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Tributary river reach analysis of Waiau River catchment, Southland

Final report submitted to Waiau River Working party as part of the project entitled "Tributary reach analysis of Waiau River" by

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Preface

The rivers are our brothers, they quench our thirst. The rivers carry our canoes, and feed our children. If we sell you our land, you must remember, and teach your children, that the rivers are our brothers, and yours, and you must henceforth give the rivers the kindness you would give any brother.

Excerpt from the reply by Chief Seattle (1854) to the offer for a large area of Indian land made by the "Great White Chief" in Washington

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Summary

1) Contribution of Geomorphology to Waiau River Working Party

Numerous reports written as part of the Tributary River Reach Analysis project constitute baseline information on the geomorphological behaviour of Waiau catchment. Combined with the channel adjustments report, this provides direct insight into river responses to flow regulation associated with Manapouri Power scheme. This information is used to suggest two potential monitoring programs that can be established by Waiau River Working party, assessing long-term changes in the sediment budget of lower Waiau River and using geomorphology as a basis to assess river health.

2) Use of baseline data on river behaviour

The assessment of river character and behaviour for Waiau trunk stream, Mararoa River, Whitestone River, Home Creek, tributary streams draining from the Takitumu's (Excelsior, Whare and Redcliff Creeks), Borland Burn, Wairaki River and Lill Burn constitute primary data for comparison in future years. The reach analysis framework, which outlines the geomorphologic character of sections of river defined on the basis of physical parameters, forms a suitable framework for assessment of subsequent adjustments. Series of photographs, grain size statistics and assessment of the assemblage of geomorphic units in each river reach can form the baseline for comparison of changes for decades into the future. Such information would ideally have been compiled prior to implementation of Manapouri Power Scheme, such that direct basis for assessment of system response to flow regulation could have been determined.

3) Geomorphological responses to altered flow regimes

Principles of environmental and channel maintenance flows are briefly outlined and their application to the altered flow regime of Waiau River is discussed. Emphasis is placed on the need to model the sediment budget of Waiau River under the modified flow regime and develop a monitoring program to assess impacts on future sediment movement and implications for river health.

4) Proposed development of a sediment budget model

It is proposed that a hydraulic engineering exercise be undertaken to model the implications of the altered flow regime of Waiau River on the sediment budget of the system, in terms of both the calibre and volume of material moved. This exercise should retrodictively assess the impacts of the modified flow regime over the past 25 years, and predict likely system responses to the proposed low-level (environmental) flow/reduced flood duration-lower peakedness flows.

5) Sediment monitoring

Reliability of the sediment budget model must be ratified by field measurement in a long-term monitoring program. The proposed framework has three components, assessing sediment

composition and build-up in the lower course of the river, changes to the longitudinal profile of the lower course, and assessment of adjustments to the river and barrier system from air photo analysis.

6) Assessment of river health

It is proposed that geomorphology forms an ideal basis for assessment of the relative health of Waiau River. Unless some form of measurement is performed to assess the relative condition of Waiau River at present, there will be no framework to assess whether system health has improved or otherwise. A range of criteria that can be used to measure river health are outlined, and a community-based approach to prioritorise measures of river health is proposed. It is suggested that this framework could be applied using an approach called "Adaptive Environmental Assessment and Management".

1.1. Geomorphology and Integrative catchment management

> *"It is the key concept in the wider education of politicians, planners and the public that river systems are an interconnected transport system, albeit often working invisibly ... or over extremely long timescales. ... The essential thing about water management with an environmental objective is that the catchment or river basin is an easily appreciated plan projection of the ecosystem requiring management, an area within which the population have one form of common identity. Consequently ... river basins are an ideal unit for many forms of environmental management and popular participation."*
>
> Newson, 1992, pp 19-21; 242-243

> *"Any river ... tends to express the sum of the activities occurring in the basin. ... River conservation is ... largely a problem of conservation of catchment areas."*
>
> Welcomme, 1992, p454

Drainage basins have been defined as the fundamental geomorphic unit (Chorley, 1969). Interconnected sets of processes that operate within river catchments form the dynamic context within which landscape changes and material redistribution take place. Changes to the geomorphologic character of rivers have profound implications for numerous other attributes of river behaviour, such as water quality, riverine habitat, riparian vegetation, etc. Hence, understanding of the within-catchment distribution of geomorphological processes must form the basis for integrative catchment management and assessment of river/catchment health. Prior to assessing human impacts on river character and behaviour and their implications for system health, the 'natural range of behaviour' of the system must be determined.

Geomorphology can contribute significant information at all stages in 'development' programs:

(i) Baseline assessment of catchment condition

Pre-impact surveys to determine system character and dynamics can be used to assess controls on the spatial and temporal variability of differing processes and their interaction. Process-based behaviour of the system, assessed over decadal intervals, must evaluate interactions between processes operative on slopes, within the river network, and at the river mouth. Such information forms the basis for assessment of river/catchment stability and identification of potential 'sensitive' zones for further catchment disturbance.

(ii) Process monitoring and post-impact assessment: Environmental Auditing

Background insights into system behaviour can be used to predict likely future changes in response to external impacts. While direction of adjustments can be readily extrapolated from trends, prediction of rate of change is much more difficult. Feedback linkages may induce complex responses, wherein the system responds in differing ways to events of similar type and magnitude. For example, system sensitivity to change is hard to determine if threshold conditions are breached. Monitoring programs should be implemented, and data used to evaluate the reliability of predictions. Contingency plans can be established to determine response programs should certain situations eventuate. In turn, predictions can be modified as more insights into system behaviour become available.

