te Waewae Bay in kilometres
0
20
40
60
80
100
200
300

surfaces, while other sites may represent recent accretional surfaces deposited by the latest flood event. Samples taken at these two locations are clearly not recording the same phenomenon. This tendency for local-scale variation is supported by the D50 data and the confused patterns for D95, D84 and D50 parameters in the lower 15 km.

The D50 data shown in Figure 8 indicate some within-reach tendency for diminution in grain size, but no overall trend is evident. Indeed, perhaps the most prevalent tendency is for roughly equivalent grain sizes throughout the study area. The 'chaotic' nature of the downstream distribution is confirmed by the 10 samples collected in Tuatapere reach. While the D50 data crudely indicate a downstream reduction in median clast size over the lower 15 km of the Waiau, exactly the opposite trends are indicated for D84 and D95 data. This is reflected in within-reach variation in modal 0.5ø grain size class at each sample location. Site-specific properties seemingly dictate the particle size distribution, conditioned by local sediment supply, local scour, and the recent erosion/sedimentation history.

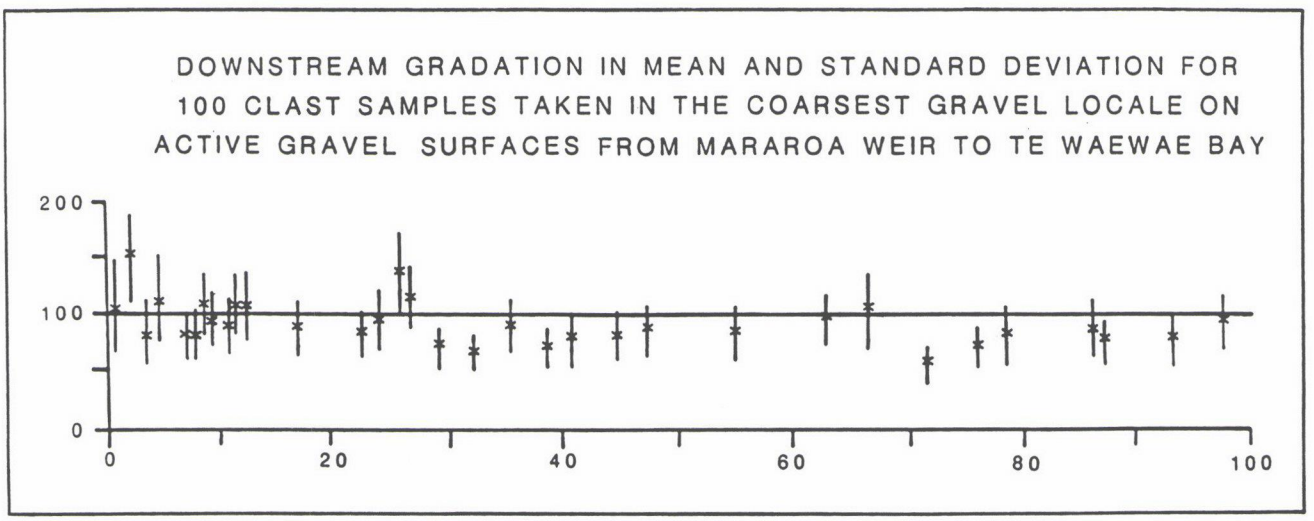
Trends outlined above are echoed by the downstream gradation in mean and standard deviation values for the thirty-three 100-clast samples (Figure 9). Local within-reach diminution is recorded from 100-85 km, 85-70 km, 70-50 km, 50-35 km, 35-30 km, and 25-20 km. These upstream distances are roughly equivalent with Redcliff, Waicoe, Mangapiri, Wairaki, Lill Burn and Downstream o'Clifden reaches. It is also evident that standard deviation values, which reflect sediment sorting, are distinctly greater for 'downstream' samples, especially in Tuatapere reach. This is interpreted to reflect the mixed particle size distribution and local scour phenomena on gravel bar surfaces in this lowland reach.

Grain size distributions along the lower 100 km of the Waiau River must be understood in the context of local sample site character and sediment source/supply variations down-river. While there is a tendency for within-reach diminution in clast sizes within laterally unconfined reaches, these trends must be placed in context of minimal 'overall' grain-size tendencies. Indeed, coarsest samples taken were in the lower, Tuatapere reach.

Geomorphic theory predicts a concave-upwards trend in downstream grain-size distribution. This is not the case along the lower course of the Waiau River. Two factors seemingly account for this discrepancy. First, the great variation in character between laterally confined and unconfined reaches dictates the ability of the river to move gravels, and single-channelled confined reaches tend to 'flush' coarser-sized gravels. Second, the sediment budget in Southland is dominated by the regional glacial history. This has left a legacy of massive fluvioglacial outwash terraces which extend almost to Te Waewae Bay. The Waiau River has a constant supply of whatever sized materials it is locally able to move - this appears to be the primary control on the grain-size distribution along the river.

Just as grain-size parameters are largely determined by local-scale factors, so are those characteristics describing the packing condition on gravel bar surfaces (summarized in Table 2). Other than at the very first sample location, just downstream of Mararoa Weir, active gravel bar surfaces along the lower 100 km of the Waiau River are dominated by highly mobile, 'overloose' and jumbled gravels, which are typically very poorly sorted. Many discrete locales, reflecting bar platforms, sheets washed onto bar surfaces, local scour, etc result in highly complex gravel assemblages. Accordingly, bar surfaces are only locally imbricated and packed, and winnowing effects are also locally highly variable.

FIGURE 9


DOWNSTREAM GRADATION IN MEAN AND STANDARD DEVIATION FOR
100 CLAST SAMPLES TAKEN IN THE COARSEST GRAVEL LOCALE ON
ACTIVE GRAVEL SURFACES FROM MARAROA WEIR TO TE WAEWAE BAY
200
100
0
0
20
40
60
80
100

Gravel packing trends along the lower course of the Waiau may be explained as follows. The upstream sample location (Sample Point 1 in Duncraigen reach) is essentially sediment starved. Accordingly, flow at this point has stripped surficial deposits, and exposed a coarse basal pavement. Other than at localized sections of particular bar surfaces, such effects are not noted elsewhere along the studied river reach. Rather, bar surfaces are made up of varying assemblages of depositional units, in which recent scour has exposed bar platform materials at some locations, while diffuse gravel sheets have been launched onto bar surfaces elsewhere. Spatial variation in these factors relate to bar position within-reach, chute channel reworking of deposits, and local sediment supply. One feature that is characteristic of reaches in the lower course of the river, however, is the preponderance of fist-sized gravel lenses which are evident on bar surfaces. These are distinctly finer than the materials which they overlie.

4.3 Summary interpretation of controls on river reaches of the Waiau River

Controls of the character of the Waiau River vary from reach to reach, based primarily on the scale of observation. The overall control on reach designation is geological, reflecting both structural control on bedrock type and distribution, and the regional Quaternary history and distribution of fluvioglacial outwash deposits. These two "valley setting" factors have induced an alternating sequence of constrained and less constrained reaches, with large sediment sources available to the river along its entire lower course.

In response to this geologic control, the Waiau River has adopted an alternating pattern of straight to broadly-sinuous, single-channelled reaches and multi-channelled, laterally unstable reaches of varying sinuosity. Controls on gravel bar type within these reaches are determined by local flow conditions (determined by within-reach position, and relation to upstream/downstream reaches), and sediment supply, whether associated with bank/terrace erosion or tributary input. A general pattern of within-reach variation in bar types can be determined, in which bank-attached bars at the reach head are transitional to mid-channel compound bars and compound point bars, with lateral or point bars at the downstream margin of these reaches. Just as the channel configuration is determined by valley setting, so gravel bar types and the character of bar surfaces are determined by planform geometry.

Grain-size characteristics and packing arrangements on gravel bar surfaces demonstrated little overall pattern. Rather, local-scale factors dictate the arrangement on depositional units on bar surfaces, while within-reach position is a primary control on grain size.

Unravelling controls on landscape patterns at differing scales has been a fundamental concern in geomorphology for over 25 years (see Schumm and Lichty, 1965). Unless such considerations are emplaced within the conceptual framework through which structured observations on landscape features are characterized, the means of interpreting causality and controls on landscape evolution will always be less instructive and insightful than they might otherwise be.

5.0 Implications and recommendations for future study

Given the range of controls on river character and behaviour described in previous sections, it is clear that any river management procedures undertaken within the auspices of "Total catchment management" must have a well-developed understanding of both site-specific information and its relations to the bigger picture. The conceptual framework adopted in this study is a scale-dependent approach, based in geographic enquiry.

River reach analysis of the Waiau River downstream of Mararoa Weir has provided the background information with which to develop an understanding of controls on form/process associations and evolution of the Waiau catchment. It is from this basis that human impacts on the 'natural system' can be evaluated. In this section, likely impacts of flow regulation associated with the Manapouri Scheme are assessed from the perspective of changes to the character of the river itself, with particular emphasis on the erosion/sedimentation regime.

5.1 Adjustments to channel geometry following flow regulation

Among the many impacts of flow regulation, one particular feature is especially evident. As the flow regime is altered, flow acts to modify its channel boundary condition. This modification can take various forms, such as changes to channel geometry (e.g. width/depth ratio), channel planform, local channel bed slope, etc. Perhaps the most sensitive indicator, however, is the nature of the channel bed itself, and its associated packing condition. Following regulation, the 'energy' of flow is altered, affecting the ability of the flow to move materials of differing sizes. This impacts significantly on paving and winnowing properties of the river. In recent years, large quantities of fist-sized gravels have accumulated along the lower course of the Waiau. These have adopted the form of discrete within-channel bars or diffuse gravel sheets, launched onto bar surfaces. Movement of these materials may impact on the local channel bed slope, as reflected in the density and spacing of riffles. At broader scales, these large slugs of material may be moving gradually downstream as 'sedimentation zones'. This has enormous implications for channel capacity and resulting changes to the flood regime, and may well impact on localized erosion along particular subreaches of the river.

For these reasons, channel adjustments that have taken place along the Waiau River since flow regulation need to be rigorously interpreted in the context of river reach analysis. Since air photos are available from 1946 onwards, with large numbers of photo runs in the 1980's, it is possible to assess not only the character, but also the rate of channel change, and by relating this to the hydrology records, an assessment of the character and extent of changes to flood events of varying magnitude and return interval can be made. This must be applied on a reach by reach basis.

Channel adjustments of the Waiau River following flow regulation have been restricted primarily to those reaches where the river has space to adjust laterally or reaches where there are significant inputs of sediment from tributary catchments. In most instances, these reaches are coincident. These effects operate to differing extents in seven reaches, namely: Redcliff, Waicoe, Wairaki, Lill Burn, Downstream o'Clifden, Orauea and Tuatapere. While the Tuatapere reach has

experienced considerably greater channel adjustments than all other reaches in the past 10 years, significant adjustments are also evident in the Wairaki, Lill Burn and Downstream o'Clifden reaches. Several islands in Redcliff, Lill Burn and Tuatapere reaches have become bank-attached following flow regulation, marking a transition from a braided planform to a wandering gravel-bed river style.

This study is not a retrodictive analysis; rather it is a base-line inventory of the contemporary condition of the Waiau. However, some post-regulation impacts have been observed, such as abandoned channels on alluvial flats, aggradational ledges adjacent to channels, localized erosion, adjustments to the gravel 'bed-condition' and discrete inputs of finer gravels from tributaries. These topics all warrant further study, within the context of a project on "*Channel adjustments of the Waiau River following flow regulation*". Questions to be addressed include :

a) What is the impact of flood peakedness on sediment yield? For example, were effects of the peaked 1984 flood greater or less than impacts from the lengthy period of continuous high discharge in 1988?

b) Under what flow conditions is the coarsest basal lag material mobilized?

c) What is impact of the movement of fine gravels on channel geometry? Do these sheets impose a capacity limit such that high magnitude flood events are no longer able to scour coarse basal gravels?

5.2 Tributary effects

To be effective, any assessment of river adjustments to environmental change (whether advertent or inadvertent) must employ a "total catchment" approach. This implies that study should focus not only on the trunk stream of the Waiau, but also on the primary subcatchments. For example, it is evident that significant channel adjustments are associated with tributary confluences. The character and rates of inputs at these confluences (of both water and sediment) should be assessed. It is important to assess whether impacts of flow regulation on the Waiau can be traced upstream along tributary courses. Has the equilibrium condition affecting both channel geometry and the erosion/sedimentation balance been altered? This constitutes a second project, on "*Tributary impacts of flow regulation along the lower Waiau*", and should probably run in-tandem with the project on channel adjustments in the Waiau itself.

5.3 Monitoring program for flow dynamics and sediment movement implications

An appropriate strategy should be emplaced to monitor the nature, rate and controls of sediment movement in the Waiau River. Given the extensive nature of channel change and large volume of fine-gravel sheets evident in Tuatapere reach, this appears to be the reach most sensitive to change following flow regulation. This is perhaps explained by the "alluvial" nature of this reach, and the distinct changes which have taken place at the mouth of the river following flow regulation. Changes within the lower course of the Waiau must be viewed in light of changes to the morphodynamic regime at the channel mouth and the development of the massive gravel barrier.

In this third project, tentatively titled "*Monitoring sediment movement in Tuatapere reach*", several criteria need to be assessed. First, the fluvial hydraulics of the system need to be evaluated. To assess the 'paved' condition of the reach, the surface layer of gravels needs to be compared with subsurface samples. Through assessment of bed shear stresses, or stream power, discharges required to mobilize differing size fractions of bedload can be estimated. Among the primary data required for such analysis is water surface slope - this is a crucial parameter in flow hydraulic investigations, and reliable estimates are required for subsections of Tuatapere reach. This is especially pertinent given the possible differentiation of transportation and sedimentation zones in this reach, and the possibility of local oversteepening of the channel bed as indicated by riffle spacing. Monitoring this spacing, and evaluating past changes from the air photograph record, would be most insightful in unravelling the erosion/sedimentation balance of Tuatapere reach.

Beyond this, given the enormous complexity in the gravel depositional environments of the Waiau River, great caution must be employed in assessing grain size characteristics. The monitoring of size fractions moving through the reach must entail detailed field mapping of depositional units at strategic locations within the reach. The locations should focus on locally oversteepened locations, as these are the zones of active gravel accumulation.

From this data, changes to the hydraulic geometry of the channel, and channel width-depth ratio can be viewed in the context of mobile grain size fractions, and the storage function of each subreach can be assessed in relation to the erosion/sedimentation regime.

5.4 Conceptual framework and data base management

Strategies for environmental management of river systems must be assessed on a catchment by catchment basis. The Waiau is no exception to this principle. It is clear from the preceding sections, however, that downstream variations in channel planform character, and the ability of the river to deform its bed and banks laterally and downstream, are extremely variable from reach to reach. It is at this scale that appropriate management procedures need to be implemented. The complex pattern of reaches does not accord with simple text-book notions of river behaviour. Each river reach must be studied and understood separately prior to implementation of river management procedures.

The conceptual framework utilized to undertake scientific investigation of river reach analysis is based on a geographic approach to analysis of river landscapes, in which several scales of approach are identified in an hierarchical framework. This framework provides a suitable genetic basis for inventory of base-line information for various aspects of study in the Waiau Working Party. Data-base management structures derived on a generic or *ad hoc* basis may not provide the right kind of information in an accessible form for other users. It is imperative that an integrative approach to management concerns be addressed within the working party, as the most significant questions or concerns are often at the interface of tasks groups, and effective communication must be promoted. A scalar framework, based on physical units, may form the basis for discussion and implementation of an appropriate GIS approach to integration of information on the Waiau catchment. Several scales of analysis have been identified :

i) The catchment scale

ii) Sub-catchments - tributary contributions to the main trunk channel

iii) River reach scale - determined primarily by the configuration of a river in plan view and its relation to valley setting,

iv) Channel-scale - relates to channel geometry and flow

v) Gravel bar

vi) Depositional units on bar surfaces (locales or morphostratigraphic units)

vii) Sedimentary structures (e.g. particle clusters, gravel lobes, diffuse gravel sheets)

viii) Individual clasts.

5.5 Relation to other task groups in Waiau Working Party

If "total catchment management" is to be effectively undertaken, further study must extend river reach analysis upstream along the trunk system, and include major tributaries. The 'dynamic' perspective implicit within a geomorphic framework provides insights and direct linkage to many other task groups in the Waiau Working Party. For example, changes to gravel bar surfaces impact on local environments or habitats, of significance to faunal and floral surveys. Channel adjustments and an altered flow regime are of enormous concern to hydrology and fisheries groups, as channel capacity and riffle spacing impose greatly on impacts of floods and local stream bed gradient. The altered flow regime, and adjustments to the erosion/sedimentation balance, have direct impact on fluvial/marine interaction at the mouth of the river, and there is need for collaboration among geomorphologists studying river dynamics and nearshore morphodynamics along the gravel barrier.

If implications from these topics are to be fully attested, the complete picture is much more significant than the sum of the individual parts. As such, each project should ideally continue hand-in-hand. Monitoring of changes within the Waiau catchment provide an ideal opportunity for environmental auditing, as the reliability of predicted trends and rates of change within the river system can be tested. The Waiau Working Party has an opportunity for integrative environmental assessment and ratification that is seldom attempted, and even less frequently achieved. Unless viewed in its totality, however, the impacts of flow regulation on environmental management will be far less fruitful than it might otherwise be.

6.0 Conclusions

River reach analysis is based on interpretation of landscape forms and processes at valley setting, channel planform and gravel bar scales. It provides a simple and straightforward procedure for compiling a base-line inventory of channel character. Alternating laterally constrained and unconstrained reaches along the Waiau reflect antecedent control on channel condition - the present character of the Waiau River is an artifact of regional history, driven by tectonic uplift of the South Island and the ever-pervasive glacial deposits of the region. Present-day processes must be placed in the context of former activity - it is in this light that the impacts of flow regulation on the Waiau River must be viewed. Engineering solutions to site-specific problems must be assessed with regard to reach by reach geomorphic setting and the broader regional geological context.

The Waiau is typical of many New Zealand rivers in that it is highly sediment charged and has a fluctuating flow regime; indeed, the river has as much sediment available to move as it wishes. This is reflected in the series of actively eroding outwash terraces along the course of the modern river. Beyond this, however, the Waiau River has adopted a route to the sea with considerable lateral constraints imposed by bedrock topography. It is only in the lowland plains beyond Tuatapere that a truly alluvial regime can be described. The river must be viewed as a series of reaches, rather than a single trunk stream. While human impacts on the Waiau are catchment-scale concerns, their implications will be highly variable from reach to reach. It is for these reasons that impacts of flow regulation on the Waiau River must be assessed with great caution. There are many lessons to be learnt from future scientific investigation of this river.

In the context of the Erosion/Sedimentation Task Group of the Waiau Working Party, three primary themes are suggested for further study of river-related impacts following flow regulation. These focus on an assessment of controls on channel adjustments over the last fifty years on a reach by reach basis, interpretation of the impacts of flow regulation on tributary junctions and the tributary channels themselves, and an integrative monitoring program to measure sediment movement through Tuatapere reach. To achieve maximum effectiveness, these research projects should proceed in-tandem. Scientific credibility is essential, so a well-developed conceptual framework must be adopted. It is only when the behaviour of the river itself is truly understood that human impacts can be reliably placed within the context of "total catchment management."

Glossary of geomorphological terms used in the report

Accretion
Process by which deposits are added to a depositional unit. In a river, accretionary processes result in growth or extension of the feature, either laterally, downstream or vertically.

Aggradation
Process of accumulation of materials such that the channel bed is raised over time

Alluvial
Pertaining to a river. River deposits are termed alluvium.

Alluvial flats
Flat surface adjacent to the channel, and typically raised a couple of metres above it. While flow will cover this surface in times of flood, this is not viewed to be a major depositional surface. As such, it differs from a formative floodplain.

Antecedence
A state in which conditions in the past have determined landscape configuration in the present. This is sometimes referred to as *inheritance*.

Armor
Gravel bed condition in which the surface material is coarser than subsurface material. The coarser surface acts as an armor such that finer material cannot be moved by low flows. The surface material themselves have to be mobilized before the subsurface fraction can be moved. Armoring differs from paving in that an armored surface is composed solely of materials that are coarser than the subsurface materials, whereas a paved surface may have materials of equivalent size in the subsurface fraction.

Bank-attached compound bar
River bar made up of a range of smaller depositional units (typically representing different phases and styles of deposition) which is attached to one of the channel banks.

Bar
Within-channel depositional unit of scale roughly equal to that of the channel itself.

Basal
'At the bottom of'. Used in fluvial geomorphology to describe features at the channel bed.

Bedrock step
Ledge of rock on the bed of the river.

Bed shear stress
Drag forces exerted by flow on the bed of a river.

Braided river
A river reach with three or more active channels.

Braidplain
The flattish surface adjacent to and associated with a braided river.

Capacity limit
Channel condition in which there is too much sediment for the flow to carry (i.e. the flow does not have the *capacity* to carry the load available to it).

Catchment
The geographic area from which water flows to a particular stream. Catchments are the same as watersheds, and are separated by watershed divides.

Channel capacity
The volumetric limit which defines how much flow a channel is able to maintain before it overflows or breaches its banks.

Chute channel

Erosive channel which short-circuits the main channel. This is typically associated with a channel bend, which the chute channel will attempt to 'cut-off' during flood stages. Sometimes referred to as a 'runner'.

Clast

An individual gravel particle. The term usually applies to gravels coarser than fist-sized material and smaller than boulders (< 256 mm wide).

Competence limit

Channel condition which describes the coarsest grain size that flow of a particular magnitude is able to carry. For example, during the rising stage of a flood event, the flow energy gradually increases. As flow energy increases, the flow is gradually able to pick up coarser and coarser gravels. The size of this gravel is determined by the *competence* limit.

Compound bar

Within-channel depositional unit made up of a variety of smaller-scale features. These smaller scale features are termed either locales or morphostratigraphic units. Three primary compound bar types are described, namely mid-channel, bank-attached, and compound point bars. For example, a compound point bar may have a chute channel at its head, a distinct gravel platform, and various ridge features on its surface. In contrast, a *unit* bar is made up of just one locale or morphostratigraphic unit.

Concomitant

'At the same time as, and directly related to'.

Confluence

The point at which two (or more) channels join or converge.

Contemporary

This descriptor applies to 'modern day' features. In river terms, it means that the feature was formed by the present day flow regime of the river.

Cut-off

An old bend of a river which has subsequently moved.

D50, D84, D95

The fiftieth, eighty-fourth and ninety-fifth coarsest clasts in a 100 clast sample.

Degradation

Channel bed condition in which material is gradually being removed from the channel and the surface is lowered over time.

Diagonal bar

A type of *unit* bar with a diamond shape in which flow is oriented diagonally over the surface. Appears similar to an extended riffle feature.

Diffuse gravel sheet

Layer or sheet of gravels one or two grain diameters thick which moves over the channel bed (or over bar surfaces during higher discharge stages).

Drape

Thin cover of deposits, laid down typically in the waning (i.e. falling) stages of a flood event.

Environmental auditing

Procedure by which the reliability of predicted consequences of an environmental impact are assessed.

Equilibrium

A state of balance, when various forces have created a state or form which will not be altered with passage of time unless controlling factors change.

Exposure

Face cut into any landscape feature such that the materials or structure of the feature can be examined. Examples include road cuts in which differing rock types can be observed, or eroded river banks in which river deposits can be observed.

Extrinsic

'External to'. Used to define contols on system evolution, extrinsic variables are those controls which operate beyond the scale of the individual system. An example would be the role of climatic variablity in river behaviour.

Filament

'Slender threadlike body' - refers to a section of a water body. The thalweg of a river is the highest velocity filament of the flow.

Flood channel

Channel perched above the contemporary channel position, whether on a bar/island surface, an alluvial flat, or even the valley flat, which is only active under flood conditions.

Flow regime

The range or variability in the discharge (i.e. flow) of a river. While typically measured annually, this term may also be used to assess daily, weekly, monthly or inter-annual variability.

Fluvio-glacial

Processes, landforms or deposits resulting from river channels which extend beneath or in front of glaciers. The deposits from such processes are frequently termed *outwash*.

Friable

Readily prone to fracture - falls apart easily.

Geomorphology

Study of the form of the earth. Discipline that focusses on form/process interactions in the landscape and evaluates landscape evolution.

GIS (Geographic Information System)

Computer-oriented framework for synthesizing geographic information used to integrate various forms of data and map spatial patterns.

Histogram

Diagram in which columns represent frequencies of various ranges of values of a quantity.

Homogenous

'Of similar character'.

Igneous

'Of fire' - refers to rocks derived from molten materials.

Imbricated

Channel bed condition in which gravels are tightly packed and aligned with their upper surface pointed downstream.

Imposed

A state in which the landscape condition is determined by a particular factor. For example, in most bedrock areas a river is unable to shift its channel, so the channel position is said to be *imposed*.

Incision

Cut into. Used to describe the process by which rivers cut a groove in their own deposits.

Intrinsic

'Within a system'. Used to define controls that operate to determine system behaviour which are internal to the system.

Island

Within-channel accumulation of deposits which is vegetated. This essentially constitutes a vegetated river bar.

Isostatic rebound

Process by which the earth's crust attempts to regain an equilibrium condition. For example, following removal of dense ice sheets at the earth's surface, the crust has 'rebounded' following release of this weight.

Lag

Materials left behind when adjacent deposits have been removed.

Lateral bar

Type of unit bar in which a channel-scaled depositional unit has accumulated at the channel margin (i.e. adjacent to the channel bank).

Lobe

Roundish, flattish accumulation of deposits, typically deposited as a sheet.

Locale

Local depositional environment on a bar surface. For example, a chute channel or bar platform are distinct features on bar surfaces. More commonly referred to as morphostratigraphic units.

Lithology

Rock type - this is a critical control on the 'strength' of gravels, which determines how easily they erode.

Lowland

The downstream, low-lying reach of a river adjacent to the channel mouth.

Mean

The average.

Meander loop

The old meandering course of a river that is left behind as the channel shifts its position in its entirety.

Meandering river

Single-channelled river reach with a sinuosity (bendiness) > 1.5. Sinuosity is the ratio of channel length to valley length for a paricular reach.

Metamorphosis

Change in condition or shape.

Mid-channel compound bar

Bar unit made up of a range of smaller-scale depositional units located in the middle of a channel.

Mode

The most frequently recurring value in a distribution.

Morphodynamics

Processes which mould the landscape in which there is a direct association between form and mechanisms shaping the landscape.

Morphology

The three-dimensional shape of a feature.

Morphostratigraphic unit

Discrete depositional unit of definitive morphology for which the associated sedimentary assemblage is known (or can be determined).

Outwash

Materials deposited in front of a glacier - i.e. washed out from the glacier.

Overloose

Gravel bed condition in which gravels are not tightly packed, and are accordingly highly mobile.

Parameter

Characteristic or feature which is constant in each case considered, but varies in different cases.

Perched

'Elevated and lodged on the side of'

Planform

The configuration of the channel in plan view (i.e. as seen from above). This is described by three parameters, namely the number of channels, channel sinuosity, and the lateral stability of the channel(s). This is alternatively termed 'channel pattern'.

Platform

Typically a relatively flat gravel accumulation zone on a bar surface adjacent to the main channel. These are usually formed during higher flow stages.

Platey

Shape of a gravel clast with a flat, blade-like appearance.

Plutonic

Igneous rock which cooled beneath the earth's surface (e.g. granite).

Point bar

Unit bar type formed on the inside of meander bends.

Quaternary Era

Geologic term which defines the last two-million years - divided into two periods, the Pleistocene and the Holocene (last 10,000 years).

Regulation

Altered or adjusted condition - used in this study to describe flow reduction.

Riffle

Within channel zone of deposition which marks a local oversteepening of the channel bed gradient. Typically alternates with a series of pools. Water flows over these depositional featues with a 'rippled' surface.

Scalar framework

A conceptual approach to a problem in which the mechanisms undertaken to address questions asked are based on the spatial and temporal scales of the particular problem.

Secondary circulation cell

Flow cell which separates from the main flow, and results in localized flow upstream. Typically associated with flow around tight bends or associated with flow convergence at tributary confluences.

Sediment wedge

Unit of sediment, with a wedge-shape, that moves down a river.

Sedimentation

Process of deposition.

Sedimentation zone

Sub-reach of a river in which sediments are accumulating over time.

Side bar

A non-formative zone of within-channel deposits attached to a channel bank. As these are non-formative features, they are *not* unit bars. Rather, they are typically associated with gravel accumulations upstream or immediately downstream of tributary confluences.

Side channel

Distinct channels located at the margin of bar units or alluvial flats and the bank or terrace. These differ from chute channels in that they are not short-circuiting channels

Sinuosity

The 'bendiness' of the channel outline, defined by the ratio of channel lenth to valley length.

Size fraction

Class interval in a data distribution.

Sorting

The degree of uniformity with a size distribution

Spatial variation
The extent to which particular patterns vary over space.

Stream power
Rate at which work is being done on the bed of a river.

Sub-reach
A segment of a reach of distinctive 'local' character.

Subrounded
Gravel clasts which have rounded edges but are not very spherical (or ball-shaped).

Supra-platform
The basal gravel fraction of a river bar. This lies beneath the bar platform itself, and is usually composed of coarser, lag gravels.

Tectonic uplift
Internal forces within the earth which 'build-up' or form features of the crust.

Terrain
The physical character of an area.

Terrace
Alluvial or bedrock feature with a flat surface perched some distance above the modern channel. Several types of terrace may be described :

- *Aggradational terrace*
  Terrace formed by deposition and accumulation of deposits within a valley.
- *Asymmetrical terrace*
  Pattern of terraces across a valley in which terrace elevation alternates from one valley side to the other.
- *Continuous terrace*
  Condition in which terraces extend along the length of a river reach
- *Fragmentary terrace*
  Condition in which only remnants of terraces are found within a river reach, as surrounding deposits have been removed.
- *Incised terrace*
  Terrace formed as the river cuts into its valley bottom.
- *Inset terrace*
  Small aggradational terrace deposited within the valley.
- *Paired terrace*
  Condition in which terraces on opposite sides of a valley are of equivalent elevation.
- *Strath terrace*
  Rock cut terrace, formed as a river incised into its valley bottom

Terrace riser
The face of each terrace, which marks the step from the alluvial flat to the terrace, or from one terrace to the next.

Topography
Description of the surface features of an area, including not only landforms, but all other aspects both of natural and human origin.

Transportation zone
Sub-reach of a river in which deposits are essentially being flushed through and not-accumulating over time.

Unit bar
Formative within-channel depositional units of simple geometry, typically associated with uniform flow conditions. Four primary types can be discerned, namely longitudinal, diagonal, lateral and point bars.

Volcanic
Rock derived from a former volcano or extrusive lava flow (i.e. lava which cooled at the earth's surface).

Wandering gravel-bed river

River reach with two or three active channels which are laterally unstable.

Watershed

The line separating headstream which flow to different river systems; alternatively the term is used in the equivalent sense to catchment or drainage basin.

Winnowed

Gravel bed condition in which smaller sized gravels have been selectively removed from the bar surface.

References cited in the text

Brierley, G.J., 1991, Bar sedimentology of the Squamish River, British Columbia: Definition and application of morphostratigraphic units, *Journal of Sedimentary Petrology*, 61, 211-225.

Brierley, G.J. and Hickin, E.J., 1985, The downstream gradation of particle sizes in the Squamish River, British Columbia, *Earth Surface Processes and Landforms*, 10, 597-606.

Desloges, J.R. and M. Church, 1987, Channel and floodplain facies in a wandering gravel-bed river, In : F.G. Ethridge, R.M. Flores and M.D. Harvey, (Eds.), *Recent developments in Fluvial Sedimentology*, Soc. Econ. Palaeontol. Mineral., Tulsa, Okla., Spec. Publ., 39, 99-109.

Hickin, E.J., 1983, *River channel changes: retrospect and prospect*, Spec. Publs. Int. Ass. Sediment., 6, 61-83

Kellerhals, R., M. Church and D.I. Bray, 1976, Classification and analysis of river processes, *Journal of the Hydraulics Division, American Society of Civil Engineers*, 102, HY7, 813-829.

Leopold, L.B. 1970, An improved method for size distribution of stream bed gravel, *Water Reseources Research*, 6, 1357-1366.

McGowen, J.H. and L.E. Garner, 1970, Physiographic features and stratification types of coarse-grained point bars: modern and ancient examples, *Sedimentology*, 14, 77-111.

Schumm, S.A. and R.W. Lichty, 1965, Time, space and causality in geomorphology, *American Journal of Science*, 263, 110-119.

Williams, P.F. and B.R. Rust, 1969, The sedimentology of a braided river, *Journal of Sedimentary Petrology*, 39, 649-679.

Wolman, M.G., 1954, A method of sampling coarse river-bed material, *Transactions of the American Geophysical Union*, 35, 951-956.

River reach analysis of the Waiau River, Southland, from Mararoa Weir to Te Waewae Bay

(Appendices)

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APPENDIX 1 : Methodology

The methodology employed to undertake river reach analysis in this report entails three geographic scales of enquiry, namely valley, channel and gravel bar characteristics. A range of parameters are described for each scale. The adopted approach is an integrative procedure which relates those features observed on relevant topographic maps and air photographs with field observations and some simple field measurements. The procedure adopted is based loosely on the framework described by Kellerhals et al (1976). River reaches are defined as "channel reaches (of variable length) within which hydrological, geological, and adjacent watershed surficial conditions remain sufficiently uniform so that a sufficiently uniform river morphology results." The primary characteristic used to designate river reaches of the Waiau River downstream of Mararoa Weir is the *planform geometry* of the channel. Along the lower course of the Waiau, quite distinct reaches can be determined based on lateral constrictions of the channel (whether imposed by bedrock or proximity to terraces), while other reaches demonstrate variable channel patterns in terms of channel multiplicity and sinuosity.

In the adopted methodology, planform geometry is first assessed from available maps and photos. Insights so gained are used to propose tentative margins for river reaches, but these are then ratified by field observation. Geographic location and grid co-ordinates etc for each reach can be completed from afar. However, to undertake assessment of valley, channel and gravel bar characteristics, some field observations are necessary. The best approach is to start at the big picture, and move down in scale as each step is completed.

In this study, the starting point for analysis of each reach was the highest look-out point in any pre-designated reach. From this location, valley characteritics were described, and controls on channel planform were assessed. Morphometric aspects of channel planform are best described from air photographs, as site-specific information may not necessarily relate to properties of the overall reach. Finally, appropriate within-channel bars were selected for analysis of grain size and other properties of the channel bed. Access to these sites were determined from available maps and and air photos. Selected bars were 'representative' of each reach. The primary criteria in their selection was to ensure that each site was 'active' (i.e. the gravel surface was largely unvegetated), and that sample spacing was neither too close nor too distant.

Each section in the *field inventory* of the river reach analysis field inventory is described in Appendix II, while *grain size data* are presented in Appendix III. Observations on *vegetation distribution* are considered separately (in Appendix IV). Prior to presenting data collected, the specifics of the field coding sheet are outlined.

The GB approach to river reach analysis

Details of Analysis

This simply describes the geographic location of the reach, with reference to the map sheet and air photo runs used, grid locations, and the date of analysis and names of field analysts.

VALLEY CHARACTERISTICS

This describes the broad setting within which each river reach is located. This is schematically represented by a valley cross-section, interpreted from the 1:50,000 topographic map. Valley characteristics are described by integrating insights from the map and photos with field observations. Each characteristic analysed is described in turn.

This scale of analysis is important as it describes the context or boundary conditions within which the channel is able to adjust.

Terrain

This describes the topographic character of the reach above the valley floor. Several components are recorded.

Valley setting

This refers to the broad topographic position, whether mountainous, foothills, uplands, hills, plains or lowlands. Names of geographic features should be included where known.

Extent of valley flat

This refers to the cross-valley length of the upper flat surface within the valley. It is represented by the upper terrace surface in the Waiau. This is estimated from the map and ratified by field observation.

Extent of alluvial flat

This is the alluvial surface which is interpreted on field observation to be active during flood stage. It differs from a floodplain in that this is not necessarily a 'formative' surface (i.e. those flood events which flow across this surface have not necessarily been responsible for its formation).

Degree and character of channel constriction

This describes the relationship between the channel and its valley, as reflected by the ratio of alluvial flats to valley flats. Any features contraining lateral movement of the channel are described, such as bedrock, terrace features, tributary confluences or alluvial fans. Included in this section are descriptors of the aggradational/degradational condition of the channel. This is simply an assessment as to whether the channel is eroding into its bed or building up its bed. Reference should also be made to whether the channel is underfit (i.e. too small for the valley which it has cut).

Terrace character

The number and extent of terraces are described for both banks of the channel. The downstream continuity of terrace surfaces is documented, along with an assessment whether the terraces are paired or unpaired, or asymmetrical.

Surficial geology

This simply describes the character of materials into which the valley has cut, along with materials which infill the valley. If observed, bedrock type in the study reach is defined. Beyond this, the character of glacial deposits, lake deposits, etc are documented.

Land use

This characterizes whether the reach is cultivated or otherwise, and what the character of land use may be (e.g. pastoral, urbanized etc).

CHANNEL CHARACTERISTICS

Planform geometry
This describes the configuration of the channel in plan view and is measured using three parameters, namely the number of channels, their sinuosity, and their lateral stability.

Number of channels
This documents the primary number of channels within the reach, although any within-reach variation should be described.

Sinuosity
This describes the 'bendiness' of the river outline. This is defined as the ratio of channel length to valley length.

