Regional setting of Waiau River catchment, Southland

Report submitted to Waiau River Working Party as part of Tributary River Reach Analysis Project by

Gary J. Brierley[1], Alistair Beveridge[2] and Amanda Hajnal[1]

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1) School of Earth Sciences, Macquarie University, North Ryde, NSW 2109, Australia
2) Department of Geography, University of Otago, PO Box 56, Dunedin

Summary

This report outlines the broad regional setting of Waiau River as a means of providing the background context, or boundary conditions, within which the river operates. Summary information was compiled on regional geology, geomorphology, soils, climate and social history from various reports, assessed in conjunction with field observations and analysis of relevant air photographs, 1:50,000 and 1:63,360 topographic maps, 1:50,000 and 1:250,000 geological maps and various N.Z. Meteorological Service sheets.

Introduction

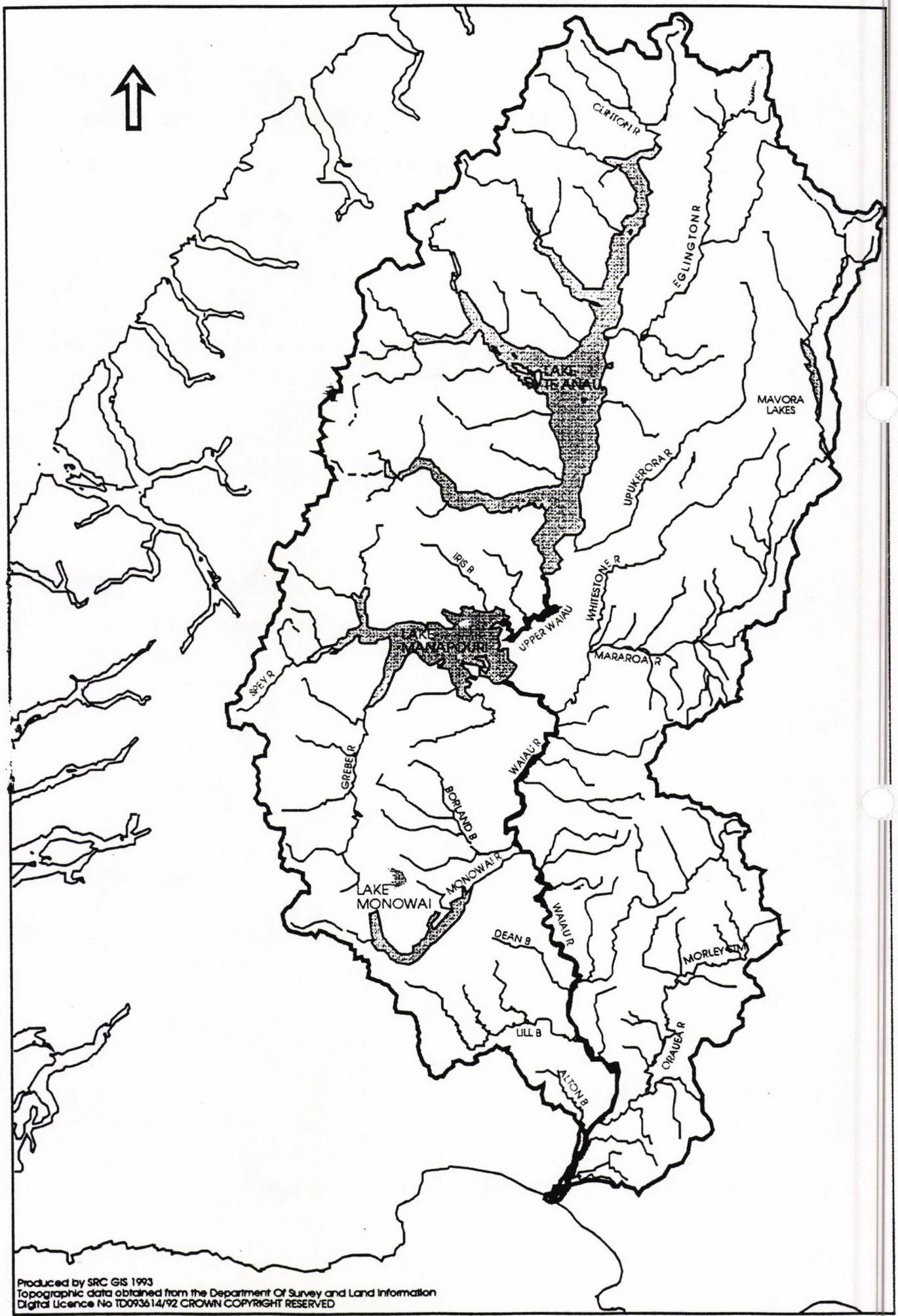
The broad valley landscape of Waiau River drains a catchment area of about 8,200 km^2 along the eastern margin of Fiordland, in the southwest corner of South Island, New Zealand. Takitimu and Longwood Ranges form part of the eastern catchment margin, while Lakes Te Anau and Manapouri are dominant features in the north of the catchment (**Figure 1**).

Waiau catchment receives most of its water from Fiordland National Park, an area of high inaccessible mountains with steep slopes and glacially excavated valleys in which relief ranges up to 2,700 m. The high mountains, extensive deposits of unconsolidated sediments, and high mean annual precipitation of Waiau region result in very dynamic and active geomorphic systems, with high rates of erosion and sediment transport. Abundant gravels are supplied along most of the course of Waiau River, as the river reworks alluvial flats and terraces. Lateral constraints imposed by bedrock topography have determined that only in the lowland plains can the river be described as truly alluvial.

Geology and landscape evolution

Western Southland region lies immediately east of the Pacific-Australian Plate boundary. At this boundary there is an oblique subduction zone to the south, the Puysegur Trench, which is transitional northwards to a strike-slip fault (the Alpine Fault), west of Fiordland. The tectonic and sedimentary

Figure 1: Waiau River catchment



history of the region reflect changing movements of the plate boundary from the early Miocene (28 Million years ago) (Turnbull et al., 1993).

Basement rocks in western Southland form Permian-Mesozoic terranes, and range from plutonic and high-grade metamorphic gneisses in Fiordland to plutonic, volcanic, volcaniclastic and ophiolite sequences in Takitimu, Longwood and Livingstone Ranges. Schist and semi-schists form a major terrane to the north of the region. These terranes are bounded by major high-angle fault systems that were reactivated during the Cenozoic, and represent a major phase of terrane accretion on the margin of Gondwanaland (Turnbull et al., 1993).

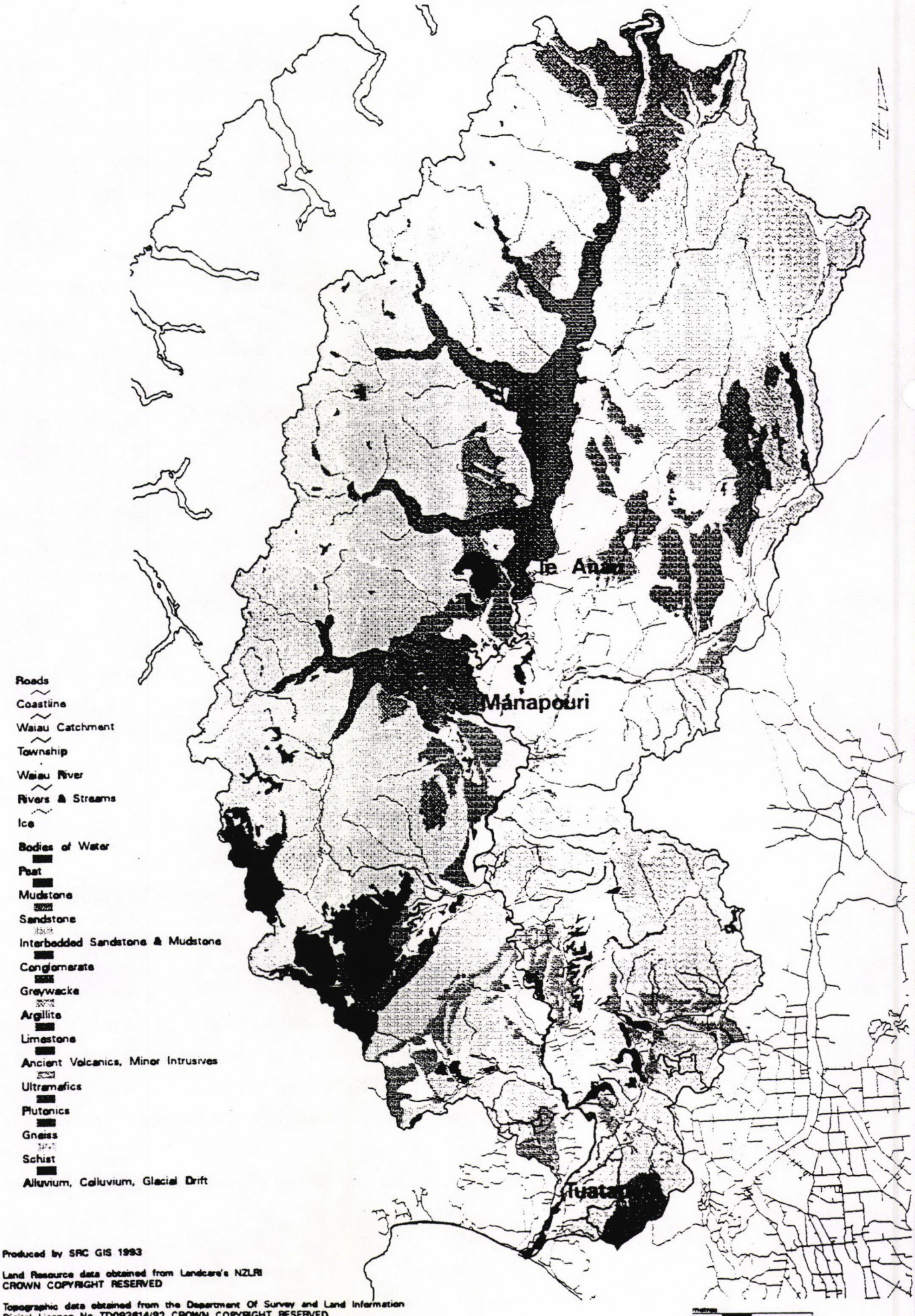
Fluvial and lacustrine depositional environments reflect accumulation in generally north-easterly trending, fault-controlled basins formed during Cretaceous rifting of New Zealand from Antarctica. Parts of Southland sank under water during the Tertiary period, and siltstones and sandstones, with extensive areas of limestone, underlie the lowlands. Later uplifted in the Kaikoura orogeny about 3 Million years ago, these soft rocks form the Te Anau-au caves, the Clifden Caves, and the limestone knolls of central Southland such as Forest Hill.