(iii) Assessment of system/catchment health

Relationships between geomorphology/hydrology and in-stream ecology can be used to determine measures with which to evaluate river/catchment 'health'. Application of monitoring programs to measure system 'health' can evaluate progress made in achieving management goals, aspects of relative improvement or deterioration can be isolated and addressed, and goals for the future can be targeted. Implicit within each step in this process is community involvement in policy determination.

1.2 Application of Geomorphology to Waiau River Working Party

No pre-impact assessment on the geomorphic character of Waiau catchment was undertaken prior to implementation of the Manapouri scheme, and hence no prediction of likely geomorphologic responses was determined. Baseline surveys of catchment character have been produced for Waiau River Working Party (WRWP) by fluvial (river) and coastal geomorphologists. A series of reports have provided background assessment of river and barrier character and dynamics (eg baseline character of Waiau trunk stream (Brierley, 1992) and various tributary streams (Brierley, 1993, a-h; Brierley, 1994a, b); similar study of the coastal barrier system (Kirk and Shulmeister, 1994)). Assessment of regulation effects on channel adjustments has also been performed (Brierley and Fitchett, 1994).

Work completed in the "Tributary river reach analysis" project has been concerned with baseline geomorphological surveys of tributary catchments, as the character of Waiau River must be viewed in context of the condition of the catchment, which is largely driven by the tributary network. In many catchments, river character changes dramatically downstream of tributary confluences, as the relationship between flow and sediment availability is altered and the space within which the river can adjust is enlarged. This project has provided an extension to the baseline inventory of river character completed initially for the trunk stream of Waiau River from Mararoa Weir to Te Waewae Bay (Brierley, 1992). Analysis of the trunk stream was extended upstream to Pearl Harbour reach (between Lake Manapouri and Mararoa Weir) and Wairoa (Upper Waiau) reach (between Lakes Te Anau and Manapouri) (Brierley 1993a, b), prior to completion of a series of reports characterising the behaviour of tributary streams (namely Home Creek (downstream from Kakapo Swamp), Mararoa River (downstream from Mavora Lakes), Whitestone River (downstream from Lady Burn), tributaries immediately downstream of Mararoa Weir (Lower Excelsior Creek, Lower Whare Creek, and Lower Redcliff Creek), Borland Burn, Wairaki River, and Lill Burn (Brierley 1993 c-g; 1994a, b). These various reports constitute primary baseline information on the geomorphic character and behaviour of individual reaches of most major tributary streams and their relations to the trunk river. River reach characterisation forms a suitable basis for understanding and predicting river response to future external changes, and assessing linkages between differing components of the 'total' catchment. These insights form suitable bases for assessment and implementation of future monitoring programs, whether to measure sediment transport (Section 2

of this report) or river health (Section 3). More fundamentally, however, these reports record the baseline condition of a large part of Waiau catchment in the early 1990's, with description of geomorphic units that make up each reach, grain size data on bed material, and series of photographs of each significant river feature. In decades to come, when future impacts on the character of Waiau River are assessed, these data will be of major importance as baseline surveys for comparison of river condition and change. The task of environmental auditing would have been all the more pertinent had such studies been performed in the 1960's, prior to implementation of the Manapouri scheme.

Reach characterisation work on tributary catchments performed in this project was supplemented by a summary of the geographic character of Waiau catchment (the 'Regional Setting' report, Brierley et al., 1994) and characterisation of tributary catchment impacts on Waiau trunk stream (Brierley and Beveridge, 1994). Analysis of primary physical characteristics for each tributary catchment and geomorphic impacts at the confluence zone, forms the basis for an MSc thesis presently being undertaken by Alistair Beveridge in the Department of Geography at University of Otago, supervised by Gary Brierley and Sean Fitzsimons. A BSc (Honours) thesis by Amanda Hajnal, completed in the School of Earth Sciences at Macquarie University, under the supervision of Gary Brierley, has also been funded through the 'Tributary River Reach Analysis" project (Hajnal, 1993). This study examined the role played by willows in bringing about significant adjustment in channel character of Mararoa River, stressing the need to develop a multifaceted approach to understanding river form.

At this stage, little assessment of interaction between the river and coastal system has been made, yet this is critical in terms of the integrative behaviour of the system, and the changing character of the system associated with the modified flow regime. Since no predictions were made about river/barrier behaviour at the time of development, no predictions or projections regarding system response to flow regulation were determined. A proposal for monitoring of likely modifications to the sediment budget of Waiau River associated with flow regulation is outlined in Section 2 of this report. It is considered critical to the whole operation of WRWP that environmental auditing be undertaken, and that the effectiveness and reliability of environmental management be assessed such that lessons from this exercise can be carefully applied elsewhere. Suggestions for an approach to environmental auditing of river health are presented in Section 3.

1.3 Impacts of flow regulation on channel adjustments along Waiau River

Boundary conditions which condition the downstream reach character of Waiau River also induce pronounced spatial and temporal variability in the pattern of channel adjustments following flow regulation (Brierley and Fitchett, 1994). Channel adjustments were negligible along most of the river

course, as large sections of Waiau River are constrained by either bedrock or outwash terraces. Channel changes were restricted to those reaches in which the river has the space to shift laterally, namely:

a) Redcliff reach - First laterally unconfined reach beyond Mararoa Weir
b) Wairaki and Lill Burn reaches - Tributary confluence zones
c) Downstream o'Clifden and Tuatapere reaches - Lowland, alluvial reaches

Following flow regulation, Waiau River endeavoured to attain a new equilibrium condition as the width of the active channel zone contracted. Numerous bars became bank-attached as secondary channels were abandoned. Accordingly, there was a reduction in braided index and reduction in channel multiplicity. Effects on channel sinuosity were spatially variable. While sinuosity increased marginally in most laterally unconfined reaches, some subreaches straightened.