Channel stability
This must be based on an assessment from field observation. The best indicators of instability are active deposition on the inside of bends in the flow, with concomitant erosion on the outside of the bend. Any cut-offs or related features are documented.

Bar type and scale
Types of river bar are described, as these can be used to determine the character of channel change, while the character of the flow and bank materials are also described. These features are especially significant as they provide indicators of the migration pattern of the river (either downstream or laterally), and can be used as predictors of likely future channel changes.

A wide range of bar types are observed in rivers. Bars are differentiated into two primary styles, namely unit and compound features. *Unit* bars refer to simple depositional units with distinct geometries. These are differentiated into:

a)	longitudinal bar	-	elongate, mid-channel features,
b)	diagonal bar	-	diamond-shaped, mid-channel features
c)	lateral bars	-	bank-attached, elongate features, and
d)	point bars	-	arcuate, bank-attached features formed on the inside of meander bends.

Most bars on the Waiau are not simple unit bar features; rather, they are composed of a range of depositional units with complex assemblages and morphologies. These are referred to as *compound* bars, while the discrete geomorphic units making up each bar are referred to as morphostratigraphic units. The spatial patterns of morphostratigraphic units can be used to determine bar evolution. Two types of compound bar are recognized, based on their within-channel position, namely *mid-channel compound* bars and *bank-attached compound* bars. In several instances along the lower course of the Waiau there are large bank-attached compound bars which adopt the morphology of highly dissected point bars on the insides of bends. These are referred to as *compound point* bars.

Extent and character of alluvial flat
Describes the ratio of channel width to that of the alluvial flats. The character of the alluvial flats are also described as continuous or otherwise, and their degree of dissection is characterized.

Bank character
Describes the materials and height of banks along both sides of the river. From this, bank erodibility can be assessed.

Flow character
Differentiates among uniform water surface, uniform water surface with occasional rapids within-reach, irregular flow, pool and riffle sequences, and tumbling flow.

SAMPLE SITE CHARACTERISTICS

This scale of field analysis describes *gravel bar characteristics* at selected sites. Various grain size properties are recorded. These characteristics record the ease with which the river is able to move materials on the channel bed, and are a highly sensitive indicator of sediment transport within the channel. Of particular significance is the paving or armoring of gravels on the bed of a river, as this is a major indicator of the 'stability' of the channel bed.

Sample site details and description
This simply documents the geographic location of the sample site, and describes local site characteristics such as bar type etc.

Sample Number
Samples are numbered in their downstream position from Mararoa Weir.

Grid reference
Interpreted from 1:50,000 topographic map.

Bar type
Described using criteria outlined in channel characteristics section above.

Position on bar
Each sample was collected in the coarsest gravel unit on the sampled bar. The position of this coarsest unit varies from sample site to sample site.

Sample type
Each particle size sample consisted of analysis of 100 gravel clasts. Clasts were measured at 1 m interval along a tape, in accordance with a procedure described below. If the 100 m sample length encountered a finer gravel unit, the sample length was reduced to 50 m, and 2 x 50 m samples were collected within the coarsest gravel unit.

Grain size analysis procedure employed in this study
Grain-size analysis undertaken in any study is goal-specific. Whenever the data are used in any way, *great care* must be taken to ensure that the data are pertinent. In this instance data on grain size are collected to provide an inventory of the *coarsest grain size fraction* on active gravel bar surfaces for each river reach downstream of Mararoa Weir. This is **not** an estimate of average bed material size, or the average size of materials presently moving through the river system. The coarsest grain size fraction is critical in assessment of *thresholds of motion* on the channel bed. Once the coarsest material is mobilized, the entire channel bed is active.

The following step-by-step approach, based on Brierley and Hickin (1985) and modified after Wolman (1954), was used.

1) The coarsest gravel depositional unit on each pre-selected gravel bar was located. This is referred to as a gravel locale (Leopold, 1970) or a morphostratigraphic unit (Brierley, 1991). Typically this unit is located close to the bar head at the channel margin, although many sampled sites in this study are located within chute channels.

2) Within the coarsest gravel unit a 50 m tape was laid on the bar surface. Once analysis of the first 50 m is completed the tape is moved. If the coarse gravel unit extends for a further 50 m, the tape is placed as an extension of the original sample. If the coarse gravel unit is relatively small, the second tape position is located parallel to the first, separated by a few metres.

3) As a general principle, the sampling interval along the tape is determined by the coarsest clast encountered on the bar surface. As a rule of thumb, sampled gravels must be separated by at least 2 other clasts to be independent of each other. Hence, if gravels have diameters in excess of 400 mm, the sampling interval between selected gravel clasts must be > 1.2 m. In this study coarsest clasts encountered were around 250 mm, so a sampling interval of 1.0 m was used at all sample sites.

4) One of the key criteria in any sampling procedure is rigour, and it is vital that equivalent procedures be employed at each sampling site. This is especially critical in selecting individual gravel clasts to be sampled. Wolman (1954) used a 1 m paced interval and selected clasts with "out-stretched finger and eyes closed", the sampled gravel clasts being the first clast his finger encountered. In this study one side of the 50 m tape was used, and the clast immediately beneath each 1 m interval was analysed. If this particle had a *b axis* smaller than 8 mm (see point 5 below), it was noted in the field noted by a check mark, and the nearest adjacent particle with a *b axis* coarser than 8 mm was selected. The reason for this step is that rivers generally demonstrate a "sand-gap", in which sands and fine gravels are frequently flushed through river systems, but are washed onto bar surfaces following flood events. As such, they may not be representative of the 'average' size of material on the bar.

5) The *b axis* of each selected clast coarser than 8 mm was measured using a ruler. The *b axis* is simply the axis of the clast perpendicular to the long axis. The *b axis* is measured rather than the long axis as it is the measure which provides the closest approximation to the volume of the clast.

6) Analysis is undertaken by one operator until 100 clasts have been measured.

Particle characteristics

Histogram
This graphic is simply a number count of how many particles within the 100 particle sample occur within each 0.5ø grain size interval. The symbol ø (phi) refers to a geometrically-based interval procedure used in grain size analysis. A geometric interval is used because the difference between gravel clast sizes changes with the magnitude of the clast. For example, a 2 mm difference is significant between a particle with a diameter size of 3 mm and a clast of 5 mm diameter (40 % difference). However, 2 mm difference is virtually insignificant between, say 150 mm and 152 mm (1.3 % difference). Although fairly straightforward, the ø system is not very user-friendly, and employs the following size classes :

ø interval	mm equivalent
-3	8
-3.5	11
-4	16
-4.5	23
-5	32
-5.5	45
-6	64
-6.5	91
-7	128
-7.5	181
-8	256
-8.5	362
-9	512

Grain size parameters

Modal grain size class
This is the 0.5 ø size class which has the highest count of the 100 sampled clasts.

D95, D84, D50
These are the ninety-fifth, eighty-fourth, and fiftieth coarsest clasts in the 100 sampled clasts. These particular sizes are recorded as they are used in calculations on thresholds of motion in gravel bed rivers.

Mean and standard deviation (S.D.)
The mean clast size is simply the average of the 100 clast sample, while standard deviation is a statistical measure of variability away from the mean within the 100 clast sample. Standard deviation, as such, is a measure of the sorting of the gravels (i.e. how similarly-sized they are).

Gravel bar 'condition'

These observations refer to various parameters describing the ability of channel bed materials to be mobilized and move through the river system, as well as factors describing thir origin.

Sorting
This describes the variation in gravel clast sizes observed over the bar surface.

Packing arrangement
This describes the 'density' of the clasts, or the tightness with which the clasts are packed on the gravel bar surface. Other parameters described in this section are the *imbricated* condition (i.e. whether clasts are packed together and uniformly inclined down-flow) and the *winnowing* condition (i.e. whether finer materials have been removed from between coarser clasts). These characteristics can be used to determine whether the bed of the river is *paved* or not. A

paved bed is one in which the surface materials are coarser than subsurface materials (i.e.the surface protects the finer materials beneath from being eroded).

Shape
This describes the roundness and sphericity of gravel clasts. As a rule of thumb, angular clasts have been carried shorter distances down-river than rounded clasts. This condition reflects rock type in large part.

Lithology
Rock type of clasts affects their density, shape etc, but is also a useful indicator of source of materials within the catchment.

Other characteristics
A range of other features can be used to describe the channel bed condition. For example, particular sedimentary structures (gravel lenses, particle clusters etc) provide insights into the nature of movement of materials along the bed of the river.

APPENDIX 2 : River reach summaries

In this appendix each river reach is summarized at three scales: valley, channel and gravel bar characteristics. In each instance a river reach map is presented. Each river reach map is a simplified interpretation of channel planform and terrace configuration, taken from the 18.12.91 air photo run at 1:16,000 scale by Southland Regional Council, Aerial Mapping Division, Survey 960. Relevant photo numbers are indicated on each figure. The base map was interpreted by Keith Fitchett, Department of Biogeography and Geomorphology, RSPacS, Australian National University. Keith also drafted the figures. The terrace pattern is incomplete, due to inconsistent stereo coverage; additional interpolation of terraces has been made from 1:50,000 topographic maps. North arrows have been interpreted by alignment with the relevant topographic map.

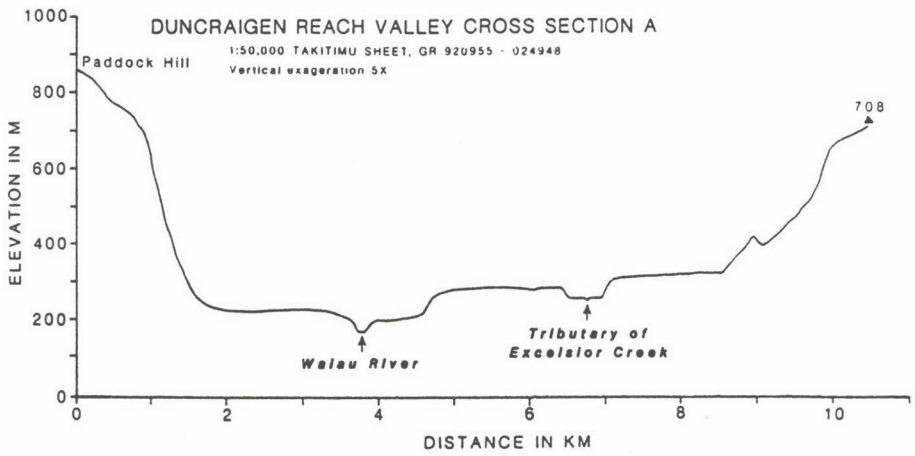
DUNCRAIGEN REACH

Details of Analysis

Geographic Location: Mararoa Weir to Whare Creek confluence.
Map Sheet: Takitimu 1:50 000 *Grid Reference:* 960966-956946
Air Photos: 24/6/84: 613 #20,19
4/4/89: 787 #28,27
18/12/91: 960 #25,24,23
Date of Analysis: 18/3/92 *Analysts:* GB/SB

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

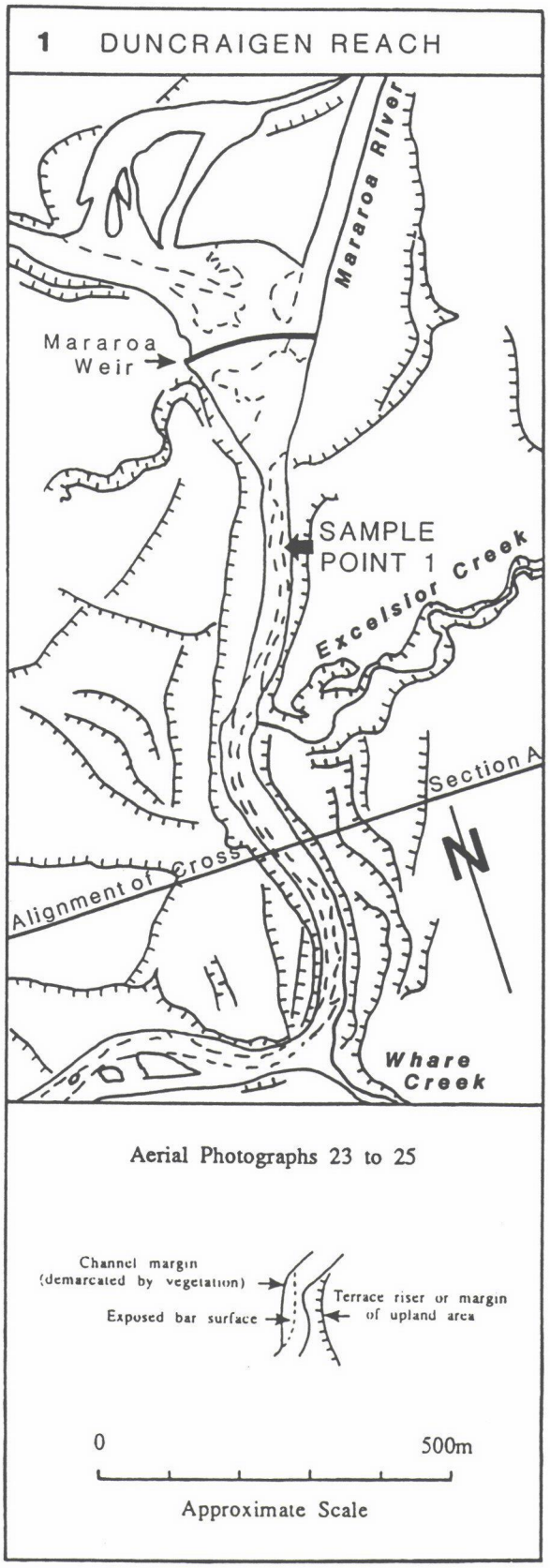


Valley Setting: Stream-cut valley at lower end of Te Anau Basin adjacent to upland region, with Paddock Hill (905m) on right bank and Takitimu Mountains on left bank.
Extent of Valley Flat: Valley width c.80m.
No valley flat; stream-cut valley, too incised.
Extent of Alluvial Flats: None.
Degree and Character of Channel Constriction: Laterally constrained by fluvioglacial terraces but present channel condition does not appear to be degraded. Loose angular boulders (up to 1.5m wide) have been placed at the valley margins and channel bed immediately downstream of the weir, for protection against degradation. Valley walls are steep with no evident slumping, although some scree was observed at the base of the right bank downstream of the sampling site on the outside of a bend.
Terrace Character: Two terraces, the upper of which is prominent and continuous. The upper terrace is probably paired and is c.100m above the confined reach.

SURFICIAL GEOLOGY
Bedrock not evident; distinct fluvioglacial terraces and imported boulders (rip-rap).

LAND USE
Pastoral on upper terraces; none within confined valley.

Air Photo Interpretation of Reach



CHANNEL CHARACTERISTICS: DUNCRAIGEN REACH

PLANFORM GEOMETRY
Number of Channels: 1.
Sinuosity: Straight to gently sinuous.
Channel Stability: Laterally stable, confined.
Bar Type and Scale: Alternating lateral bars; no islands.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: Today channel width is 15-20m; at higher discharge river covers entire valley flat (c.80m).
Ratio of Alluvial Flat Width to Channel Width: No alluvial or valley flat.

BANK CHARACTER
Extent: Fluvioglacial terraces up to tens of meters high. Upper terrace is c.100m above the reach. Imposed boulders at top end of reach extend 250m downstream of bridge, at channel margins.
Materials: Fluvioglacial outwash. Imposed boulders (riprap) at top end of reach.

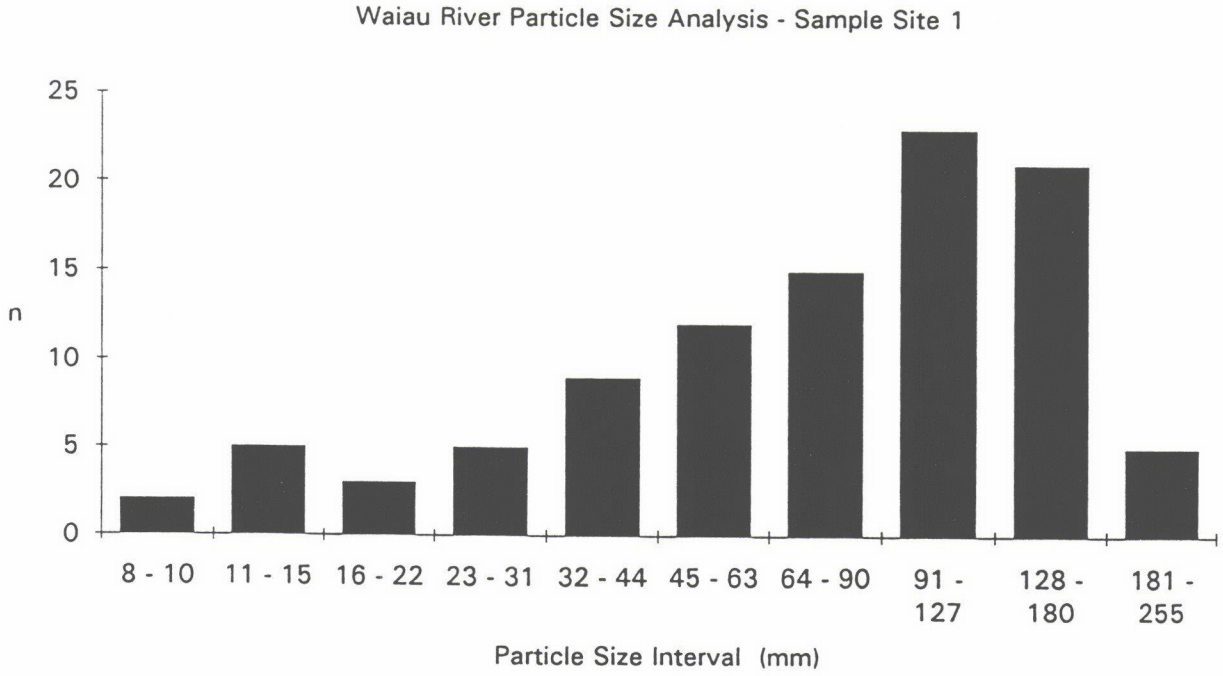
FLOW CHARACTER
Irregular. (Note high seepage rate from left bank).

SAMPLE SITE CHARACTERISTICS: DUNCRAIGEN REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 1 *Grid Reference:* 959963
Bar Type: Alternating lateral bar on left bank of river.
Position on Bar: Adjacent to channel in downstream orientation, sampled in coarsest gravel locale free from human modification (rip-rap boulders), c.600m downstream of bridge.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 178mm
D84 154mm
D50 90mm
Mean 92.8mm
S.D. 53.5mm

GRAVEL BAR CONDITIONS
Sorting: Very poorly sorted.
Packing Arrangement: Well imbricated, well winnowed.
Shape: Platey to sub rounded.
Lithology: Very diverse.
Other Characteristics: Distinct coarse gravel clusters present in valley flat.

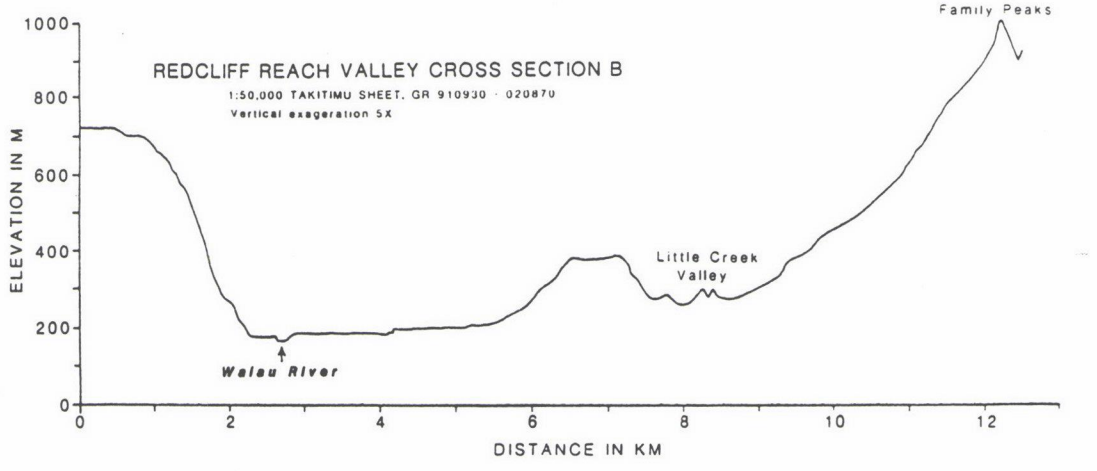
REDCLIFF REACH

Details of Analysis

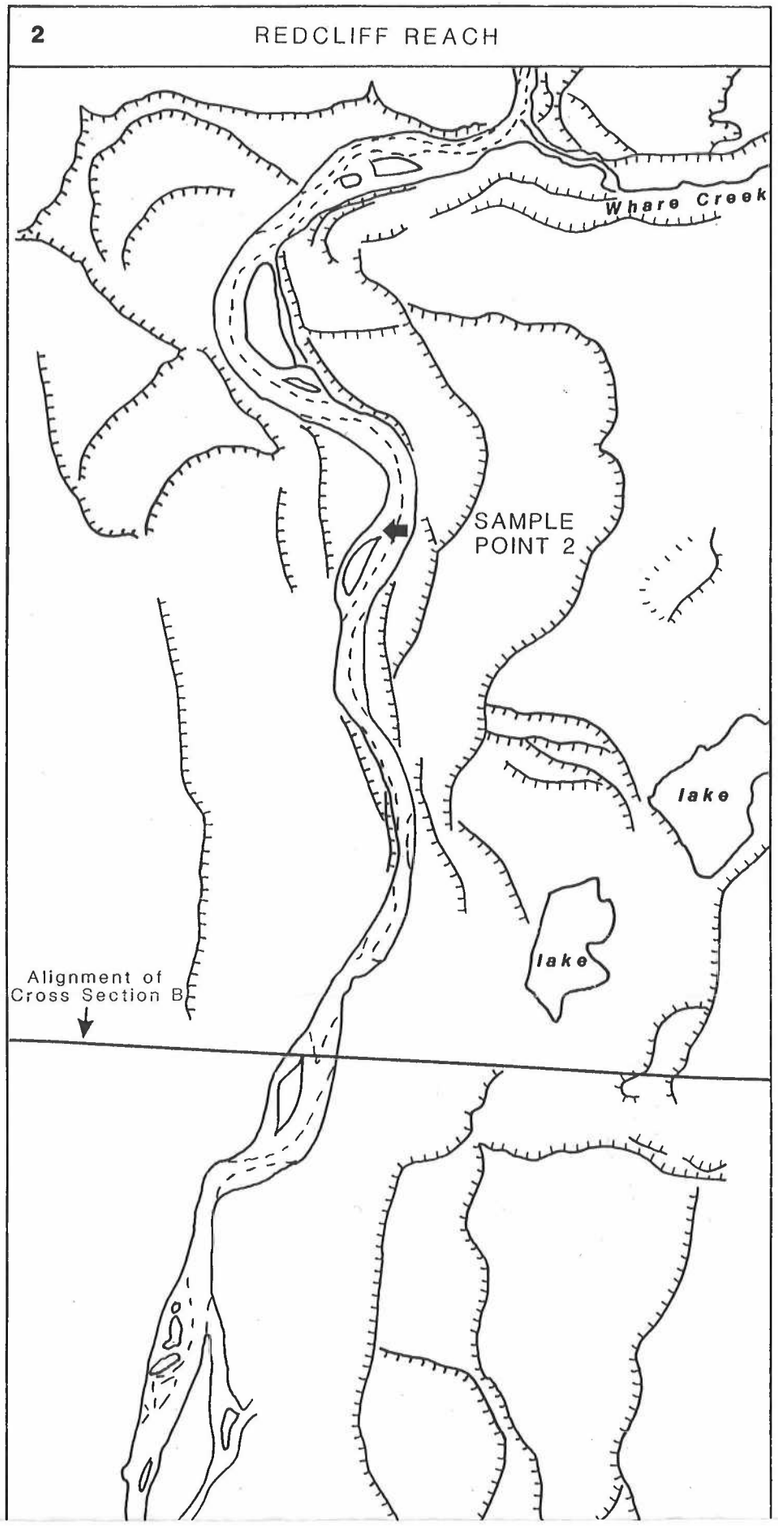
Geographic Location: Just upstream of Whare Creek confluence to 4km downstream of Redcliff confluence.
Map Sheet: Takitimu 1:50 000 *Grid Reference:* 956946-914846
Air Photos: 24/6/84: 613 #19,18,17,16,15,14,13,12,11,10
4/4/89: 787 #28,27,26,25,24
18/12/91: 960 #24,23,22,21,20
Date of Analysis: 18/3/92 *Analysts:* GB/SB

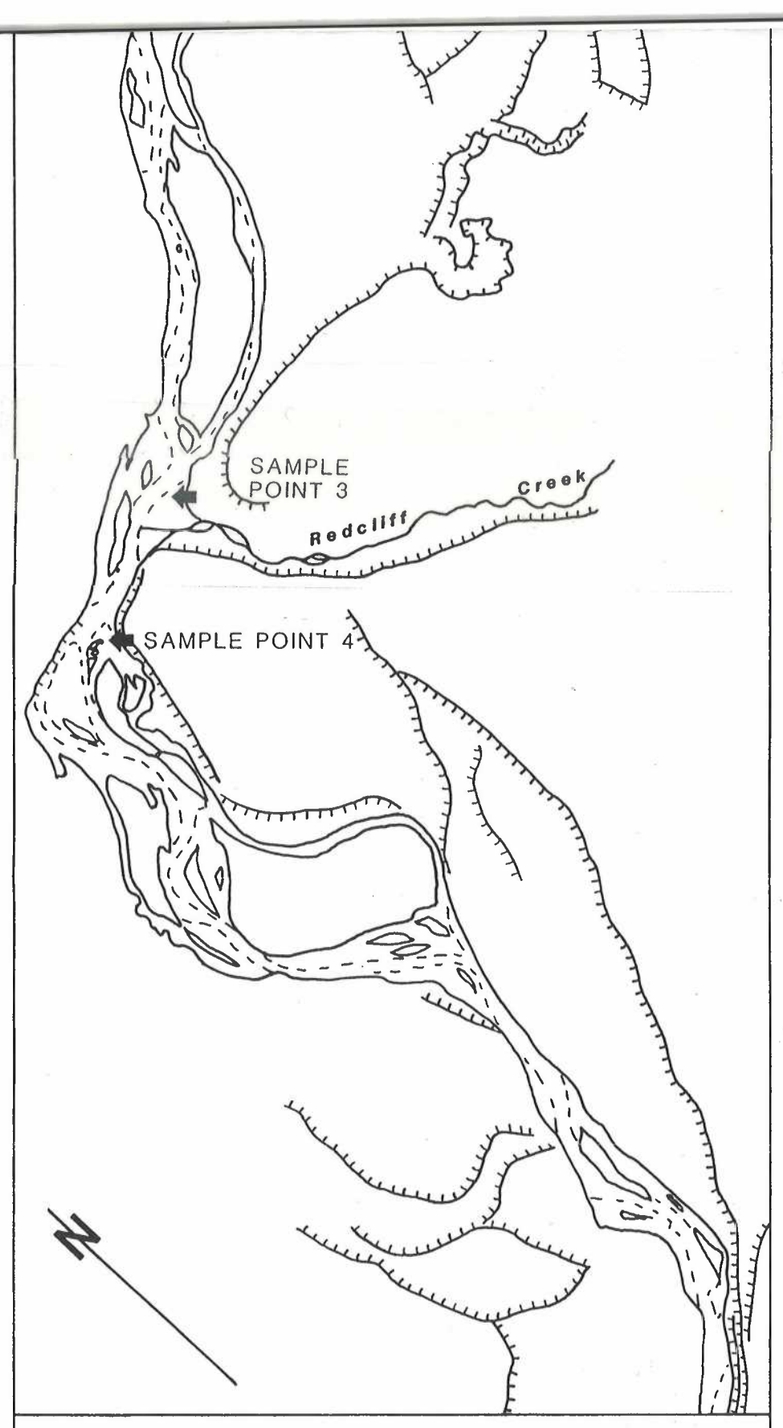
VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

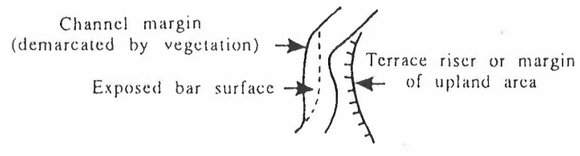


Valley Setting: Valley basin between the foothills of the Takitimu Mountains to the East, and Paddock Hill to the West, although the downstream end of the reach extends beyond Paddock Hill to where there is a prominent outwash terrace. Prominent alluvial fans observed in foothills on East (left) side of valley.
Extent of Valley Flat: 2.5-3.0km, although somewhat wider downstream.
Extent of Alluvial Flats: Generally <200m of unvegetated flats, but occasionally >500m (eg. old surface with loops at 948939).
Degree and Character of Channel Constriction: Constrained by fluvioglacial terraces, but notably less constrained at downstream end of reach.
Terrace Character: Terrace risers are steep.
Left Bank: >5 prominent terraces on left (Takitimu) side. These are extensive features up to 2km wide in total; highest terrace is c.100m above river level. (Note Redcliff Wetland Reserve on terrace 2).
Right Bank: Generally just 1 terrace on right (Paddock Hill) side. This is laterally restricted since the Waiau is pinned against the valley side, leaving terraces as a bench perched c.10m above the river. Terrace riser is incised at 943942 and 904883. Note also, landslips on Paddock Hill.


2
REDCLIFF REACH
Whare Creek
SAMPLE
POINT 2
lake
lake
Alignment of
Cross Section B



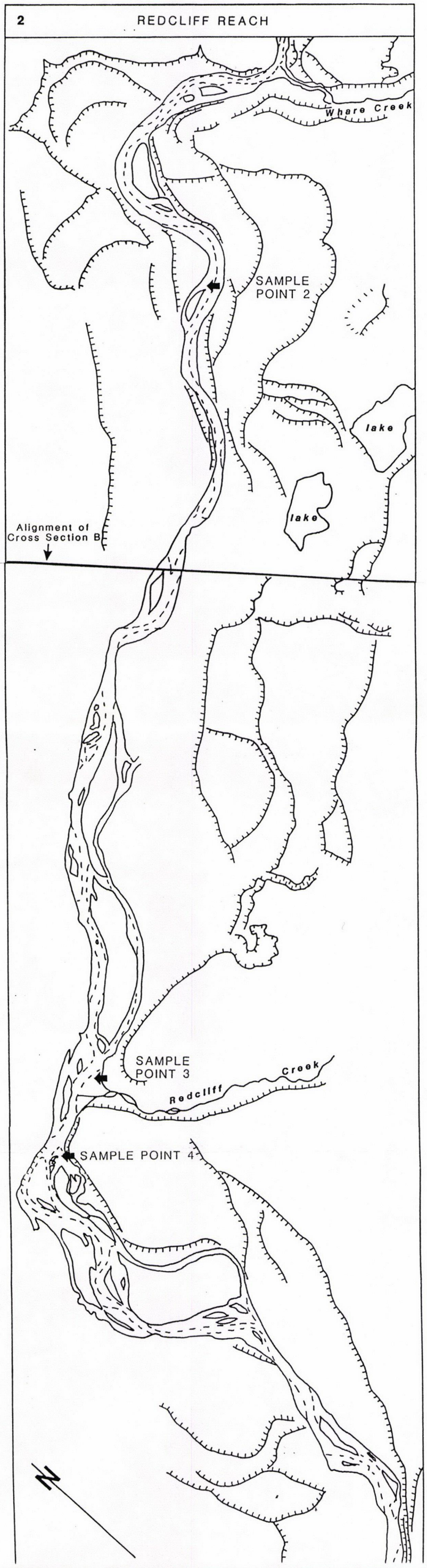
Aerial Photographs 20 to 23



0 500m

Approximate Scale

Air Photo Interpretation of Reach



Aerial Photographs 20 to 23

Channel margin (demarcated by vegetation)

Exposed bar surface

Terrace riser or margin of upland area

0 500m

Approximate Scale

SURFICIAL GEOLOGY
Fluvioglacial terraces; bedrock not evident.

LAND USE
Pastoral and plantation forestry.

CHANNEL CHARACTERISTICS: REDCLIFF REACH

PLANFORM GEOMETRY
Number of Channels: 1 in upper reach; splits in lower reach. Marked increase in channel multiplicity to 4-5 channels immediately downstream of Redcliff Creek (channels aligned diagonally and downstream with one prominent chute channel)
Sinuosity: Broadly sinuous in upper reach transitional to irregular meanders in lower reach.
Channel Stability: Little evidence for active lateral migration in upper reach. In lower reach, channel exhibits irregular lateral activity, while primary movement appears to be downstream.
Bar Type and Scale: Transitional within-reach, from compound point bars and lateral bars at the reach head, to large "longitudinal" islands with minor side channels in mid reach. These non-formative islands have irregular gravel accumulations as recent extensions. The latter adopt the form of marginal lateral and point bars. Beyond Redcliff confluence the channel divides around a series of dissected compound bars. Compound point bars, mid-channel point bars and bank-attached features are observed. As flow becomes confined at the downstream limit of the reach, lateral bars are observed.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: 80m width of gravel in upper reach:- river occupies c.25m (gates not open).
Ratio of Alluvial Flat Width to Channel Width: c.6:1 (alluvial flats are 500-600m wide with active gravel over 80-100m).

BANK CHARACTER
Extent: Fluvioglacial terraces up to 2km wide on left bank; highest terrace is c.100m above river level. Generally just 1 terrace on right where river is pinned against valley side. This terrace is more of a bench, c.10-15m above the river.
Materials: Fluvioglacial: Banks and islands are gravel based with sand and vegetation atop. Large boulders in stream appear to be reworked fluvioglacial deposits as they are irregular and discontinuous. Note also several logs.

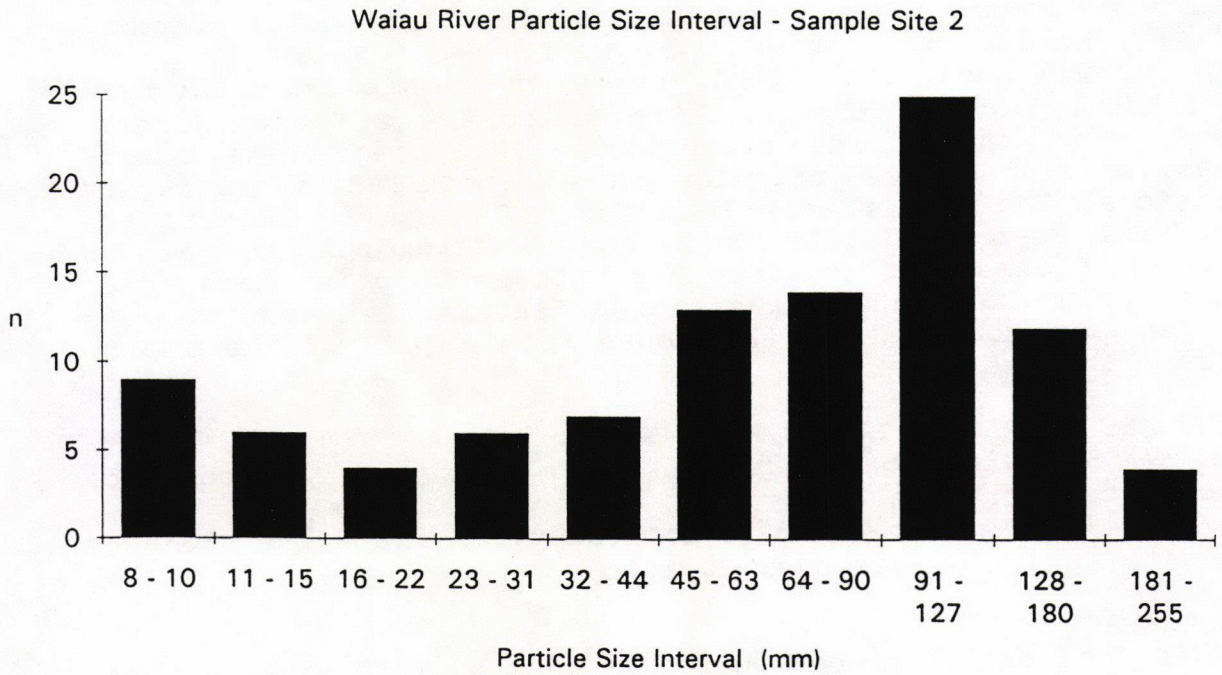
FLOW CHARACTER
Shallow with riffles, spaced c.500m apart. Riffles are more closely spaced at lower end of reach (c.200m adjacent to Redcliff confluence).