Minor Plio-Pleistocene volcanic activity, associated with subduction on the Puysegur trench beneath the Balleny and Solander Basins, is now quiescent, but seismic activity on the Alpine Fault and Puysegur trench has been prevalent in recent times (Turnbull et al., 1993). Uplifted marine terraces cap the sedimentary basins adjacent to the coast.

During the Pleistocene Period ice sheets extended across Te Anau-Manapouri basin. Numerous phases of glacial activity extensively modified valley form, creating overdeepened U-shaped valleys, while mountain ice sheets deposited large volumes of till across Te Anau Basin (McKellar, 1973). Terminal moraines, together with post-glacial fans, created poor drainage in many catchments (Suggate, 1982). Base level adjustments resulted in pronounced incision and reworking of glacially-derived debris. Oversteepened slopes, meltwater floods from retreating ice sheets, and negligible vegetation cover at the end of each glaciation induced rapid sediment redistribution by wind and water, as rivers produced a more dissected landscape (O'Loughlin and Pearce, 1982; Pillans et al., 1982; Williams, 1990).

The western boundary of Waiau catchment extends into the 'Fiordland Block' while the eastern boundary encompasses the Takitimu Mountains to the north and Longwood Range to the south. The remainder of the catchment is underlain by a sandstone, limestone and mudstone group formed during the Eocene-Miocene period (**Figure 2**). Overlying this formation are recent sediments derived from till, colluvium, and other reworked post-glacial sediments. Additional thick sequences of deposits have been laid down in alluvial fan sequences marginal to the Takitimu's. Bedrock 'dams' at Blackmount and Mangapiri have conditioned sediment distribution and hence the extent of

Figure 2: Geology of Waiau River catchment



river incision into fluvio-glacial outwash. Adjacent to the Takitimu's, the upper terrace lies about 80 m above the contemporary channel (Fitzharris, 1967).

Geomorphic characterisation of Waiau River

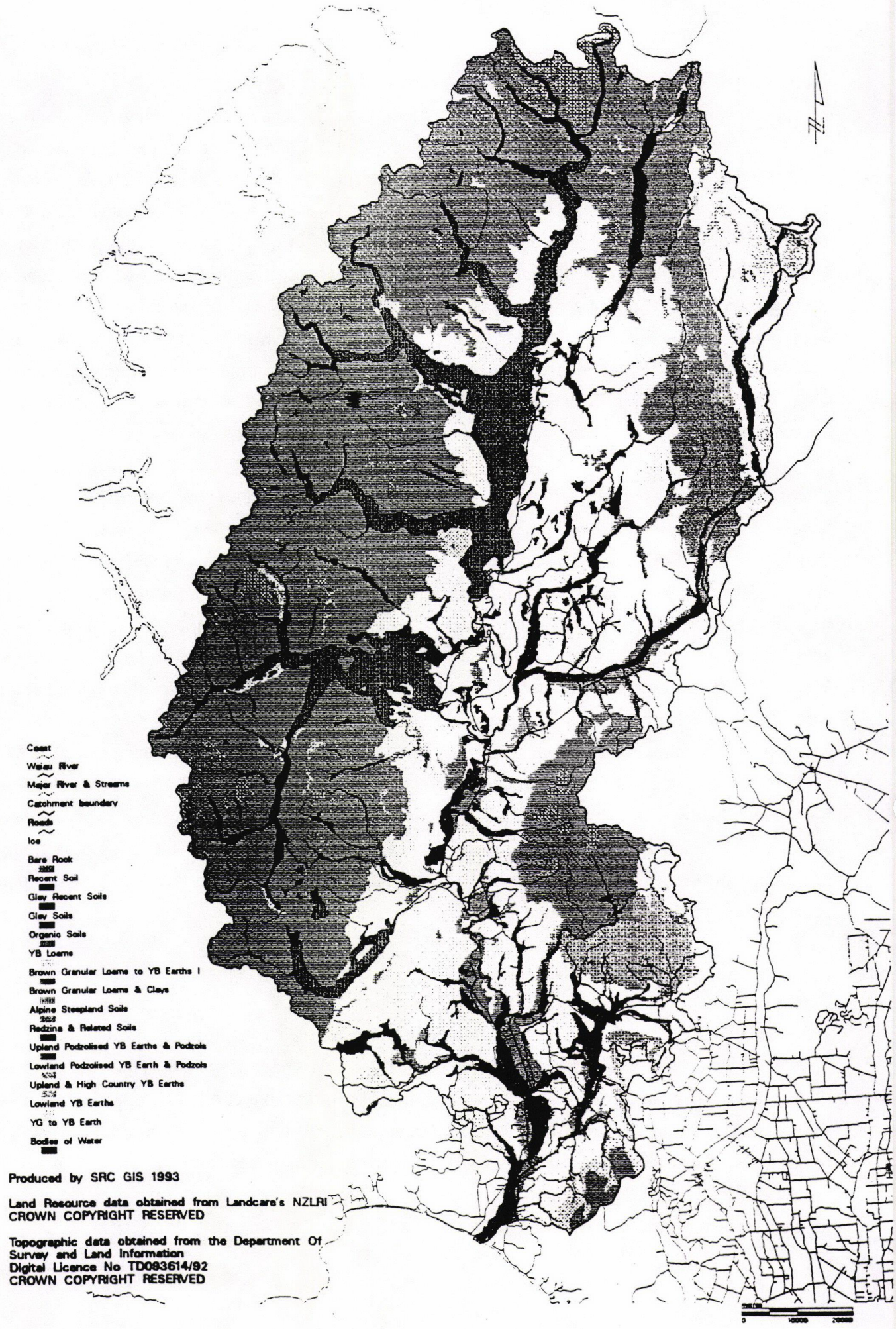
The geomorphic character of Waiau River between Lake Te Anau and Te Waewae Bay reflects antecedent controls, conditioned largely by the history of uplift and Quaternary glaciation (Brierley, 1992, 1993a, 1993b). Waiau River is a meandering gravel bed river which alternates between confined and less-confined reaches. In upstream reaches (Wairoa and Pearl Harbour) Waiau River has an imposed low-moderate sinuosity, single-channelled outline. Six more reaches downstream of Mararoa Weir are laterally constrained, as the channel abuts against either Eocene-Miocene bedrock or terrace sediments (Duncraigen, Blackmount-Mangapiri, Motu, Clifden Suspension Bridge, Hagen Road and Orauea). These bedrock or terrace-constrained reaches either have an imposed broad sinuosity (eg. Blackmount-Mangapiri) or are short, relatively straight reaches (eg. Duncraigen, Motu, Clifden Suspension Bridge, Hagen Road, Orauea). Within-channel sedimentation is restricted to occasional lateral bars or compound point bars in broad meander loops.

Unconfined reaches are characterised by multiple channels that are laterally unstable. These reaches have wide alluvial and valley flats, with a well developed terrace sequence (Wairaki, Lill Burn, Downstream O'Clifden and Tuatapere). Gravel bar types change down-reach in a systematic manner, from bank-attached compound bars, to longitudinal, diagonal or mid-channel compound bars. In Redcliff, Wairaki and Lill Burn reaches, within-channel sedimentation is augmented by the addition of sediment at tributary confluences. Downstream of Wairaki and Lill Burn confluences, Waiau River has a broadly sinuous outline with compound point bars and bank-attached compound bars. Bedrock constraints at the downstream limit of these reaches restricts sedimentation to lateral and point bar features. Within-reach trends in bar types are more complex in Tuatapere reach than elsewhere, associated with extensive active gravel surfaces. Bank-attached bars at the reach head are transitional downstream to a large mid-channel compound bar. Beyond this bar, flow is concentrated into a single channel. In the lower half of Tuatapere reach Waiau River has adopted a freely-migrating pattern of broadly sinuous bends. Adjacent to the river mouth, Waiau River broadens considerably, and mid-channel bars have formed.

Soils

O'Byrne (1986) related soils in western Southland to six physiographic units (**Table 1**). Physiographic control on soil type in Waiau catchment is indicated in **Figure 3**. The western part of the catchment is characterised by Upland podzolised yellow-brown earths and podzols, while the Takitimu's are dominated by Brown granular loams to yellow-brown earths, with occasional bare rock. Foothills on both sides of the valley are characterised by Lowland yellow-brown earths. Upper (northern) parts of Te Anau Basin are dominated by Yellow-brown loams, while 'Recent' loams are interspered with Brown granular loams to yellow-brown earths along the river terraces.

Figure 3: Soils of Waiau River catchment



The upper-middle courses of numerous tributary valleys are characterised by poorly drained gley soils.