A depositional regime prevailed in the decade following flow regulation (1969-1982), until major floods between 1982-1984 induced substantial erosion along most of the river. The channel zone was effectively flushed during these floods, but channel recovery between February-June 1984 was rapid. Impacts of the sustained high discharge condition in late 1988 were most dramatic along the lower course of the river. At sites of long-standing bank erosion, rates of volumetric removal of material were generally greater before flow regulation. Bank erosion seemingly reflects sustained moderate to high flow levels, and flushing of the within-channel zone only occurs during floods > 1500 m^3s^{-1}.

Within-catchment distribution of rainfall during storm events induces significant variability in the character of channel adjustments, as localised erosion downstream of tributary catchments was pronounced for lower catchment runoff events > 800 m^3s^{-1}. In general, discharge conditions between 500-800 m^3s^{-1} were primarily depositional, although localised erosion continued in alluvial reaches. Sites of substantial recent (post-regulation) bank erosion are few in number, and are restricted to:

a) banks adjacent to, or immediately downstream of, tributary confluences, and
b) bends that are expanding as channel multiplicity has reduced, the single channel has become better defined, and sinuosity has increased (cf Mahmood and Shen, 1971).

In general, rates of erosion and deposition were crudely balanced prior to flow regulation. Effects of flow regulation were most pronounced on the first laterally unconfined reach downstream of Mararoa Weir, namely Lower Redcliff reach. This reach was the only reach in which erosion rate diminished after 1969 and was the reach in which deposition rate increased most dramatically. The statistical similarity of rate of change of erosional and depositional adjustments pre- and post flow regulation in

Wairaki, Lill Burn and Downstream o'Clifden reaches is remarkable. In all three reaches there is less than 10 % variability in the relative rates of change of erosion and deposition after 1969. This suggests that whatever balance in erosion and deposition was evident before 1969, it was maintained or reestablished after 1969. In other words, the erosion and depositional regime was either never significantly affected by flow regulation in these reaches or an equilibrium condition has subsequently been regained.

Long-term sediment build-up following flow regulation (recorded as greater rate in increase of deposition over erosion) was recorded in Tuatapere reach. This probably relates to altered fluvial/coastal morphodynamics at the river mouth. The 4 km subreach of Waiau River upstream of the river mouth has experienced the most dramatic change in planform style along the entire river course between 1946-1992. Channel adjustments have been especially pronounced since 1969, as the main channel has become better defined and the river has adopted a more sinuous outline.

2.1 Geomorphological responses to altered flow regimes

"It is clearly wrong to consider that the 'best' river regime for settled, civilised life is a constant flow! Ecologically the pattern of fluvial systems and habitats derives just as much from flow variability through time as from the physiographic and nutritional features of river systems."

Newson, 1992, p72

Channel morphology, sediment character, and riparian vegetation are dynamically adjusted in alluvial rivers, such that change in one variable can modify other parts of the system. Indeed, change is an integral and a natural part of all ecosystems. Alteration of riverine systems by development of water resources and by land-use changes, however, has introduced a source of change that is foreign to the geomorphic and biotic conditions of rivers and their floodplains. For example, hydrologic changes that modify the timing, duration, frequency, or magnitude of floods can alter the channel geometry (through changes in bed elevation, channel width/depth or planform character), bed substrate, and the health and extent of riparian vegetation with results that cascade down to fish and wildlife (Whiting et al., 1993, *pers. comm.*). In recent years, two issues have commanded significant attention regarding the character and impact of flow regulation schemes, namely *environmental flows* which determine suitable conditions for sustaining instream biodiversity, and *channel maintenance flows* which determine flow levels necessary to maintain channel form to some mean condition.

(i) Environmental flows

Procedures for evaluating impacts of streamflow changes have largely focussed around the concept of instream flow requirements, which recognises that aquatic species have preferred habitat preferences, with habitat defined by physical properties (flow velocity, water depth, substrate and vegetal/channel cover). Because some of the physical properties that determine habitat vary with discharge, so species have different preference for different discharges. Quantification of habitat preferences, notwithstanding the inherent imprecisions, permits the negotiation and setting of optimal flows for ecological management (Whiting et al., 1993, *pers. comm.*). Such reductionist approaches to river management are defensible scientifically, as they both define and quantify the need for water. However, they implicitly assume that all is possible, they require massive data and time inputs, and there is an assumption that all indicators combined should lead to the 'total flow requirement'. Alternative management-oriented responses to environmental flows emphasise the trade-off component of the equation, rather than the environmental need. Deviations from the 'natural' hydrologic regime are minimised by tweaking the system, in tune with hydraulic impacts as determined by 'scientists', but the key component is the reliability and supply component for anthropogenic use, which permits storage at certain intervals and supply in times of plenty.