SAMPLE SITE CHARACTERISTICS: REDCLIFF REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 2 *Grid Reference:* 946935
Bar Type: Lateral/ point bar on inside of bend apex, showing down-bar alignment of sedimentation zone with differential imbrication. (Imbrication appears best in the chute channel 945934).
Position on Bar: Alongside main channel, in downstream orientation. Overloose zone sampled.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 178mm
D84 126mm
D50 73mm
Mean 77.8mm
S.D. 51.7mm

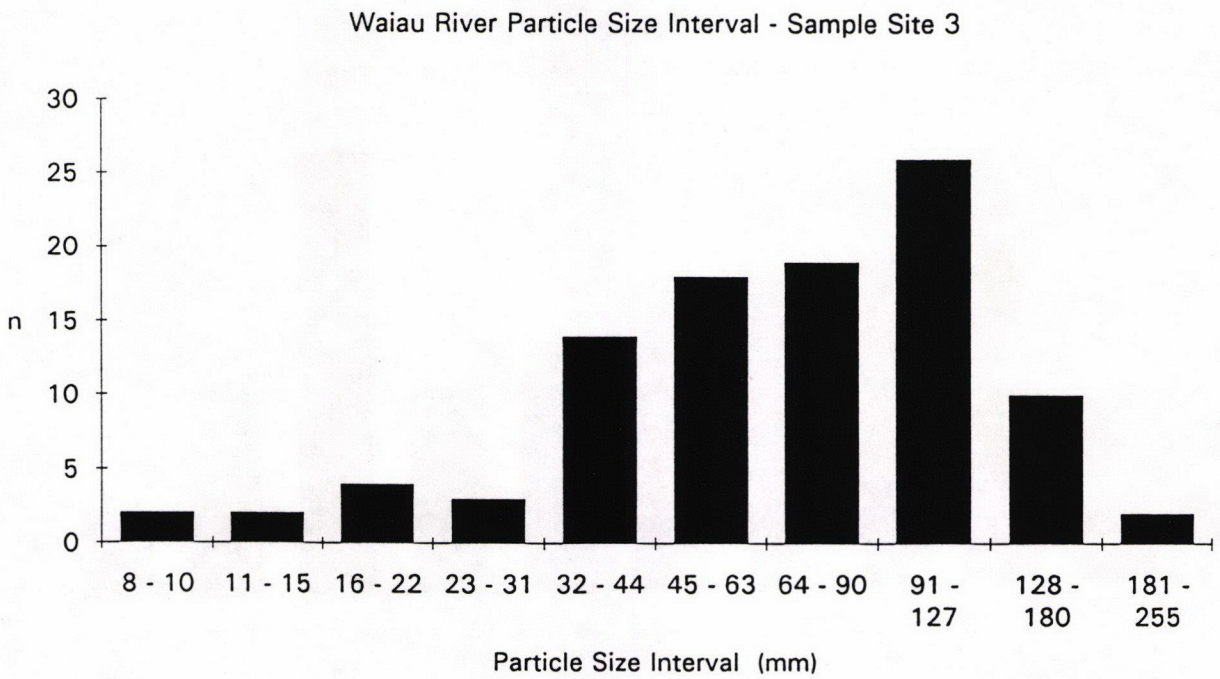
GRAVEL BAR CONDITIONS
Sorting: Very poorly sorted (indicates reworking of old terrace materials).
Packing Arrangement: Overloose zone sampled.
Shape: Generally sub rounded. Occasionally platey.
Lithology: Varied.
Other characteristics: A mobile gravel bed. Chute channel on a higher level. Series of gravel levels with finer gravels underneath larger ones.

SAMPLE SITE CHARACTERISTICS: REDCLIFF REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 3 *Grid Reference:* 913887
Bar Type: Head of a compound point bar on the shallow fan surface upstream of Redcliff confluence.
Position on Bar: Alongside main channel, in downstream orientation.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 157mm
D84 116mm
D50 75mm
Mean 77.3mm
S.D. 43.0mm

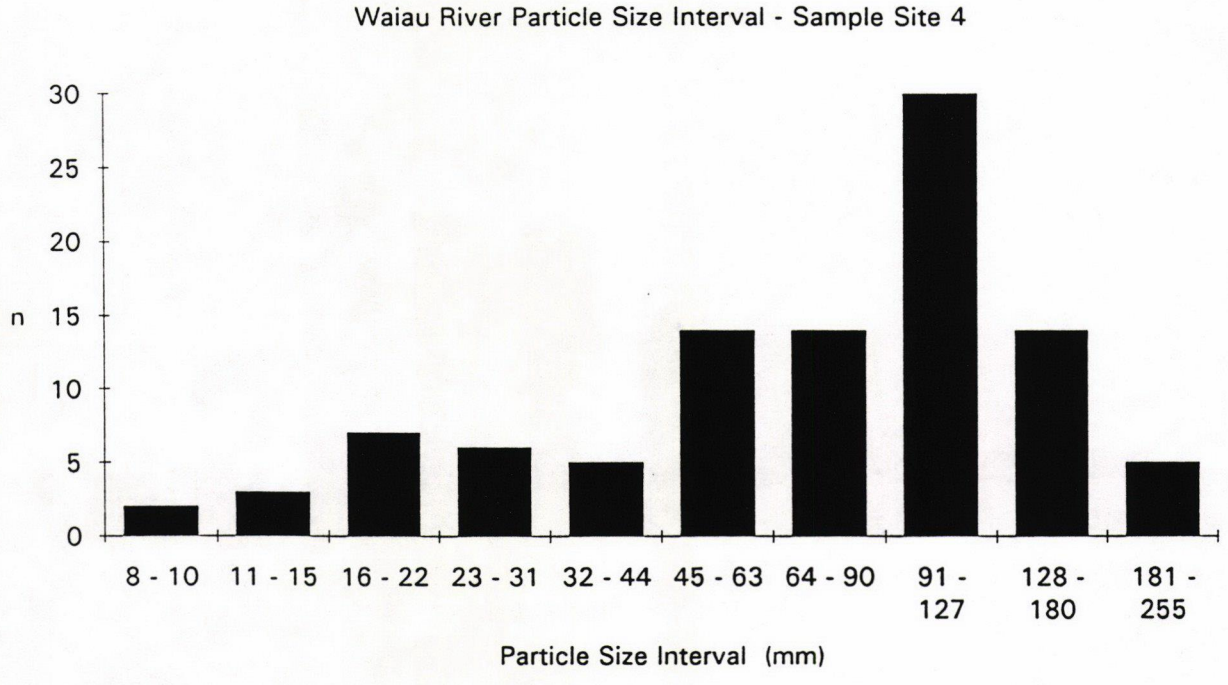
GRAVEL BAR CONDITIONS
Sorting: Moderately sorted. (Note better sorting in second 50m downstream).
Packing Arrangement: Very loose particles; overloose, jumbled surface, little clustering, not imbricated.
Shape: Generally sub rounded. Occasionally platey.
Lithology: More homogenous/ much less varied than seen in the upper reach. Grey particles.

SAMPLE SITE CHARACTERISTICS: REDCLIFF REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 4 *Grid Reference:* 907883
Bar Type: Sample taken in a chute channel aligned roughly straight down-valley on a compound point bar. Chute channel has 2 diagonal channels running off towards the main channel, close to its head and a distinct side channel on its Eastern edge, which has willows adjacent.
Position on Bar: At head of chute channel, oriented downstream.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 170mm
D84 133mm
D50 86mm
Mean 87.5mm
S.D. 49.5mm

GRAVEL BAR CONDITIONS
Sorting: Poorly sorted as minimal winnowing has taken place. (ie. deposition post flood event has deposited finer gravels among cobbles and boulders).
Packing Arrangement: Particles locally imbricated, second 50m appear almost jumbled.
Shape: Coarser gravels are decidedly sub rounded while finer clasts appear almost sub angular (probably associated with input from Redcliff Creek). Occasional platey clasts.
Lithology: More varied than at Waiau 3.

BLACKMOUNT-MANGAPIRI REACH

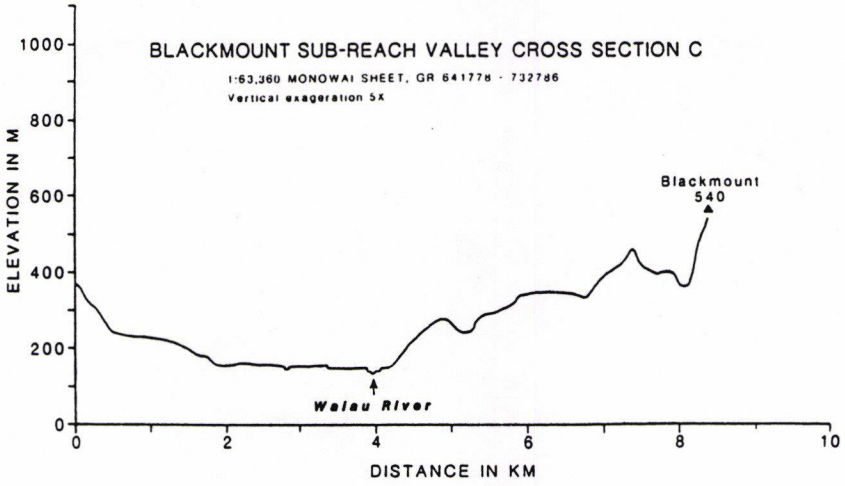
BLACKMOUNT SUB-REACH

Details of Analysis

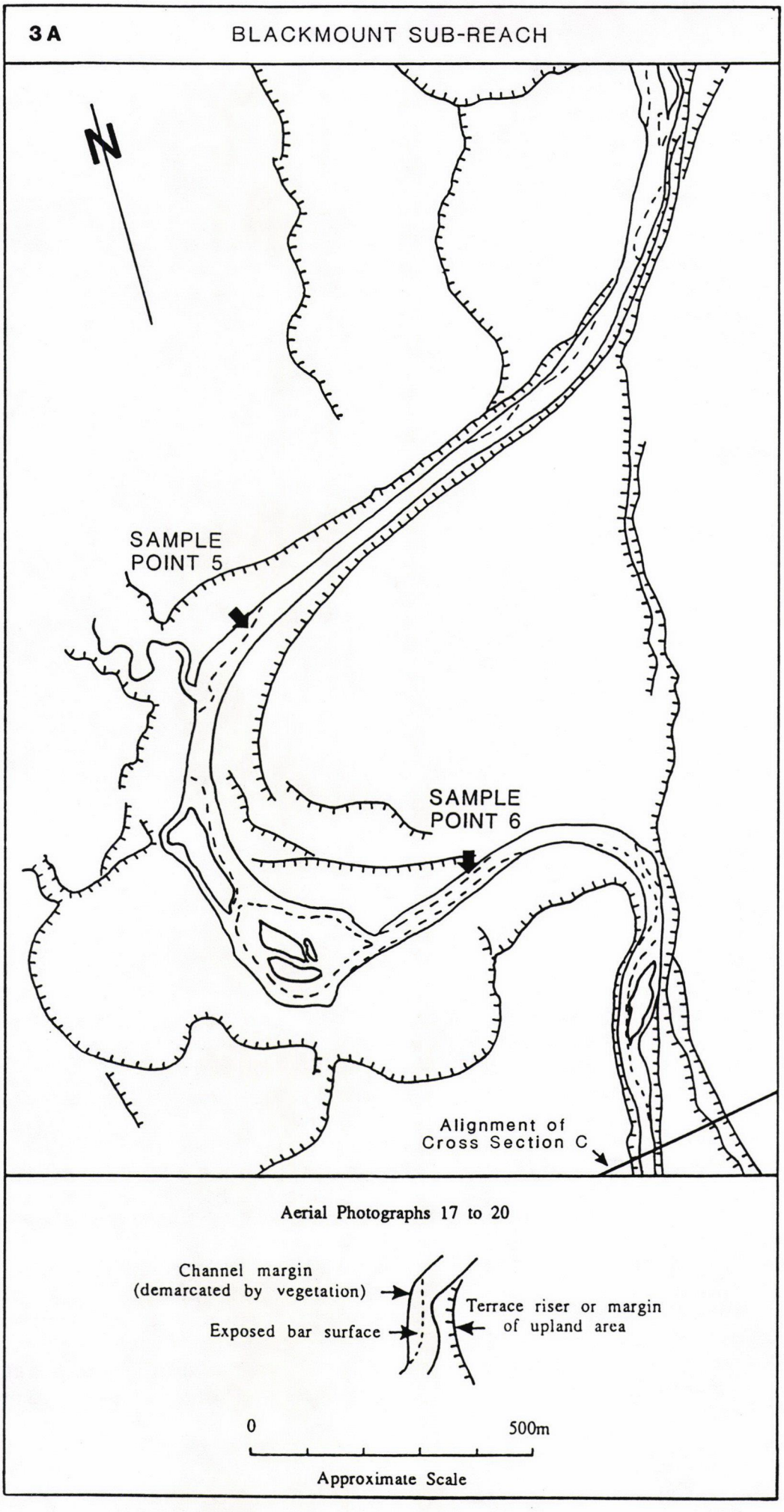
Geographic Location: 4km downstream of Redcliff confluence to 1km upstream of Borland Burn (adjacent to Blackmount).
Map Sheet: Takitimu 1:50 000 *Grid Reference:* 914846-903808
Air Photos: 24/6/84: 613 #10,9,8,7,6,5
4/4/89: 787 #24,23,22
18/12/91: 960 #19,18
Date of Analysis: 19/3/92 *Analysts:* GB/SB

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section



Valley Setting: Valley flat between Blackmount to the East and South end of Titiroa to the West.
Extent of Valley Flat: Wide fragmentary flats, 1.5-2.0km wide.
Extent of Alluvial Flats: Highly variable, from 0 to >200m wide in some bends.
Degree and Character of Channel Constriction: At upstream end of reach, channel is confined within fluvioglacial terraces in a wide valley. Downstream, channel constrictions are reduced, but near the reach limit the channel abuts against tilted mudstone/shale bedrock at Craggy Tor (908814).
Terrace Character: One primary terrace on valley flat, into which channel is incised by 15-20m. Terrace is continuous.
Left Bank: Braid plain channels can be located in pines on terrace (viewed from Craggy Tor Road, Blackmount Forest).
Right Bank: Up to 5 discontinuous terraces in lower reach. These have a braid plain configuration on a lower terrace and meander scars into the third terrace level.


3A
BLACKMOUNT SUB-REACH
N
SAMPLE POINT 5
SAMPLE POINT 6
Alignment of Cross Section C
Aerial Photographs 17 to 20
Channel margin (demarcated by vegetation)
Exposed bar surface
Terrace riser or margin of upland area
0
500m
Approximate Scale

SURFICIAL GEOLOGY
River constrained by fluvioglacial terraces at upstream end; mudstone/shale bedrock at downstream end.

LAND USE
Forestry on left, some pasture on right. Recreational use of river; fishing.

CHANNEL CHARACTERISTICS: BLACKMOUNT SUBREACH

PLANFORM GEOMETRY
Number of Channels: 1 mainly; >4 at compound bar (Monowai 1:63 360 sheet; 672794).
Sinuosity: Imposed broad sinuosity at upstream end, with bends becoming less constrained and moderately tight down the reach.
Channel Stability: No lateral channel activity other than at the compound point bar.
Bar Type and Scale: Channel demonstrates abrupt transition from non-alternating lateral bars at upstream end, to a compound point bar in a wide bend, to a lateral bar, to a tight bedrock constrained bend, to a lateral bar at the downstream end of the reach. Diffuse gravel sheets, 2-3 particle diameters thick, have been washed onto the surface of the lateral bar just downstream of the compound point bar. The latter bar has a vegetated core with a large gravel sheet on the inside of the bend, separated from the left bank by a chute channel. A distinct gravel lobe has been pushed into the river at the downstream limit of the Western-most channel (separating the compound bar from the right bank). This appears to be the preferred channel during floods. A distinct series of topographic levels are observed across the compound point bar surface. Morphostratigraphical units appear aligned down-valley and do not conform with the shape of the bend.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: 30-40m wide at head of reach; >200m at compound bar; <80m at downstream limit.
Ratio of Alluvial Flat Width to Channel Width: Alluvial flat is discontinuous but extends up to 120m wide; channel itself is 30-40m wide at upstream end.

BANK CHARACTER
Extent: Fluvioglacial terraces upstream of the compound point bar. Downstream of this, bedrock forms the channel bank and also a step in the channel which is continuous with the riffle at the downstream end of the sampled lateral bar (sample point 6).
Materials: River constrained by fluvioglacial terraces at upstream end; mudstone/shale bedrock at downstream end, with an exposure of mudstone sequences at the outside of the bend at Craggy Tor.

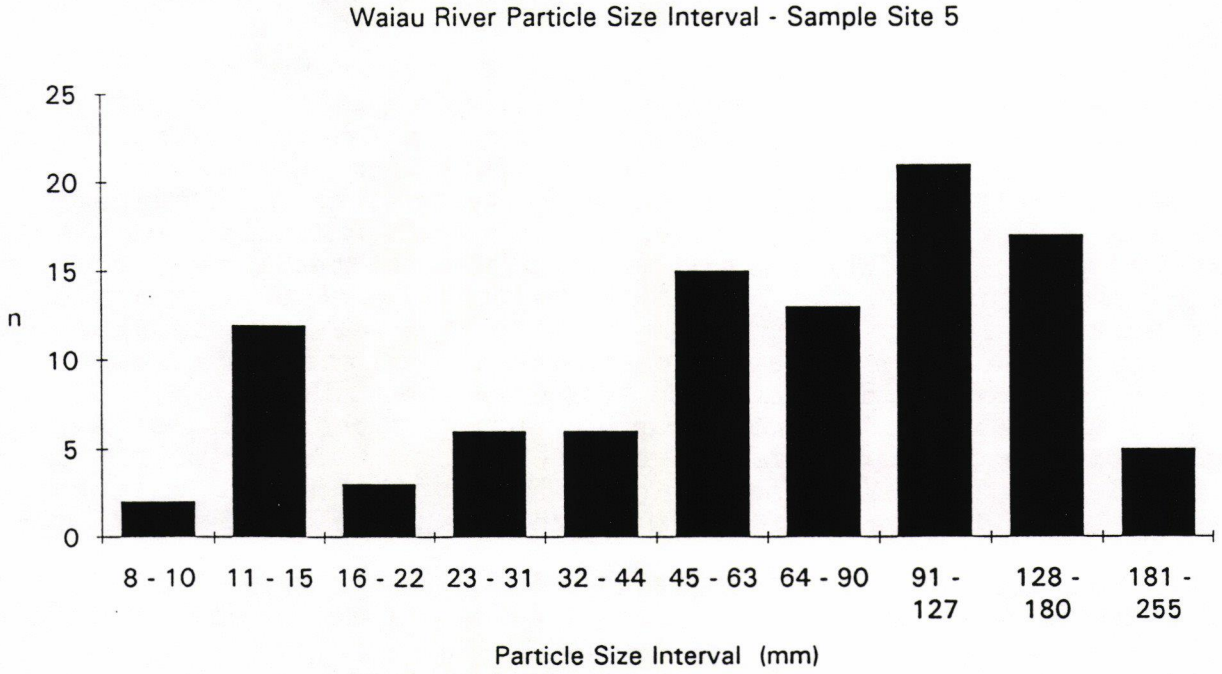
FLOW CHARACTER
Uniform water surface with riffles very widely spaced (nearly 1km). Pools adjacent to the bedrock step and a secondary circulation cell where the gravel lobe pushes the river against the bedrock

SAMPLE SITE CHARACTERISTICS: BLACKMOUNT SUBREACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 5 *Grid Reference:* 672808
Bar Type: Lateral bar on right bank, immediately upstream of a confluence.
Position on Bar: Mid section of bar, adjacent to channel in downstream orientation.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 177mm
D84 148mm
D50 74mm
Mean 82.2mm
S.D. 54.4mm

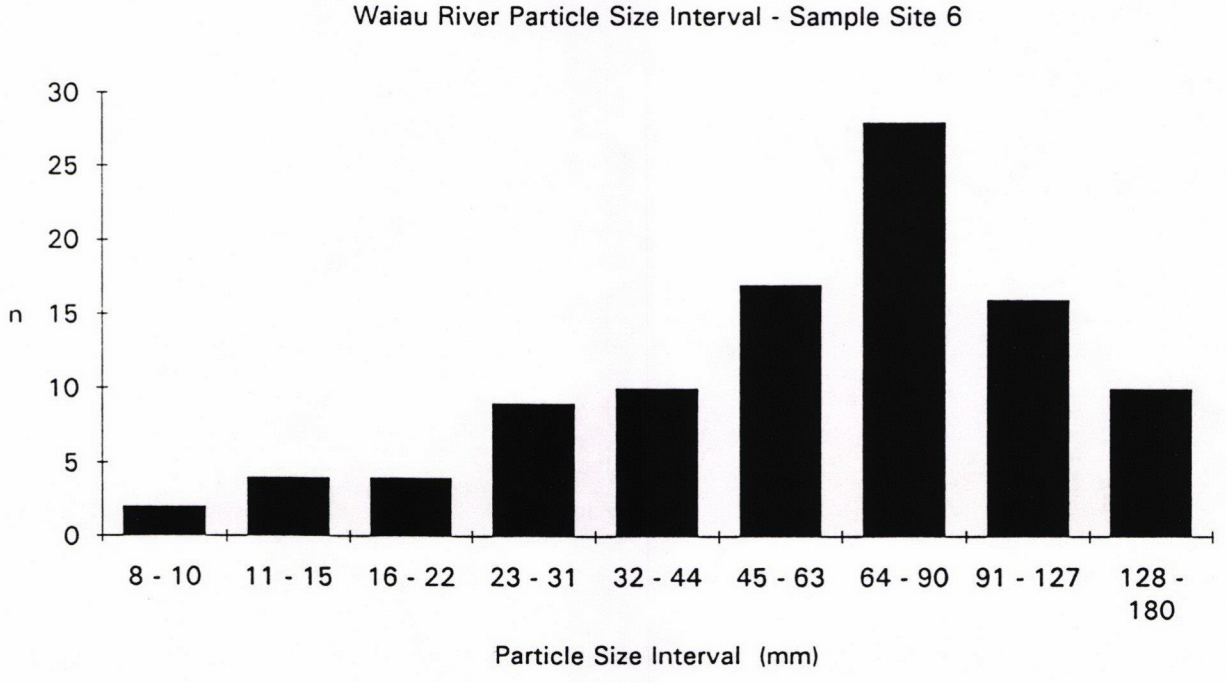
GRAVEL BAR CONDITIONS
Sorting: Quite jumbled.
Packing Arrangement: Imbricated and a wide mix of sizes.
Shape: Generally sub rounded with a significant presence of platey cobbles, but no angular fine gravels as noted just downstream of Redcliff Creek.
Lithology: Igneous. Not as diverse as seen upstream, but not homogenous.

SAMPLE SITE CHARACTERISTICS: BLACKMOUNT SUBREACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 6 *Grid Reference:* 681796
Bar Type: Lateral bar.
Position on Bar: Downstream end, adjacent to riffle.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 64-90mm
D95 132mm
D84 108mm
D50 65mm
Mean 69.6mm
S.D. 37.2mm

GRAVEL BAR CONDITIONS
Packing Arrangement: Some imbrication, but somewhat localized. Significant winnowing. Overloose.
Shape: Platey to sub rounded.
Lithology: Igneous without much variation.

BLACKMOUNT-MANGAPIRI REACH

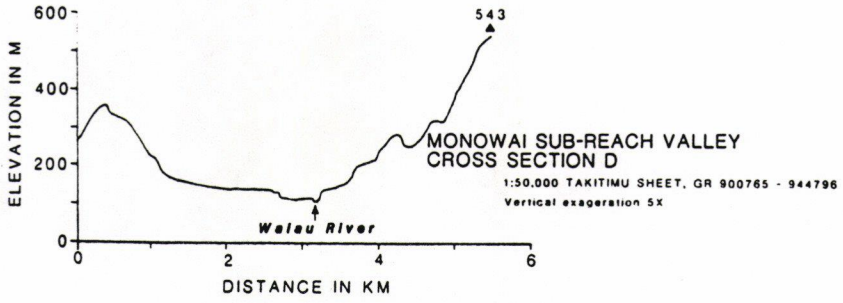
MONOWAI SUB-REACH

Details of Analysis

Geographic Location: 1km upstream of Borland Burn to immediately upstream of confluence with Waicoe Creek.
Map Sheet: Takitimu 1:50 000 *Grid Reference:* 903808-935764
Air Photos: 21/6/84: 608 #39,38,37,36,35
24/6/84: 613 #6,5,4,3,2
4/4/89: 787 #22,21
18/12/91: 960 #17,16
Date of Analysis: 20/3/92 *Analysts:* GB/SB

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

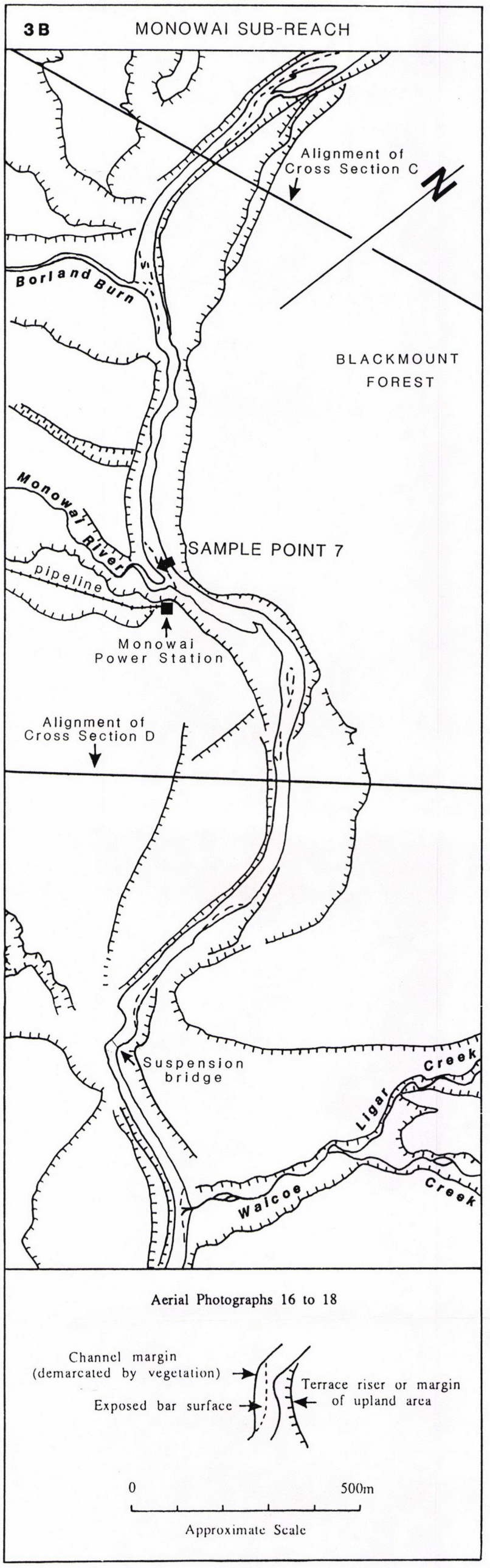


Valley Setting: Bedrock controlled valley.
Extent of Valley Flat: No valley flat present.
Extent of Alluvial Flats: None.
Degree and Character of Channel Constriction: Laterally constrained by bedrock, with an S-shaped hiatus at the suspension bridge (927767).
Terrace Character: Notably fragmentary, primarily restricted to inside of imposed bend below Monowai Power Station.
Left Bank: Inset bedrock terrace with fluvio glacial cap, c.20m high, restricted to inside of bend above Power Station.
Right Bank: Several tributaries enter Waiau across a moderately steep slope upstream of Power Station. Up to 5 stepped terraces around inside of bend downstream of Power Station, with side channels at base of terrace risers.

SURFICIAL GEOLOGY
Bedrock.

LAND USE
Not used except for power generation.

Air Photo Interpretation of Reach



CHANNEL CHARACTERISTICS: MONOWAI SUBREACH

PLANFORM GEOMETRY
Number of Channels: One main channel, with side channels at base of terrace risers.
Sinuosity: Imposed moderate sinuosity.
Channel Stability: Laterally stable.
Bar Type and Scale: Restricted within-channel sedimentation; lateral bars with side channels, non alternating and restricted to right bank immediately downstream of confluences.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: 40-50m
Ratio of Alluvial Flat Width to Channel Width: No alluvial flats.

BANK CHARACTER
Extent: Inset bedrock terrace, c.20m high, with fluvio glacial cap, located on left bank, just upstream of Power Station. Steep bedrock sides at suspension bridge.
Materials: Fluvioglacial outwash materials. Bedrock; contorted mudstones.

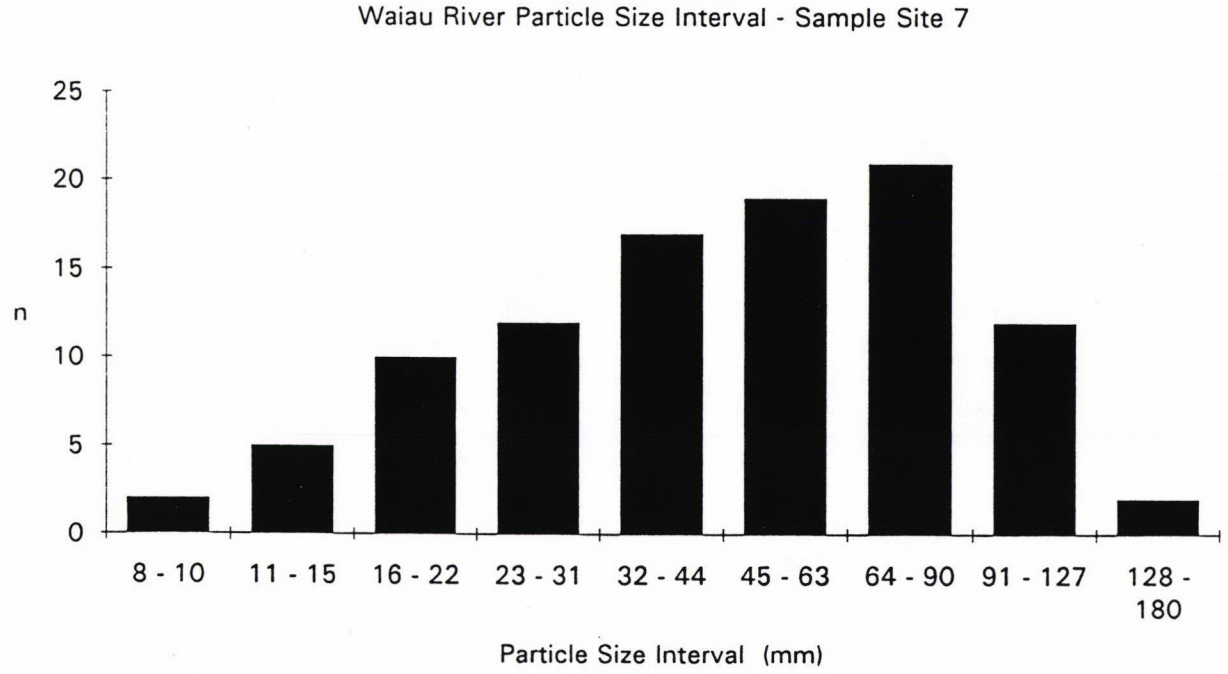
FLOW CHARACTER
Uniform, with a rapid in reach. Long riffles c.500m apart, affected by bedrock.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 7 *Grid Reference:* 914788
Bar Type: Side bar on outside of broad bend, upstream of Monowai confluence. Continuous with a riffle.
Position on Bar: Adjacent to main channel, oriented downstream.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 64-90mm
D95 119mm
D84 88mm
D50 48mm
Mean 55.1mm
S.D. 33.6mm

GRAVEL BAR CONDITIONS
Sorting: Very poor.
Packing Arrangement: Jumbled, partly imbricated, winnowed down to c.20mm. A distinct gravel pavement, possibly an armor.
Shape: Platey to sub rounded.
Lithology: Quite diverse. Occasional very coarse boulders, many with red algal growth, some broken off from adjacent sandstone units in bedrock.
Other Characteristics: At Monowai confluence is a lobe of coarse gravel: probably introduced rip-rap.

BLACKMOUNT-MANGAPIRI REACH

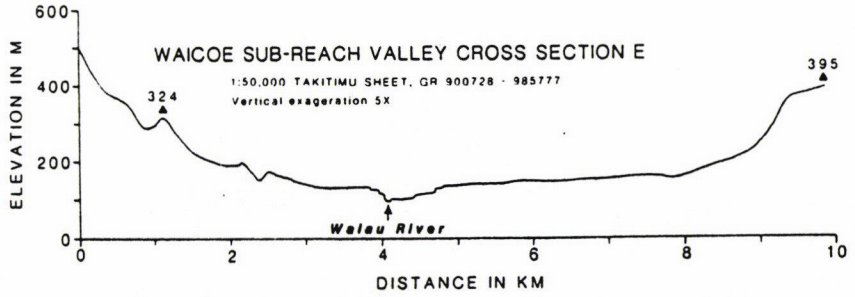
WAICOE SUB-REACH

Details of Analysis

Geographic Location: Confluence of Waicoe Creek to 1km downstream of confluence with Makarewa Stream.
Map Sheet: Takitimu 1:50 000 *Grid Reference:* 935764-949738
Air Photos: 21/6/84: 608 #35,34,33
4/4/89: 787 #21,20
18/12/91: 960 #16,15
Date of Analysis: 20/3/92 *Analysts:* GB/SB

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

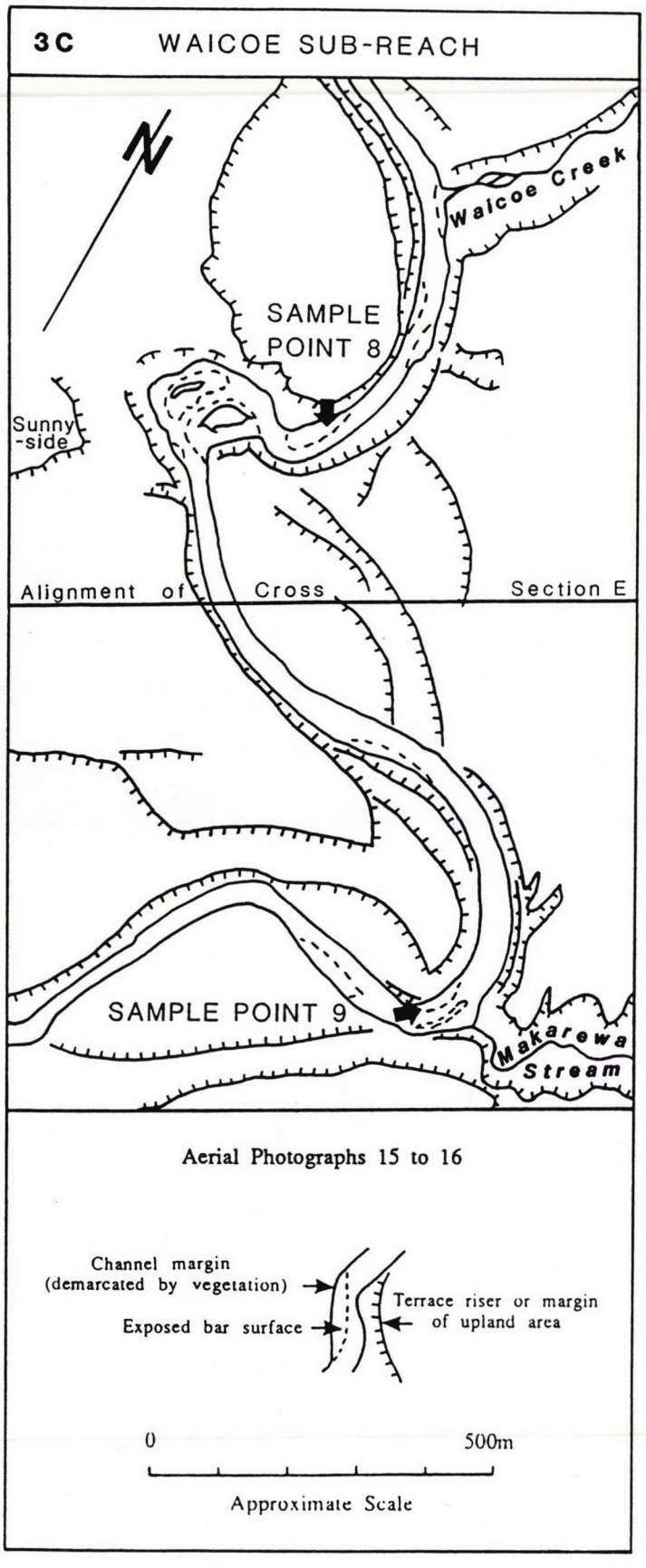


Valley Setting: Valley flats within foothills (discontinuous valley flats, associated with channel position on valley floor).
Extent of Valley Flat: Extensive (ie. several km wide) on insides of bends. Valley flats observed at upstream end of reach on left side (c.2m above channel with flat vegetated surface) may indicate within-reach degradation. Downstream of compound point bar (932753), lowest terrace on left side is only a few meters above present river level (ie. it is almost part of the alluvial flats). If this reach is degraded (as indicated by equivalent surface at upstream end of reach), then this surface may well have been inundated (ie. active) in the recent past.
Extent of Alluvial Flats: Synonymous with lowest terrace of valley flats.
Degree and Character of Channel Constriction: Meander configuration is imposed. Bedrock noted at outside of bend at Sunnyside.
Terrace Character: Upper terrace, set well back from the river channel, is distinctly less prominent than it was North of Blackmount.
Left Bank: Terrace becomes narrower down the reach.
Right Bank: Three stepped terraces.

SURFICIAL GEOLOGY
Banks vary from bedrock (mudstone) to fluvioglacial material.

LAND USE
Terraces are grazed pasture, otherwise none.

Air Photo Interpretation of Reach



CHANNEL CHARACTERISTICS: WAICOE SUBREACH

PLANFORM GEOMETRY

Number of Channels: Single channel prevails, with occasional division around dissected bars in bends.

Sinuosity: Imposed moderately tight bends.

Channel Stability: Banks appear relatively stable, but there is some potential for lateral shifting on bar surfaces (indicated by active channel surfaces on the compound point bar where flow divides around the vegetated island within the bend).