Table 1: Physiographic controls on soil character in western Southland (after O'Byrne, 1986)

Physiographic unit	Character
River flats and coastal lands	Alluvium in Waiau Valley is derived from granite, diorite and gneiss of the Fiordland Mountain Complex and tuffaceous greywacke and basic volcanic rocks of the central ranges. Coastal lands consist of sand dunes, peat swamps and estuarine deposits.
Terraces, fans, benches and related glacial outwash surfaces and associated escarpments	Marine benches on the coast and outwash surfaces near Lakes Te Anau and Manapouri consist mainly of gravels and fines derived from granite, diorite and gneiss, but an extensive area of slightly cemented current-bedded sand occurs in the vicinity of Freestone Hill.
Glacial moraines	Moraines of Te Anau Basin are undulating to rolling and consist of till derived from granite diorite and gneiss with increasing quantities derived from tuffaceous greywacke and basic volcanic rocks towards Mt Prospect. South of the lower Mararoa valley, deep loess covers the moraines. Minor moraines occur at the margins of the Mavora Lakes.
Hilly lands	Hilly lands of Waiau Basin have developed atop parent materials of soft Tertiary marine sediments such as sandstone, siltstone, mudstone, limestone and conglomerates. The low profile of this terrain is in marked contrast to the more prominent strike ridges, homoclines and hogbacks of the more resistant limestones, sandstones and conglomerates.
Central hill and mountain ranges	The Takitimu and Livingstone Ranges have rugged outlines with steep slopes, cirques and peaks that reach a height of 1700 m. The central ranges consist mainly of tuffaceous greywacke and basic volcanic rocks. Bare outcrops are common above 1600 m in Fiordland. On coastal benches east of Rowallan Burn, and on terraces in lower Waiau Valley, loess occurs to depths up to a metre or more. Further deposits occur on moraines and fans on the northwest margins of the Takitimu Range and are unevenly deposited on the flanks of the Longwood Range.
Fiordland Mountain Complex	Soils of the superhumid areas of Fiordland are fragile and have been retained in native forest vegetation. Morphologically, upland soils are very friable and have a weaker structure than lowland soils.

Climate

The bioclimatic character of Southland is termed "Southern Cool Temperate", with warm summers and cool winters. Mean air temperatures in January are 12.5 - 14.9 °C and 4 °C in July. Frosts are common and severe in Winter. The climate in the lower Waiau catchment is dominated by westerly air flow, which is responsible for intense regional orographic rainfall and the numerous stationary or slow moving fronts that pass over the region. These fronts are associated with significant precipitation events that lead to widespread regional flooding. Mean annual precipitation values of 2000 mm-plus, 1400 mm and 1600 mm have been estimated for Fiordland, Takitimu Mountains and the Longwood Range respectively (N.Z. Met. Service, 1983a, 1983b). Mountains in Fiordland create a rainshadow effect which result in average precipitation totals in Waiau Valley between 800-1200 mm. In general, upper catchment streams are in relatively wet zones (up to 8000 mm/year rainfall), whereas lower catchment streams are in quite dry areas (commonly around 1000 mm/year).

Rainfall is evenly distributed throughout the year except for a slight falling off in Winter. Snowfall is common during Winter, particularly at altitudes above 600 m. Upland regions also experience frequent frosts, snow and gusty conditions, the severity of which varies with altitude and exposure. Winter temperatures are cold enough for patches of very thin anchor ice to form on the streams. High winds are also an important climatic feature, being predominantly from the west and north-west. During Spring, frost-lifted cultivated soils can be actively eroded by these winds (Department of Conservation, 1992; Dunbar et al., 1966; Mills, 1989; Williams, 1990; Williamson et al., 1990). During Summer, upper soil horizons tend to dry out and droughts commonly occur.

Hydrology (summarised from the WRWP report by Riddell et al. (1993).

Together Lake Te Anau and Manapouri catchments cover 4483 km^2, or 55 % of Waiau catchment area, but contribute 403 m^3s^{-1} of the natural average flow (519 m^3s^{-1}) at Tuatapere (ie. 78 % of the total). The remaining 45 % of the catchment (Mararoa, Monowai and other tributaries below Manapouri Lake Control Structure) contribute an average of 116 m^3s^{-1}, or 22 % of the Tuatapere mean flow.

Generation of hydro power at Manapouri Power Station entailed diversion of water from catchments draining into Lakes Manapouri and Te Anau and from Mararoa catchment. Water was first directed through Manapouri power station in 1969 but full-scale generation did not begin until early 1973. Lakes Te Anau and Manapouri Control Structure were commissioned in July 1974 and November 1976 respectively. Prior to commissioning of the permanent Manapouri Lake Control Structure a temporary weir was placed across the river in February 1970. Between 1969-1991 outflow from Manapouri Lake Control Structure occurred less than 40 % of the time. In other words, for more than 60 % of the time discharge in Waiau River at Tuatapere reflects flow contributed by tributary catchments downstream of Manapouri Lake Control Structure.

Mean flow of Waiau River at Tuatapere between July 1964 to 1969 was 560 m^3s^{-1}, and median flow was 520 m^3s^{-1}. In contrast, mean and median flows at Tuatapere after regulation, from 1973 to 1991 inclusive were 137 m^3s^{-1} and 62 m^3s^{-1} respectively (ie. mean flow is heavily weighted by floods). In 1967 and 1968 annual mean flow exceeded 600 m^3s^{-1}, whereas since 1973 mean annual flow has exceeded 200 m^3s^{-1} only twice, in 1980 and 1988.

In nearly all floods at Tuatapere post-control, the flow of water from Manapouri into lower Waiau River has been only about half of what it was pre-control (the difference being made up by Manapouri power station discharge to Deep Cove). Exceptions were the January 1984 flood when a 'normal' amount of water was coming from Lake Manapouri and October 1988 when the bulk of water came from Lake Manapouri in what was a long duration flood event in the alpine catchments of Lake Te Anau and Manapouri. While many of the flood peaks at Tuatapere since 1979 have been

very large, they would have been even larger without Manapouri power station discharging water to Deep Cove.

By far the largest flood recorded at Tuatapere had a maximum instantaneous discharge of 3320 m^3s^{-1} on 27 January, 1984. At more than 1300 m^3s^{-1} greater than the second largest flood (1994 m^3s^{-1} on 13 January, 1983), the 1984 flood has a return period of around 200 years. The January 1984 storm was a short duration (about 18 hours) event. Rainfall was heaviest in a broad band stretching NW-SE across Manapouri catchment and Takitimu Mountains to Invercargill. Rainfall was not as high in Lake Te Anau catchment. The result was an exceptionally large inflow to Lake Manapouri from its local catchment and exceptionally high runoff from tributaries in Lower Waiau from both the Takitimu and Fiordland sides of the catchment. Given the short duration of the rainfall event, most of the inflow to Lake Manapouri was able to be stored, and the outflow, while still large, was of a much lower return period than the inflow.

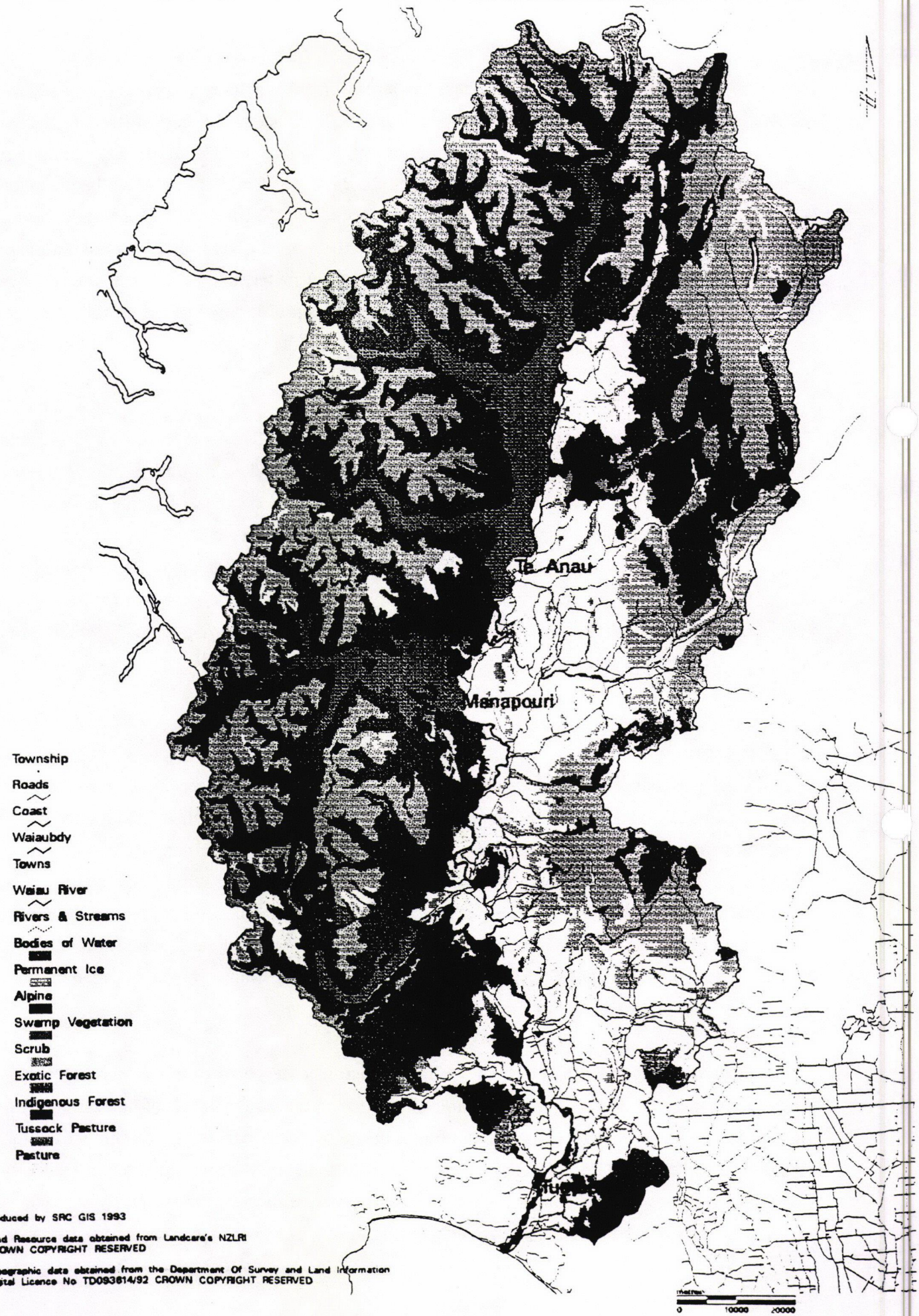
The October/November 1988 event was the most significant flood on record in Upper Waiau (Wairoa). This event resulted from a prolonged period of sustained rainfall in numerous storms, such that Lakes Te Anau and Manapouri rose gradually to flood range. Discharges in excess of 1000 m^3s^{-1} were maintained for several days between Lakes Te Anau and Manapouri and for 22 out of 23 days at Tuatapere. The maximum recorded outflow from Lake Manapouri was 1939 m^3s^{-1} on 4th November 1988. This has a return period in excess of 200 years. Because of the regulatory effects of the lakes, peak flow in lower Waiau River during the October/November 1988 flood event was not unusual for its magnitude but for the sustained high flow levels.