(ii) Channel maintenance flows

Channel maintenance flows consist of a specified range and duration of flows designed to provide for the self-maintenance of stream channels, wherein the stability and effective function of stream channels are maintained (eg Rosgen et al., 1986). If such flows are not available, stream channels

will in the long term accumulate sediment, experience localised bank erosion and increase the potential for vegetation encroachment and other processes which reduce their capacity to pass flood flows. The most basic requirement for maintaining channel morphology is that the sediment making up the channel bed and the floodplain is potentially mobile. Unless channel maintenance flows are maintained, channel morphology may adjust to an altered 'equilibrium' condition, in tune with operative flow levels, but it may take several decades for this adjustment to occur, especially given modifications in flow/sediment input from tributary catchments. Indeed, in many instances subsequent alterations in boundary conditions that control river behaviour take place before adjustment is complete, such that the river is unable to attain a new equilibrium condition and exists in a state of disequilibrium. For example, the range of river engineering strategies applied to Whitestone River have destabilised the system, such that river behaviour has been extensively disturbed (cf Leeks et al., 1988). To overcome some of these shortcomings, management strategies must aim to work with the natural range of behaviour of the system, set in context of the altered boundary conditions within which the river presently operates. It is pointless to set management goals on the basis of previous conditions, although one of the common goals of river management is to strive towards a river condition that is most in tune with the 'natural environmental setting'.

2.2 Sediment movement: The overlooked factor in WRWP

"A river basin which is physically destabilised, through natural or man-made perturbation of its morphological and sediment transfer elements, is extremely difficult to stabilise through management intervention; the current scientific and political consensus over the desirability of longer-term aims tends, therefore, to play into the geomorphologist's hands."

Newson, 1992

"Rivers exist to carry water to the sea and they develop channels able to contain their normal flow. The form of the river channel affects the flow of water in it and, through erosion and deposition, the flow modifies the form. The channel (and if it migrates, the whole valley floor) acts as a jerky conveyor belt for alluvium moving intermittently seawards."

Ferguson, 1981, p90

Waiau catchment is a dynamic system with high rates of erosion and sediment transport. Waiau River reworks materials from extensive outwash terraces along virtually its entire course, resulting in no overall tendency for downstream reduction in gravel size (Brierley, 1992). Along the lower course of the river, fist-sized gravel lenses are a prominent feature of bar surfaces. These materials seemingly reflect accentuated inputs of sediment from tributary catchments following flow regulation. Wairaki River and Lill Burn have created tributary bars (shallow fan-deltas) and significant in-channel sedimentation at their confluences with Waiau River (Brierley and Beveridge, 1994). Significant channel adjustments since regulation have been restricted to these confluence zones and the lowland reach where the morphodynamic relationship between the river and the barrier systems has been altered (Brierley and Fitchett, 1994).

In transport-dominated systems such as Waiau catchment, sediment transport and landscape development is determined by those events that are able to pick-up materials and hence modify river form. Given the relatively coarse nature of bed material in Waiau River, river character is largely determined by the history of flood events. However, flow regulation of Waiau River has primarily affected median flow levels (Riddell et al., 1993), suggesting that implications for sediment movement in the trunk stream will be significantly less than experienced for most flow regulation situations (eg Petts, 1979, 1984; Williams and Wolman, 1984; Andrews, 1986). However, flow regimes of tributary systems along Waiau River have not been modified by regulation structures, suggesting that the relationship between tributary systems and the trunk stream, and the river and coastal interaction have undoubtedly been modified in response to flow regulation. To date, implications of changes to the sediment budget, measured as adjustments to the distribution and rate of sediment movement, have not been directly addressed within Waiau River Working Party, but virtually all aspects of investigation within Waiau River Working Party are dependent in part on reliable assessment of changes to the sedimentation regime. ***It is suggested that an additional study be undertaken to assess the implications of the altered hydraulic regime on the sediment budget of lower Waiau River.*** The proposed study must stress adjustments to both sediment calibre and volume, in the trunk stream and lower course tributaries, and should focus on two issues:

(i) impacts of flow regulation on sediment movement in the past 25 years, and

(ii) likely future changes associated with reduced flood peakedness and flood duration if the proposed adjustments in water use at Manapouri Power Station are approved.

2.3 Proposed research project: The impact of flow regulation on sediment movement along lower Waiau River

Environmental management strategies must aim to work with the natural range of behaviour of the modified Waiau River. The revised 'condition' of lower Waiau River following flow regulation, with a modified flow regime, altered sediment budget, and adjusted longitudinal profile, present a different set of base-line parameters for modelling the system compared to the pre-regulation condition. Modelling and predictions of future geomorphic behaviour of the river and barrier system must be applied in context of these altered boundary conditions. Information needed to implement the sediment budgeting exercise, and assess its validity and implications for river 'condition', require an associated monitoring program. Hence, the proposed project to assess sediment movement through lower Waiau River entails two components:

a) A sediment budget exercise, outlining theoretical expectations of bedload transport predictions for the flow regime prior to flow regulation, and

b) A monitoring program to assess future channel adjustments and changes in the sediment regime of lower Waiau River and the barrier system

2.3.1 Sediment budget modelling

Movement of materials as bedload is notoriously difficult to predict accurately and consistently, because many factors affect bed material composition and effective energy exerted on the bed during any flow event. Although bedload formulae have been used for engineering purposes for over a century, no one formula, nor even a small group of formulae, has been universally accepted for practical application. Accurate predictive models for sediment movement within a particular system cannot yet be confidently extrapolated from data derived elsewhere, and monitoring programs to determine the reliability of predictions are vital if implications of a modified sediment budget are to be realistically assessed.

The proposed program to assess changes in flow regime on sediment movement should address the following questions:

- Under what flow conditions do differing clast-size fractions move through lower Waiau River?
- What is the volume and calibre of sediment moving through the lower course of Waiau River?
- How has the modified flood history impacted on sediment movement through lower Waiau River?