Bar Type and Scale: Point bar at 935754 (sample location Waiau 8), is very tight with distinct secondary circulation cell downstream. Max. bar width today (gates open) c.80m at bend apex. Bar has an imposed configuration associated with the bedrock step and fluvioglacial outwash terrace at outside of bend (bedrock c.2m above flow). Compound bar at 932753 has greater active channel gravels than elsewhere. Bedrock bar at downstream limit of reach, immediately downstream of confluence with Makarewa Stream. At this confluence are a mid- channel diagonal bar, and point bar on right bank. The point bar has distinct gravel locales including diffuse gravel sheets and chute channel features. Max. bar width today c.40m at apex. Another gravel bar on right side (a lateral bar at 943746) is part of a giant riffle composed largely of locally reworked boulders (probably from the adjacent terrace). Opposite this gravel bar the terrace is eroding as evidenced by exposure.

EXTENT AND CHARACTER OF ALLUVIAL FLATS

Channel Width: 35-40m upstream of the compound bar. 40-50m at downstream limit of reach.

Ratio of Alluvial Flat Width to Channel Width: Discontinuous flats (5:1 in bends).

BANK CHARACTER

Extent: Bedrock constrained with bars in bends. Banks 2-5m high.

Materials: Mudstone interbedded with sandstone; outwash materials and lower stepped alluvial flats.

FLOW CHARACTER

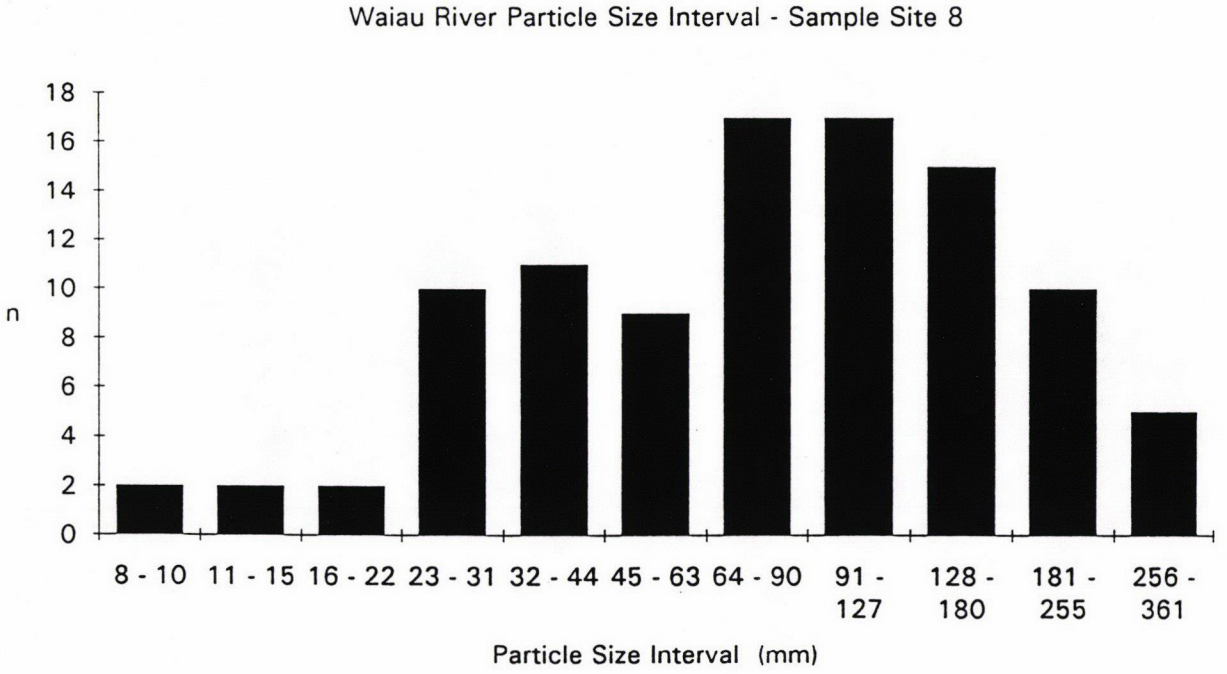
Upstream of compound bar, flow is uniform with a rapid with caps along the outside (left) bank and distinct secondary circulation cells in tight bends. Further downstream, flow is unsteady with massive riffles, c.200m apart adjacent to Makarewa confluence. Within-reach variation is probably explained by variation in slope associated with bedrock bar at downstream reach limit.

SAMPLE SITE CHARACTERISTICS: WAICOE SUBREACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 8 *Grid Reference:* 935754
Bar Type: Distinct point bar in bedrock constrained bend.
Position on Bar: Outside edge at bar head, adjacent to main channel.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 64-90; 91-127mm
D95 250mm
D84 174mm
D50 84mm
Mean 139mm
S.D. 66.0mm

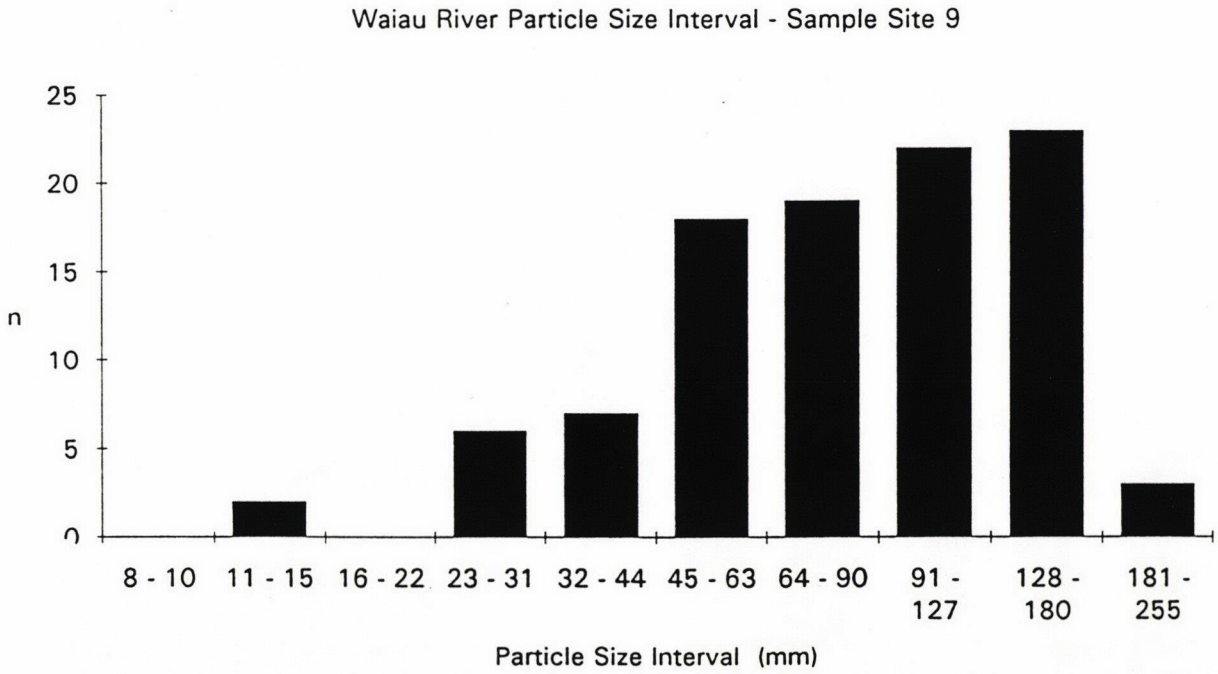
GRAVEL BAR CONDITIONS
Sorting: Largely unsorted.
Packing Arrangement: Particles occasionally imbricated, poorly packed, overloose, jumbled.
Shape: Platey to sub rounded.
Lithology: Moderately diverse.
Other Characteristics: Fines were found between larger particles and deposition of fines on the bar indicates a secondary flow cell during times of flood.

SAMPLE SITE CHARACTERISTICS: WAICOE SUBREACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 9 *Grid Reference:* 949739
Bar Type: Lateral/ point bar at Makarewa confluence.
Position on Bar: Sample taken in downstream end of chute channel.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 128-180mm
D95 170mm
D84 147mm
D50 83mm
Mean 114mm
S.D. 70.6mm

GRAVEL BAR CONDITIONS
Sorting: Very poor.
Packing Arrangement: Selectively winnowed;basal platform scoured in chute channel.
Shape: Sub rounded with occasional platey.
Lithology: Moderately diverse.
Other Characteristics: Chute channel at tail of bar has incised into supra platform and chute bar appears to be eroding at head and elongating round the downstream bend. This is the first site where active erosion has been noted on the inside of a bend.

BLACKMOUNT-MANGAPIRI REACH

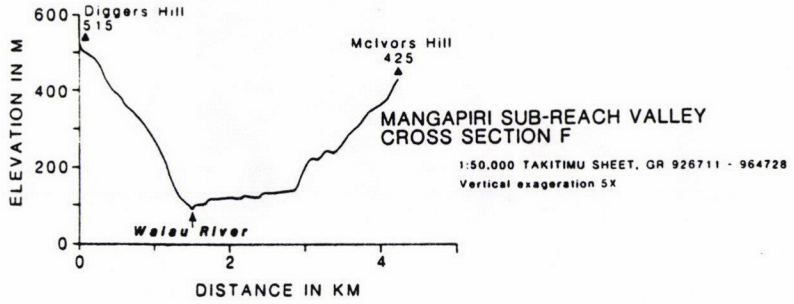
MANGAPIRI SUB-REACH

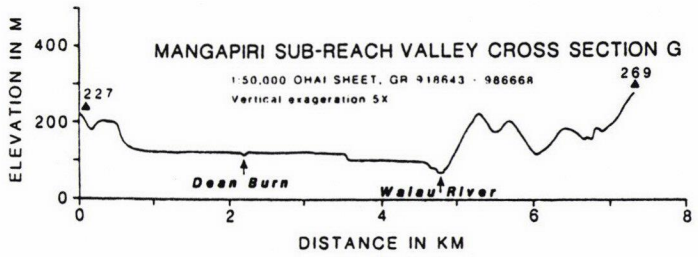
Details of Analysis

Geographic Location: From just downstream of Makarewa confluence to the large bend 2.5km upstream of Wairaki confluence.
Map Sheet: Takitimu 1:50 000 *Grid Reference:* 949738
TO *Map Sheet:* Ohai 1:50 000 *Grid Reference:* 977645
Air Photos: 21/6/84: 608 #33,32,31,30,29,28,27,26
4/4/89: 787 #20,19,18,17
18/12/91: 960 #15,14,13,12
Dates of Analysis: 20/3/92; 21/3/92 *Analysts:* GB/SB

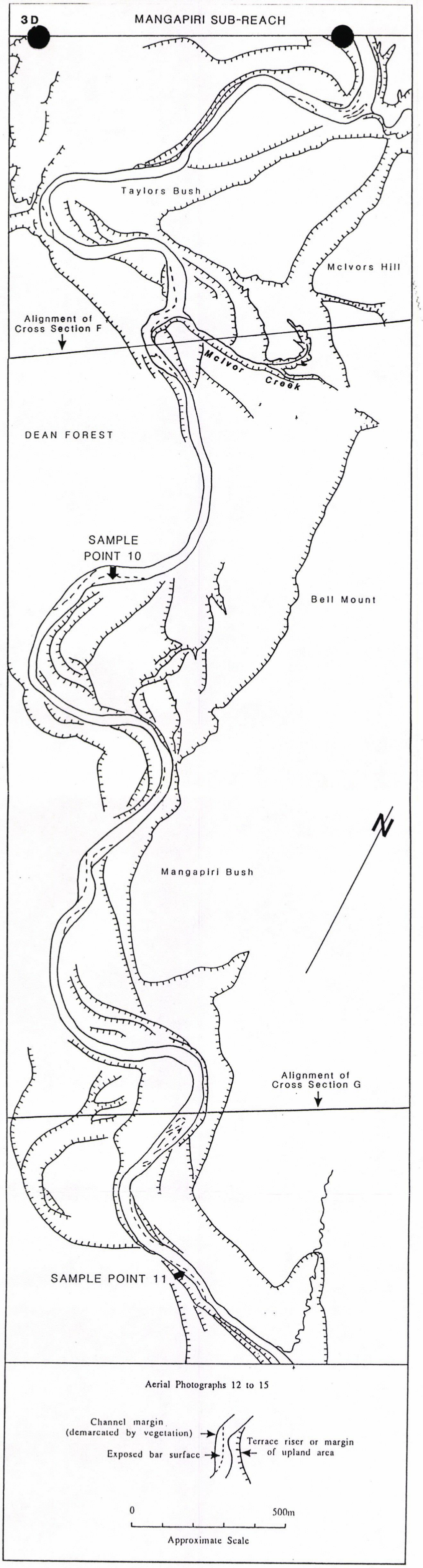
VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

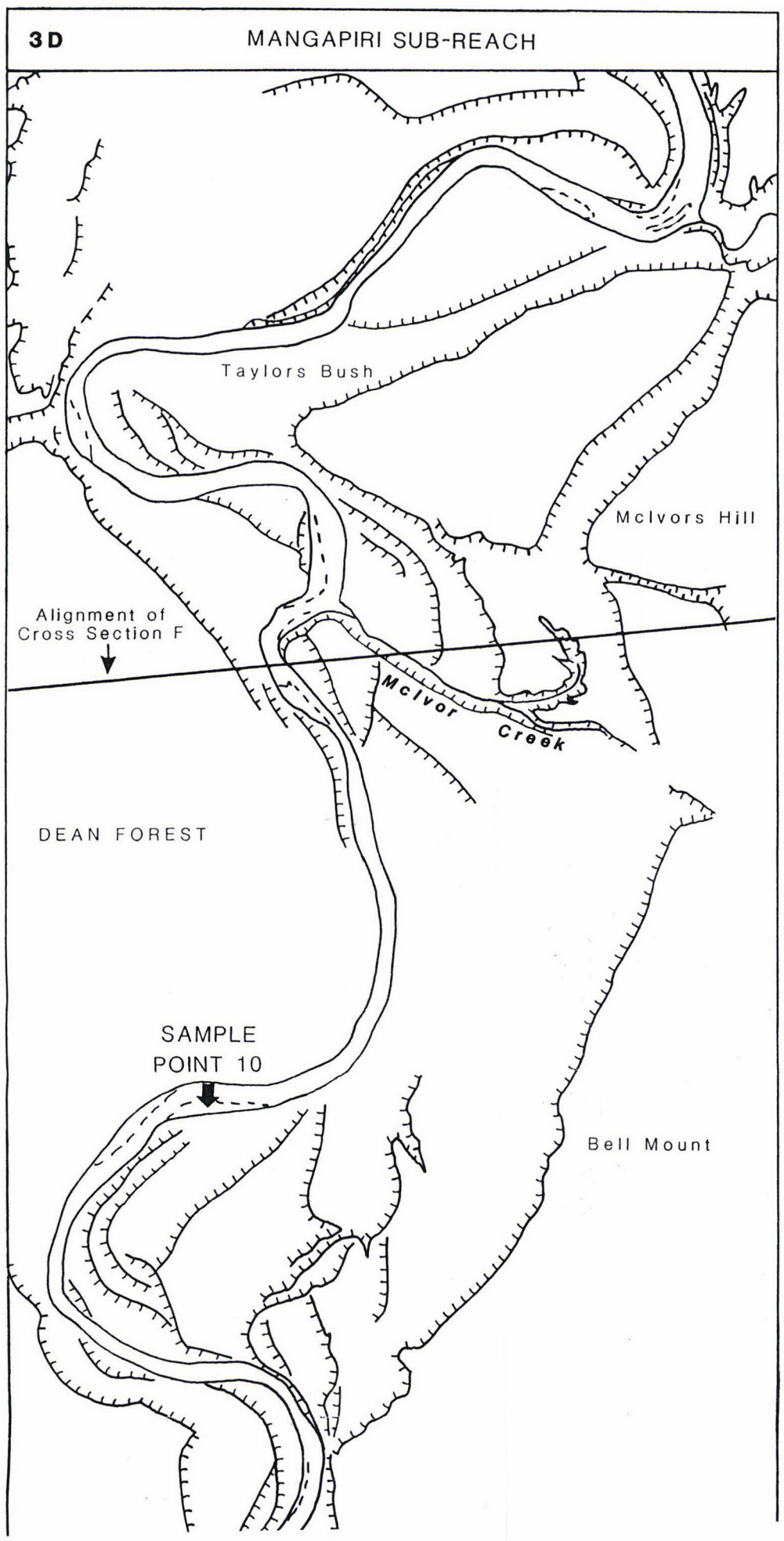


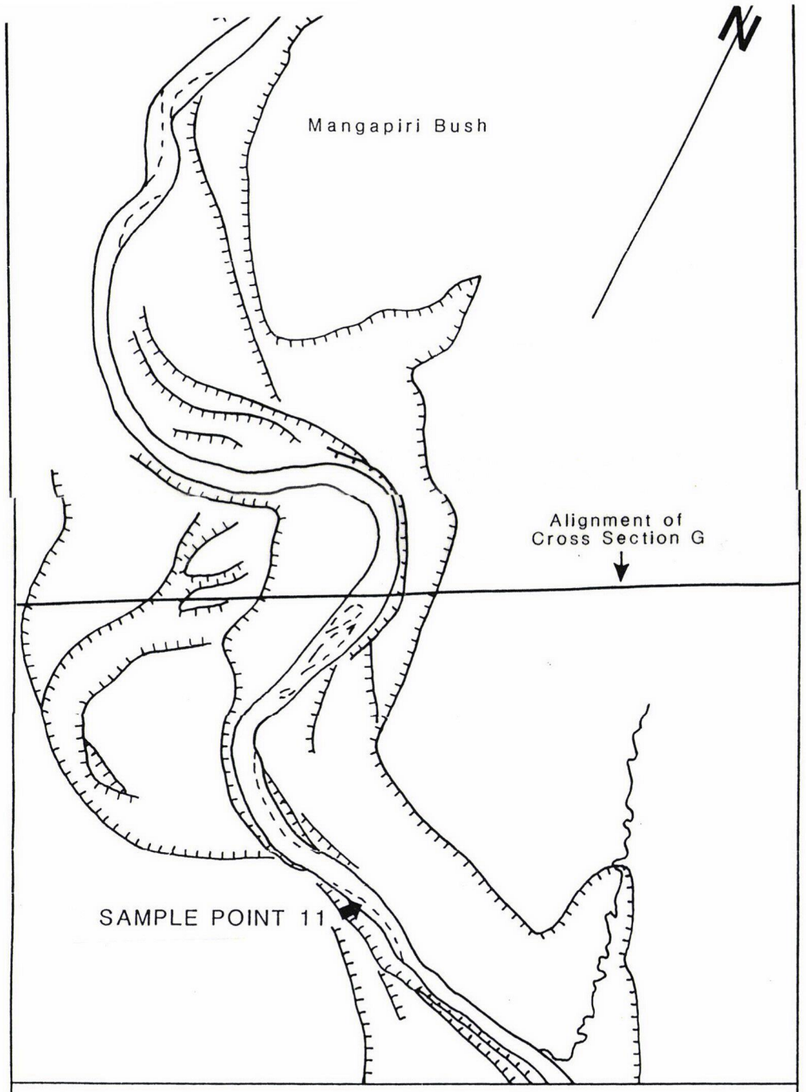


Valley Setting: Broad valley in a foothill setting; channel deeply incised down to bedrock.
Extent of Valley Flat: >4km.
Extent of Alluvial Flats: Non existent or fragmentary, restricted to areas tens of meters wide behind lateral bars, 1m or so above the contemporary channel.
Degree and Character of Channel Constriction: Laterally constained by bedrock.
Terrace Character:
Left Bank: 4-5 prominent terraces in upstream end. These are fragmentary downstream.
Right Bank: Two terraces at upstream end, of which only the lower is continuous with that (lower terrace) on the left bank. Further down the reach, up to 6 terraces are located on the insides of meander loops.

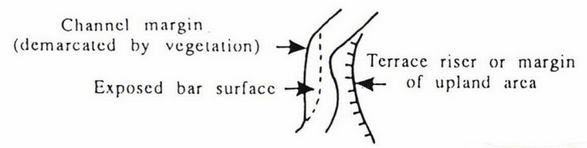

3D
MANGAPIRI SUB-REACH
Taylors Bush
McIvors Hill
Alignment of
Cross Section F
McIvor Creek
DEAN FOREST
SAMPLE
POINT 10
Bell Mount
N
Mangapiri Bush
Alignment of
Cross Section G
SAMPLE POINT 11
Aerial Photographs 12 to 15
Channel margin
(demarcated by vegetation)
Exposed bar surface
Terrace riser or margin
of upland area
0
500m
Approximate Scale

Air Photo Interpretation of Reach





Aerial Photographs 12 to 15



0 500m

Approximate Scale

SURFICIAL GEOLOGY
Bedrock with fluvio glacial terraces atop. Bedrock is mudstone interbedded with (harder) sandstone.

LAND USE
Pastoral where appropriate, otherwise bush.

CHANNEL CHARACTERISTICS: MANGAPIRI SUBREACH
Mangapiri subreach is characterized by an imposed single channel condition in which bedrock has imposed a broadly sinuous outline.

PLANFORM GEOMETRY
Number of Channels: Single channel, other than where side channels develop behind diagonal bars.
Sinuosity: Broadly sinuous.
Channel Stability: Bedrock confined reach, ie. stable. Lateral activity is constrained and channel merely becomes active over gravel surfaces in times of flood. Some evidence of valley-side slumping on left bank at 962655 (Mangapiri Bush).
Bar Type and Scale: Sedimentation is restricted to insides of bends or atop bedrock bars. A distinct bedrock ledge on the channel bottom is longitudinally discontinuous and acts as a local platform. Harder sandstone bands within the clayey mudstone act locally as bedrock bars which create a focal point for gravel accumulations, typically as diagonal bank-attached bars which appear as extensions to major riffles. The bar at 963656 is a point bar which is transitional to a large riffle with vegetated strips oriented down valley. This is the first within- channel sedimentation for some time and is transitional downstream to a sequence of alternating lateral bars, up to 50m wide at bar apex.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: 30-40m, within a valley bottom of 50-60m (gates open).
Ratio of Alluvial Flat Width to Channel Width: Alluvial flats non-existent or fragmentary; up to tens of metres wide.

BANK CHARACTER
Extent: Left bank has an 150m long erosive exposure into bedrock, with fluvioglacial outwash atop. The terrace is c.40m high with c.8m outwash at the upstream end and c.30m outwash at the downstream end (ie. steeply inclined contact downstream). Bedrock is highly friable mudstone, steeply dipping downstream, and no sandstone bands evident.
Materials: Bedrock with fluvio glacial material atop.

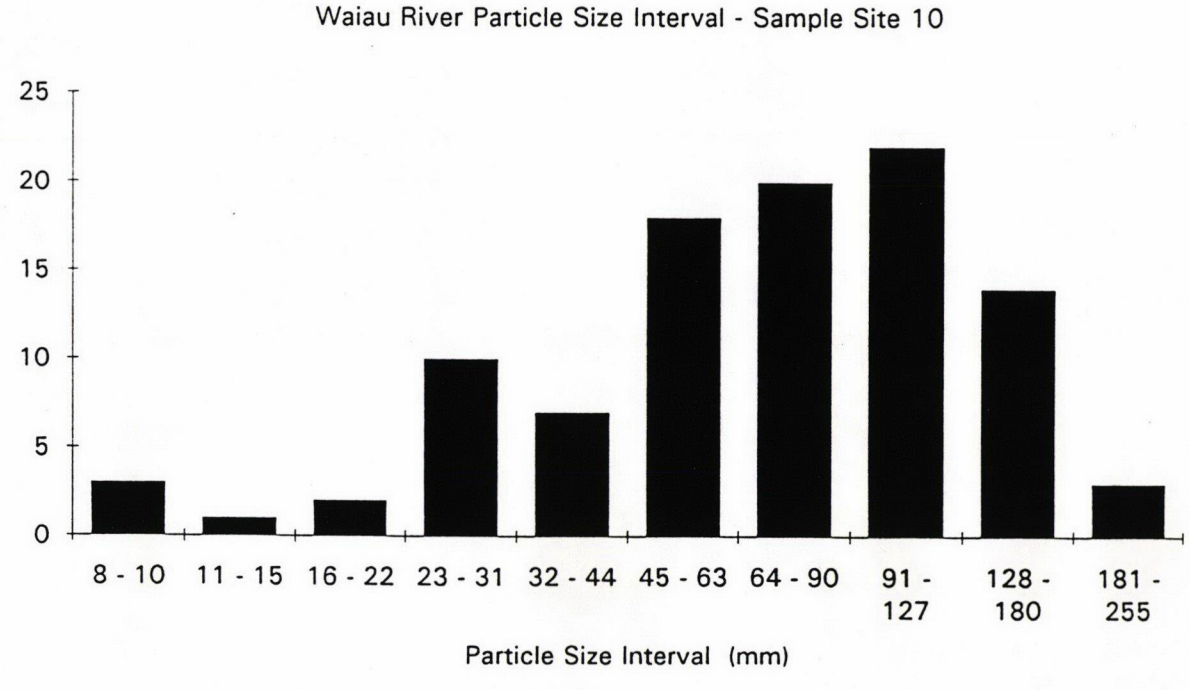
FLOW CHARACTER
Uniform with widely and irregularly spaced riffles (>500m apart), associated with bedrock bar distribution. As a confined reach, flow is highly efficient with high competence leading to transport of coarse gravels and flushing through of finer particles. Competence to transport coarse gravels is evidenced by their presence in this reach, where they cannot possibly have come from the bedrock banks but must have been imported by the river

SAMPLE SITE CHARACTERISTICS: MANGAPIRI SUBREACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 10 *Grid Reference:* 943698
Bar Type: Bank-attached diagonal bar contiguous with riffle. Gravels are just one particle layer thick, resting on the friable mudstone bedrock which breaks down to clay (known locally as papa bedrock).
Position on Bar: At bar head between main channel and side channel.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 163mm
D84 132mm
D50 73mm
Mean 82.5mm
S.D. 48.4mm

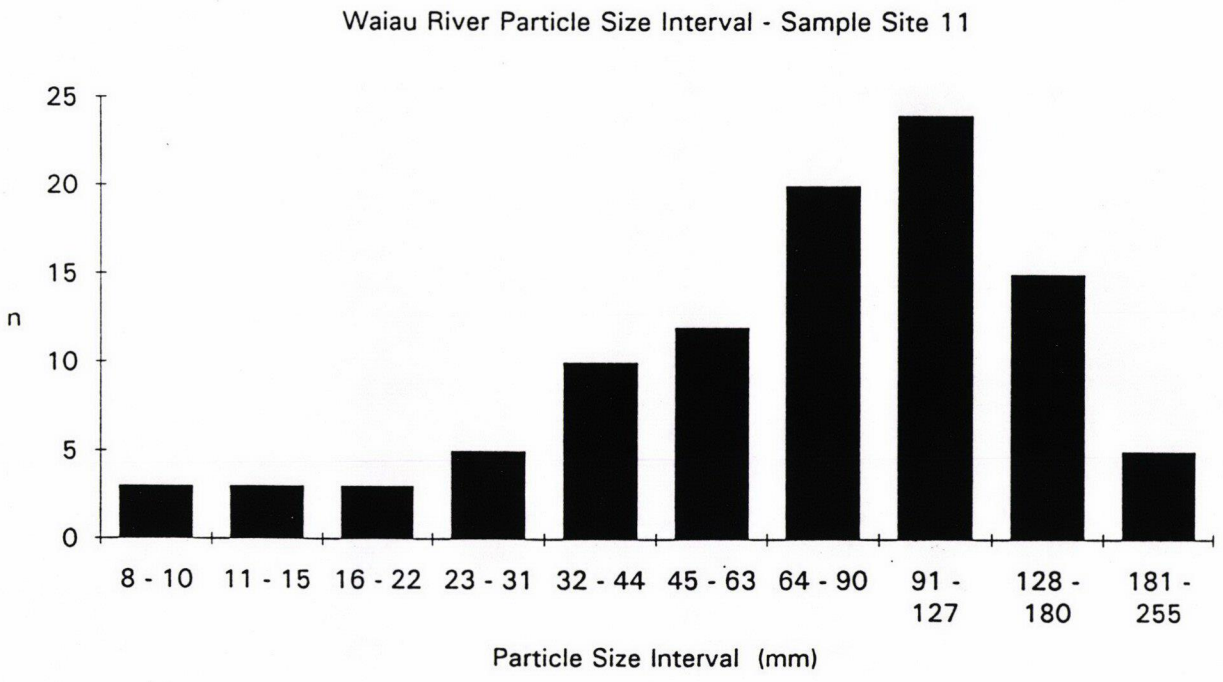
GRAVEL BAR CONDITIONS
Packing Arrangement: Jumbled, overloose but slightly imbricated. Gravels just one particle layer thick, resting on friable mudstone bedrock which breaks down to clay.
Shape: Subrounded with very few platey.
Lithology: Diverse.

SAMPLE SITE CHARACTERISTICS: MANGAPIRI SUBREACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 11 *Grid Reference:* 967649
Bar Type: Lateral bar continuous with riffle.
Position on Bar: Upstream end, parallel with river.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 180mm
D84 136mm
D50 84mm
Mean 86.4mm
S.D. 49.2mm

GRAVEL BAR CONDITIONS
Packing Arrangement: Locally imbricated and less jumbled. Many gravels still overloose. Not a densely packed bar, indicating an active bar surface.
Shape: Subrounded to platey.
Lithology: Moderately diverse (granitic/volcanic dominance, limited metamorphic).

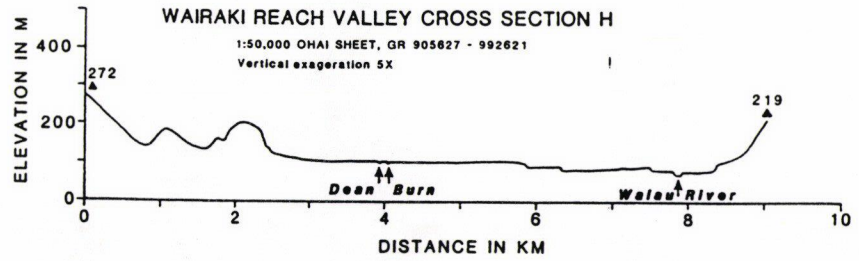
WAIRAKI REACH

Details of Analysis

Geographic location: Extends from the head of a large point bar 2.5km upstream of Wairaki confluence to a straight single-channelled reach 1.5km beyond Broadlands Bush.
Map Sheet: Ohai 1:50 000 *Grid Reference:* 977645-973579
Air Photos: 21/6/84: 608 #26,25,24,23,22
4/4/89: 787 #17,16,15
18/12/91: 960 #12,11,10
Date of Analysis: 22/3/92 *Analysts:* GB/GL

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

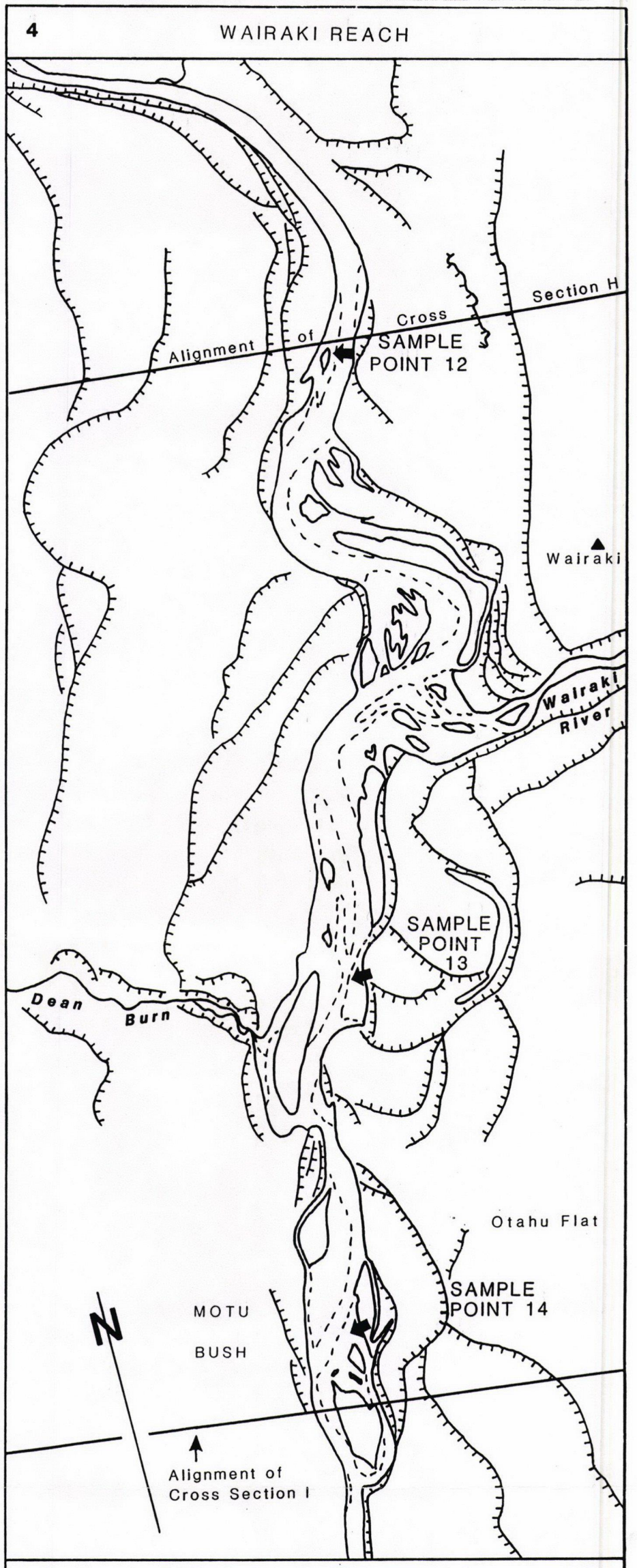


Valley Setting: Exceptionally wide valley, in foothills at head of Otahu Flat. This reach is characterized by complex patterns of alluvial flats and within-channel sedimentation. A classic wandering gravel-bed reach.
Extent of Valley Flat: Fragmentary and highly localized; width c.1km at the Wairaki confluence.
Extent of Alluvial Flats: Several hundred metres wide; complex and fragmentary, switching from valley side to valley side.
Degree and Character of Channel Constriction: Flow constrained by outwash terrace at upstream end, and bedrock bluffs upstream of Wairaki confluence. At downstream end of reach, channel becomes confined by bedrock. Reach is separated by a bedrock constriction at 974596, otherwise fluvioglacial deposits and alluvial flats predominate.
Terrace Character: Lowest terrace (c.10m high) is extensive on both sides of channel, with a series of fragmentary terraces (up to 4) above it. At downstream end of reach, left bank comprises >3 terraces while the right bank has a bedrock step with alluvial flats behind, then a major terrace c.40m high which extends back to the valley side.

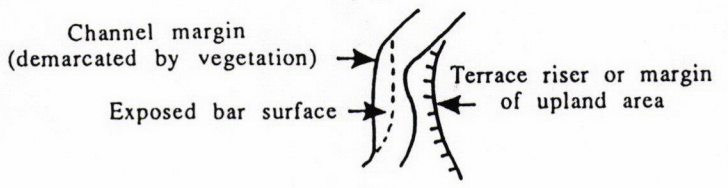
SURFICIAL GEOLOGY
Bedrock and fluvioglacial material.

LAND USE
Pastoral (low grade pasture on alluvial flats, but subject to flooding).

Air Photo Interpretation of Reach



Aerial Photographs 10 to 12



CHANNEL CHARACTERISTICS: WAIRAKI REACH

PLANFORM GEOMETRY

Number of Channels: Single channelled at upstream and downstream limits of reach, but multi channelled with >3 active channels adjacent to Wairaki confluence.

Sinuosity: In the multi channelled subreach, the channels themselves are broadly sinuous and highly variable in cross sectional geometry and scale. Further downstream the channel meanders.

Channel Stability: Channel is laterally unstable. Channel condition is induced by vast input of fist-sized gravels from the Wairaki, impacting on channel capacity.

Bar Type and Scale: At the upstream end of the reach is a point bar of intermediate curvature. This is separated from the adjacent 2m high alluvial flats by a chute channel. An elevated vegetated area separates the chute channel from the bar. Point bar gravels appear to be an active mobile sheet and there is some evidence for downstream translation and lateral expansion of the bar. On the opposite (left) bank is a lateral bar, possibly supplied with gravels from an eroding outwash terrace immediately upstream. At the Wairaki confluence, the extent of active gravel surface is greater than anywhere upstream as outwash terraces and bedrock are much further apart (valley flat up to 1km wide within 10m terraces). Extensive alluvial flats have developed just 2m above contemporary flow elevation. These commonly have a c.50cm thick silt/ sand cap. Bars are compound features which demonstrate considerable reworking by smaller chute channels.

Beyond Broadlands Bush there are two large bank-attached bars, with active gravel surfaces separated into numerous morpho-stratigraphical units. Left bank has a gravel bar with c.3m sand/ silt atop, c.100m wide. Right bank has a compound bar with island, chute channel, grassed area and side channel. Many logs have been washed onto the bar surface.

EXTENT AND CHARACTER OF ALLUVIAL FLATS

Channel Width: 40m at upstream sample location. At middle location, largest channel is c.40m wide, with other channels up to 20-30m wide.