Vegetation

Waiau catchment has a modified vegetation cover, consisting of 35% indigenous vegetation (shrub, forest and tussock) and 65% exotic vegetation (mainly pasture) (see **Figure 4**). The pre-European vegetation cover of the lower catchment was a mosaic of forest, grassland and swamp (McGlone and Bathgate, 1983). The western side of the catchment was vegetated with dense stands of beech (*Nothofagus* sp.), with mixed podocarp and/or beech forest along the southern part of the catchment and on the Longwood Range. The northern part of the catchment, and the Takitimu Mountains were for the most part covered with indigenous grassland. Scrub and swamp vegetation, manuka and flax mostly, covered the balance of the region.

Since the early nineteenth century when the first European settlers arrived in the region, much of the forest, indigenous grassland and swamp areas have been reduced as a result of agriculture, fire and sawmilling (Hanger, 1979). Most of the forest in the southern part of the catchment and on the flanks of the Longwood Range has been removed, with some areas being replanted in exotic forest. Most forest, however, has been converted to pasture, as have most of the swamp/scrub areas. The western catchment vegetation remains relatively untouched, except for the conversion of some of the

Figure 4: Vegetation distribution in Waiau River catchment



tributary catchments to pasture, due to its inclusion within the Fiordland National Park. The grassland vegetation of the Takitimu Mountains and the northern part of the catchment remained unchanged until the 1960's when indigenous grassland was converted to exotic grassland, or in less productive areas, exotic tree plantations. Many areas stripped of their natural vegetation have become infested with willow, gorse and broom. The willow is confined to channel margins whereas gorse and broom are able to occupy any site.

Social aspects (Historical component summarised from Day, 1993)

The Maori came to lower Waiau and coastal area in a series of tribal migrations, started by the Waitaha, led by Chief Rakaihaitu, in the C14th. Their expedition travelled down Waiau River to Foveaux Strait. The Ngati Mamoe arrived next, probably in the late C15th, and gradually intermarried with the Waitaha. The last migration was that of Ngai Tahu towards the end of the C17th. Waiau River was the main access route between the lakes and the sea for southern Maori. Lakes and rivers provided eels, freshwater mussels, crayfish, native trout, minnows and whitebait. Prior to the 1850's human impacts on the landscape of Waiau Basin were negligible. Along the coast flax and manuka grew, rising to a series of podocarp forests on terraces. Rimu, mati, kahikatea, miro and totara grew inland, while beech forest favoured the surrounding hill country.

European associations with Waiau region began with seafaring explorers, followed by sealers and whalers. Subsequently there was a steady flow of goldminers, surveyors, runholders, yeoman farmers, flaxmillers and sawmillers. From the 1850's, Waiau Valley was slowly populated by four main groups of settlers: sailor settlers, runholders, speculators and squatters, and the area to the west was considered *terra incognita* until the 1890's.

In 1854, Freeman Jackson and Donald Hankinson journeyed inland to investigate the possibilities of pastoral settlement. Te Anau and Manapouri runs were bought in 1854. Runs at Pahia, Orepuki, Clifden, Lilburn and Blackmount followed in 1856, and the Upper Waiau in 1857. By 1861 all readily available pastoral land was being utilised for the production of wool, and by the mid-1860's farming activities were well established (Woods, 1982). Isolation and remoteness, however, proved insurmountable, and Te Anau Basin remained geographically insulated by a wilderness of tussock, shrub and native forest.

Gold was found along beaches and in Waiau Valley, near Blackmount, in 1863. By 1885 gold returns were down, and most gold miners turned to farming and sawmilling, although beach mining continued until around 1900. Coal was discovered inland from Orepuki in 1872, leases were applied for in 1885, and mining operations continued through to the 1960's. Sawmilling followed in the wake of land clearance, housing, mining and railway construction. Throughout the C19th, access remained difficult, and it was not until the government extended the railway west to Tuatapere in 1909 that the forest industry truly expanded. Waiau River was a major obstacle to development until

bridges were built at Tuatapere in 1904 and Clifden in 1915. During World War One the demand for timber increased, and following the war further land was made available for closer settlement in accordance with the Soldier Settlement Act of 1915. However, the depressions of 1921-22 and the 1930's slowed milling and farming. In the late 1920's a reasonable access road was completed through to the Te Anau Basin, improving the opportunity for pastoralism and tourism.

The first century of European activity in Te Anau basin witnessed sustained attempts by a succession of explorers, runholders and entrepreneurs to utilise the area's scenic and pastoral potential. The Depression and World War Two slowed progress and the farming frontier contracted as holdings were amalgamated and leases abandoned or absorbed into Fiordland National Park. It was not until the 1950's that a regrowth of optimism due to rising prices, a renewed demand for labour, and adequate access to the area, provided the basis for a major revival in farming (McDonald, 1972; Woods, 1982). Government Land Development programmes bought up larger runs in Te Anau Basin and along the margins of the Takitimu's. Modern techniques provided a new lease of life where smaller farms had previously failed. While dairy farming and the family farm were in decline during the 1950's, expansion in sheep farming increased demands on indigenous forest. Over time the forestry industry has consolidated, and by 1988 there were only 2 sawmills left in Tuatapere

Hydro-Scheme

In 1904 the region was considered as a possible source of hydro-electric power, but inaccessibility and the magnitude of the project prohibited its progression. In 1959, however, the scheme was revived, principally as the result of a proposal to construct an aluminium smelter on Tiwai Point in Bluff Harbour. This culminated in the Manapouri-Te Anau Development Act 1960. Investigations were initiated by Comalco Industries Proprietary Limited of Australia (formerly Consolidated Zinc) and subsequently taken over by the New Zealand Government in 1963. Water was to be diverted out of a new outlet from West Arm into Deep Cove, Doubtful Sound and a powerhouse was to be hewn out of solid rock beneath the lake with a 10 km tailrace tunnel to the sea at Deep Cove.

The Act gave authority to raise the level of Lake Manapouri 27.4 m, turning Manapouri and Te Anau into one large lake. In 1966 the agreement was amended and the proposed mean level of Lake Manapouri reduced from 27.4 m to 8.4 m above its present mean. A temporary weir was constructed at the site of the present Mararoa Weir (Lake Manapouri Control Structure) in 1968. Rising construction costs and opposition to raising the lake turned the Manapouri controversy into a national issue. The "Save Manapouri" organisation was formed, and in 1969 the largest-ever petition was presented to Parliament with 264,906 signatures. The Government ordered a Commission of Inquiry on the subject, and the proposals for raising lake levels were dropped following a change of Government in 1972. An independent body, Guardians of Lakes Manapouri and Te Anau, was established in order to recommend suitable patterns for working levels of both lakes to the Minister for the Environment as well as to investigate other long-term effects of the power scheme (Pickrill

and Maciver, 1978). The final stage of the project involved the building of control structures on the outlets of Lakes Te Anau and Manapouri, completed in 1974 and 1976 respectively.

Acknowledgments

We are grateful to Southland Regional Council for providing the maps GIS used in this report and to Sue Bennett for proof-reading the document.

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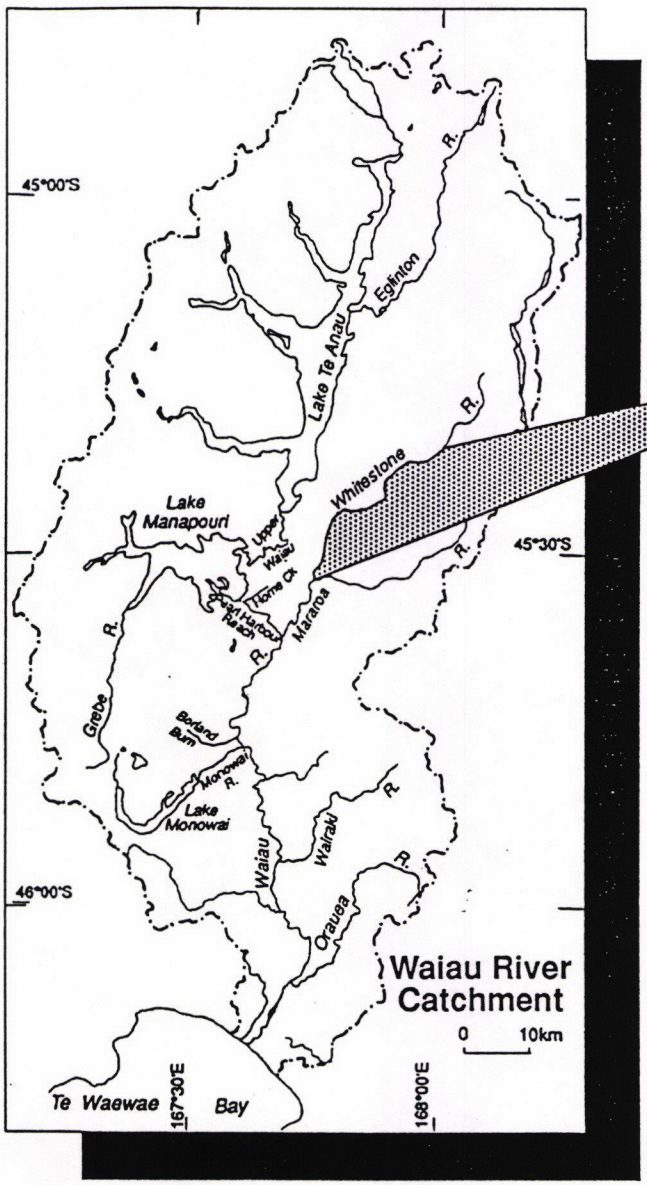
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WHITESTONE RIVER
Reach Analysis

Gary J. BRIERLEY
April, 1994



Whitestone River

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HITESTONE RIVER REACH ANALYSIS

eport submitted to Waiau River Working Party
part of Tributary river reach analysis project by

GARY J. BRIERLEY

APRIL, 1994

UPDATE

.testone River reach analysis report submitted in April 1993. Analysis has been extended :ld work completed in July 1993. Two further reaches have been identified, Lady Burn and ımed Margin Forest reach has been extended upstream and renamed Mount Prospect reach, on has been added. I am grateful to Sue Bennett and John Whitehead for their advice, field .ended during this project. Sue also kindly proof-read the document.