Estimates of the calibre and volume of material movement should be derived for various discharge intervals (eg < 500 m^3s^{-1}, 500-1000 m^3s^{-1}, 1000-1500 m^3s^{-1}, etc), and multiplied by frequency of such flow events to gain an estimate of total sediment movement. This could then be compared for intervals prior to and following flow regulation, and for a range of scenarios for potential future flows with reduced peakedness and duration of extreme floods. This would form the basis for direct comparison of variability in sediment transport rates, applied both retrodictively and predictively.

While most geomorphic processes are relatively inactive at low flow levels, modifications to the volume and timing of flow can substantially modify the ability of the river to transport materials of differing sizes. This may have profound implications for channel geometry and substrate - critical components in river habitat. While the proposed 14 m^3s^{-1} minimum (environmental) flow may well improve conditions for maintenance of aquatic life within Waiau River, such flows will likely induce trivial geomorphological impacts on river character. Bedload materials will remain relatively stable, maintaining the present channel geometry. However, movement of finer grained materials may be modified, and increased proportions of materials may be deposited from suspension. Furthermore, materials supplied from tributary catchments along the lower course of Waiau River will continue to build up in the trunk stream. Magnitudes of flushing (channel maintenance) flows need to be determined for two scenarios:

(i) to remove fine sediments from the stream gravel, thereby maintaining intragravel permeability and hence providing suitable substrate conditions for fish habitat (eg Reiser et al., 1985), and
(ii) to prevent choking of the lower course of the river.

The proposed hydraulic engineering exercise could be achieved at relatively low cost using existing grain size and discharge data and standard approaches to assessment of bedload transport rates. Numerous assumptions would have to be made, especially regarding the mix of bed material sizes and their packing arrangement, but sufficient hydrologic data exist to determine the magnitude and duration of flow levels that induce sediment movement. An additional cost would be incurred in measurement of the channel bed slope (see Section 2.3.3). Estimates of the volume and calibre of material moved during flow events of differing magnitude would need to be tied directly to field measurement and monitoring.

2.3.2 Monitoring programs

Three components are suggested for the proposed program to monitor sediment movement through lower Waiau River:

a) Within-channel aggradation along lower Waiau River

A systematic, stratified sampling framework should be established to monitor the sediment budget within the river channel and on adjacent alluvial flats. The calibre and volume of sediment

throughput to the barrier needs to be assessed, such that channel and planform geometry and the behaviour of the barrier system can be explained. A number of transects should be surveyed annually, or following specific flood events within the following reaches of the river:

- Between Tuatapere and the river mouth.
- The large bend downstream of Clifden.
- Immediately upstream of, adjacent to, and downstream of Lill Burn confluence.
- Along the lower course of Lill Burn.
- Immediately upstream of, adjacent to, and downstream of Wairaki River confluence.
- Along the lower course of Wairaki River, extending 4 km upstream of Blackmount Road.

Grain size analysis should clearly differentiate between those materials presently moving through the channel and underlying (or adjacent) lag deposits. Three components should be assessed:

(i) Coarsest grain size statistics, determined to assess competence limits to sediment movement. Grid or transect strategies should be employed.
(ii) Bulk sieve analysis should be applied at 'representative sites' using a rocker sieve, to determine the mix of bedload material moved during sediment transport events
(iii) The range of grain sizes evident in any one reach of the river may have profound implications for habitat diversity or substrate conditions, and should probably also be recorded using an extended transect procedure

Such data are necessary to elucidate longer-term directions and rates of change in the context of shorter-term perturbations, and would form the basis for ratifying sediment budget models. In the long term the monitoring exercise would be relatively inexpensive, as it would entail resurveying cross-sections and plotting results. Reports produced every few years, or in response to specific flood events, could allay fears about the nature of adjustments along lower Waiau River and the barrier system following flow regulation.

b) Measurement of bed surface slope along lower Waiau River

Longitudinal profiles of the river from Te Waewae Bay to 1 km upstream of Wairaki confluence, including the lower courses of Lill Burn and Wairaki River, should be surveyed on an annual basis.

c) Assessment of channel planform and barrier adjustments

The 'direction' and rate of morphologic changes to the channel and barrier system needs to be monitored. Air photographs would only need to be flown every 5-10 years, focussing on tributary reaches and the lower course, although impacts of larger (>2000 m^3s^{-1}) events should also be monitored. Reports could be produced every five years, say, documenting the character and pattern of longer-term processes.

3. Geomorphology and River Health

"Ideally, a classification scheme should be based on a hierarchical ranking of linkages between the geologic and climatic settings, the stream habitat features and the biota. These - the geomorphic and climatic processes that shape the abiotic and biotic features of streams - provide a conceptual and practical foundation for understanding the structure and processes of fluvial systems. Furthermore, an understanding of process allows streams to be viewed in a larger spatial and temporal perspective, and to infer the direction and magnitude of potential changes due to natural and human disturbances. An enduring stream classification system, based on patterns and processes and how they are expressed at different temporal and spatial scales (Frissell et al., 1986), should be of fundamental value in assessing conservation potential.

Naiman et al., 1992, p 96

The concluding section of this report outlines the application of the baseline geomorphologic framework of Waiau catchment to assess river health. The section is divided into three components, examining background literature on river conservation and management in New Zealand, approaches to assessment of river health, and direct application of such principles to Waiau River Working Party.