Ratio of Alluvial Flat Width to Channel Width: Alluvial flat adjacent to upstream sampling site is c.200m wide at its apex. Opposite the sample site is a lateral infill bar, with prominent alluvial flats several hundred meters wide. Alluvial flat next to middle location is <1km wide. Ratio 5:1.

BANK CHARACTER

Extent: Bedrock constrictions are discontinuous, with a 10m high terrace forming the bank throughout most of the reach.

Materials: Bedrock with fluvioglacial deposits (both terraces and alluvial flats).

FLOW CHARACTER

At upstream limit, flow is uniform with no riffles evident. Just downstream of the confluence, most flow is adjacent to the left bank, characteristic of a wandering rather than a braided river. A large number of riffles spaced 400-500m apart indicate a relatively steep slope. Further downstream, flow is confined to

a single meandering course, but at higher flow rates several channels are occupied

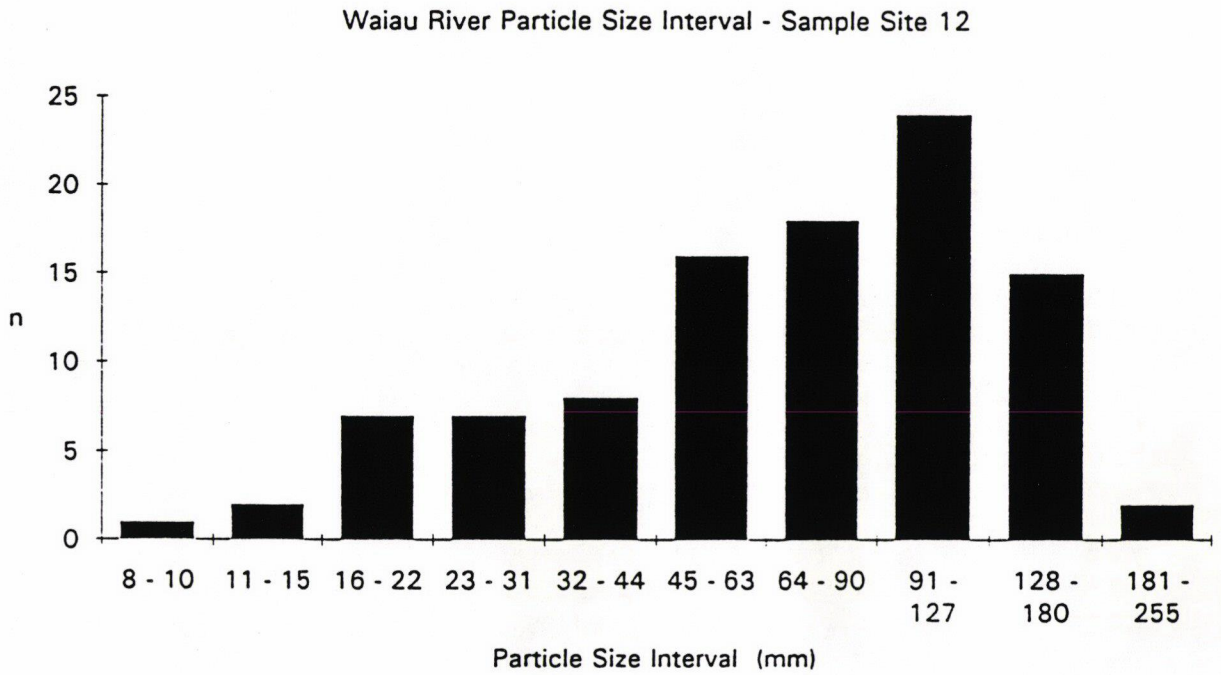
SAMPLE SITE CHARACTERISTICS: WAIRAKI REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 12 *Grid Reference:* 983633
Bar Type: Point bar on inside of a broad bend. Large chute channel evident.
Position on Bar: Upstream end, parallel with main flow.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS

Histogram



Modal grain size class: 91-127mm
D95 159mm
D84 133mm
D50 74mm
Mean 81.1mm
S.D. 45.7mm

GRAVEL BAR CONDITIONS

Sorting: Moderately sorted.
Packing Arrangement: Partly imbricated, loosely packed, jumbled, highly mobile gravels.
Shape: Platey to subrounded.
Lithology: Diverse.

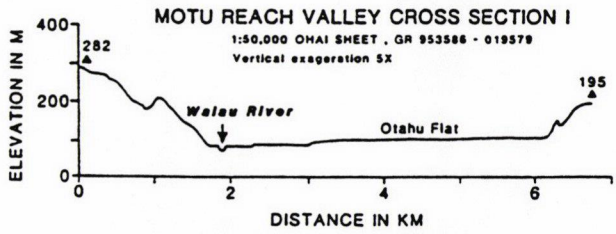
MOTU REACH

Details of Analysis

Geographic location: Extends from 1km beyond Broadlands Bush for 2.4km, to a point adjacent to the down-valley limit of Motu Bush.
Map Sheet: Ohai 1:50 000 *Grid Reference:* 973579-977557
Air Photos: 21/6/84: 608 #22,21
4/4/89: 787 #15,14
18/12/91: 960 #10,9
Date of Analysis: 24/3/92 *Analysts:* GB/CT

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section



Valley Setting: Just upstream of lowland plain; Motu Bush on right bank, Otahu flats on left bank, with ridge behind.
Extent of Valley Flat: 4.5km.
Extent of Alluvial Flats: None evident.
Degree and Character of Channel Constriction: Laterally constrained by small fragmentary outwash terrace on right bank at confluence with a small tributary. Terrace has bedrock behind. Sandy mudstone bedrock is exposed on right bank at downstream end of reach.
Terrace Character: Terraces are unpaired with little evidence of contemporary erosion. Left bank has a prominent flight of <6 terraces (Otahu flat). Right bank has a small fragmentary outwash terrace c.8m high and <20m wide, with bedrock behind. Bedrock dominates right bank.

SURFICIAL GEOLOGY
Outwash gravels are dominant.
Exposure of sandy mudstone at downstream end of reach.

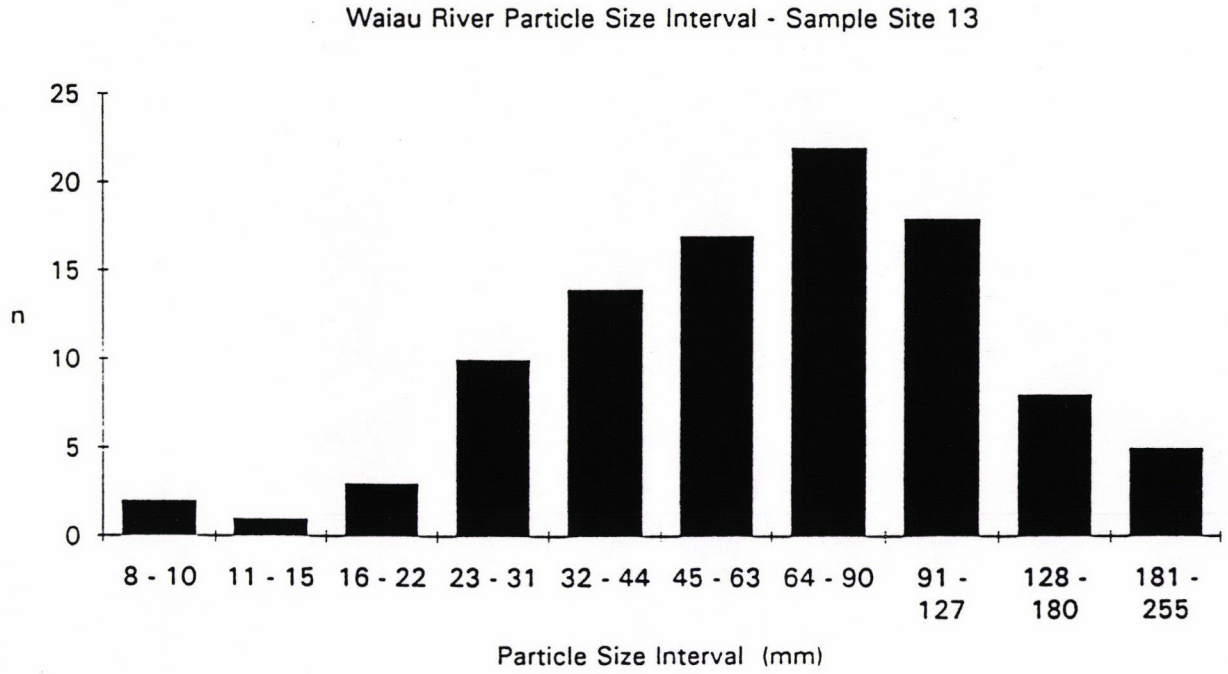
LAND USE
Pastoral.

SAMPLE SITE CHARACTERISTICS: WAIRAKI REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 13 *Grid Reference:* 977606
Bar Type: Side bar (surface appears as scoured bed feature).
Position on Bar: Parallel to main channel flow.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 64-90mm
D95 166mm
D84 116mm
D50 69mm
Mean 77.1mm
S.D. 48.8mm

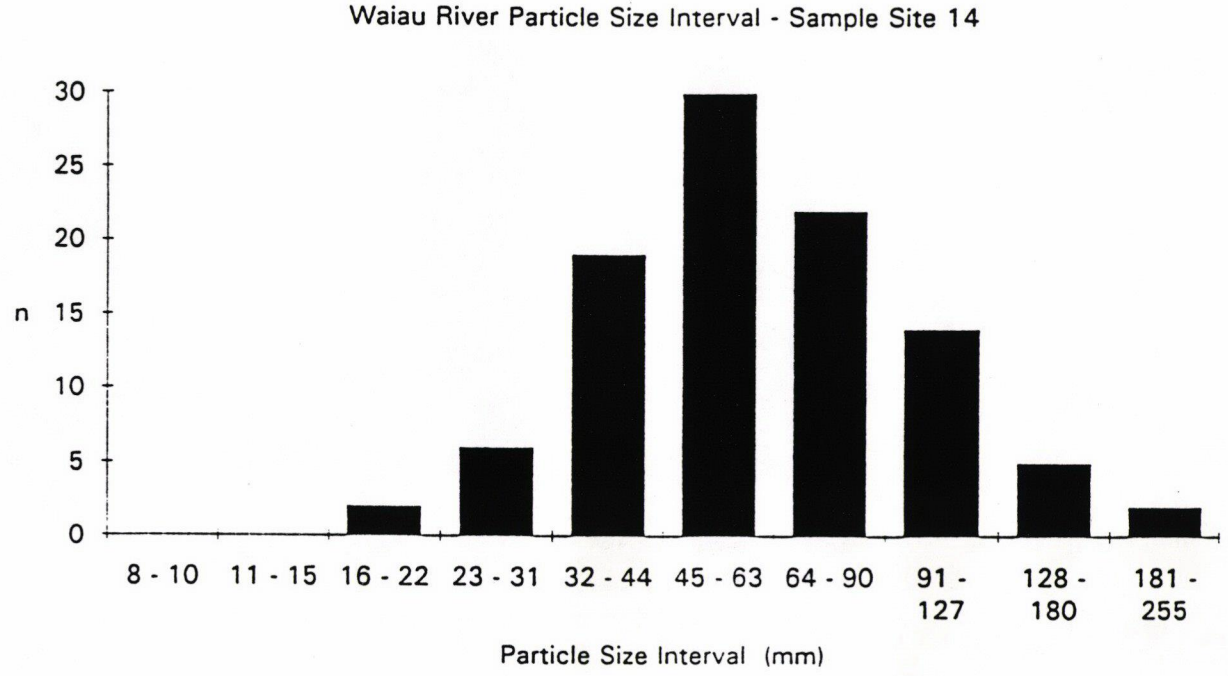
GRAVEL BAR CONDITIONS
Sorting: Moderately sorted. Not winnowed.
Packing Arrangement: Loosely packed (ie. mobile gravel surface). Minimal imbrication.
Shape: Platey to subrounded.
Lithology: Moderate range: largely igneous with a lesser percentage of plutonics (Fiordland complex) and few metamorphics.
Other Characteristics: There is a diffuse gravel sheet of fist sized gravels on this bar. Note scour in adjacent side channel. Bedrock constrained "arcuate" bar feature.

SAMPLE SITE CHARACTERISTICS: WAIRAKI REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 14 *Grid Reference:* 973587
Bar Type: Bank attached compound bar.
Position on Bar: Along chute channel.
Sample Type: 1x100

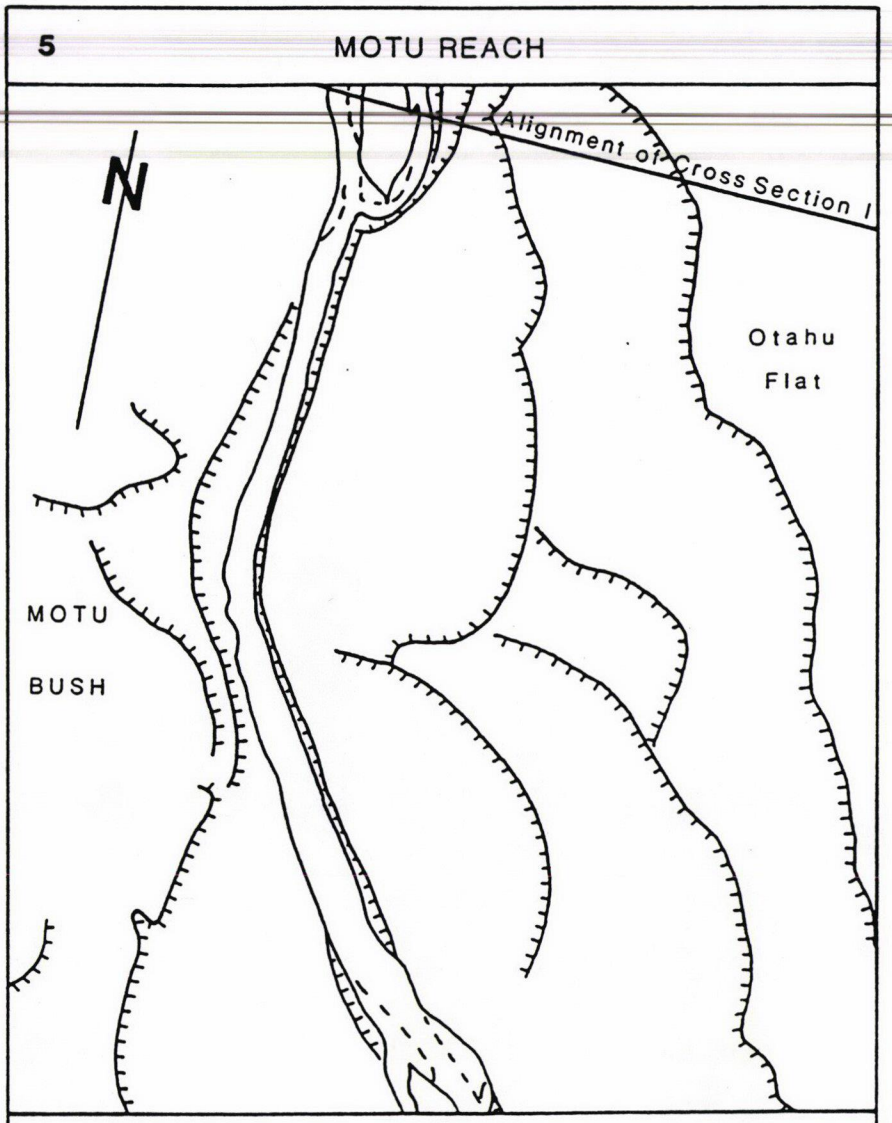
PARTICLE CHARACTERISTICS
Histogram



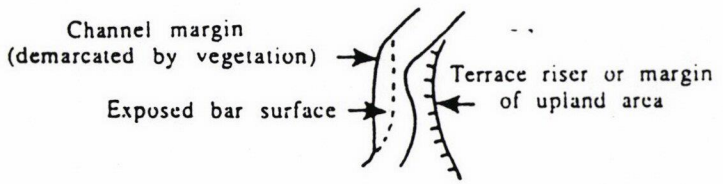
Modal grain size class: 45-63mm
D95 138mm
D84 104mm
D50 57mm
Mean 68.5mm
S.D. 36.0mm

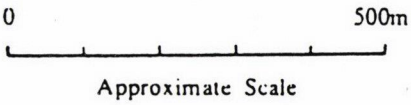
GRAVEL BAR CONDITION
Sorting: Poorly sorted cobbles.
Packing Arrangement: No evident paving, negligible imbrication (although this is evident adjacent to the main channel).
Shape: Platey to subrounded.
Lithology: Diverse.

Air Photo Interpretation of Reach



Aerial Photographs 9 to 10





CHANNEL CHARACTERISTICS: MOTU REACH

PLANFORM GEOMETRY
Number of Channels: 1
Sinuosity: Fairly straight.
Channel Stability: Stable.
Bar Type and Scale: No active gravel surfaces.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: 30-40m.
Ratio of Alluvial Flat Width to Channel Width: No alluvial flat.

BANK CHARACTER
Extent: Left bank a shallow terrace of outwash materials 3-4m high. Bedrock constrained right bank.
Materials: Fluvioglacial (left bank) and bedrock (right bank). Sandy mudstone bedrock evident in both banks at downstream end of reach.

FLOW CHARACTER
Shooting flow with boils.

SAMPLE SITE CHARACTERISTICS
No active gravel bars in this reach: gravels are flushed through.

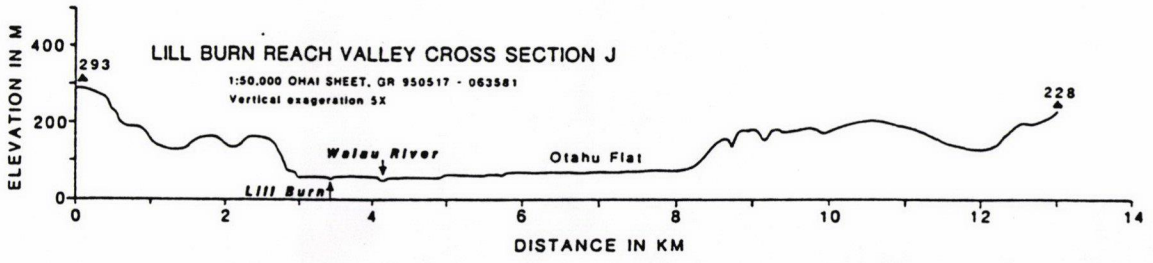
LILL BURN REACH

Details of Analysis

Geographic Location: From downstream end of Motu Bush to just upstream of Clifden suspension bridge.
Map Sheet: Ohai 1:50 000 *Grid Reference:* 977557-009511
Air Photos: 21/6/84: 608 #21,20,19,18,17
4/4/89: 787 #14,13
18/12/91: 960 #9,8
Date of Analysis: 24/3/92 *Analysts:* GB/CT

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

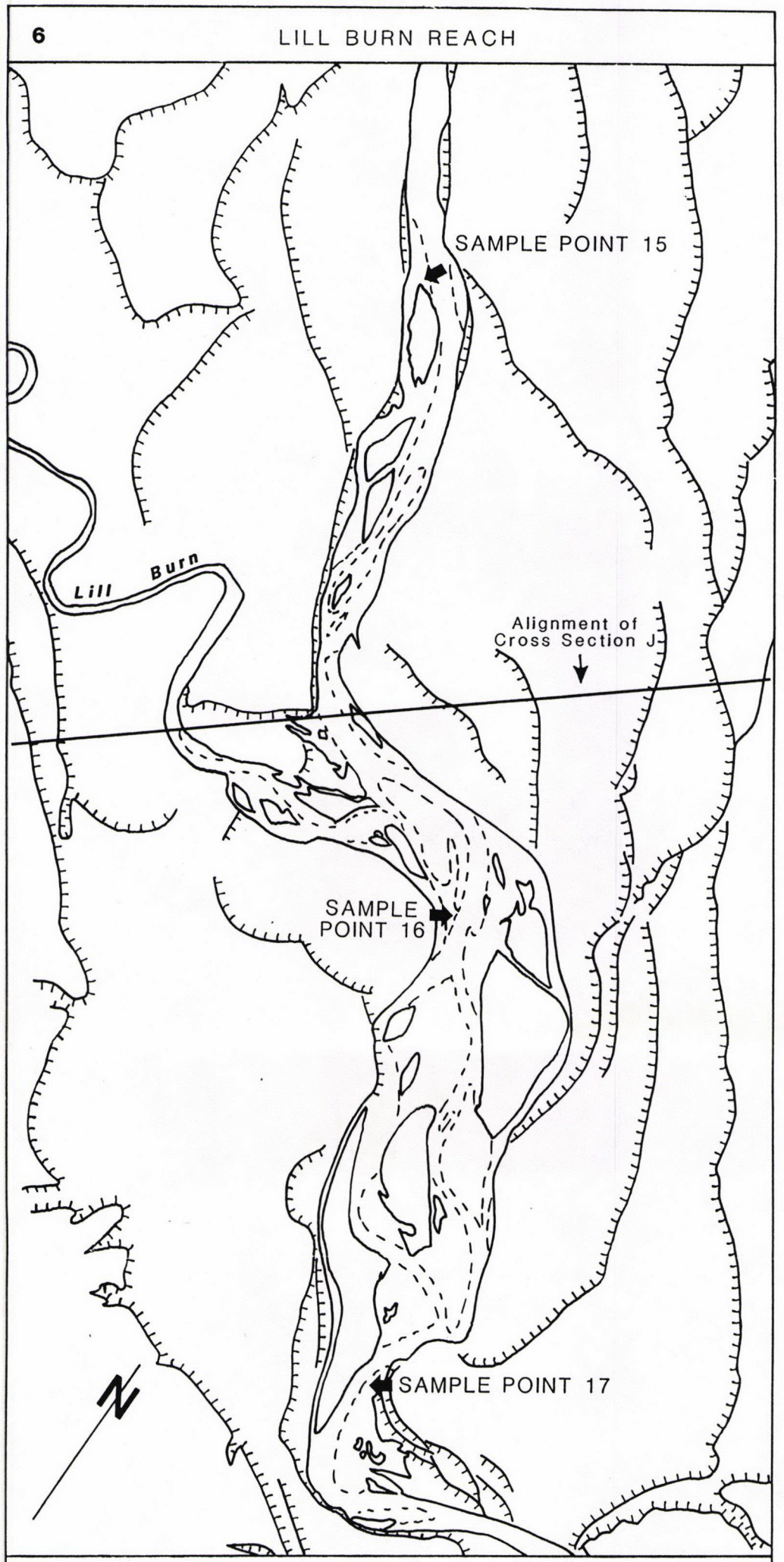


Valley Setting: Wide lowland adjacent to rolling foothills.
Extent of Valley Flat: Up to 6km wide at Lill Burn confluence.
Extent of Alluvial Flats: Many hundreds of metres wide.
Degree and Character of Channel Constriction: Not constrained; has great propensity to shift location.
Terrace Character: Unpaired and non eroding (most have already been removed).
Right Bank: Fragmentary alluvial flat (presently pasture) only a few metres above river. Dominant terrace is c.4.5m above river at Lill Burn confluence; expansive and continuous, has many braidplain style channels on its surface. Width c.1km. There is also a remnant fragmentary terrace c.5m above the dominant terrace, but the Lill Burn may have reworked any upper terrace sequences on this bank.
Left Bank: Equivalent terrace to dominant unit on right, with two prominent terraces above. The first of these is c.10m above lower terrace and even wider than it. Uppermost terrace is fragmentary; appears as a ridge unit on map.

SURFICIAL GEOLOGY
Bedrock observed on left bank at downstream limit only. Outwash materials abundant.

LAND USE
Pastoral with occasional gravel pits.

Air Photo Interpretation of Reach



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CHANNEL CHARACTERISTICS: LILL BURN REACH

PLANFORM GEOMETRY

Number of Channels: Single channel at upstream end, with a chute channel to relieve higher flows and a side channel behind recent gravel accumulations. Adjacent to Lill Burn, river is multi channelled with <4 channels of various magnitudes. At downstream end, flow is again restricted to one primary channel, although several mid channel bars still occur (possibly related to the highly sediment charged nature of flow).

Sinuosity: Broadly sinuous, with a tighter, bedrock-controlled bend at downstream limit.

Channel Stability: Relatively stable at upstream end, with predominant movement being downstream. At confluence, reach is unstable, both laterally and downstream, although bends are not very tight (material is too mobile with not enough of it to form tight bends). Reach is only laterally stable at the very downstream end (immediately upstream of the Clifden bridges).

Bar Type and Scale: Transitional within-reach, from is bank-attached compound bars at the reach head to a variety of complex bar types at the Lill Burn confluence. These are largely dissected and reworked mid-channel compound bars. Downstream of Lill Burn, side channels are being abandoned and islands are becoming bank-attached, adjacent to bedrock.

EXTENT AND CHARACTER OF ALLUVIAL FLATS

Channel Width: 40-50m, with ability to expand over active gravel bars, between channel islands and over alluvial flats, which are only a couple of metres above the contemporary channel level. At the confluence, combined width of active channels is 80-100m.

Ratio of Alluvial Flat Width to Channel Width: Variable, but commonly >8:1. Total width of alluvial flats is c.150m at the upstream sampling site and c.800m at the downstream site, where alluvial flats are present on right bank only (flow is constrained by bedrock on left bank, at the point bar head). At Lill Burn confluence total width of flats is >1km, with active channel width combined of 80-100m. The alluvial flats here are very extensive with poorly defined banks and much evidence of channel adjustment on right bank at the confluence. An equivalent 2-3m high surface is also extensive on left side.

BANK CHARACTER

Extent: 2-3m high alluvial flats, with a continuous terrace c.4.5m high. At the confluence, banks comprise poorly defined gravel surfaces, locally <3m high.

Materials: Coarse gravels (alluvial flats), although sandy mudstone bedrock evident in both banks at head of reach, and on left bank at downstream limit. Much sand observed downstream of Lill Burn confluence.

FLOW CHARACTER

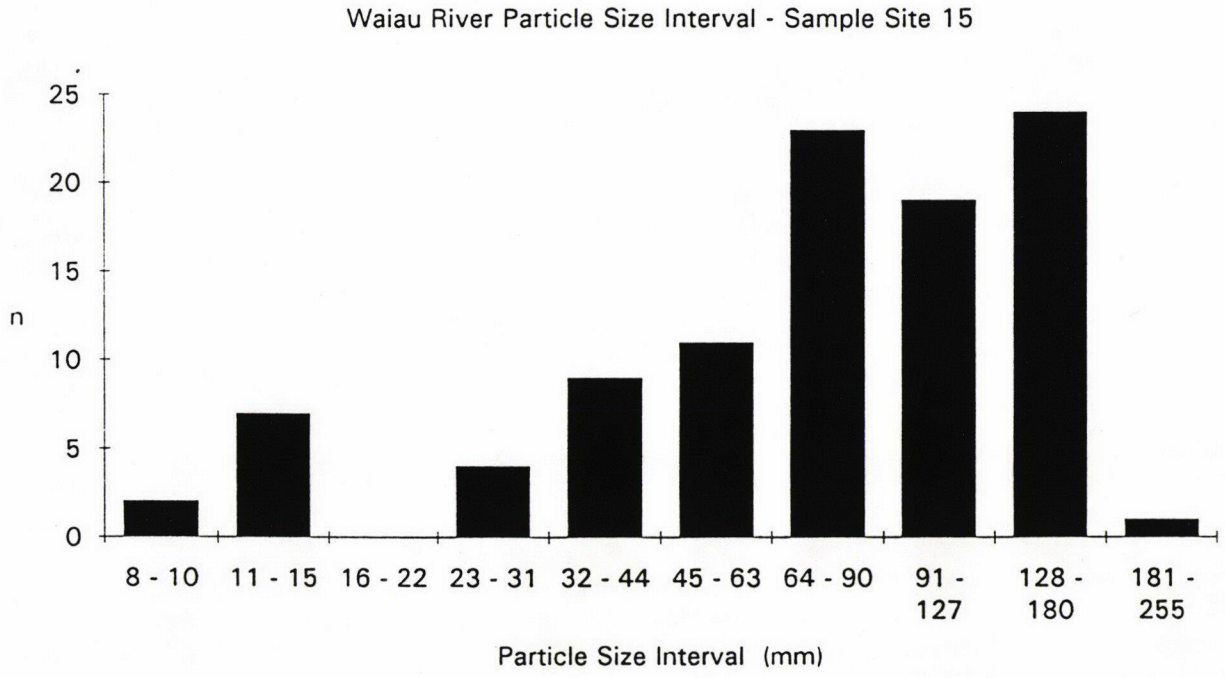
Uniform surface with occasional boils at upstream end. No riffles observed. Irregular riffled flow at confluence, concentrated into areas with a well defined thalweg. Uniform with riffles (c.800m apart) at downstream end.

SAMPLE SITE CHARACTERISTICS: LILL BURN REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 15 *Grid Reference:* 977555
Bar Type: Bank-attached compound bar within a broad bend.
Position on Bar: Upstream accretionary unit at waters edge.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 128-180mm
D95 167mm
D84 143mm
D50 84mm
Mean 88.9mm
S.D. 47.4mm

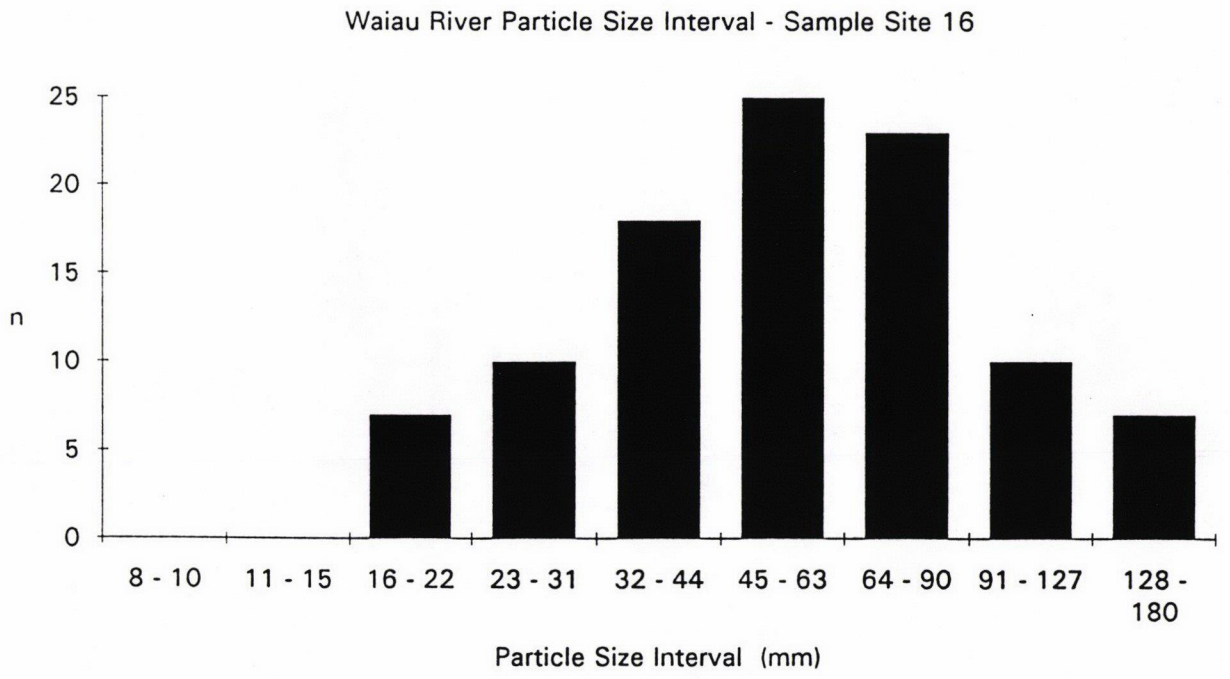
GRAVEL BAR CONDITIONS
Sorting: Poorly sorted.
Packing Arrangement: Unpaved, jumbled, overloose. Partly imbricated. Winnowed below 20mm.
Shape: Subrounded to platey.
Lithology: Primarily volcanics with larger granite cobbles.
Other Characteristics: Bar surface a mobile sheet, although some gravel particle clusters are evident.

SAMPLE SITE CHARACTERISTICS: LILL BURN REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 16 *Grid Reference:* 994534
Bar Type: Chaotic assemblage of reworked bar deposits at Waiau/ Lill Burn confluence. Sample taken at margin of a bank-attached compound bar on a gravel step adjacent to a riffle.
Position on Bar: At waters edge, oriented downstream.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 45-63mm
D95 139mm
D84 92mm
D50 56mm
Mean 62.8mm
S.D. 34.7mm

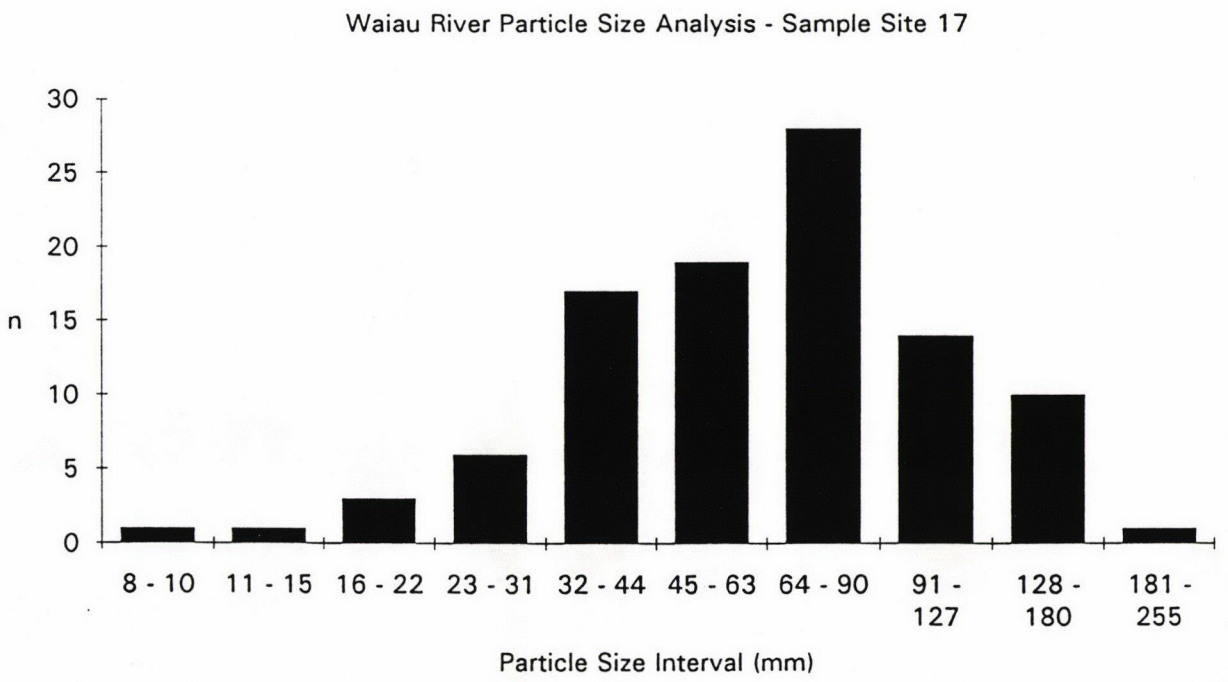
GRAVEL BAR CONDITIONS
Sorting: Poorly sorted.
Packing Arrangement: Significantly imbricated. Well winnowed. Less loose and less jumbled than at sample site 15, but still probably fairly mobile. Although not a visible pavement, this appears to be a lens of well-packed material.
Shape: Many platey particles in subrounded to platey mix.
Lithology: Larger percentage of plutonic rocks, related to the Lill Burn's influence.
Other Characteristics: Lill Burn supplies many fist-sized materials and there are even accumulations of sand lenses in protected areas downstream of the confluence.

SAMPLE SITE CHARACTERISTICS: LILL BURN REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 17 *Grid Reference:* 002513
Bar Type: A coarse gravel point bar.
Position on Bar: Fist-sized gravel locale next to water. Sample taken 10m from water's edge.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class:64-90mm
D95 145mm
D84 109mm
D50 64mm
Mean 71.3mm
S.D. 38.2mm

GRAVEL BAR CONDITIONS
Sorting: Fairly poorly sorted.
Packing Arrangement: Moderately imbricated. Fairly well packed with distinctly less loose gravels in active gravel zone. Moderate winnowing (sand drape post flood event in many places).
Shape: Subrounded to platey.
Lithology: Large percentage of granitic rocks, especially coarse boulders, with smaller volcanics.