OVERVIEW

:f, removal of most terrace materials, and the lack of a regulating lake at its headwaters, te different river character to that demonstrated by Mararoa River. Whitestone River alley with few remnants of Pleistocene outwash terraces. While glacial activity largely lity, reworking of deposits by meltwater channels played a major role in determining valley ely 'clearing-out' valley-marginal deposits producing broad valley flats. Valley and alluvial ınnel has switched position across the entire valley bottom.

reaches, coarse basal deposits likely reflect lag deposits from former channels, possibly ons. Adjacent alluvial flats are covered by red tussock, with occasional swamps. Some ft bank, but in no instance do these resemble the flights of terraces evident along Mararoa ely stable in this reach; indeed, adjacent to Lady Burn, Whitestone River is confined to a ınel with no within-channel sedimentation.

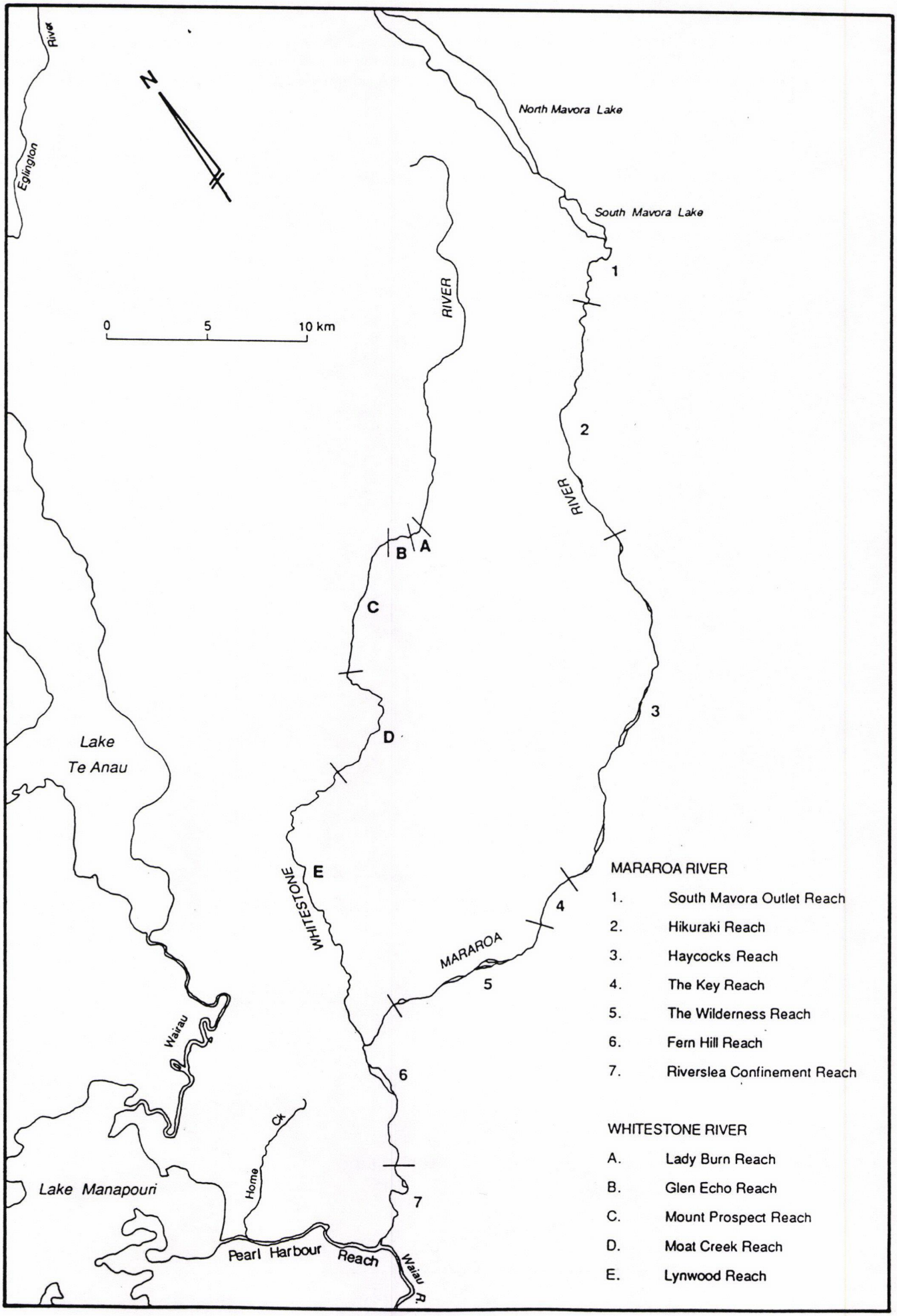
ur of Whitestone River downstream of Lady Burn is markedly different to that upstream. minent upstream are covered by reworked alluvium. Air photographs indicate the avulsive of the river. Numerous former channel positions, some of which are distinctly meandering, indicating that Whitestone River has switched its position at various stages in the past. l sweeps across the active channel zone, bank erosion ensues. This suggests a two-phase er:

low to moderate magnitude floods induce sweeping of the channel, with concomitant bank

gnitude events induce abandonment or switching of channels, and reoccupation of former

man modification of Lower Whitestone River has resulted in a disequilibrium river style. els, and bank protection structures such as rip-rap, groynes, mounded gravels and willow l behaviour of the river. The irregular distribution and timing of engineering controls has a permanent state of adjustment, in terms of its planform geometry, bed material calibre Bed gravels are generally poorly sorted and discrete lobes of finer clasts (< 50 mm) are ensive sand sheets. For example, at the time of field work in July 1993, extensive sand re evident on the flats immediately upstream of Fred Burn confluence and at Mararoa ıy have resulted from channel-bed disturbance, as matrix materials are winnowed from y armoured surfaces, and may contribute to the 'dirty water' recorded in lower Mararoa

Base map of Whitestone/Mararoa river reaches



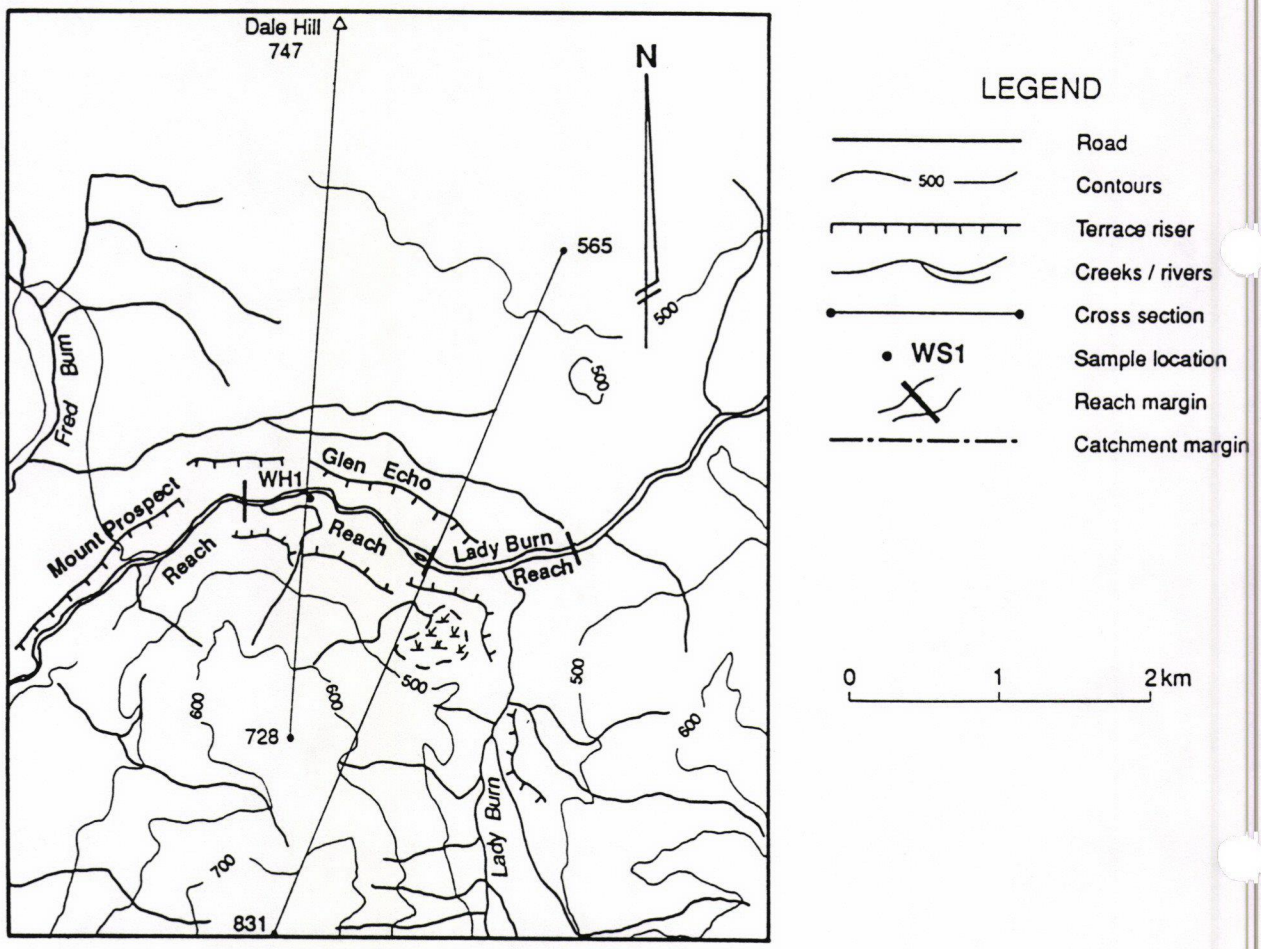
REACH NAME: LADY BURN REACH

Geographic description of reach
Lady Burn reach, a 1 km stretch of Whitestone River adjacent to Lady Burn confluence, is characterized by a stable, straight single channel, with no within-channel sedimentation and negligible bedload throughput. Upstream of Lady Burn reach, Whitestone River has a stable channel configuration, with occasional channel division around lag boulders. Flats are covered by tussock grass with some swamps. A prominent left bank terrace/fan complex is evident beneath Bare Peak.