3.1 River Conservation and Management in New Zealand

"New Zealand appears to have experienced a relatively stable period of careful water management policies, made necessary by earlier misdeeds in a very unstable natural background. The ability of the New Zealand system to combine central strategy with local planning and implementation seems, however, to be crumbling in the face of devolved politics."

Newson, 1992, p135

"New Zealand has a reputation for throwing hastily-prepared legislation at its problems then making corrective amendments as experience highlights the shortcomings."

Ericksen, 1990, p83

River health of most New Zealand rivers has deteriorated notably in the period since human settlement, with significant loss of habitat, modification of channel character (induced by direct and indirect changes to flow and sediment regimes), loss of native flora and fauna, and incursion of exotic flora and fauna. Geographic location and tectonic history have resulted in a very high degree of endemism in the biota of New Zealand (Collier and McColl, 1992, p200). For example, about 90 % of the arthropods and fish are endemic to New Zealand, and the diversity of aquatic invertebrate, plant and fish communities is quite low compared with many running water ecosystems overseas. New Zealand has no native aquatic mammals, but many species of native birds utilise rivers and their associated floodplains and wetlands as breeding and feeding habitat (Hughey, 1987). In pre-human times, the vascular plant and bryophyte communities of streams are thought to have consisted predominantly of species adapted to the heavily shaded conditions provided by native forest cover (Howard-Williams et al., 1987). Approximately 90 % of natural wetlands have been drained or otherwise lost since the arrival of humans (Howard-Williams et al., 1987), and unmodified indigenous forest cover has been reduced from 78 % to about 22 % of land surface (Molloy, 1980). Loss of native forest has been particularly pronounced in the lowlands, where it now represents only about 15 % of its pre-human extent, and deciduous Northern Hemisphere willow species (*salix fragilis*) are now the typical riparian tree (Johnson and Brooke, 1989). Removal of native forest

along rivers has been detrimental to the shade-adapted aquatic flora which could not compete with those adventive colonists that are tolerant of high light levels (Howard-Williams et al., 1987). As a result, the macrophytic flora of most of New Zealand's lowland streams is characterised by adventive species such as watercress, sweet grass and starwort (Collier and McColl, 1992, p201). Given these dramatic changes in river health over the past two hundred years, emphasis in river management strategies must be oriented towards preservation of those river systems that remain in a relatively intact (near-pristine) condition, while most systems must be subjected to river restoration procedures (eg Gore and Petts, 1989; Osborne et al., 1993; Peterson et al., 1987; 1992) which are adapted to contemporary river behaviour (ie working with the present structure and function of the 'natural' system).

In assessing river health of Waiau River, it is instructive to make direct comparison with the adjacent watershed of Wairaurahiri River in Fiordland National Park. Forest clearance of the entire lowland plain of Waiau catchment, extending from the valley margins to the channel banks, clearly presents a differing set of boundary conditions for river behaviour to those of a near-intact system. While inherent differences in the geomorphic behaviour of these two catchments are recognised, it is self-evident that the relative 'health' of these systems is fundamentally different, and assessments of future river 'condition' (ie management goals for determining river health) must be viewed in differing lights.

3.2 How can River Health be assessed?

In order to improve sustainable use of resources, river/catchment health must also be improved. It is impossible to reestablish baseline 'naturalness' of river systems to a pristine condition, and management strategies must work with the condition (or health) of the contemporary system. Integrative river basin management strategies must incorporate baseline surveys of catchment operation and monitor changes through time as a basis for assessment of human impacts on river behaviour. Assessment of river health provides a useful tool in this operation, in that it can be an instrument to facilitate:

- Marketing, education, and promotion of holistic awareness of "environmental condition"
- Setting management objectives, based on bench marks for river condition and performance indicators
- Framing new legislation/policy
- Reporting long-term trends

The first step in development of a river management strategy must entail assessment of the relative condition of a river and its associated catchment. Classification of this condition forms the basis for assessment of change over time, such that determinations can be made as to whether there has been

improvement or deterioration of river condition. The values attached to river classification differ substantially from user to user, and some consensus must be arrived at within the community as to which outcomes are desired (ie just what river condition is sought). Appropriate measurement and monitoring programs must be established for each parameter of concern, determining what is to be measured, in what way, how often, and at what points within the river system. Data need to be collected and analysed, reports produced, and implications communicated directly to the community. The following step-by-step procedure is suggested as a framework to assess river health:

(i) Develop an appropriate classification system based on available data on river and water quality indicators.
(ii) Assess health indices and define reference conditions for each river reach.
(iii) Set long-term management goals for each river reach.
(iv) Implement monitoring procedures to measure how far from the reference condition each river reach is, isolating which components of river health are the cause of most concern.
(v) Determine the conservation status of the river system, and communicate these results between scientists, managers and landowners.
(vi) Establish revised goals and continue the monitoring program, responding to difficulties as necessary.

In the past, undue emphasis has been placed on assessment of river health based solely on biological characteristics, such as 'diversity', 'naturalness' and 'representativeness' (Boon, 1992). Of greater concern, however, is the need to evaluate those factors which drive change within river systems over long time intervals, inducing responses in the biological character of the system. To achieve this, broader-based criteria must be evaluated, such as the geomorphology and hydrology of the catchment, and land use character. Biological functioning of systems cannot be determined on the basis of presence/absence data for certain biological features. It is vital to understand controls on in-stream dynamics, and fine-scale measures of system metabolism need to be evaluated (eg hydraulic ecology; see Statzner et al., 1988). River health cannot be assessed using measures based on fish, macroinvertebrates, riparian vegetation, or geomorphic character *in isolation*. Of much greater significance is how these components 'interact', because it is the sum total of these components, their structure and function, that constitutes the relative health of a river system, and this sum total is never equal to the sum of the individual parts.