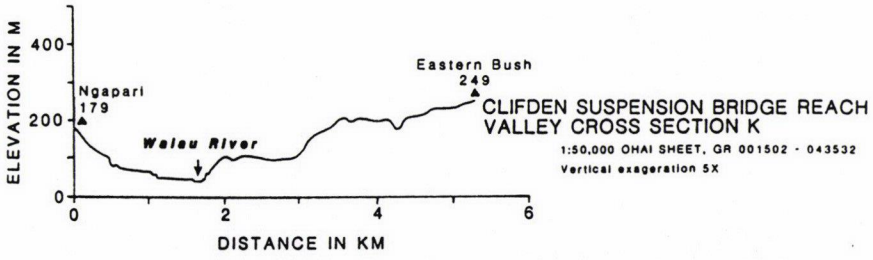
CLIFDEN SUSPENSION BRIDGE REACH

Details of Analysis

Geographic Location: Short, 1km reach, adjacent to the two bridges at Clifden.
Map Sheet: Ohai 1:50 000 *Grid Reference:* 008511-017508
Air Photos: 21/6/84: 608 #17,16
4/4/89: 787 #12
18/12/91: 960 #8,7
Date of Analysis: 25/3/92 *Analysts:* GB/SB/CT

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

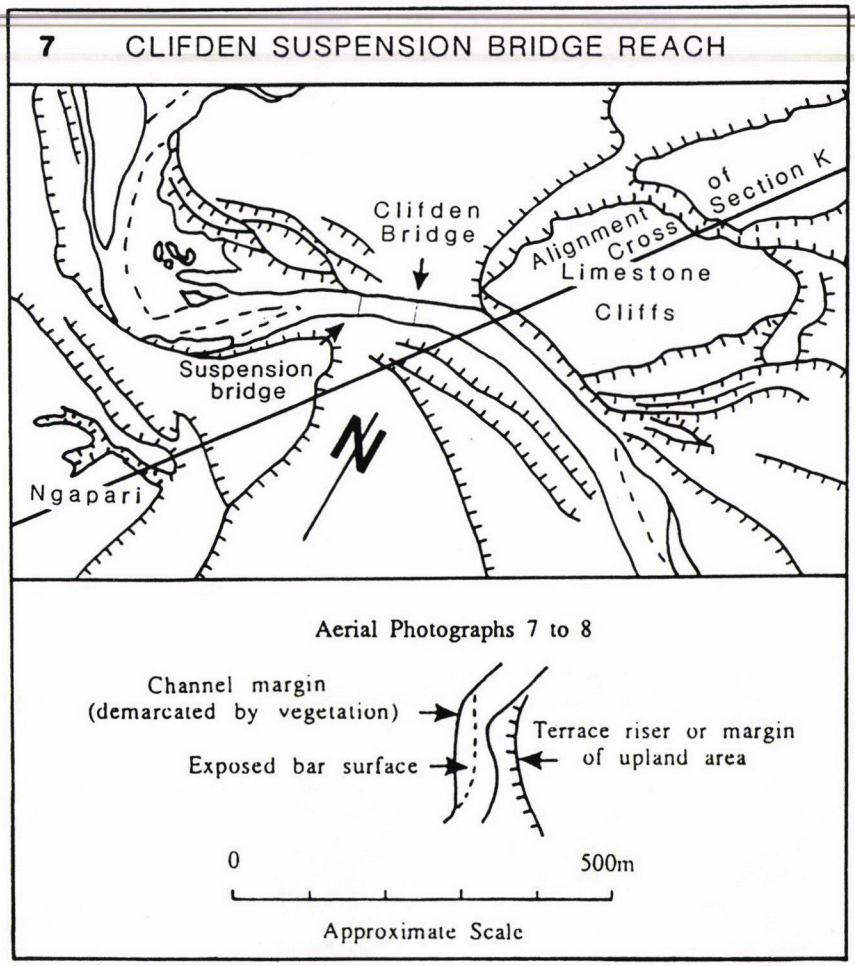


Valley Setting: Limestone constrained bedrock reach adjacent to lowland plain.
Extent of Valley Flat: 500-800m.
Extent of Alluvial Flats: 80-100m.
Degree and Character of Channel Constriction: Laterally constrained reach.
Terrace Character: 1-2 terrace units perched 3-5 and c.12m above channel.

SURFICIAL GEOLOGY
Limestone.

LAND USE
Pastoral.

Air Photo Interpretation of Reach



CHANNEL CHARACTERISTICS: CLIFDEN SUSPENSION BRIDGE REACH

PLANFORM GEOMETRY
Number of Channels: 1
Sinuosity: Imposed broad sinuousity.
Channel Stability: Stable.
Bar Type and Scale: No active bars.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: 80-100m.
Ratio of Alluvial Flat Width to Channel Width: No alluvial flats.

BANK CHARACTER
Extent: 3-5m.
Materials: Bedrock step and limestone face on left side. Gravel bank on right.

FLOW CHARACTER
Uniform flow; no riffles.

SAMPLE SITE CHARACTERISTICS
No sample (no bar).

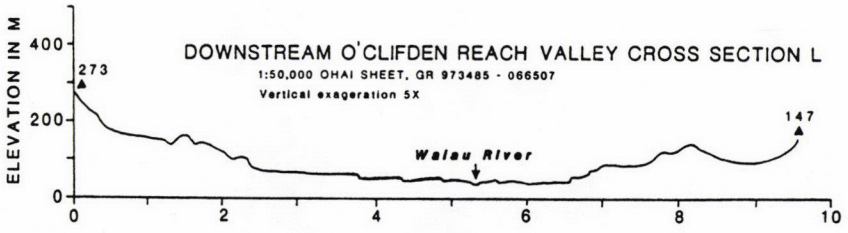
DOWNSTREAM O'CLIFDEN REACH

Details of Analysis

Geographic Location: Extends for 5.4 river kilometres from the limestone cliffs at Clifden to bush-covered hillslopes with Hagen Road atop.
Map Sheet: Ohai 1:50 000 *Grid Reference:* 017508-036477
Air Photos: 21/6/84: 608 #16,15,14
4/4/89: 787 #12,11
18/12/91: 960 #7,6
Date of Analysis: 25/3/92 *Analysts:* GB/SB/CT

VALLEY CHARACTERISTICS

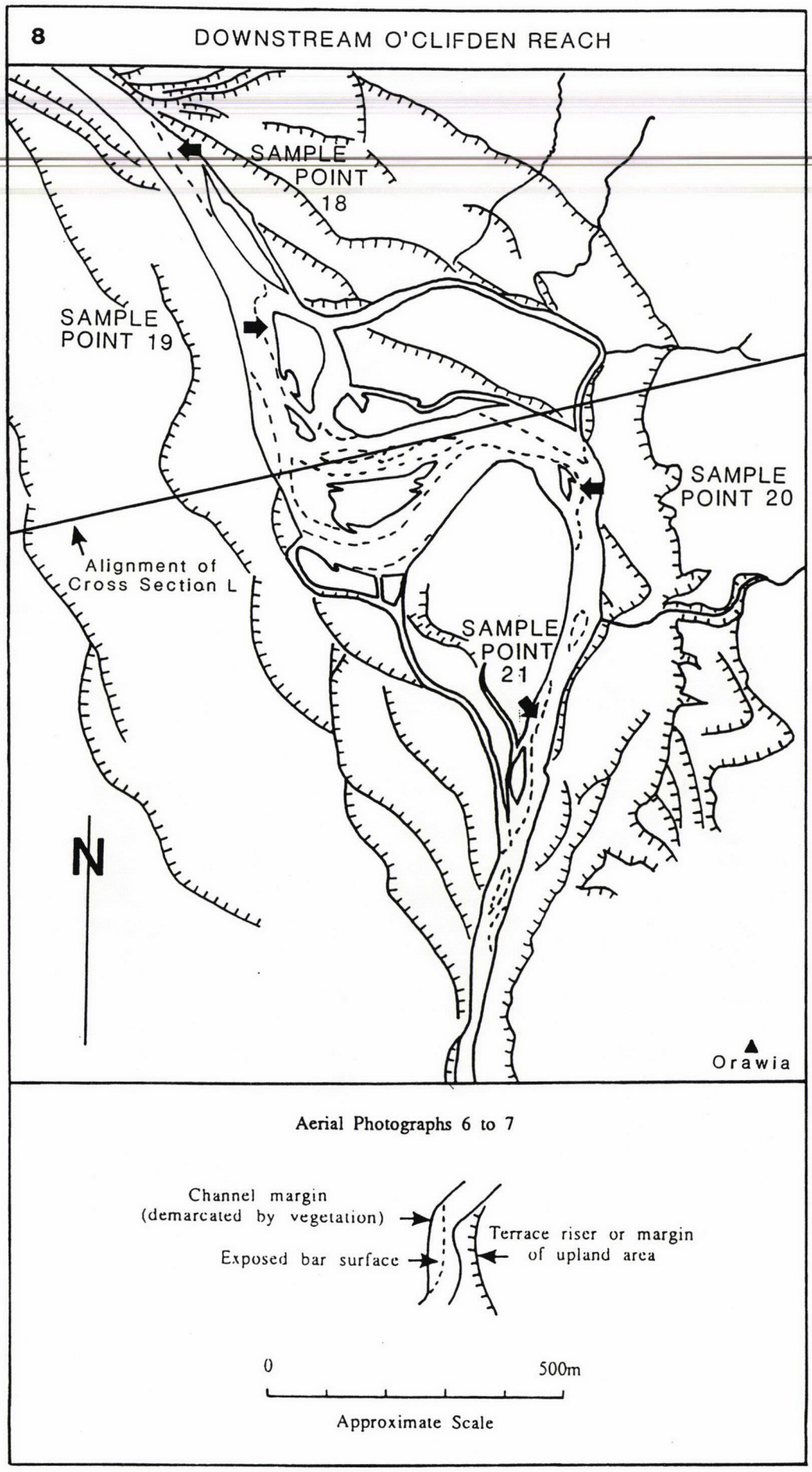
TERRAIN
Valley Cross-section



Valley Setting: Lowlands with shallow gradient valley margin.
Extent of Valley Flat: c.5km.
Extent of Alluvial Flats: <1.2km.
Degree and Character of Channel Constriction: Immediately downstream of a constrained reach, but here river is laterally unstable. At downstream end of reach, however, flow is laterally constrained by a bank of papa bedrock on outside of a bend.
Terrace Character: Continuous and paired.
Left Bank: 3 fragmentary terraces positioned well back from river; non-eroding.
Right Bank: 1 very extensive lower terrace, with large number of braid channels on its surface, and a second terrace 1.5km from the river, 4-5m high.

SURFICIAL GEOLOGY
Dominated by shallow outwash terraces. Papa (mudstone) bedrock forms left bank at outside of the bend and a step within the channel at lower end of the reach.

LAND USE
Pastoral. Recreational use of river also observed; kayaking.


8
DOWNSTREAM O'CLIFDEN REACH
SAMPLE POINT 18
SAMPLE POINT 19
SAMPLE POINT 20
SAMPLE POINT 21
Alignment of Cross Section L
N
Orawia
Aerial Photographs 6 to 7
Channel margin (demarcated by vegetation)
Exposed bar surface
Terrace riser or margin of upland area
0
500m
Approximate Scale

CHANNEL CHARACTERISTICS: DOWNSTREAM O'CLIFDEN REACH

PLANFORM GEOMETRY

Number of Channels: Up to 4, but at downstream end of reach a single channel is again imposed. During high flow, however, at least 2 chute channels are activated (these have unvegetated gravels).

Sinuosity: Moderately tight bends.

Channel Stability: Distinctly laterally unstable until papa bedrock is reached, where lateral stability is imposed, so that the compound bar at site 20 can only move downstream.

Bar Type and Scale: Transitional: lateral to mid-channel compound to point bars. Immediately downstream of sample site 20, gravels are highly active, flow is sediment charged and, although the gradient is steep, within-channel sedimentation occurs as riffles.

EXTENT AND CHARACTER OF ALLUVIAL FLATS

Channel Width: Combined channel width c.100m. At downstream end the single channel is 30-40m wide.

Ratio of Alluvial Flat Width to Channel Width: Generally >10:1. Alluvial flats c.1.2km (combined channel width c.100m). At downstream end, there are no alluvial flats to the left but those to the right are extensive.

BANK CHARACTER

Extent: Gravels a few metres high form most of the banks, except for the downstream left bank (papa bedrock with outwash materials atop). Alluvial flats are also extensive.

Materials: Other than the downstream left bank, fluvioglacial materials predominate (terraces and alluvial flats).

FLOW CHARACTER

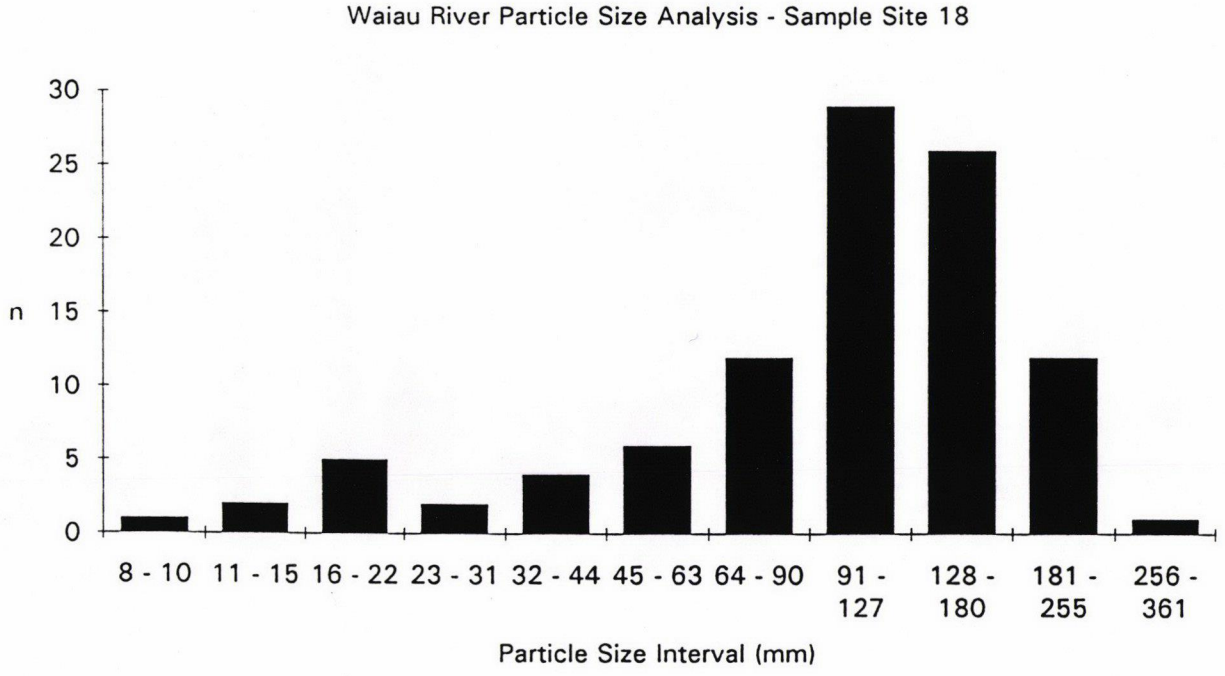
Uniform, with irregular riffles associated with smaller channels at the upstream end, changing to shooting flow with irregular boils and riffles downstream.

SAMPLE SITE CHARACTERISTICS: DOWNSTREAM O'CLIFDEN REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 18 *Grid Reference:* 018508
Bar Type: Bank-attached compound bar.
Position on Bar: Unvegetated coarse gravel locale at head of bar, adjacent to channel.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 215mm
D84 166mm
D50 112mm
Mean 114mm
S.D. 58mm

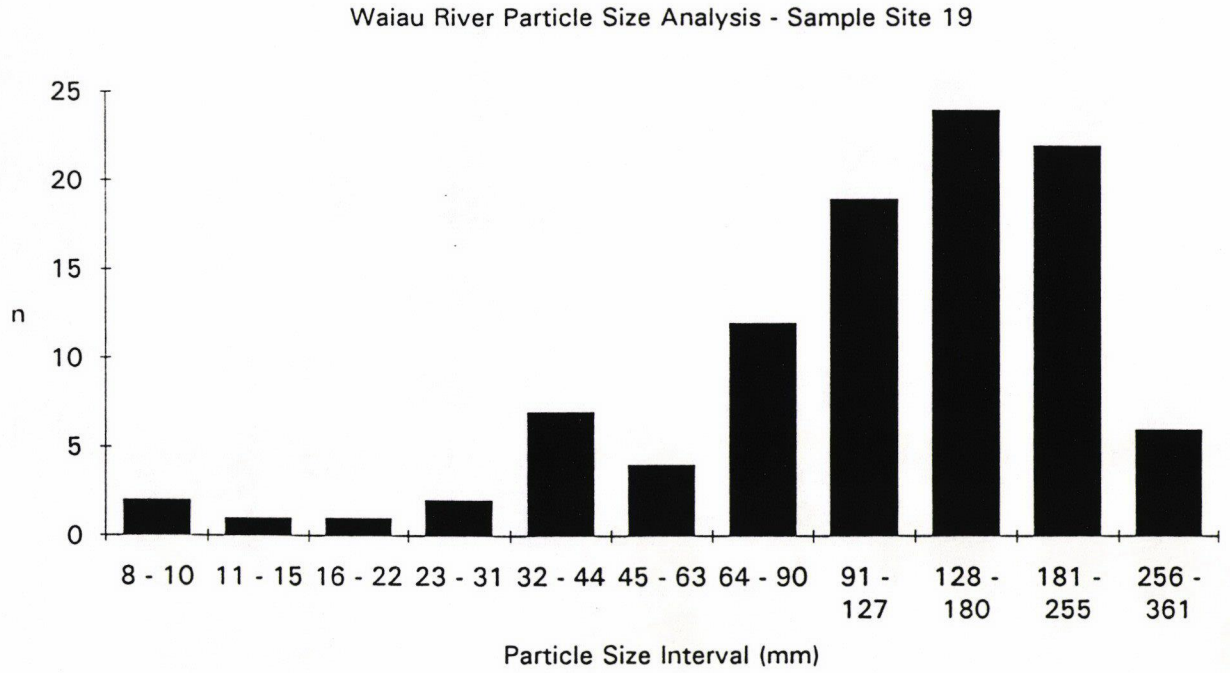
GRAVEL BAR CONDITIONS
Sorting: Poor.
Packing Arrangement: Moderately packed. Moderately imbricated with loose gravels atop. Winnowed to c.20mm in general.
Shape: Subrounded to platey.
Lithology: Larger clasts granitic, with mixed lithology in smaller clasts.

SAMPLE SITE CHARACTERISTICS: DOWNSTREAM O'CLIFDEN REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 19 *Grid Reference:* 023503
Bar Type: Mid-channel compound bar.
Position on Bar: Unvegetated coarse gravel locale at head of bar, adjacent to channel.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 128-180mm
D95 262mm
D84 219mm
D50 132mm
Mean 137mm
S.D. 73.6mm

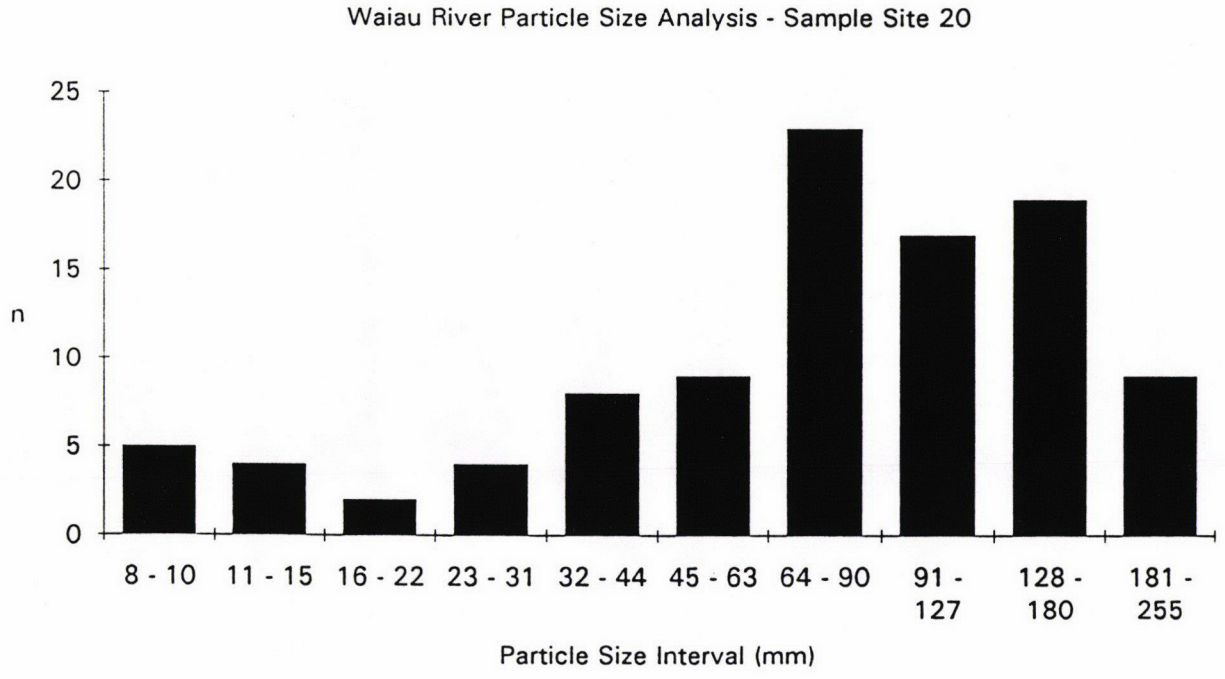
GRAVEL BAR CONDITIONS
Sorting: Moderately sorted in discrete locales.
Packing Arrangement: Moderately packed. Moderately imbricated with less loose gravels than upstream. Winnowed only for sand; many fine gravels remain.
Shape: Subrounded to platey.
Lithology: Larger clasts granitic, with mixed igneous (plutonic and volcanic) in smaller clasts.
Other Characteristics: Grassed sandy remnants at the bar margin suggest this is a laterally erosive site.

SAMPLE SITE CHARACTERISTICS: DOWNSTREAM O'CLIFDEN REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 20 *Grid Reference:* 037497
Bar Type: Laterally constrained compound point bar.
Position on Bar: Active gravels just downstream of bend apex: a thinnish lens attached to the alluvial flats.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 64-90mm
D95 195mm
D84 161mm
D50 84mm
Mean 94mm
S.D. 57.2mm

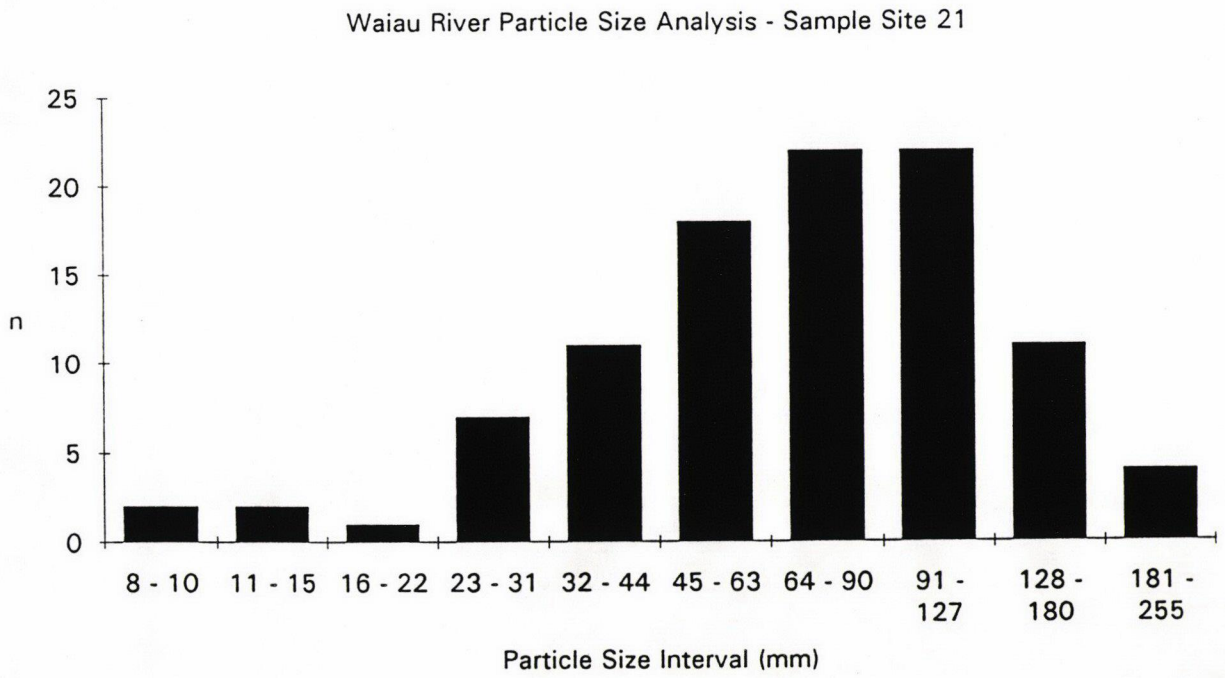
GRAVEL BAR CONDITIONS
Packing Arrangement: Poorly imbricated, jumbled and largely unwinnowed.
Shape: Platey to subrounded.
Lithology: Mixed plutonic and volcanic with occasional shattered mudstone.
Other Characteristics: Immediately downstream of this site gravels are highly active, flow is sediment charged and, although gradient is steep, within-channel sedimentation occurs as riffles.

SAMPLE SITE CHARACTERISTICS: DOWNSTREAM O'CLIFDEN REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 21 *Grid Reference:* 037487
Bar Type: Side bar which may be an extension of the riffle.
Position on Bar: At head of bar, parallel to channel.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 64-90; 91-127mm
D95 174mm
D84 120mm
D50 74mm
Mean 81.8mm
S.D. 44.3mm

GRAVEL BAR CONDITIONS
Sorting: Poorly sorted .
Packing Arrangement: Not well packed, partly imbricated, moderately winnowed, jumbled surface of recently active gravels.
Shape: Subrounded to platey.
Lithology: Coarse sub rounded gravels are plutonic (granitic) with mixed igneous (plutonic and volcanic) in smaller clasts.
Other Characteristics: Sample taken at downstream end of Downstream o'Clifden reach, as noted by limit of within channel sedimentation. Irregular riffles continue downstream, associated with bedrock steps.

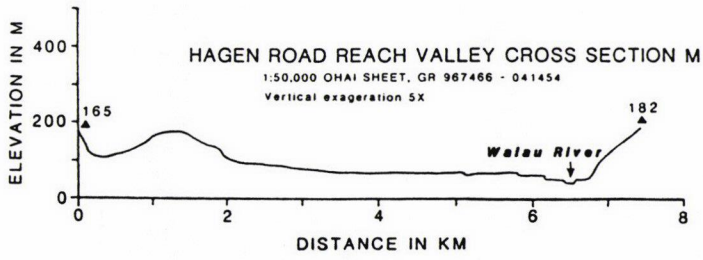
HAGEN ROAD REACH

Details of Analysis

Geographic Location: Midway between Clifden and Tuatapere; a 4.3km long reach, at base of ridge with Hagen Road atop.
Map Sheet: Ohai 1:50 000 *Grid Reference:* 036477-024438
Air Photos: 21/6/84: 608 #14,13,12,11
4/4/89: 787 #11,10
18/12/91: 960 #6,5
Date of Analysis: 26/3/92 *Analysts:* GB/SB/CT

VALLEY CHARACTERISTICS

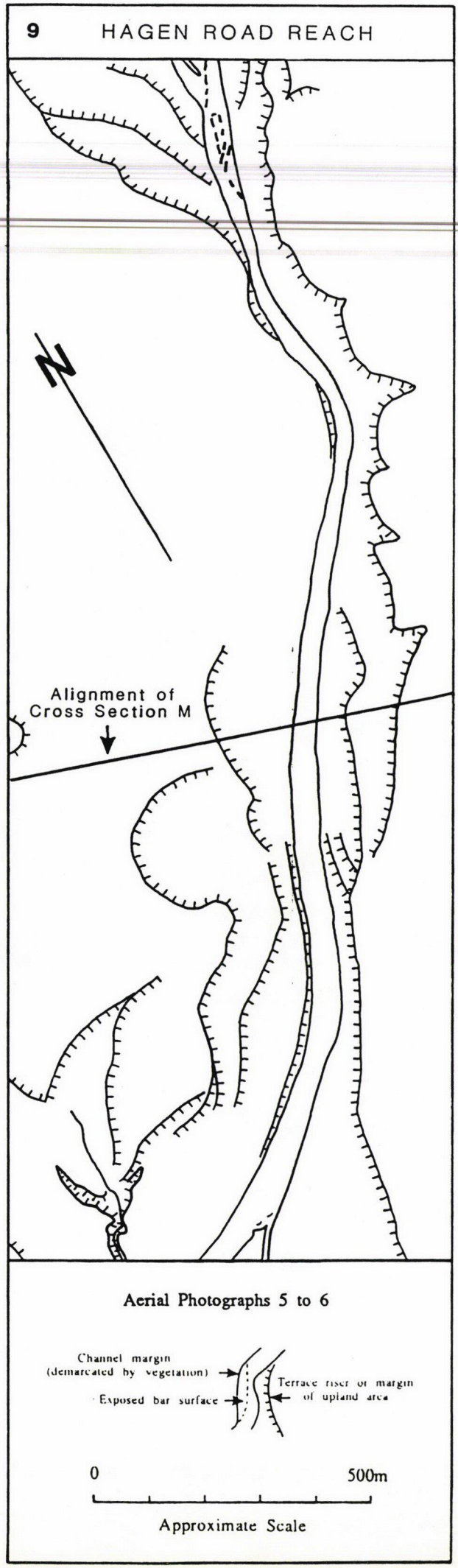
TERRAIN
Valley Cross-section



Valley Setting: Lowland.
Extent of Valley Flat: <4km.
Extent of Alluvial Flats: <300m.
Degree and Character of Channel Constriction: A bedrock/ valley flat constrained reach.
Terrace Character:
Left Bank: No terraces evident (papa bedrock).
Right Bank: 3 continuous terrace surfaces, unpaired, non eroding.

SURFICIAL GEOLOGY
Papa (mudstone) bedrock.

LAND USE
Pastoral.


9 HAGEN ROAD REACH
N
Alignment of
Cross Section M
Aerial Photographs 5 to 6
Channel margin
(demarcated by vegetation)
Exposed bar surface
Terrace riser or margin
of upland area
0
500m
Approximate Scale

CHANNEL CHARACTERISTICS: HAGEN ROAD REACH

PLANFORM GEOMETRY
Number of Channels: 1
Sinuosity: Almost straight.
Channel Stability: Laterally stable.
Bar Type and Scale: No bars.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: c.100m.
Ratio of Alluvial Flat Width to Channel Width: Alluvial flats almost non-existent, and certainly <300m wide.

BANK CHARACTER
Extent: Right bank comprises shallow valley flat c.1.5km wide, with distinct braidplain configurations, then terrace riser c.3m high. Next level of flats c.1.5km wide. Left bank bedrock.
Materials: Bedrock on left; reworked fluvioglacial and alluvial flat material on right.

FLOW CHARACTER
Uniform

SAMPLE SITE CHARACTERISTICS
No sample (no bars)

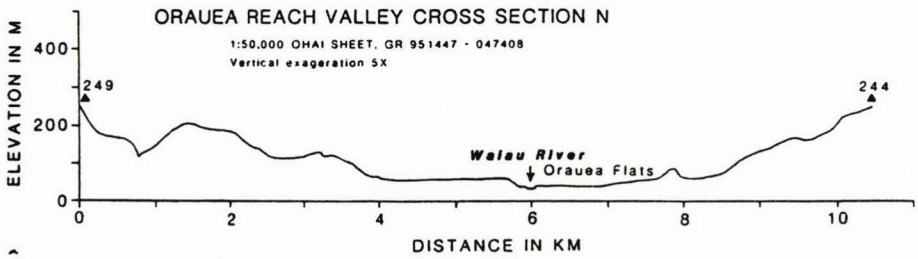
ORAUEA REACH

Details of Analysis

Geographic Location: Base of ridge with Hagen Road atop (2km upstream of Orauea confluence) to just downstream of bridge in Tuatapere.
Map Sheet: Ohai and Riverton 1:50 000
Grid Reference: 024438-994397
Air Photos: 21/6/84: 608 #11,10,9,8
4/4/89: 787 #10,9
12/4/89: 816 #2
18/12/91: 960 #5,4
Date of Analysis: 26/3/92 *Analysts:* GB/SB/CT

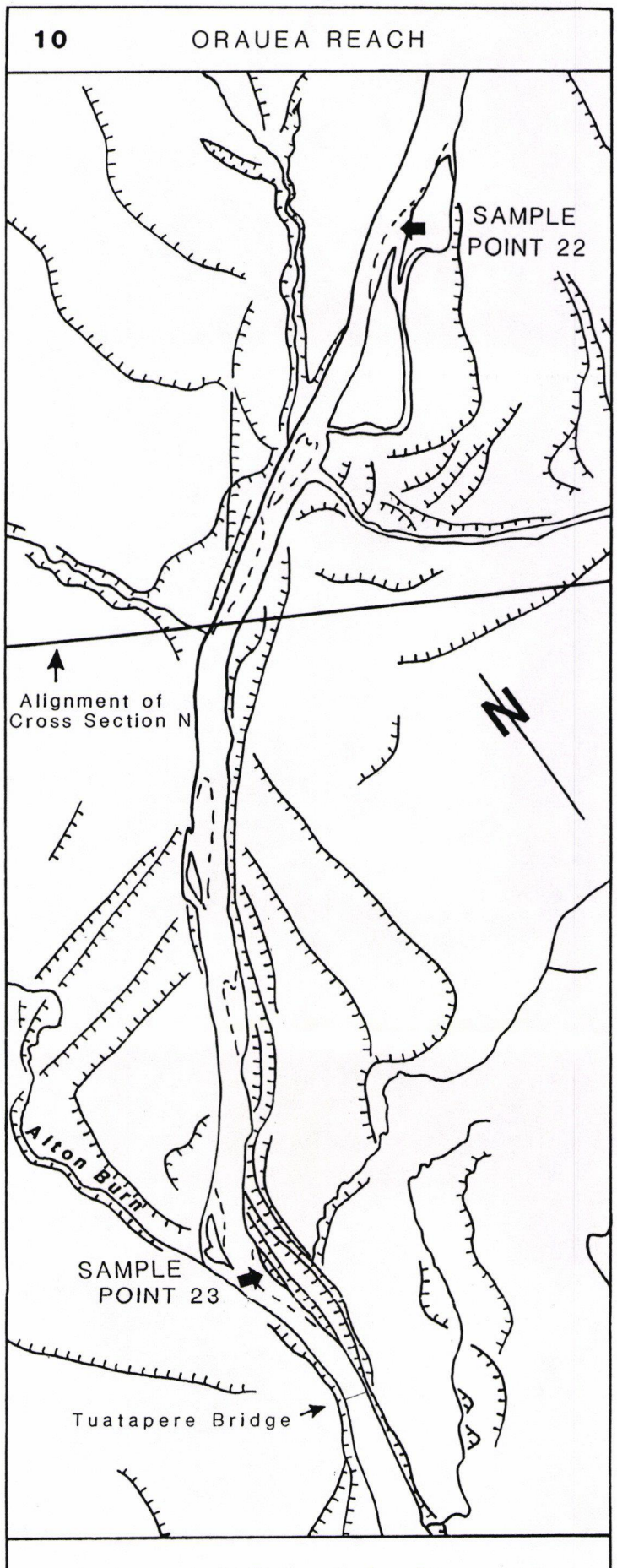
VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section

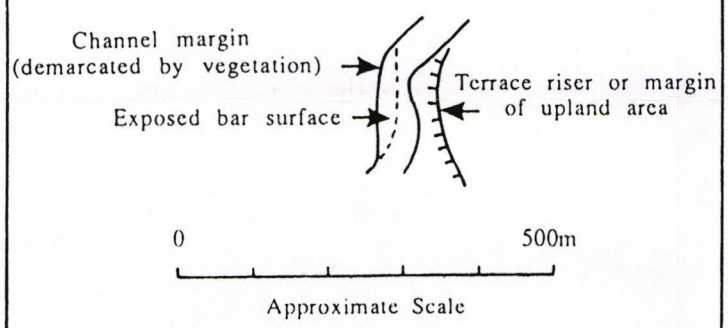


Valley Setting: Lowland reach.
Extent of Valley Flat: <5km.
Extent of Alluvial Flats: <300m.
Degree and Character of Channel Constriction: Although not especially high, terraces atop a bedrock base impose severe lateral constraint on the channel, and alluvial flats are not laterally extensive. The channel appears to be laterally stable other than a short subreach just upstream of Orauea confluence. Bedrock forms a shallow step in both banks immediately downstream of the sampling site (020435) and a sandstone band in the mudstone forms a distinct step on the channel bed (with an associated mid-channel bar) just upstream of the Orauea confluence.
Terrace Character: Curved, fragmentary, paired and non-eroding. A large number of flood channels oriented parallel to the main channel are evident on the alluvial flats and first terrace surface upstream of the Orauea confluence. Terraces on the left bank are relatively shallow and extend virtually to the valley margin. This surface is somewhat higher atop bedrock near Tuatapere. On the right bank, two terraces extend back about 1.5km from the channel at the upstream end of the reach. These are marginal to a bedrock based terrace. The latter terrace is not parallel to the present channel position, which it abuts just upstream of Tuatapere domain.

Air Photo Interpretation of Reach



Aerial Photographs 3 to 5



Note that downstream of Clifden the valley-marginal fluvioglacial terraces are less prevalent than upstream - this implies that they either never were here or have subsequently been reworked (cf Maori dam story at Clifden limestone cliffs).

SURFICIAL GEOLOGY
Papa bedrock terrace upstream of Tuatapere.

LAND USE
Pastoral.

CHANNEL CHARACTERISTICS: ORAUEA REACH

PLANFORM GEOMETRY
Number of Channels: Predominantly single channel, with two channels around bedrock-controlled mid-channel bar adjacent to Orauea confluence.
Sinuosity: The broad channel configuration is roughly straight, while the flow alternates around lateral bars (a response to discharge reduction?)
Channel Stability: Banks appear laterally stable, while flow adjusts around a series of bars/ riffles.
Bar Type and Scale: Alternating lateral bars with a mid-channel bar formed downstream of a sandstone band adjacent to Orauea confluence.