Analysts: GB, JW, SB Date of Analysis: 17.07.93

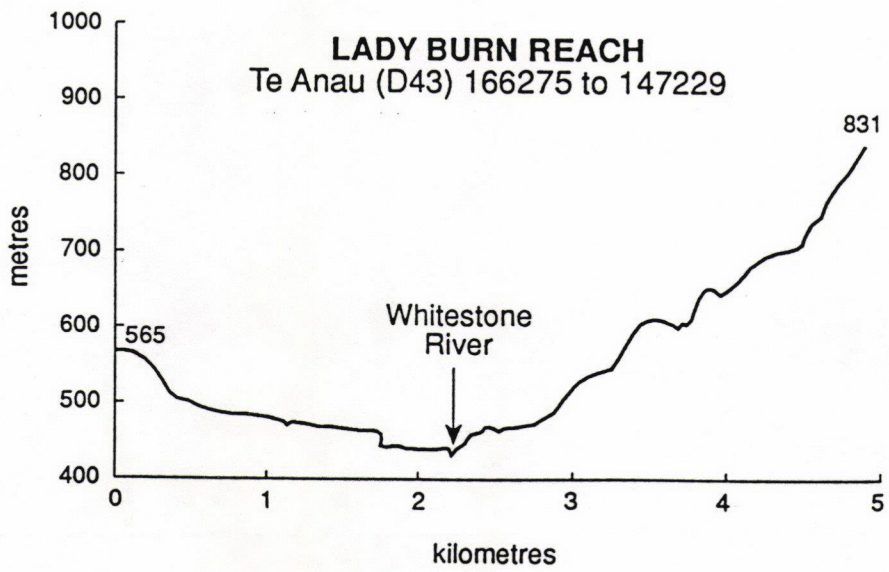
Grid co-ordinates of reach: Te Anau (D43) 1:50,000, 167256 to 158255

Lady Burn reach Base Map:



VALLEY CHARACTERISTICS

Valley cross section



Valley setting
Relatively narrow valley, with perched terrace remnants.

Extent of Valley flat
Generally restricted to a few hundred metres.

Terrace character
Whitestone Valley only has remnant perched upper terraces, resulting in a rectangular valley cross-sectional form. Left bank is generally unterraced, as Whitestone River abuts against bedrock. Terrace on right bank is 4-5 m above channel and is continuous downstream in Glen Echo reach. Prominent terraces are evident along Lady Burn, recording extensive outwash materials incised by a meltwater channel.

Extent and character of Alluvial flat
Narrow and discontinuous, with abandoned channel/bar complex evident on flats.

Degree and character of channel constriction
Laterally confined reach as channel abuts against large volumes of materials supplied from Lady Burn.

Character and impact of tributary streams
Lady Burn is a small left bank tributary that presently exerts negligible impact on Whitestone River. This small, sinuous stream is clearly misfit within a relatively broad, former meltwater course. Within this valley there is a prominent fan/terrace sequence adjacent to tributary streams that flow from Snowdon Forest. These surfaces are no longer active.

Surficial geology
Mount Prospect Formation.

Vegetation
Valley side/flats: Pocket remnants of beech forest; Good cover of hard and silver tussock on valley sides, with scattered manuka and brown top

Alluvial flats/Bank/Bars: Grasses (brown top), with sedges, cutty grass, matagouri, occasional tussock and rumex (dock).

Land use
Pasture.

Direct human impacts
Negligible; cattle grazing

Other comments
The primary difference between Whitestone Valley and Mararoa Valley appears to be the extent of removal of outwash gravels terraces. Channel configuration in Lady Burn reach is induced by constriction associated with Lady Burn sediment inputs. Lady Burn channel is very stable and there appears to be negligible contemporary sediment throughput.

CHANNEL CHARACTERISTICS

Number of channels
Single-channelled.

Channel geometry
Relatively high width:depth. Reach is too short for a predictable pool-riffle sequence to be discerned.

Sinuosity
Channel is virtually straight.

Lateral stability of channel(s)
The channel is laterally stable, with negligible sediment throughput.

Bar type and scale
No within-channel bars are evident in this short, straight reach, other than a riffle upstream of Lady Burn confluence and a riffle just upstream of Glen Echo reach.

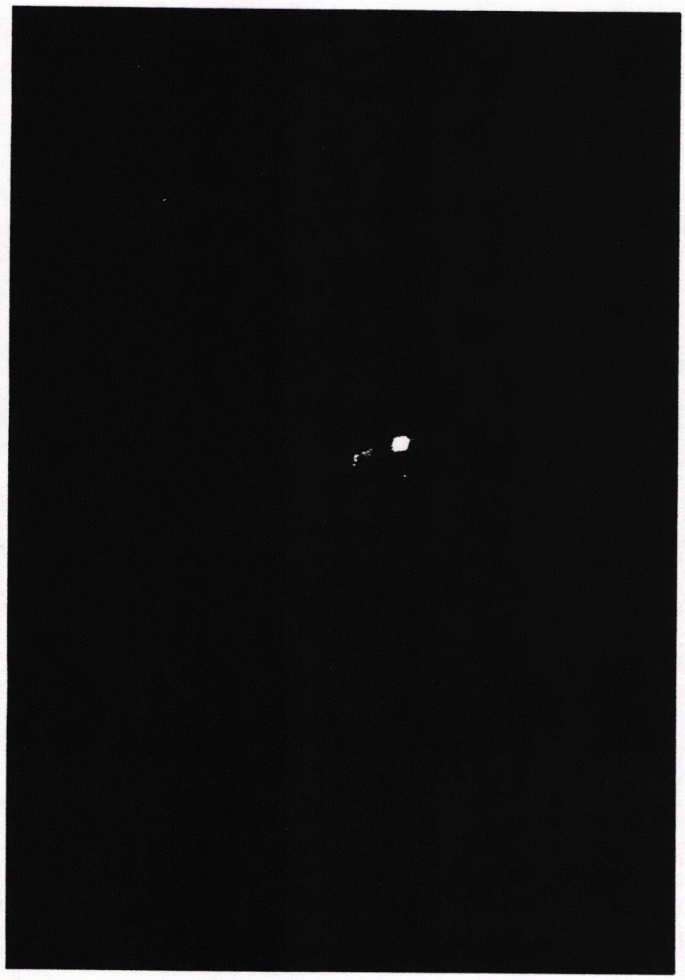
Bed/Bank character (extent and materials)
Banks are a couple of metres high and appear stable.

Flow character
Uniform flow with occasional white water over riffles.

SAMPLE SITE CHARACTERISTICS

No samples collected, as no within-channel sedimentation is evident.

Whitestone River Photo 1, Headwater reach
Low sinuosity, single-channelled configuration of upper Whitestone River. Although the channelized zone is relatively narrow, the natural switching behaviour of Whitestone River is evident. Note the dense beech forest cover.
16.01.93 GBF 1:16



Whitestone River Photo 2, Lady Burn Reach
View upstream over Lady Burn and Upper Whitestone River. The small bar in mid-channel marks the upstream limit of Lady Burn reach, which is characterised by a relatively stable, single channel, with no active within-channel sedimentation.
17.07.93 WH 3/24A



Whitestone River Photo 3, Lady Burn Reach
Alluvial flats in Lady Burn reach are perched a metre or so above the channel. Note the similarity between the lozenge-shaped bar in the foreground and the abandoned flats in mid-photo. Lady Burn enters Whitestone River on the right hand side in mid-photo.
17.07.93 WH 3/22A Te Anau (D43) 1:50,000, GR 158254