Examples of criteria which drive river/catchment health, and measures that can be used to assess them, are presented in **Table 1**. While some of these variables are readily quantifiable, others are not, and can only be evaluated using subjective criteria. Hence, differing types of indicator can be identified, such as core and supplementary indicators. Further constraints are imposed by data availability and the costs incurred in collecting additional data. Monitoring programs need to be established in a highly efficient and practicable manner, such as 'rapid biological assessment', but it

is equally critical that data are representative, and that any limiting factors which may impose constraints on the capacity of the system to function effectively are isolated and measured. It is easy to see how procedures to assess river health in an integrative manner quickly become impractical and indeterminate, but it is equally vital that practical responses to this complexity are determined, as river/catchment health can only be truly appreciated as the sum of structure and functioning of the entire biophysical system.

Table 1 Measures used to assess catchment character and condition

Characteristic	Examples of measures that could be applied
Catchment character	proportion developed/uncleared/replanted land and water uses point/diffuse sources of pollutants
Geomorphology/hydrology	assemblage of geomorphic units flow regime (water quantity) - trends flow hydraulics bed and bank character sediment character wetland status
Riparian vegetation	aquatic vegetation status (indicator of long term nutrient enrichment) native vs exotic components
Water characteristics	quantity/quality - note cyclicity/variability temperature oxygen status organics (COD, DOC, etc), nutrients (eg phosphorus) trace elements (metals)/toxics pH colour turbidity conductivity
Biological characteristics	biodiversity bioaccumulation value macroinvertebrate indices fish population/diversity/community status (native vs exotic) birds (native vs exotic) macrophytes (native vs exotic)
Microbiological	coliforms, pathogens (faecal), etc
System metabolism	P/R ratio; N fixation; Δ C ratios litter (leaf, wood, snags) chlorophyll (suspended and attached) loading rates (sediment, metals, nutrients, etc.)
Spiritual/Aesthetic attributes	Maintaining the 'mana' of the system Perception of river behaviour
Recreational issues	Ecotourism potential Fishing Jet-boating/canoeing Fishing

3.3 Proposed framework for assessment of Waiau River 'health'

"As long as management is directed totally toward perceived human requirements of the moment, and focused on single species, frequently aliens, it is unlikely to play any useful role in the long-term perpetuation of natural running-water ecosystems. Because the management field has such a poor record of achievement, it is both surprising and disappointing that, even now, so little basic science has enjoyed technological transfer to management strategies."

Cummins, 1992, p128.

Numerous reports commissioned through Waiau River Working Party have outlined significant baseline data on numerous indicators of relative health of Waiau River. The challenge now is to integrate these measures into a framework that can be used to assess the relative health of the river system both now and in the future. This can serve various ends:

(i) To ensure that the modified condition of Waiau River and tributaries meets the desires of the stipulated goals of the water consents agreement,
(ii) To identify which components of the river condition are acceptable within the guidelines laid down, and make moves towards correcting those components that are unsatisfactory (ie prioritorising research and management efforts), and
(iii) To test the predictions made in various scientific reports, so that inaccuracies can be corrected and alternative predictions proposed (hopefully ensuring that we can learn from past mistakes).

Geomorphology serves as a suitable framework for holistic thinking about practical, realistic and sustainable management of complex river systems, given the appreciation of long-term and large-space scales. Geomorphic assessment of controls on the character, rate, permanence and spatial variability of channel changes has enormous implications for integrative catchment management and assessment of river/catchment health. For example, bedload materials are the primary determinant of channel morphology, and play a major role in determining channel bed/bank habitat. Adjustments in their quantity or size can transform the character of a river and its associated bed condition, substrate, geometry, pool spacing, condition of riparian vegetation, instream habitat, etc. Hence, changes in sediment movement may cause variations in stream habitat, and must be carefully monitored in order to assess the geomorphologic impacts of external changes on river behaviour. Of equal significance is changes to the flood pulse, which is the principal driving force responsible for the existence, productivity, and interactions of the major river-floodplain biota in river-floodplain systems (Junk et al., 1989). Adjustments to the flood regime, as such, may trigger a series of river adjustments that modify measures of river health, and must be evaluated interactively if the future condition of Waiau River to modified flow conditions is to be assessed realistically.

At the outset, Waiau River Working Party must achieve a consensus view of just what they wish the river to be like. While it is clear that management strategies must work with the range of behaviour of the present river, various alternative goals can be defined for the desired future condition of Waiau River, such as the following end-member options:

i) The natural condition: A highly dynamic, unpredictable and erosive system,

ii) An equilibrium river, which oscillates around a mean condition,

iii) A disequilibrium river system, which oscillates between long periods of relative stability and short periods of dramatic change,

iv) A nonequilibrium river system in a permanent state of adjustment, unable to achieve an equilibrium condition

v) An overly engineered system: A highly stable canal

Available baseline data can be used to guide management options in striving to achieve the prescribed river condition. In order to assess the effectiveness in reaching the desired goals, system responses to modified low and high flow regimes must be determined through sustained, long-term monitoring programs. Contingency plans should be determined to maintain the present condition of the river as a worst possible outcome, and procedural responses should be set in place for certain worst-case scenarios, such as if the river mouth become blocked on a recurrent basis, or if instream river habitat along the lower course deteriorated as fine gravels continued to accumulate.