EXTENT AND CHARACTER OF ALLUVIAL FLATS
Channel Width: 80-100m.
Ratio of Alluvial Flat Width to Channel Width: 1:3.

BANK CHARACTER
Extent: Highly variable, ranging from zero adjacent to bars on left bank at upstream end of reach, to around 5m on terraces adjacent to the bridge at Tuatapere.
Materials: Alluvial gravels with finer cap, or bedrock step at base of terraces.

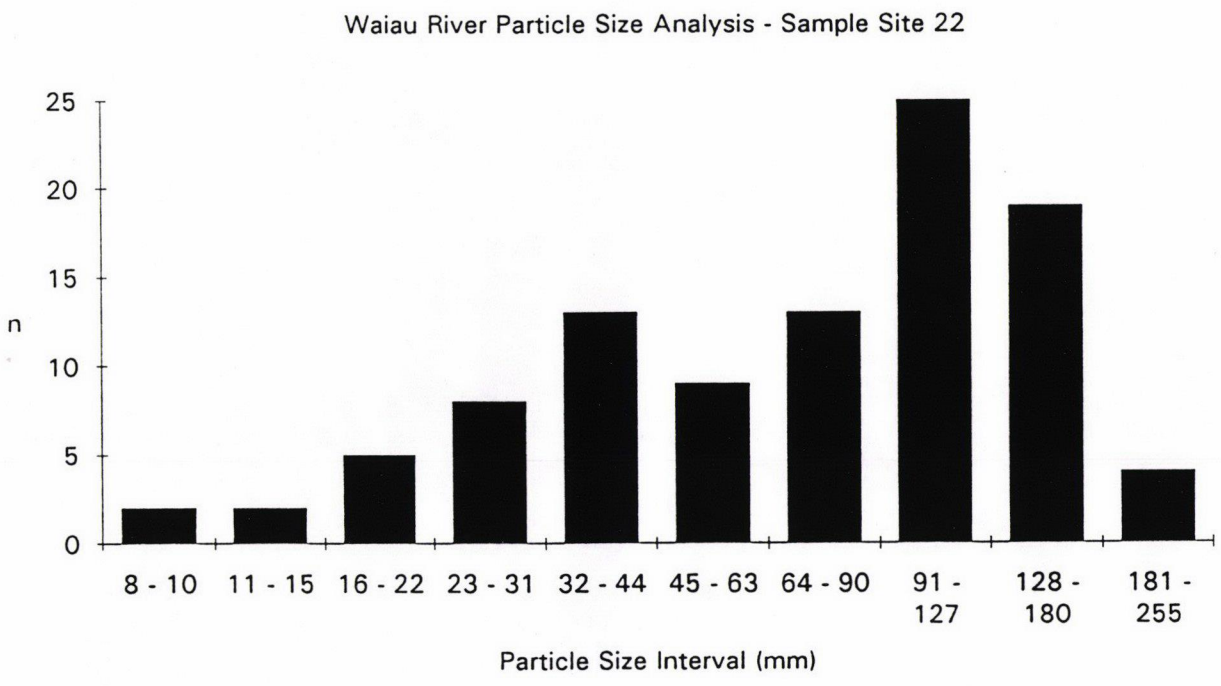
FLOW CHARACTER
Uniform with semi-regularly spaced riffles.

SAMPLE SITE CHARACTERISTICS: ORAUEA REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 22 *Grid Reference:* 020435
Bar Type: Lateral bar adjacent to reworked alluvial flats. The adjacent grassed surface is actively eroding.
Position on Bar: At bar apex, adjacent to channel, on gravels not covered by algae.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 173mm
D84 134mm
D50 89mm
Mean 86.4mm
S.D. 51.1mm

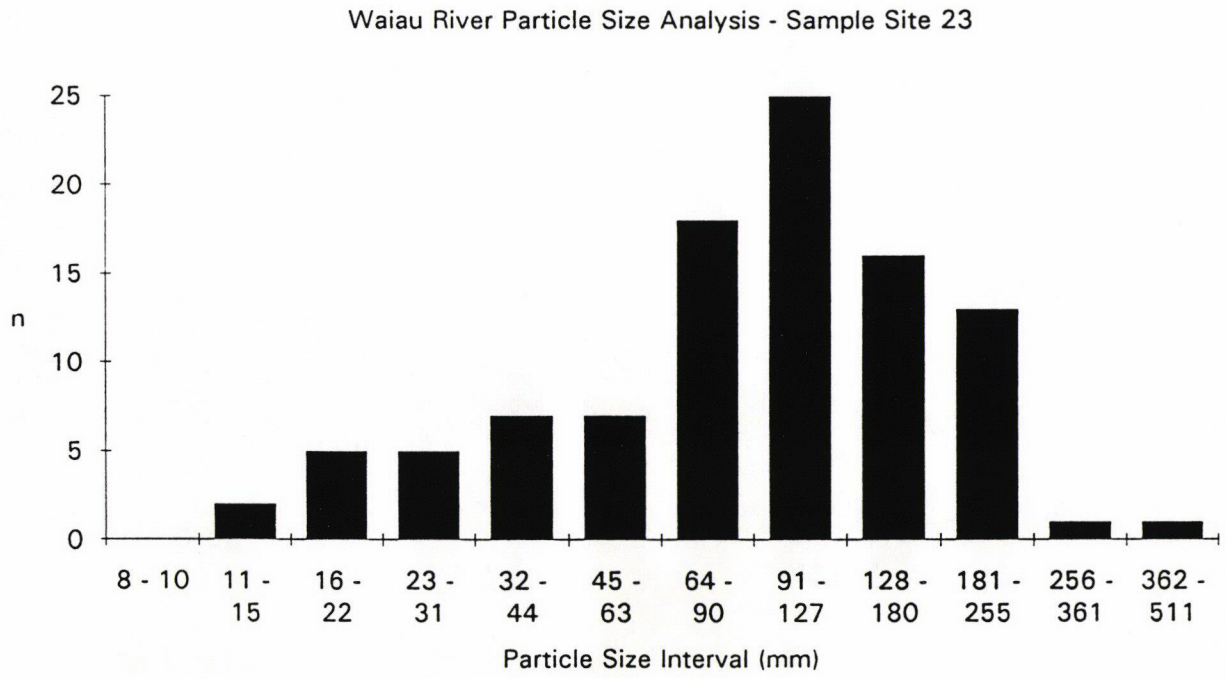
GRAVEL BAR CONDITION
Sorting: Poor.
Packing Arrangement: Jumbled, loose. Partly imbricated; moderately winnowed to c.20mm.
Shape: Subrounded to platey.
Lithology: Igneous, with a higher proportion of non-plutonic rocks than noted upstream.
Other Characteristics: Papa bedrock forms a shallow step in both banks immediately downstream of this site. This has coarser gravels atop than the active bar surface.

SAMPLE SITE CHARACTERISTICS: ORAUEA REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 23 *Grid Reference:* 994403
Bar Type: Lateral bar at the downstream end of a major riffle, on the left bank just upstream of Tuatapere bridge.
Position on Bar: At bar head in the coarsest gravel locale. Many finer sheets noted down-bar.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 215mm
D84 167mm
D50 98mm
Mean 106mm
S.D. 63.6mm

GRAVEL BAR CONDITION
Sorting: Moderate to poor.
Packing Arrangement: Jumbled; occasionally loose, but finer gravels beneath are quite well packed. Partly imbricated; not well winnowed - only materials <10mm appear to have been removed, other deposits appear to have been dumped relatively rapidly.
Shape: Mainly subrounded; some platey.
Lithology: Mixed igneous.
Other Characteristics: Many fine gravel sheets; gravels are slimey - drapes of fines atop.

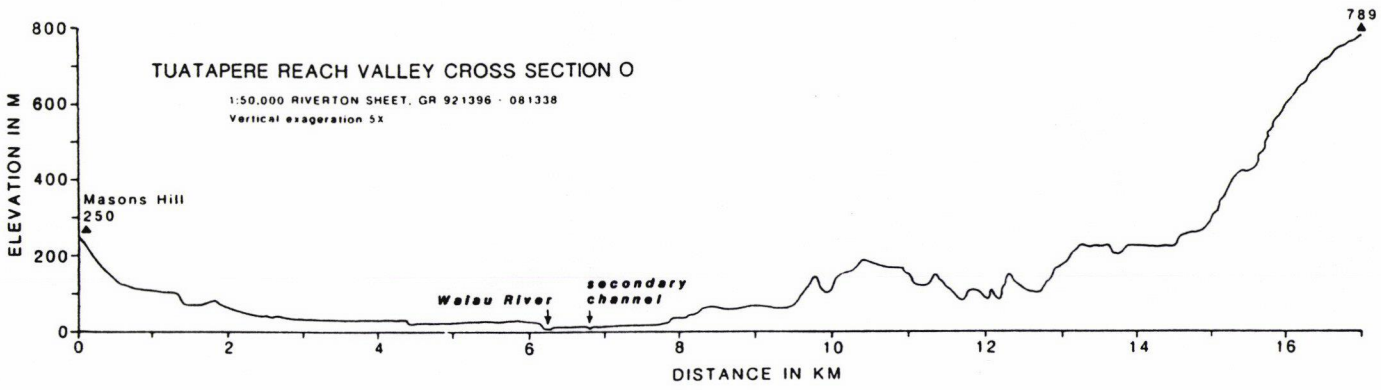
TUATAPERE REACH

Details of Analysis

Geographic Location: Just downstream of Tuatapere Bridge to Te Waewae Bay.
Map Sheet: Riverton 1:50 000 *Grid Reference:* 994397-942323
Air Photos: 21/6/84: 608 #8,7,6,5,4
4/4/89: 787 #7,6
12/4/89: 816 #2
18/12/91: 960 #3,2,1
Date of Analysis: 27/3/92 *Analysts:* GB/SB/CT

VALLEY CHARACTERISTICS

TERRAIN
Valley Cross-section



Valley Setting: Lowland reach with extensive channel-marginal flats.
Extent of Valley Flat: 6km
Extent of Alluvial Flats: Up to 1km
Degree and Character of Channel Constriction: Minimal constriction compared to elsewhere. Beyond terrace constriction at Tuatapere, the Waiau only abuts against terrace deposits in a couple of instances in this lowland reach. Papa bedrock is noted at the base of one of these terraces; indeed, the bedrock is also observed on the channel bed, forming a ledge at this point.
Terrace Character: Although set back from the channel itself, distinct flights of terraces are observed on both valley sides. While not as high as terraces upstream, these still constitute extremely significant depositional units.

SURFICIAL GEOLOGY
Papa bedrock observed within-reach, but reworked fluvioglacial outwash deposits predominate.

LAND USE
Pastoral, with many sawmills around Tuatapere township.

Aerial Photographs 1 to 3

Channel margin
(demarcated by vegetation)

Exposed bar surface

Terrace riser or margin
of upland area

0 500m

Approximate Scale

Air Photo Interpretation of Reach

11 TUATAPERE REACH

Tuatapere Bridge

SAMPLE POINT 24

SAMPLE POINT 25

SAMPLE POINT 26

SAMPLE POINT 27

Alignment of Cross Section O

Camp Creek

SAMPLE POINT 28

SAMPLE POINT 29

SAMPLE POINT 30

SAMPLE POINT 31

SAMPLE POINT 32

SAMPLE POINT 33

Holly Burn

gravel barrier

Walau lagoon

river mouth

Te Waewae Bay

Kowhai Creek

N

CHANNEL CHARACTERISTICS: TUATAPERE REACH

PLANFORM GEOMETRY

Number of Channels: While a single channel is evident immediately downstream of Tuatapere, this is very uncharacteristic of Tuatapere reach. There are typically two or three channels, but many chute and side channels are evident on bar surfaces and adjacent alluvial flats. Some of these channels are occupied at high flood stages; others reflect former high discharge levels. On and adjacent to the mid-channel compound bar about 2km downstream of Tuatapere are abundant channels of variable scale and orientation, presenting a somewhat chaotic configuration. The large channel which cuts across this mid-channel compound bar has a distinct sandy drape.

Sinuosity: While the broad channel strip is roughly straight, the channel itself wanders from side to side within a zone roughly 1km wide. In this zone the Waiau has moderate sinuosity, but the relatively steep slope induces a primary downstream rather than lateral movement pattern.

Channel Stability: Typically the channels are laterally unconstrained, with only a couple of instances in which the channel is less able to migrate laterally. Rates of channel adjustment appear to be highly variable within-reach, as reflected by the changes in bar pattern and notable differences in riffle spacing.

Bar Type and Scale: Highly variable within-reach. Bank-attached compound bars are found at the reach head. These are transitional downstream to mid-channel compound bars. These have many chute channels on their surfaces, and side channels themselves are frequently divided around riffles and small mid-channel (longitudinal and diagonal) bars. As the two primary channels rejoin in mid-reach, flow is concentrated into a single channel once more, and bar types change to bank-attached compound bars. Associated with this change, there is notable channel-marginal sedimentation, with discrete sheets washed onto bar surfaces. Beyond this, flow switches position around a series of bank-attached compound bars and compound point bars. These extend virtually to the river mouth. At their downstream limit, in a locally oversteepened reach with many riffles, these bars are highly dissected. As chamnnel width increases at the mouth, mid-channel bars are observed.

EXTENT AND CHARACTER OF ALLUVIAL FLATS

Channel Width: Highly variable, with the main channel typically 80-100m wide. As flow divides into a series of smaller channels,their combined width is somewhat greater.

Ratio of Alluvial Flat Width to Channel Width: Roughly 10:1, or greater.

BANK CHARACTER

Extent: Typically a couple of metres high, with terraces up to 4m high in two instances.

Materials: Shallow gravel banks witha discontinuous sand/silt cap. The sand cap appears to increase in thickness down-reach. Adjacent to sample site 29 (976360) is a vast accumulation of logs with roots intact which are eroding out of the bank. At the

mouth of the river many small channels on the lowest alluvial flat surface have infilled with mud.

FLOW CHARACTER

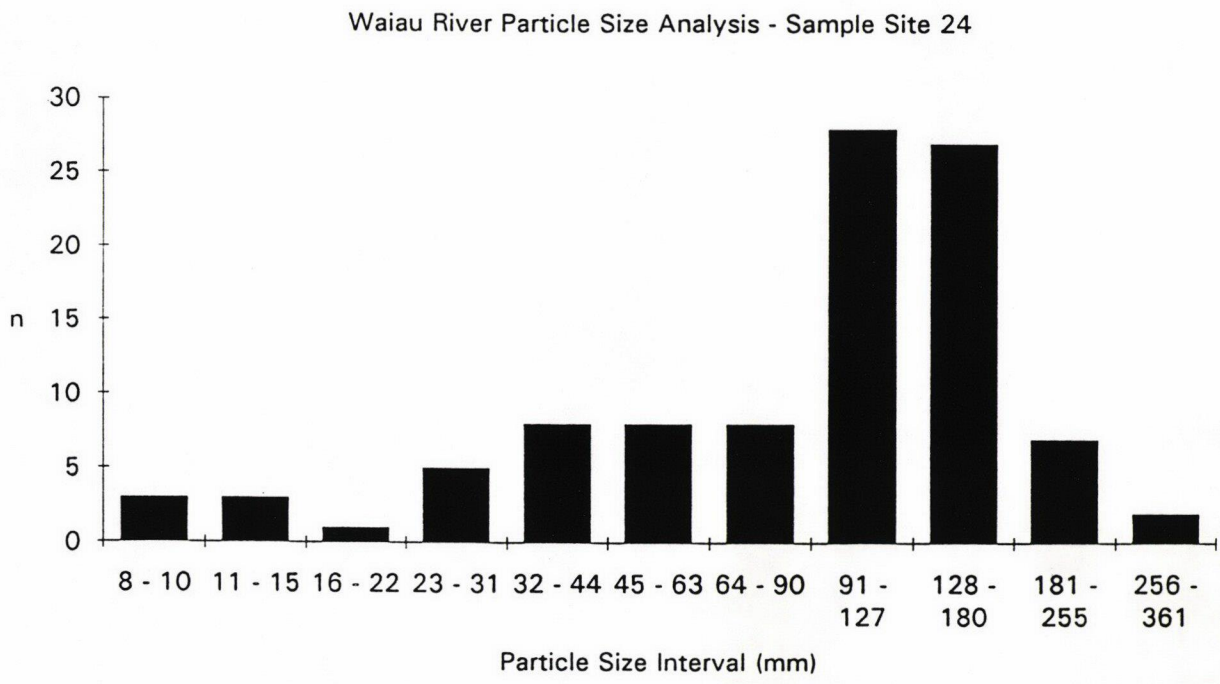
Uniform at the upstream end of the reach, transitional to a zone of occasional white caps at the head of the major mid-channel compound bar. These indicate supercritical flow conditions in this locally oversteepened reach (associated with riffle pattern). As the channels rejoin at the downstream limit of the mid-channel compound bar, flow is "shooting", with a large number of turbulent boils. Flow "settles" considerably downstream of this point, with fewer riffles. However, a couple of kilometres from the mouth the downstream compound bar is highly dissected and flow is irregular with many white caps as flow separates over a multitude of riffles. This is a narrow zone and flow is much calmer in the subreach adjacent to the mid-channel bar at the river mouth.

SAMPLE SITE CHARACTERISTICS: TUATAPERE REACH

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 24 *Grid Reference:* 994392
Bar Type: Bank attached compound bar (first major bar downstream of Tuatapere).
Position on Bar: In chute channel at head of bar; oriented down valley.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 193mm
D84 156mm
D50 105mm
Mean 106mm
S.D. 58.1mm

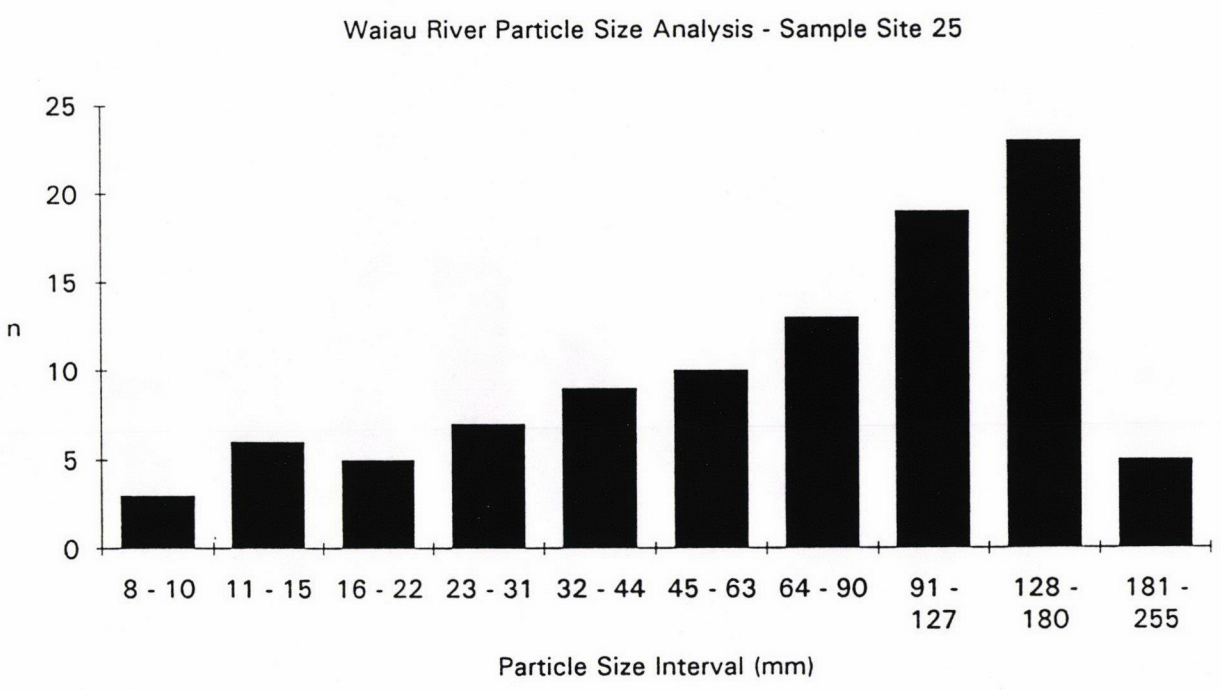
GRAVEL BAR CONDITIONS
Sorting: Moderately to poorly sorted.
Packing Arrangement: Jumbled, moderately loose surface. Surface is only moderately imbricated, and locally highly variable. Discrete sheets of mobile gravels have been launched into the chute channel (*sensu* McGowen and Garner, 1970). Barely winnowed.
Shape: Sub-rounded, with a smaller proportion platey gravels than upstream.
Lithology: Mixed plutonic/ volcanic, although most large clasts are granitic.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 25 *Grid Reference:* 991388
Bar Type: Mid-channel diagonal bar associated with channel widening and riffle development at the head of a major mid-channel compound bar.
Position on Bar: Aligned at the water margin of the left-hand channel at the bar head.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 128-180mm
D95 167mm
D84 144mm
D50 79mm
Mean 87.5mm
S.D. 54.5mm

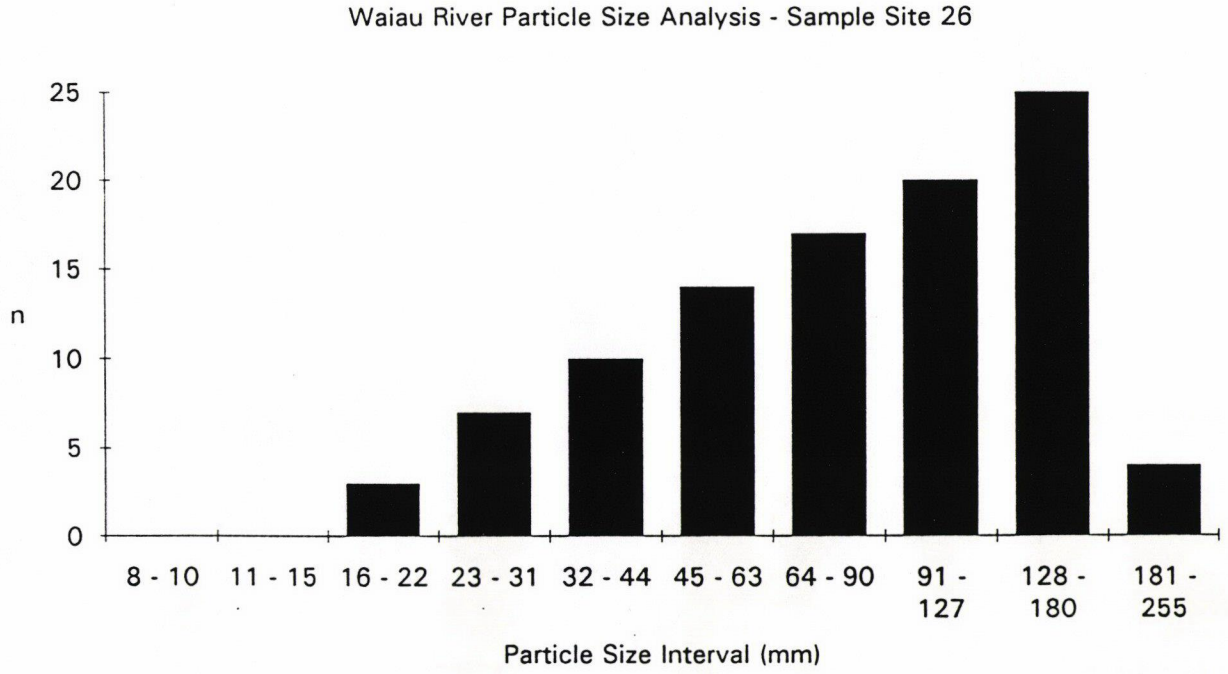
GRAVEL BAR CONDITIONS
Sorting: Poor; note the widely dispersed particle size distribution.
Packing Arrangement: Imbricated at the head of the sample, but increasingly jumbled down-bar. A similar variation in packing is observed, with gravels becoming increasingly 'loose' down-bar.
Shape: Subrounded with occasional platey.
Lithology: Larger clasts plutonic (mainly granitic), while the remainder are mixed igneous.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 26 *Grid Reference:* 981382
Bar Type: Longitudial bar in side channel at the western margin of the extensive active channel zone.
Position on Bar: Along the left margin at the bar head.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 128-180mm
D95 172mm
D84 150mm
D50 84mm
Mean 94.2mm
S.D. 51.2mm

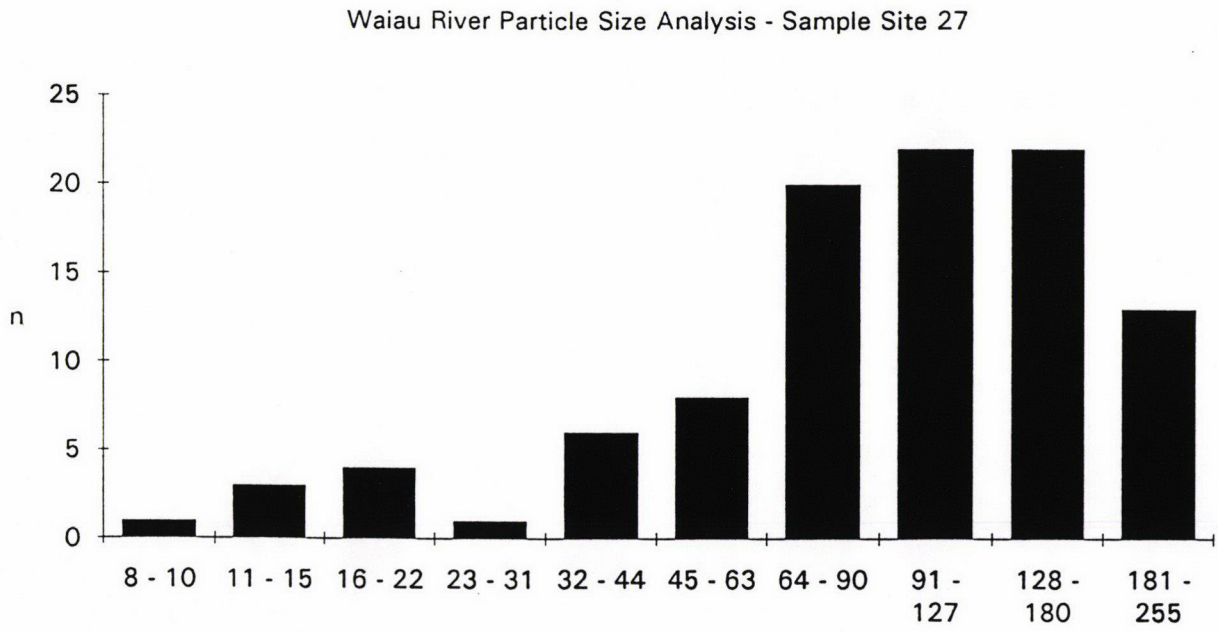
GRAVEL BAR CONDITIONS
Sorting: Poor.
Packing Arrangement: Moderately tightly packed, although there is little evidence of imbrication other than a small zone at the bar head. Distinct lobe of gravels noted downstream of a large log. Somewhat jumbled, and largely unwinnowed surface.
Shape: Subrounded to platey.
Lithology: Coarser clasts primarily plutonic (granitic) while the smaller clasts are mixed igneous.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 27 *Grid Reference:* 979375
Bar Type: Point bar, immediately downstream of eroding bank.
Position on Bar: Channel margin at the bar head.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm; 128-180mm
D95 202mm
D84 174mm
D50 101mm
Mean 107mm
S.D. 56.6mm

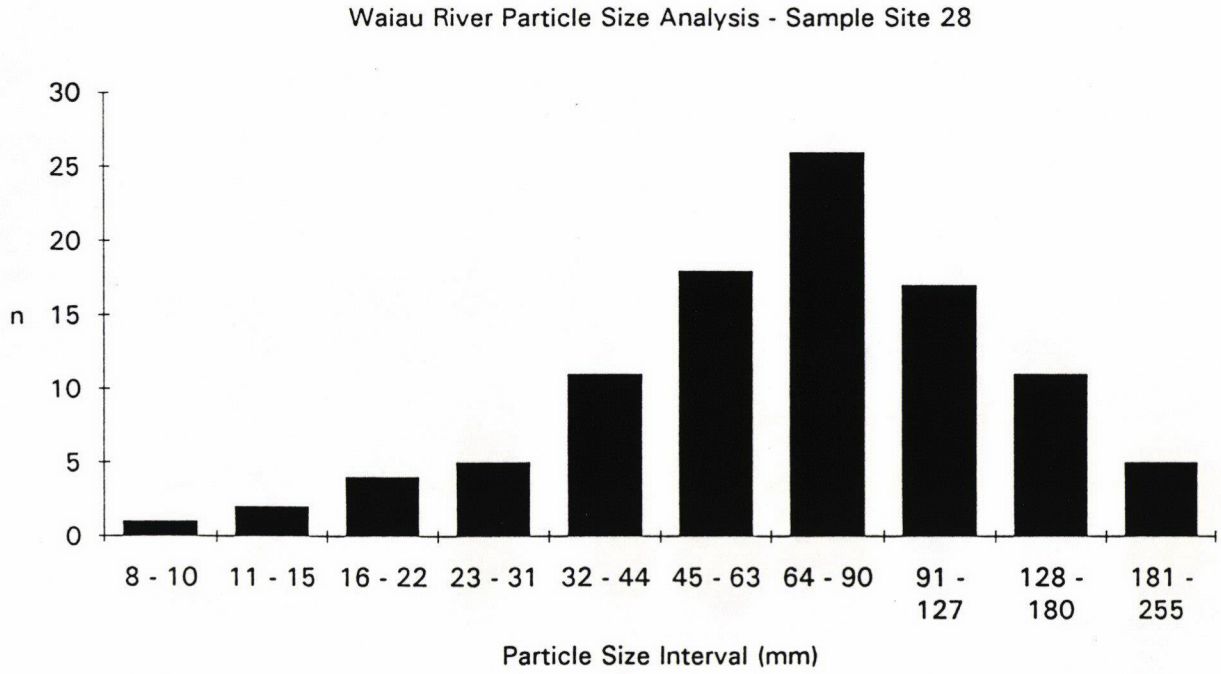
GRAVEL BAR CONDITIONS
Sorting: Very poor.
Packing Arrangement: Moderately winnowed to 30mm; somewhat jumbled surface; barely imbricated or packed.
Shape: Subrounded to platey.
Lithology: Mixed igneous.
Other Characteristics: Gravels on this bar may reflect local supply from the eroding bend upstream, but are more likely deposits from reworking of bar deposits.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 28 *Grid Reference:* 979367
Bar Type: Bank-attached compound bar immediately downstream of the confluence of the divided channels around the major mid-channel compound bar.
Position on Bar: At the margin of the active gravel surface and the bank, away from a series of sheets of finer gravels (20-80mm diameter) washed onto the bar surface at the channel margin. The sample was oriented down-bar, and extended into a chute channel at the bar head.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 64-90mm
D95 175mm
D84 127mm
D50 68mm
Mean 79.5mm
S.D. 46.3mm

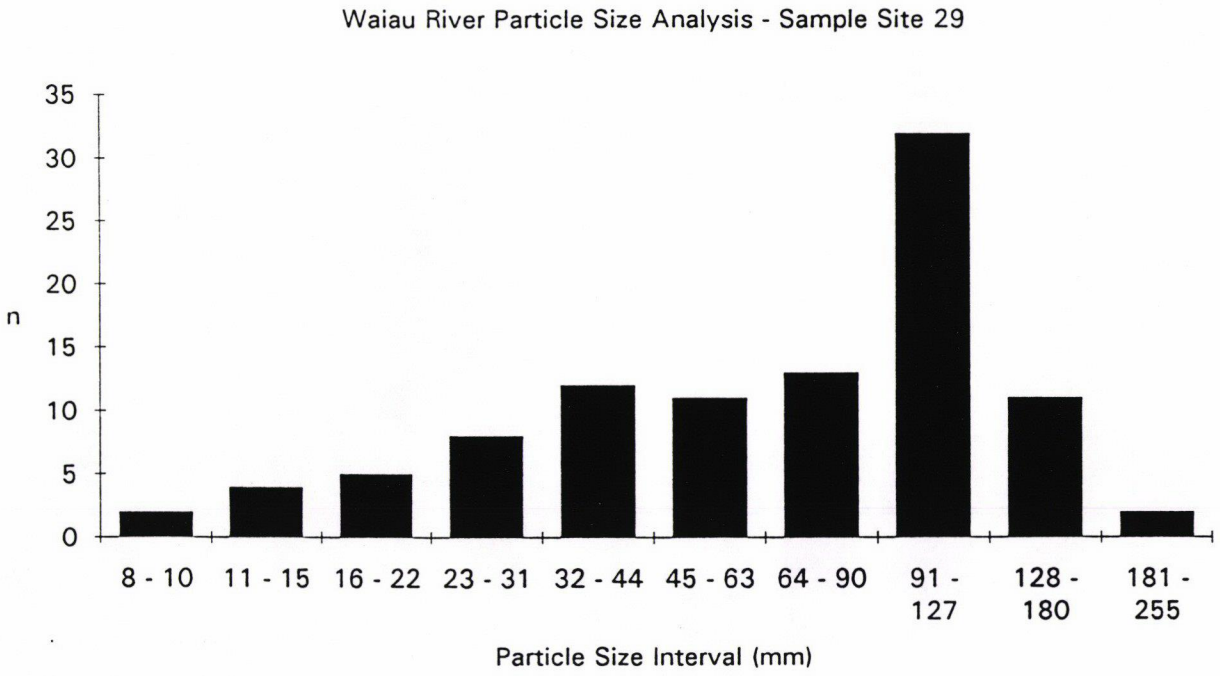
GRAVEL BAR CONDITIONS
Sorting: Moderate to poor.
Packing Arrangement: Discrete sheets observed adjacent to sample. Along sample transect gravels are largely unwinnowed, jumbled and only occasionally imbricated.
Shape: Subrounded to platey.
Lithology: Mixed igneous.
Other Characteristics: Irregular bar with much recent modification. Scour is noted adjacent to bank, while many sheets of finer gravels are being washed onto the bar surface.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 29 *Grid Reference:* 976360
Bar Type: Compound point bar.
Position on Bar: Water's margin at the bar head.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 91-127mm
D95 149mm
D84 125mm
D50 79mm
Mean 80.7mm
S.D. 46.7mm

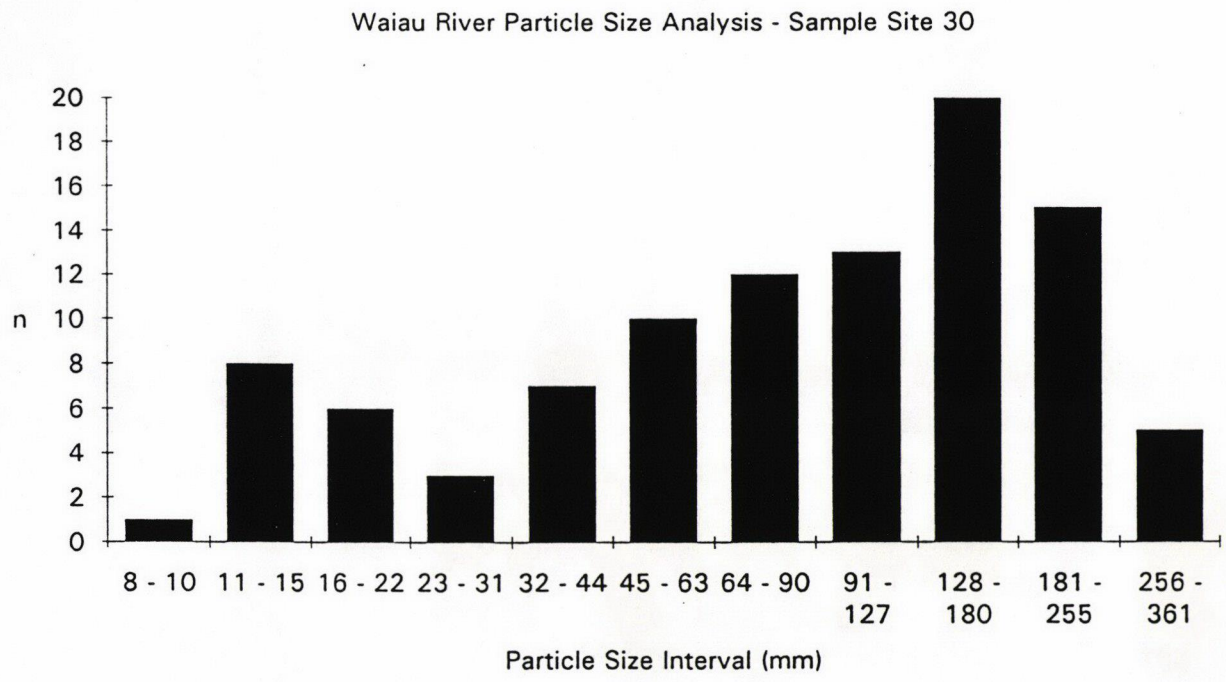
GRAVEL BAR CONDITIONS
Sorting: Moderate to poor.
Packing Arrangement: Distinct gravel locales evident. Gravels are generally relatively loose and not imbricated.
Shape: Predominantly subrounded, with a significant proportion of platey particles.
Lithology: Coarser clasts are granitic, but these appear to be less abundant than upstream.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 30 *Grid Reference:* 971346
Bar Type: Compound point bar.
Position on Bar: Sample oriented down a chute channel at the bar head. The sample was not collected adjacent to the main channel; rather it was collected beyond a series of sheets at the chute head and was located at the chute tail. This chute channel has clearly short-circuited the bend, and is relatively steep and scoured.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 128-180mm
D95 240mm
D84 190mm
D50 94mm
Mean 109mm
S.D. 76.3mm