REACH NAME: GLEN ECHO REACH

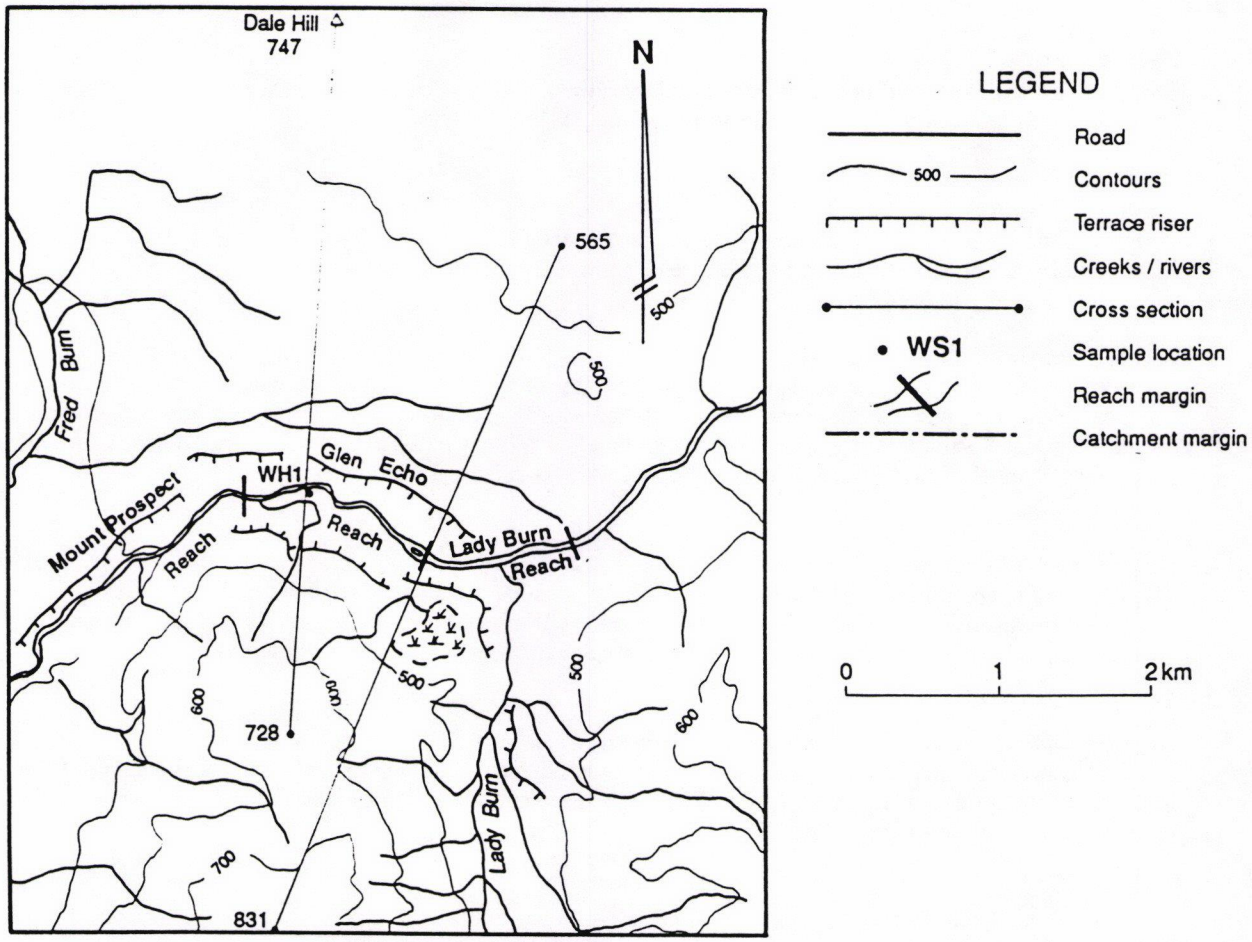
Geographic description of reach

Glen Echo reach is less constrained than Lady Burn reach, as Whitestone River divides around mid-channel compound bars. Several topographic levels are common, with broad areas of active gravel bars and alluvial flats. Swamps are evident on alluvial flats at valley margins. Glen Echo reach is significantly less disturbed than downstream reaches and clasts are texturally well-segregated, with distinct depositional zones. Distinctly coarser basal gravel zones are apparent, with imbricated surfaces (especially at bar heads, in chute channels and adjacent to riffles). Scour pools are prevalent between pools and a relatively deep pool was observed in an abandoned channel. The downstream reach limit is demarcated by the first instance in which Whitestone River abuts against prominent stop banks.

Analysts: GB, JW, SB Date of Analysis: 17.07.93

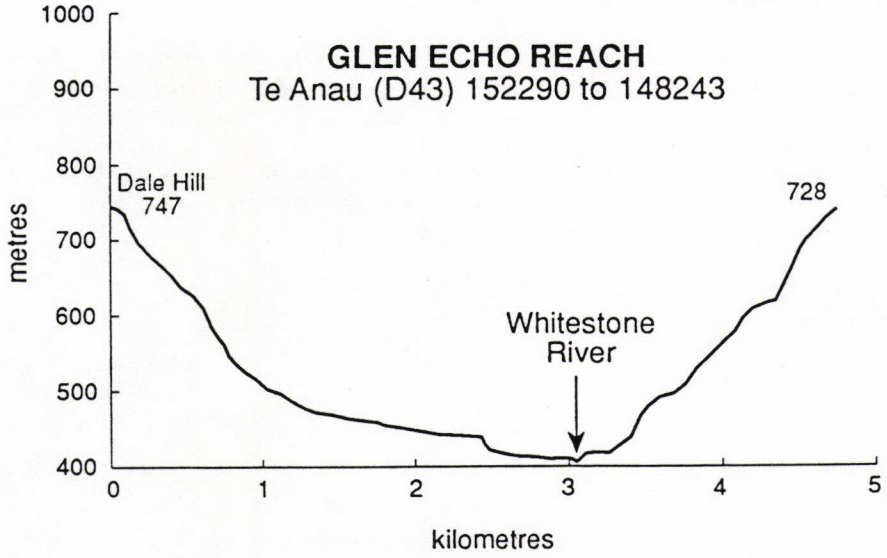
Grid co-ordinates of reach: Te Anau (D43) 1:50,000, 158255 to 145258

Glen Echo reach Base Map:



VALLEY CHARACTERISTICS

Valley cross section



Valley setting
Broad valley with remnant upper terraces at its margins. Valley is set between Dale Hill and Margin Forest on the right bank, and the foothills of Mount Prospect on the left bank.

Extent of Valley flat
Valley widens from about 600-800 m wide at the reach head to about 1000 m wide down-reach. Valley is notably wider adjacent to Fred Burn, which follows the course of a former meltwater channel.

Terrace character
Up to three terrace levels are evident on the left valley margin, the highest of which is > 25 m above the present channel. However, these terraces are never observed as a flight; rather, they occur as a series of remnants cored by Mount Prospect Formation. In contrast, the right side has a fairly extensive lower terrace surface about 4-5 m above the present channel. This presents a rectangular valley cross-sectional form.

Extent and character of Alluvial flat
Alluvial flats have an hummocky surface, with windy secondary channels and are readily reworked at high discharge stages. Many abandoned bends of the formerly sinuous Whitestone River are evident. Flats are notably wider than downstream, where stop banks constrain the channel. Several topographic levels are present.

Degree and character of channel constriction
Channel is not confined and is able to shift readily over adjacent flats. Fan unit from an unnamed left bank tributary at the downstream end of the reach (GR 147258) has undercut, but the marginal channel has subsequently shifted and now has planted willows at the cliff-base.

Character and impact of tributary streams
No tributaries enter in this reach *per se*, but Fred Burn follows along the right valley margin, prior to joining Whitestone River in Mount Prospect reach. A fan built by a tributary stream at the downstream limit of the reach (GR 146258) is no longer accreting, but may erode during floods and is protected by a series of planted willows.

Surficial geology
Mount Prospect Formation.

Vegetation
Valley side/flats: Remnants of beech forest; terrace risers have a cover of introduced grasses with scattered manuka (some recently burnt off) and ferns in sheltered locations.

Alluvial flats/Bank/Bars: Grasses, with coprosma, poplars, willows, sweet thorny briar (rosehip), lupins and other exotic weeds.

Land use
Pasture.

Direct human impacts
This is a relatively 'natural' reach in which human impacts are less pronounced than downstream. The channel is less constrained than downstream, but there are occasional gravel mounds and planted willows at the downstream end of the reach.

CHANNEL CHARACTERISTICS

Number of channels
Generally 2-3 channels are evident, as Whitestone River divides around/atop riffles.

Channel geometry:
Generally low width:depth (ie relatively wide, up to 1 m deep), but some notable exceptions.

Sinuosity:
Quite variable from segment to segment; generally low sinuosity, but some broad bends.

Lateral stability of channel(s)
Relatively unconstrained, with extensive active gravel surfaces.

Bar type and scale
Diverse range of bar styles, with large expanses of active surfaces. Bars are generally quite well graded with distinct depositional units.

Bed/Bank character (extent and materials)
Generally shallow features (< 1 m), with very small proportion of fines.

Flow character
Large number of riffles, with uniform flow in intervening riffles. Not much by way of standing waves (ie. energy seems to be dissipated rather than concentrated).

SAMPLE SITE CHARACTERISTICS

Sample number: **WH1** Analysts: GB, SB, JW

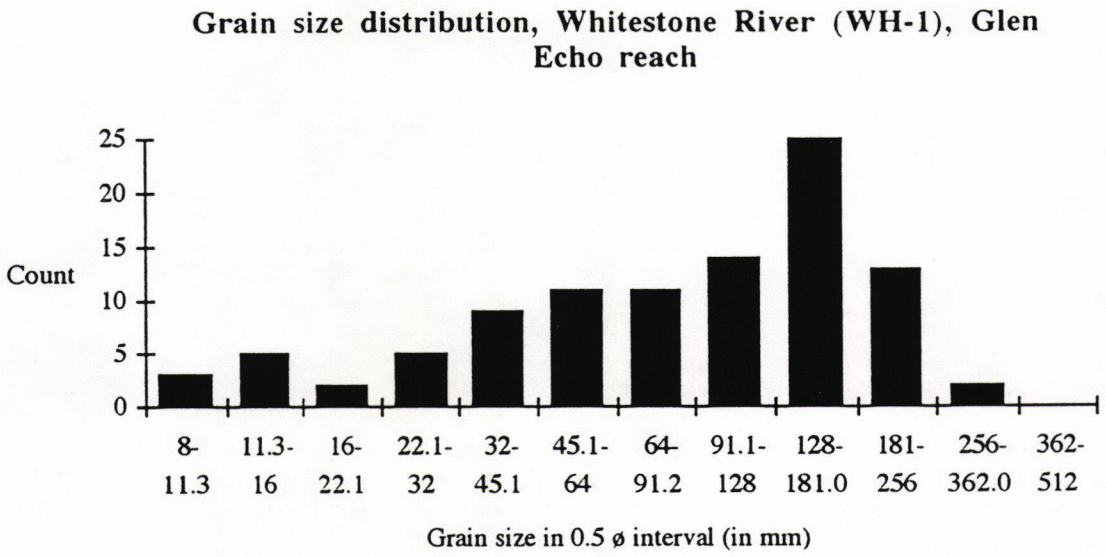
Grid reference: Te Anau Sheet (D43), 149259

Sample type: 2 x 50 m @ 1.0 m interval

Bar type: Compound point bar, characterised by distinct diagonally-aligned depositional units, including sand and fine gravel units.