The monitoring program suggested in Section 2 of this report would be most effectively emplaced if it was integrated with various other measures of river health, such as turbidity, water quality, etc, as determined by Waiau River Working Party. Criteria listed in **Table 1** could be used as a starting point for discussion of perceived river health, and positive or negative weightings could be determined for criteria which are considered to be more/less important, based on whether they contribute or detract from the health of the system. Evaluation of community-determined measures of river health can be used to check whether management programs are working as desired. Monitoring programs need to be established to measure and report on each component. These various measures, both objective and subjective, can be used in a variety of approaches to measure the relative health of a river system, thereby determining whether things are improving or otherwise:

(i) Individual measures can be evaluated in isolation,

(ii) A tally score can be determined (using some form of weighting index for differing criteria),

(iii) A group of individuals representing various interest groups (stressing scientific, management and community groups) can debate the issue around a table.

The lack of representativeness of individual criteria, along with problems associated with generation of cumulative indices of 'total health', suggest that the third, round-table approach may be the most suitable procedure with which to stress linkage between measures of catchment health. Appropriate management strategies need to be emplaced for these procedures, outlining who will measure each component and how frequently. Responsibilities of individual parties need to be clearly prescribed and timetables assigned for implementation of the monitoring program, reporting, and redefining

goals as more information becomes available. Communication between scientists and managers needs to ensure optimum application of knowledge to river management. These insights need to be transferred rapidly and effectively to the broader-based community. Structural arrangements for assessment of river health could be linked directly with the monitoring program to assess the long term sediment budget. Such environmental auditing procedures could be written into the Water Rights Consents Agreement, and co-ordinated through Southland Regional Council, thereby integrating longer-term environmental management issues (on a 50-100 year time frame) with community-level awareness and participation. Among the available management options that can be used with this regard is a procedure called Adaptive Environmental Assessment and Management (AEAM).

3.4 Adaptive Environmental Assessment and Management

AEAM employs a workshop-oriented approach designed to assist exploration of the environmental impact of projects and of policy alternatives to address those impacts (Gilmour, 1994, *pers. comm.*). It uses an exploratory, experimental approach to management problems, emphasising the values of continuous monitoring and periodic adjustment of management regimes. AEAM explicitly recognises (Holling, 1978):

- The need for management decisions to heed economic, social and environmental values in an integrated way. The process respects the needs and concerns of diverse stakeholders, and recognises that policy evaluation must be holistic.
- The presence of many, diverse stakeholders in environmental management issues. Broad support from stakeholders is needed to implement effective responses and planning processes need to facilitate the development of consensus.
- Decision making must be effective amidst significant uncertainties inherent in environmental processes. Management plans should therefore take uncertainties into account explicitly.

A series of AEAM workshops commences with a scoping process in which the broad features of a management problems are defined. This is followed by workshops in which a detailed description of the ecological-social-economic system is developed. The workshop series is concluded with gaming workshops in which policy scenarios are evaluated. AEAM workshop participants develop a computer-based simulation model of the environmental and decision-making system. The model building process does not provide policy prescriptions, rather, it provides a context (the workshops) and a tool (the simulation model) with which policy options can be explored. Workshop participants take responsibility for identifying data from which simulation rules can be derived. The AEAM facilitation team takes responsibility for writing the software. Gaming with an AEAM model provides a focus for negotiation among stakeholders, allowing investigation of potential trade-offs and development of mutually beneficial policy mixes.

To ensure that problems are considered in adequate breadth, and to assist in resolving conflicts over alternative management strategies, workshop participants represent major stakeholders. Participants normally include representatives from relevant public, private and community sector organisations with expertise in a variety of relevant disciplines. AEAM workshops are designed to bring stakeholders into constructive discussion of how the system works, the key processes, the extent of knowledge of the system, the most important indicators of its state, and appropriate management options. The analysis has the advantage of being sharply focussed on management priorities rather than being driven by what is, and what is not, known in the science of each area examined. The workshops are intended to bridge the gaps between the views of different disciplines and the competing perceptions of best resource use. The AEAM process obliges participants to make their perceptions of, and prejudices about, the system explicit. It requires participants to acknowledge and address both data and process uncertainties, and it makes the assumptions and rationales used by decision makers to justify decisions visible to all participants. AEAM workshops assist in building consensus among parties by helping to correct misperceptions and by enabling optimum trade-offs to be negotiated. The process is designed to encourage interaction among workshop participants, and to ensure that the workshop team takes responsibility for developing the description of the system.

Formal policy definition builds on the workshop results, taking account of emerging consensus within a group of key participants, and of system sensitivities revealed in gaming with a simulation model. Once policies have been put into practice, and components of the system measured for some time, policy development can be improved by contrasting the model with actual system behaviour. If the model is *not* a good predictor of system behaviour, deficiencies in the workshop team's policy analysis can be sought. Given that this was an holistic analysis carried out by representatives of major stakeholders, the gaps may well prove illuminating for further policy work. At this point the model should be revised to make it more representative of the 'real' world.

It is proposed that the framework implicit to AEAM could provide an ideal approach to resolution of conflicting interests regarding water use within Waiau River Working Party. Adoption of the AEAM approach, coordinated by ECNZ and Southland Regional Council, could form a suitable platform for assessment of river/catchment health of Waiau River, ensuring that community interests and perspectives on river condition are integrated with broader water use concerns. Stipulation of measures of river health could reflect all interested parties, negotiated by stakeholders in round-table discussions. Desired goals for river health could be assessed as a group outcome, and monitoring programs established to ensure that there is no sustained deterioration in the condition of the river and its associated catchment.

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