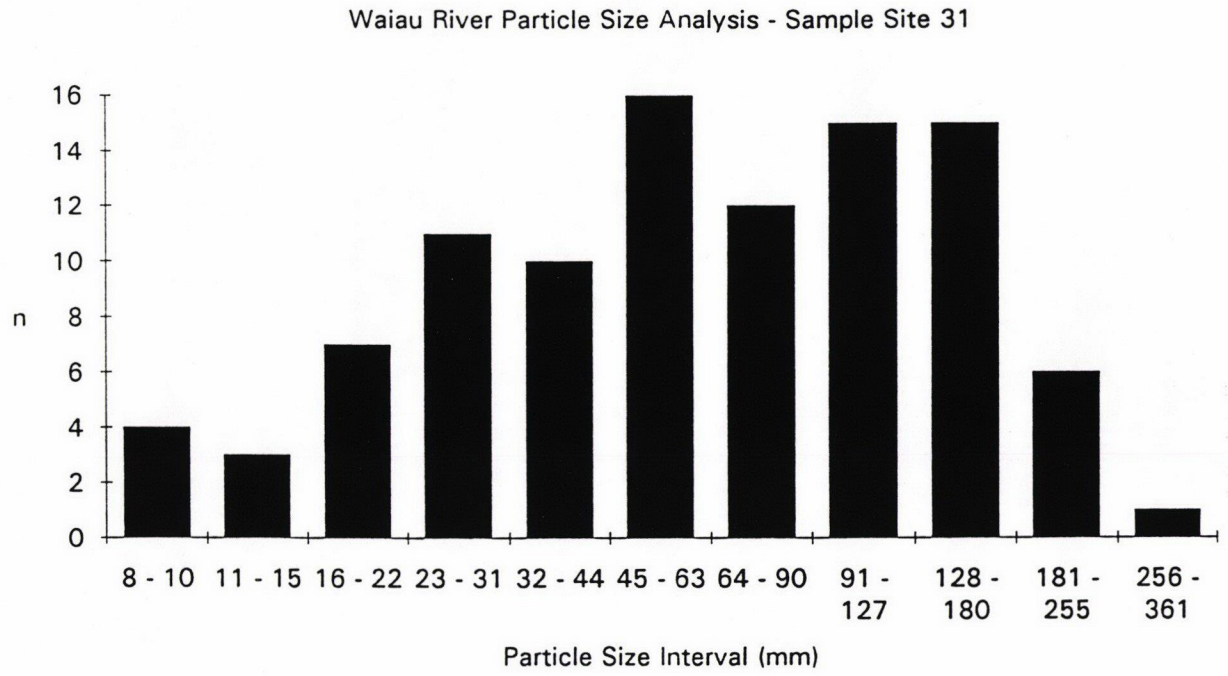
GRAVEL BAR CONDITION
Sorting: Very poor.
Packing Arrangement: Coarser clasts appear well packed, while finer materials (<70mm) have been loosely draped over the bar surface at the head of the chute channel (a chute bar?). Gravels are moderately imbricated but somewhat jumbled.
Shape: Subrounded to platey.
Lithology: Mixed igneous.
Other Characteristics: Sample may be in bar supra-platform particles, associated with basal scour into floor of chute channel.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 31 *Grid Reference:* 968339
Bar Type: Compound point bar.
Position on Bar: Aligned across the bar, rather than around the bend, as this is the configuration of the imbricated bar surface gravels.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 45-63mm
D95 193mm
D84 146mm
D50 54mm
Mean 80.3mm
S.D. 59.5mm

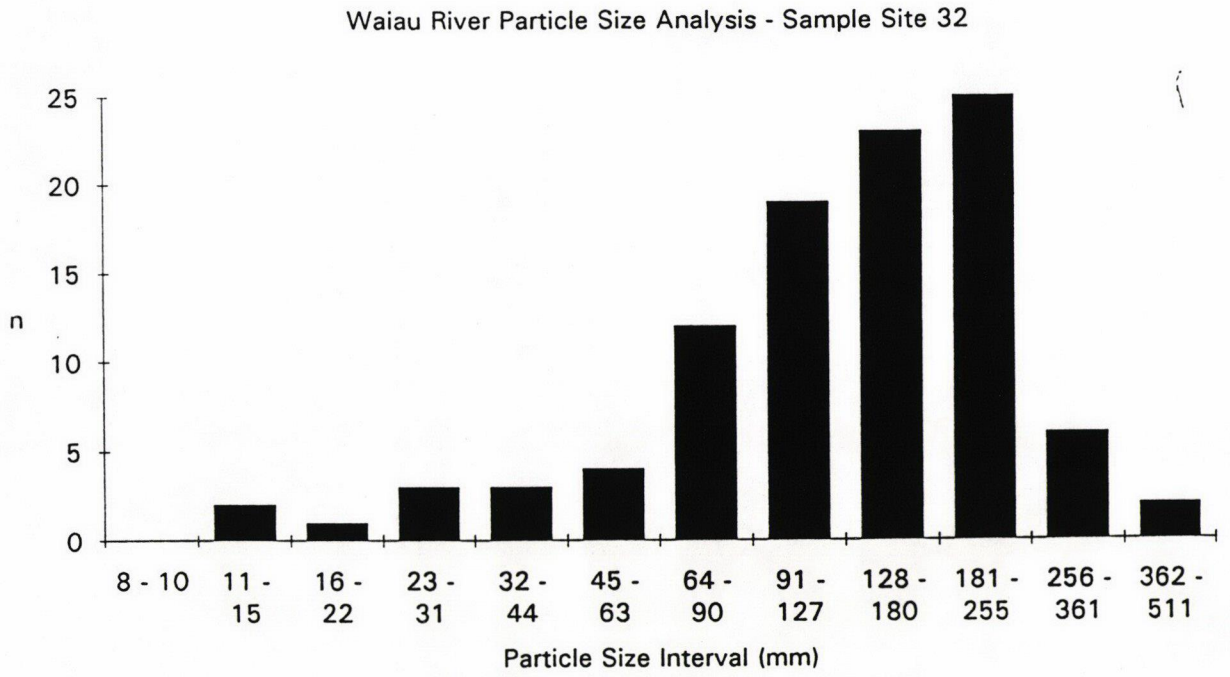
GRAVEL BAR CONDITIONS
Sorting: Very poorly sorted, with fines trapped in the lee of large boulders.
Packing Arrangement: Moderately to well imbricated and packed, but unwinnowed, with mud drape.
Shape: Subrounded to platey.
Lithology: Mixed igneous.
Other Characteristics: Many logs on bar surface.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 32 *Grid Reference:* 957334
Bar Type: Compound point bar.
Position on Bar: Oriented down valley (rather than around the bend) in accordance with alignment of imbricated clasts.
Sample Type: 1x100m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 181-255mm
D95 265mm
D84 224mm
D50 142mm
Mean 149mm
S.D. 80.1mm

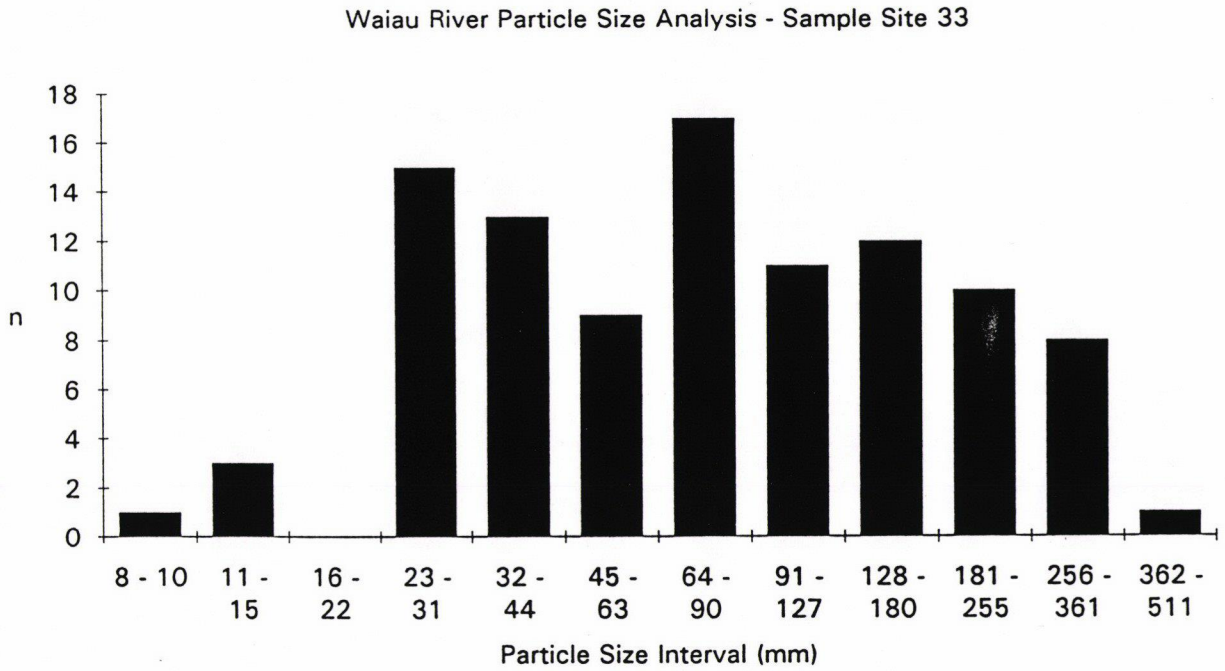
GRAVEL BAR CONDITION
Sorting: Moderate to poor.
Packing Arrangement: Moderately packed and imbricated, with only a small proportion of gravels <60mm.
Shape: Subrounded with a few platey.
Lithology: Mixed igneous.
Other Characteristics: Totally unvegetated (scoured?) bar surface, with many logs. Gravels are slimey in the adjacent channel.

SAMPLE SITE CHARACTERISTICS

SITE DETAILS AND DESCRIPTION

Sample Number: Waiau 33 *Grid Reference:* 946326
Bar Type: Mid-channel bar.
Position on Bar: Adjacent to vegetation in mid-bar. Sample located in scour unit downstream of a large log.
Sample Type: 2x50m

PARTICLE CHARACTERISTICS
Histogram



Modal grain size class: 64-90mm
D95 275mm
D84 185mm
D50 76mm
Mean 104mm
S.D. 85.4mm

GRAVEL BAR CONDITION
Sorting: Very poor.
Packing Arrangement: Partly imbricated and moderately packed. Much reworking of deposits is evident. Surface is not well winnowed; a distinct mud drape covers the surface following the opening of the Mararoa control gates a week earlier.
Shape: Subrounded to platey.
Lithology: Mixed igneous.
Other Characteristics: Many discrete locales are evident on the bar surface, separated by a range of chute channels of differing scales and orientation.

APPENDIX 3 : River particle size data

In this appendix the particle size data is presented for the 33 Waiau River sites sampled.

Summary particle size parameters include;

Percentile data (D95, D84, D50, D16, D5)

Mean and Standard Deviation data

Distance Upstream from River Mouth

Number of clasts less than 8mm (b-axis dimension)

Sample Type (1x100m or 2x50m)

The actual raw data (b-axis dimension) for the hundred clast size measurements made at each sample site is also included.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
Summary Particle Size Parameters																																		
Percentile Data																																		
Sample:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	
D-95	178	178	157	170	177	132	119	250	170	163	180	159	166	138	167	139	145	215	262	195	174	173	215	193	167	172	202	175	149	240	193	265	275	
D-84	154	126	116	133	148	108	88	174	147	132	136	133	116	104	143	92	109	166	219	161	120	134	167	156	144	150	174	127	125	190	146	224	185	
D-50	90	73	75	86	74	65	48	84	83	73	84	74	69	57	84	56	64	112	132	84	74	89	98	105	79	84	101	68	79	94	54	142	76	
D-16	32	16	35	29	16	28	21	31	45	30	35	28	31	35	39	31	35	46	53	33	36	31	43	37	23	37	47	36	28	26	25	68	28	
D-05	13	9	18	14	10	13	12	16	27	16	13	17	20	27	12	19	19	19	31	10	20	16	19	14	12	24	16	17	13	12	14	26	24	
Mean and Standard Deviation Data																																		
Sample:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	
Mean	92.8	77.8	77.3	87.5	82.2	69.6	55.1	103	94.8	82.5	86.4	81.1	77.1	68.5	88.9	62.8	71.3	114	137	94	81.8	86.2	106	106	87.5	94.2	107	79.5	80.7	109	80.3	149	104	
Std Dev	53.5	51.7	43	49.5	54.4	37.2	33.6	73.2	48.3	48.4	49.2	45.7	48.8	36	47.4	34.7	38.2	58	73.6	57.2	44.3	51.1	63.6	58.1	54.5	51.2	56.6	46.3	46.7	76.3	59.5	80.1	85.4	
Miscellaneous																																		
Sample:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	
Distance Upstream from River Mouth (km)																																		
	97.7	93.3	86.9	86	78.5	75.8	71.7	66.4	62.8	55.2	47.2	44.6	40.9	38.8	35.4	32.3	29.3	27	26.2	23.8	22.8	16.9	12.5	11.4	10.9	9.4	8.7	7.8	7	4.6	3.9	2.4	0.7	
# Clasts <8mm																																		
	12	5	6	21	3	4	2	13	22	14	1	7	3	11	2	11	3	2	4	39	11	5	7	6	11	18	8	7	13	5	7	8	19	
Sample Type (*)																																		
	A	A	A	A	A	B	B	B	B	B	B	A	A	A	B	B	A	A	B	A	A	A	B	B	B	A	A	A	A	B	A	A	B	
* A = 1x100m; B = 2x50m																																		

Waiau River Particle Size Analysis - Raw Grain Size Data

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1	105	109	157	62	11	40	102	127	17	188	82	26	92	149	47	113	76	33	104	42	61	31	120	133	164	62	75	126	26	148	79	95	64
2	37	265	83	219	84	56	154	141	9	236	167	164	56	129	168	113	80	220	14	79	166	92	23	66	23	80	71	36	72	18	59	167	26
3	56	134	16	11	164	15	39	99	104	32	130	153	28	27	114	44	65	45	10	39	157	68	137	9	86	68	74	123	70	19	42	76	163
4	164	48	190	152	43	82	149	84	172	63	151	73	73	18	120	80	185	99	43	80	50	108	17	150	9	53	63	18	27	15	87	18	99
5	48	340	78	219	137	58	109	48	11	133	101	116	10	59	104	52	107	68	59	47	130	81	40	62	104	43	130	18	39	46	65	194	44
6	85	32	97	103	22	57	19	25	83	75	182	23	9	33	144	63	109	109	80	147	68	76	46	159	156	82	103	46	88	73	88	95	58
7	206	270	45	68	135	46	45	98	26	395	55	55	73	134	109	94	63	77	126	88	196	109	24	162	177	46	73	35	56	55	42	82	58
8	170	43	63	26	208	166	78	87	75	84	137	129	38	12	98	181	35	97	122	162	156	160	152	138	76	40	8	59	52	124	108	158	98
9	115	29	72	32	153	176	51	97	123	231	103	20	36	44	18	74	72	134	58	175	38	55	31	71	68	16	69	45	67	81	136	12	59
10	39	155	134	83	39	58	142	263	84	78	68	194	51	33	117	77	144	79	15	104	154	104	8	118	49	70	18	84	121	76	84	181	23
11	150	14	10	37	231	95	145	75	78	98	97	64	86	43	135	110	67	79	9	90	33	113	198	104	102	150	84	40	102	33	187	18	85
12	96	29	36	30	11	57	88	223	126	54	176	136	50	50	75	59	107	20	92	15	84	118	163	116	149	108	73	83	57	139	113	40	13
13	28	32	217	37	189	55	97	112	124	160	135	11	117	107	129	9	9	237	204	130	45	88	122	93	52	68	55	90	129	48	90	78	125
14	153	28	146	293	41	103	89	112	54	215	77	114	30	49	56	82	61	165	56	133	144	79	110	107	128	105	114	21	88	158	225	78	78
15	188	64	124	19	145	168	123	129	30	124	81	33	50	91	103	146	144	88	57	90	34	41	108	137	118	45	32	40	76	32	203	82	17
16	147	137	142	46	31	135	8	108	102	175	149	141	29	30	21	44	62	40	198	167	150	184	30	33	114	27	202	54	56	68	124	185	140
17	28	172	164	84	154	94	32	215	32	55	158	85	37	37	124	94	145	28	99	28	136	122	84	36	114	80	28	16	32	149	54	56	77
18	212	61	97	20	230	130	123	142	161	92	146	112	51	31	26	150	65	135	184	8	165	30	17	208	26	60	61	104	71	102	87	182	53
19	197	24	139	108	40	30	144	85	15	65	73	13	30	43	13	75	42	46	94	11	129	177	95	19	60	56	45	52	109	41	108	28	128
20	45	12	13	233	146	116	34	54	40	116	66	89	33	50	49	123	124	133	25	127	153	12	19	91	73	31	45	68	82	22	60	36	8
21	115	103	115	16	64	158	56	184	26	244	200	40	22	19	56	114	46	27	13	181	93	84	119	136	52	58	152	36	49	38	51	52	56
22	69	27	184	13	133	165	94	76	112	28	221	76	30	79	34	68	113	112	10	41	26	103	131	162	24	28	63	124	56	104	93	50	109
23	54	32	181	17	124	170	122	187	114	130	170	12	38	129	38	36	58	90	162	113	47	129	91	114	8	19	108	12	26	58	168	39	13
24	244	39	90	58	134	142	60	89	90	287	73	134	134	85	152	61	36	8	75	152	104	124	107	53	87	57	13	41	48	106	65	62	28
25	82	119	186	48	82	115	44	233	49	105	72	79	27	20	108	120	139	50	148	39	80	8	85	115	42	47	36	88	20	50	29	48	40
26	144	75	108	54	120	42	273	103	166	142	202	120	114	109	143	128	57	54	105	38	147	58	133	133	9	81	121	38	98	100	59	120	86
27	23	28	86	79	130	76	91	72	155	203	116	144	56	137	98	57	154	120	11	124	83	111	106	66	161	35	30	76	35	49	104	36	72
28	25	162	144	229	148	57	127	74	42	24	129	53	54	16	121	152	28	129	10	43	22	47	141	27	21	47	77	72	91	11	18	48	128
29	41	78	141	190	67	108	14	22	200	194	126	71	60	35	104	59	93	9	20	116	48	33	118	99	58	69	127	61	62	94	163	32	44
30	11	49	61	117	50	47	9	44	162	37	88	58	89	131	149	116	87	64	10	114	152	87	84	59	12	83	25	29	49	69	102	69	99
31	53	34	145	148	244	124	73	66	56	152	9	194	35	88	31	50	155	52	114	74	218	225	84	23	14	25	106	41	32	97	42	67	29
32	40	26	133	27	194	120	149	370	63	249	104	12	46	37	104	20	35	52	108	128	172	147	14	60	148	43	162	28	54	36	36	73	84
33	99	30	25	300	82	114	10	98	119	34	101	153	10	9	106	89	137	9	141	163	30	25	58	98	109	88	43	118	60	159	81	67	97
34	63	35	154	137	242	72	127	97	13	91	38	21	75	13	118	57	97	15	73	154	96	74	118	145	83	64	111	101	39	107	29	109	64
35	37	98	130	16	118	165	226	105	122	14	82	147	110	60	126	56	11	42	136	165	24	34	19	57	99	73	93	123	41	85	33	62	69
36	39	45	118	209	217	203	143	31	10	189	40	36	62	159	98	108	48	20	110	80	147	129	118	74	66	124	79	20	27	101	106	71	76
37	31	116	155	192	219	81	92	16	112	170	119	113	59	28	49	89	44	26	73	140	105	11	86	13	114	160	83	87	104	80	46	100	53
38	110	185	62	155	322	126	60	197	45	67	78	62	91	68	40	38	86	136	35	88	37	104	44	119	114	67	9	52	48	8	95	38	64
39	41	70	139	133	208	204	60	154	56	88	121	112	87	144	39	11	17	88	22	119	80	138	107	155	166	37	61	94	33	57	9	117	34
40	162	68	21	143	73	147	156	105	137	184	47	60	73	49	30	114	109	44	76	165	67	10	102	92	16	44	63	73	51	102	148	149	25
41	118	51	243	178	145	153	171	46	82	76	208	25	48	156	28	74	30	95	103	101	130	74	125	22	143	43	20	60	75	86	73	184	111
42	98	375	73	58	161	45	136	110	11	107	95	194	87	67	43	36	118	154	40	143	73	84	121	69	11	39	91	73	58	37	122	148	105
43	63	74	69	227	103	120	100	112	47	120	108	122	118	114	114	84	44	25	85	60	115	92	38	16	183	167	148	12	50	37	180	32	167
44	36	82	173	109	145	147	54	181	101	123	12	113	71	90	96	13	18	148	114	97	83	183	91	157	113	53	225	98	25	49	147	117	96
45	130	39	11	152	148	75	105	160	98	191	221	121	73	207	28	183	41	14	53	153	47	65	134	25	168	37	27	49	52	68	94	74	38
46	97	340	108	258	156	44	131	143	106	177	87	79	137	34	34	158	35	36	66	88	159	171	66	28	32	34	66	67	71	9	67	26	68
47	71	198	119	189	214	37	179	198	40	256	26	126	234	43	76	69	44	246	117	30	164	107	17	27	95	42	89	148	29	23	112	95	86
48	57	255	155	40	234	124	42	167	138	189	214	14	120	46	76	67	31	50	178	121	77	29	110	61	134	22	49	27	138	92	132	25	85
49	51	78	20	136	166	98	139	117	140	246	87	167	75	132	39	70	57	46	93	145	54	84	203	30	64	92	98	46	49	112	75	64	101
50	174	115	106	75	233	27	137	162	22	254	22	50	13	199	61	27	84	15	164	13	35	76	170	61	149	31	25	64	43	147	103	66	128
51	305	157	97	76	215	154	193	153	13	124	156	73	103	90	11	31	73	38	90	148	73	44	125	40	23	57	88	70	89	45	68	66	59
52	106	66	137	87	114	56	36	38	152	286	113	23	73	96	125	53	49	90	56	169	25	112	60	39	13	61	77	59	34	224	35	109	125
53	162	76	92	12	33	77	146	81	68	213	131	71	29	23	126	99	38	110	26	124	44	42	89	28	62	56	22	16	150	35	57	61	84
54	114	76	94	103	121	224	134	82	164	147	93	94	74	33	51	97	62	116	26	98	48	9	98	35	90	32	43	15	43	92	85	59	63
55	70	260	117	16	97	35	202	99	147	147	148	37	156	51	10	174	38	47	9	140	64	173	85	85	9	50	50	20	106	137	39	68	28
56	142	11	100	44	9	161	225	66	67	68	124	100	134	67	80	90	80	198	50	62	100	167	29	20	73	16	32	23	79	101	133	60	132
57	226	210	98	103	132	49	12	100	85	164	63	137	108	130	51	132	68	18	64	140	77	62	157	98	185	88	95	10	184	20	90	104	15
58	80	87	34	68	191	98	122	56	80	85	73	46	245	111	115	203	113	79	36	84	16	153	54	123	16	105	42	48	144	68	97	71	84
59	305	91	93	174	74	90	26	43	189	26	108	148	114	134	76	112	156	261	77	123	108	47	28	121	23	141	75	85	54	150	27	55	67
60	75	155	112	293	182	47	141	84	158	410	197	10	70	89	124	40	78	95	57	13	117	13	143	163	10	138	104	48	34	139	15	37	70
61	26	275	101	199	110	156	27	44	23	265	130	137	104	54	21	113	159	117	105	139	48	62	73	55	49	49	159	67	87	76	16	159	24
62	84	57	86	157	288	54	71	131	170	46	182	166	57	9	74	57	69	48	188	42	49	45	116	90	62	21	34	39	80	77	154	53	65
63	107	28	112	62	93	29	192	113	42	87	144	84	94	113	224	112	48	27	130	170	119	216	47	124	136	30	104	49	57	75	102	68	22
64	14	46	19	263	33	128	26	98	43	114	197	120	160	174	74	84	69	26	136	167	88	161	127	77	101	66	77	57	44	49	20	87	97
65	103	87	175	136	184	33	154	115	16	153	181	56	132	23	156	44	45	148	13	23	112	14	110	17	167	139	43	167	93	75	72	131	77
66	202	27	147	140	254	62	79	43	51	74	41	26	83	171	84	107	125	75	120	9	131	87	122	71	58	27	70	67	56	54	99	156	38
67	26	26	81	42	123	15	96	117	134	185	16	141	136	71	41	71	34	56	9	110	41	70	56	79	52	62	43	34	37	32	13	162	69
68	264	55	166	126	135	172	109	185	39	148	53	63	125	194	20	51	68	180	69	68	117	42	194	19	107	74	203	37	33	127	37	149	29
69	44	80	110	187	65	59	156	140	80	179	105	111	109	173	72	104	46	37	28	91	46	60	70	77	40	94	26	84	124	105	194	70	128
70	36	24	124	215	9	31	125	19	152	121	136	33	147	31	13	35	41	28	104	50	21	10	50	83	186	42	23	33	28	96	57	56	49
71	32	79	44	93	38	144	122	56	90	162	99	144	116	169	26	48	42	50	74	98	138	92	61	61	166	19	116	51	59	62	71	37	126
72	155	38	93	154	31	120	184	57	119	154	107	28	36	99	90	70	37	19	63	83	63	217	117	123	10	58	31	9	170	37	155	55	48
73	8	9	218	12	68	110	54	182	57	214	179	23	93	164	124	29	50	27	93	77	106	180	39	58	187	35	47	27	36	58	96	24	139
74	186	104	104	128	298	112	109	17	22	133	77	16	127	171	126	74	61	52	94	83	28	53	69	100	150	114	78	105	48	47	80	24	63
75	27	305	160	240	265	119	65	143	178	132	56	162	117	188	122	30	86	155	101	58	30	136	108	33	29	66	197	39	126	158	126	64	85
76	10	103	173	84	158	83	136	179	117	248	171	133	108	103	34	53	30	43	91	84	52	150	202	57	204	75	36	27	110	104	74	120	33
77	242	157	152	179	164	147	180	74	192	216	32	194	168	111	144	157	68	25	108	33	127	67	50	192	93	65	54	26	53	75	39	38	63
78	74	52	138	202	90	85	104	57	43	127	214	19	16	89	135	52	84	32	55	100	43	33	138	45	55	47	94	33	52	113	9	68	108
79	264	148	154	58	62	83	103	74	106	207	174	8	165	131	30	44	87	87	122	12	126	85	54	119	11	31	101	61	61	188	51	175	72
80	88	290	46	167	104	76	260	35	126	19	40	110	116	118	10	105	23	124	85	63	32	144	105	96	109	112	99	60	83	65	52	80	50
81	290	185	88	154	142	65	96	199	190	209	12	139	77	34	88	106	82	22	9	69	221	138	68	32	125	30	30	85	42	116	189	109	63
82	103	68	21	55	262	73	101	11	167	187	52	190	46	120	39	99	47	22	8	77	24	19	51	64	35	50	62	12	58	36	97	17	8
83	92	198	232	189	114	45	30	155	154	105	151	14	105	121	194	27	91	95	123	58	114	67	76	86	173	36	161	119	53	97	110	95	38
84	98	35	165	130	122	135	148	22	132	137	79	163	62	101	48	37	33	146	31	14	116	43	165	50	100	27	229	73	83	82	12	114	80
85	250	234	207	14	98	115	127	205	169	158	54	136	65	104	25	82	54	23	58	103	37	28	152	76	15	152	77	18	50	29	40	36	13
86	73	106	35	61	125	42	146	44	213	213	85	41	147	103	113	24	28	184	39	12	173	19	58	57	147	39	146	15	47	119	125	11	65
87	27	40	98	13	223	74	144	150	47	249	12	39	30	98	46	134	34	10	146	26	80	173	91	102	80	77	127	101	22	88	111	104	22
88	141	116	95	34	226	79	104	159	136	142	18	150	90	95	117	63	19	40	49	49	139	207	101	86	94	53	166	62	107	95	93	70	29
89	115	181	46	99	51	91	41	30	124	224	90	8	198	64	20	144	95	38	33	40	131	174	37	58	79	123	45	20	85	57	59	17	19
90	176	41	127	97	294	69	157	27	51	335	64	116	54	114	61	106	64	193	44	102	57	82	55	66	74	48	48	33	67	53	112	113	99
91	82	147	24	10	88	96	184	12	112	123	47	58	48	113	108	55	70	53	158	72	100	195	13	144	105	47	88	83	36	124	149	66	81
92	16	24	119	62	92	68	112	80	59	88	179	76	72	87	104	29	102	50	27	69	83	9	9	137	48	67	69	29	106	92	148	50	74
93	120	28	77	94	107	124	161	98	77	11	102	23	150	120	34	90	53	29	12	128	121	136	132	22	12	32	82	23	35	85	9	103	86
94	144	154	153	68	53	73	118	82	120	127	77	69	163	104	79	60	55	22	90	68	59	103	20	133	36	82	42	31	72	93	130	48	137
95	72	28	215	101	167	78	23	76	32	180	32	108	91	97	99	97	64	94	22	64	128	120	124	99	35	57	58	22	42	30	136	73	52
96	77	181	197	65	152	55	37	223	91	110	19	114	70	155	13	191	67	172	167	67	170	188	185	11	114	58	24	89	83	58	63	130	52
97	24	36	122	13	187	23	14	113	79	100	81	159	48	40	119	68	69	91	53	61	69	69	103	55	120	72	43	30	199	47	24	53	66
98	88	172	288	84	246	132	96	24	119	261	202	40	133	20	39	174	68	107	179	62	222	200	22	109	58	111	32	38	80	37	73	8	38
99	76	67	117	12	126	39	87	106	27	92	123	18	29	23	90	8	72	159	113	78	96	74	13	116	46	36	79	36	71	34	78	75	118
100	64	118	204	93	116	163	166	97	70	211	92	34	97	115	45	35	132	45	16	43	69	67	74	72	54	17	45	28	108	44	144	62	63

b axis clast size (mm)

APPENDIX 4

VEGETATION OF THE LOWER WAIAU

by

Sue Bennett

In conjunction with the geomorphological survey of the lower Waiau river, a cursory botanical survey was also made.
While this in no way aims to be a comprehensive inventory of all the plant species and their density and distribution in the sampled area, it does, however, provide a baseline database of the riparian vegetation of the lower Waiau.
It is included here as an Appendix to the Geomorphological Study and, as such, is arranged on a reach by reach basis.

Sue Bennett
Te Anau

April 1992

DUNCRAIGEN REACH

Valley Sides: Pasture on upper terraces. Gorse (*Ulex europaeus*) and broom (*Cytisus scoparius*) on terrace risers and lower terraces. Some beech (*Nothofagus* sp.)

Channel Banks: Gorse, broom, some beech. Grasses, dock (*Rumex* sp.), monkey flower (*Mimulus guttatus*), watercress (*Rorippa nasturtium-aquaticum*) and willow weed (*Polygonum* sp.) growing densely on left bank, in seepage moisture.

Gravel Bars: Sparsely vegetated. Occasional rushes (*Juncus articulatus*), dock, monkey flower, watercress, willow weed, pearlwort (*Sagina procumbens*) and cudweed (*Gnaphalium* sp.).

REDCLIFF REACH

Valley Sides: Paddock Hill has been burned and has remnants of native bush in the gullies with scrub on burned areas. To the East is a pine plantation (*Pinus radiata*) on the higher terraces, pasture on lower terraces and scrub on terrace risers.

Alluvial Flats: Grasses and ragwort (*Senecio jacobaea*).

Channel Banks: Grasses, toe-toe (*Cortaderia richardii*), manuka (*Leptospermum scoparium*), willow (*Salix fragilis*), *Coprosma* sp., gorse and broom.

Gravel Bars: Sparsely vegetated. Occasional rushes, dock, ragwort, pearlwort, willow weed, cudweed and lupin (*Lupinus arboreus*). Some semi-permanent islands with grasses, toe-toe, manuka, willow, gorse and broom. Those bars closest to the main channel are vegetated with grasses only.

BLACKMOUNT-MANGAPIRI REACH

Blackmount Sub-reach

Valley Sides: Pine plantation on East (Blackmount Forest). Native bush on West (flanks of Titiroa) with pasture and occasional patches of bush on Western terraces.

Alluvial Flats: Pine plantation on East, also beech, manuka, eucalypts (*Eucalyptus* sp.), broom. Scrubby terrace on West.

Channel Banks: Grasses, toe-toe, flax (*Phormium tenax*) and willow. Dense herbaceous weeds in silty deposits on channel margins: lupin, lotus (*Lotus pedunculatus*) and St. John's wort (*Hypericum* sp.).

Gravel Bars: Sparse vegetation including thallose liverworts, *Coprosma* seedlings, grasses, rushes, dock, cudweed, willow weed, lotus, monkey flower, pearlwort, watercress, water speedwell (*Veronica anagallis-aquatica*), Scarlet pimpernel (*Anagallis arvensis*), buttercup (*Ranunculus* sp.), clover (*Trifolium repens*), forget-me-not (*Myosotis* sp.) and *Pratia* sp..

Monowai Sub-reach

Valley Sides: Bush.

Channel Banks: Bush, grasses, toe-toe, willow, flax and lotus.

Gravel Bars: Sparsely vegetated. Mainly grass, also dock, pearlwort and lotus.

Waicoe Sub-reach

Valley Sides: Terraces in pasture, with scrub on terrace risers and valley sides. One small patch of bush on right, downstream of compound bar.

Alluvial Flats: Grasses, toe-toe, flax, cabbage trees (*Cordyline australis*) and bracken (*Pteridium esculentum*).

Channel Banks: Native scrub; manuka, kowhai (*Sophora microphylla*), *Pittosporum tenuifolium*, *Olearia avicennifolia* and cabbage tree. Some broom and willow.

Gravel Bars: Almost zero vegetation. Occasional grasses and lupin.

Mangapiri Sub-reach

Valley Sides: Native bush on right (Dean Forest) and on left at Taylors Bush and Mangapiri Bush. Predominantly pasture on valley flats.

Alluvial Flats: Grasses, cutty grass (*Carex coriacea*), Californian thistle (*Cirsium arvense*), gorse and willow.

Channel Banks: Native bush; beech, *Pittosporum*, *Olearia*, tutu (*Coriaria* sp.), toe-toe, cabbage tree, ferns and flax. Willow present. Grasses along channel margins, also ragwort and lotus.

Gravel Bars: Sparse grasses. Some ragwort, pearlwort, cudweed, thistle, dock, watercress, water speedwell, buttercup, clover and lotus.

WAIRAKI REACH

Valley Sides: Motu Bush on right. Pasture on terraces.

Alluvial Flats: Scrubby pasture, grasses and gorse.

Channel Banks: Scrubby pasture, grasses and gorse.

Gravel Bars: Active gravels unvegetated. Stable bars have grasses and gorse. Some willow.

MOTU REACH

Valley Sides: Bush on right. Pasture on terraces (Otahu flat) on left.

Channel Banks: Beech, willow, gorse and broom, with grasses.

Gravel bars: No gravel bars.

LILLBURN REACH

Valley Sides: Bush on valley sides, increasing in density further away from the river. Terraces in pasture, with tree lanes of pine and flax.

Alluvial Flats: Willow, gorse and grasses. Flax and rushes on recently formed alluvial flats on inside of bend at confluence.

Channel Banks: Willow, broom, gorse and grasses.

Gravel Bars: Many unvegetated bar surfaces although many also have grasses, cutty grass, toe-toe, lupins, gorse, broom and some willow.

SUSPENSION BRIDGE REACH

Valley Sides: Pasture on valley flats. Pine plantation on distant right side.

Channel Banks: Patch of native bush on left bank. Willow, cabbage tree, flax and grasses on right bank.

Gravel Bars: No gravel bars.

DOWNSTREAM O'CLIFDEN

Valley Sides: Largely cleared of bush. Pasture on valley flats with tree lanes of pine.

Alluvial Flats: Grasses, ragwort, gorse, willow and manuka.

Channel Banks: Remnant patch of totara (*Podocarpus hallii*) and beech on left bank. Willow and gorse on right.

Gravel Bars: Mainly grass with ragwort, lupin and gorse. Active gravels are unvegetated.

HAGEN ROAD REACH

Valley Sides: Partly cleared, pasture, with pine plantation to the distant right.

Alluvial Flats: Grasses with gorse and willow.

Channel Banks: Willow (exposed bedrock).

Gravel Bars: No gravel bars.

ORAUEA REACH

Valley Sides: Distant bush on both sides, partly cleared closer to terraces. Pasture on terraces.

Alluvial Flats: Willows, gorse, rushes, grasses and catsear (*Hypochoeris radicata*).

Channel Banks: Bush on both banks, with willow on left bank.

Gravel Bars: Generally unvegetated. Sparse grasses and watercress.

TUATAPERE REACH

Valley sides: Pasture on terraces. Native bush in distance.

Alluvial Flats: Grasses, some broom and gorse. Willow abundant.

Channel Banks: Grasses and willow. Some gorse and broom.

Gravel bars: Generally unvegetated; some grasses, dock, lupin, watercress, willow weed and Scarlet pimpernel.