Sample position on bar: Tail end of scoured section of chute channel, 2 m apart.

'Particle characteristics'



D95	225 mm		
D84	180 mm		
D50	103 mm	Mean	107.59 mm
D16	33 mm		
D5	14 mm		

Sorting: 70.25 mm. Bar demonstrates wide range of grain sizes, but individual depositional units are quite well sorted.

Packing arrangement: Moderately imbricated, moderately packed gravels. Quite effectively winnowed down to about 25 mm, although some fines are trapped in lee of coarser clasts.

Shape: Subrounded; platey to blocky

Lithology: Greywacke is dominant.

Other characteristics: Vegetation is sparse in chute channel itself. Adjacent bar surfaces have cover of grasses and also small plants such as pearlwort, *Raoulia australis* and clover. Alluvial flats are covered by grasses including red tussock, thistles and rumex.

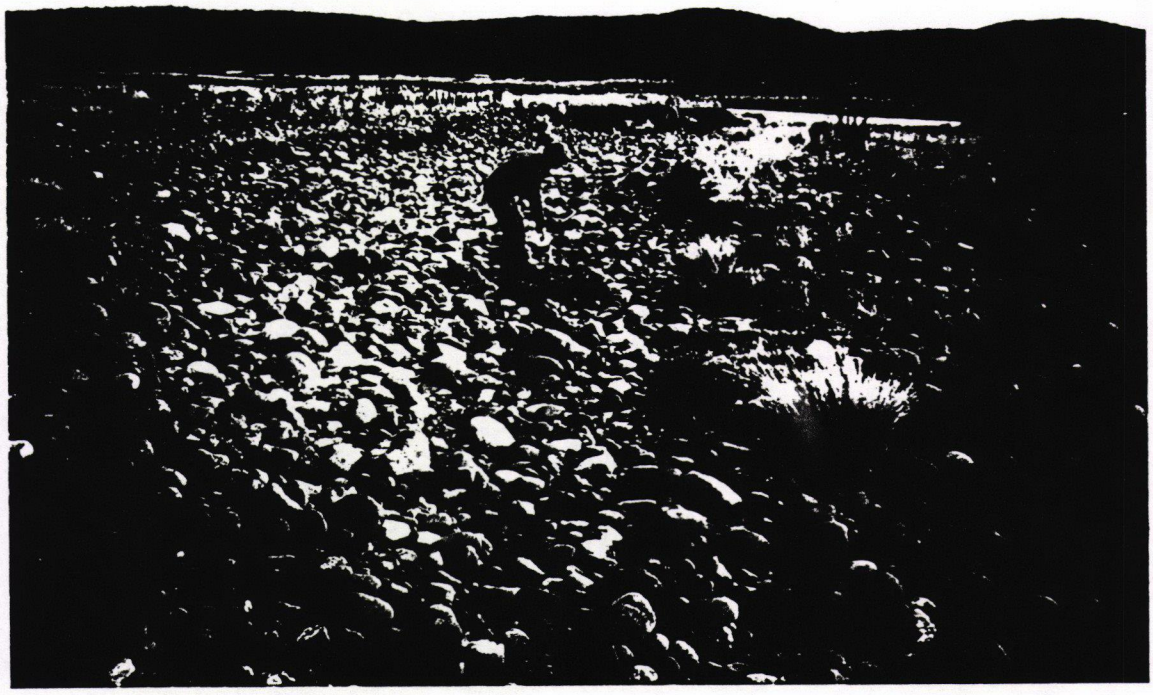
Whitestone River Photo 4, Glen Echo reach
View downstream overlooking Glen Echo reach. Note the broad sweeping nature of the channels and the extensive active gravel surfaces, alluvial flats and valley flats.
17.07.93 WH 3/23A



Whitestone River Photo 5, Glen Echo reach
View upstream of Glen Echo reach. Note the extensive gravel surface and the shallow alluvial flats/low terrace on the right bank (left hand side of photograph).
17.07.93 WH 3 21A



Whitestone River Photo 6, Glen Echo reach
Sample site WH-1, located within a chute channel on a compound point bar.
17.07.93 WH 3/17A Te Anau (D43) 1:50,000, GR 153258



Whitestone River Photo 7, Glen Echo reach
Downstream end of Glen Echo reach, characterised by a well-defined riffle-pool sequence. Such features are less well defined in modified reaches downstream.
17.07.93 WH 3/15A



Whitestone River Photo 8, Glen Echo reach
The lower section of Glen Echo reach is not as multichannelled as upstream, but the channel is still able to sweep laterally. Abandoned former courses are also evident. Pool-riffle sequences are indicated by the transition in flow character in the foreground.
17.07.93 WH 3 14A



Whitestone River Photo 9, Glen Echo reach
Sample site WH-2. Sample was located across the head of an abandoned channel. Note the clumps of grasses in mid-channel, indicating erosion of banks upstream.
17.07.93 WH 3 13A Te Anau (D43) 1:50,000, GR 148258



Whitestone River Photo 10, Glen Echo reach
Abandoned concave bank of channel that previously eroded unnamed tributary fan at the downstream end of Glen Echo reach. Willows have been planted to inhibit flood-stage erosion.
17.07.93 WH 3/10A



Whitestone River Photo 11, Glen Echo reach
Downstream end of Glen Echo reach, viewed from the fan surface at GR 146258. Note the divided nature of the channel at this point, and the planted willows against the left bank in the foreground.
17.07.93 WH 3/11A



REACH NAME: MOUNT PROSPECT REACH

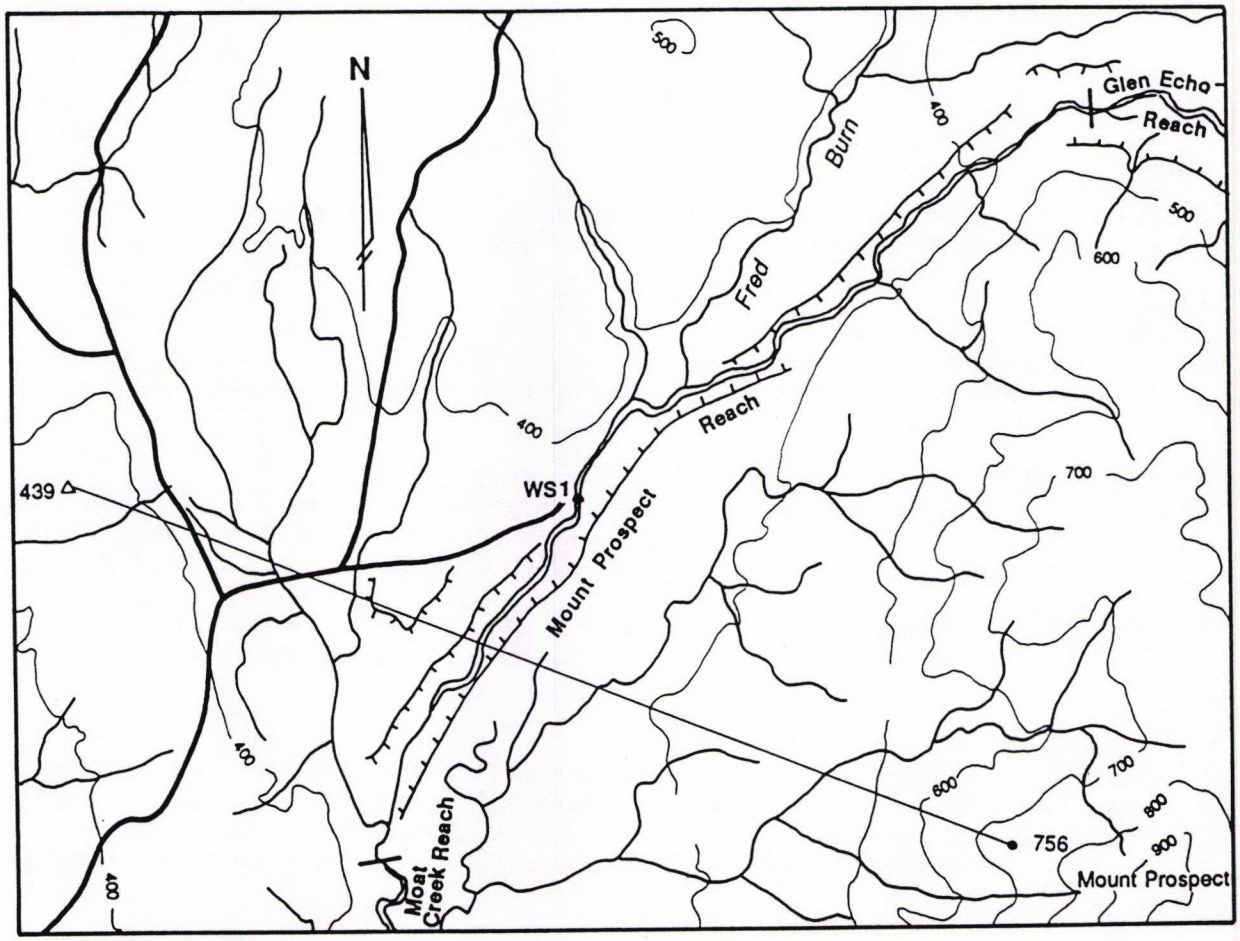
Geographic description of reach

In Mount Prospect reach, which extends from the stop-banked right bank at the downstream end of Glen Echo reach to 2 km downstream of Kakapo Road Bridge, Whitestone River has been extensively modified, with stop banks along the entire length and major straight diversion channels at the upstream and downstream ends of the reach. These artificial channels contrast starkly with the highly sinuous course of former channels evident on the alluvial flats. Gravel surfaces are extensive. Local scale variability in bar style, channel definition and accumulations of fine gravel lobes on bars surfaces attest to indirect consequences of the various management strategies carried out in this river reach.

Analysts: GB, AH, BJ, JW, SB Date of Analysis: 20.01.93 and 17.07.93

Grid co-ordinates of reach: Te Anau (D43) 1:50,000, 145258 to 099210

Mount Prospect reach Base Map:



Mount Prospect Reach

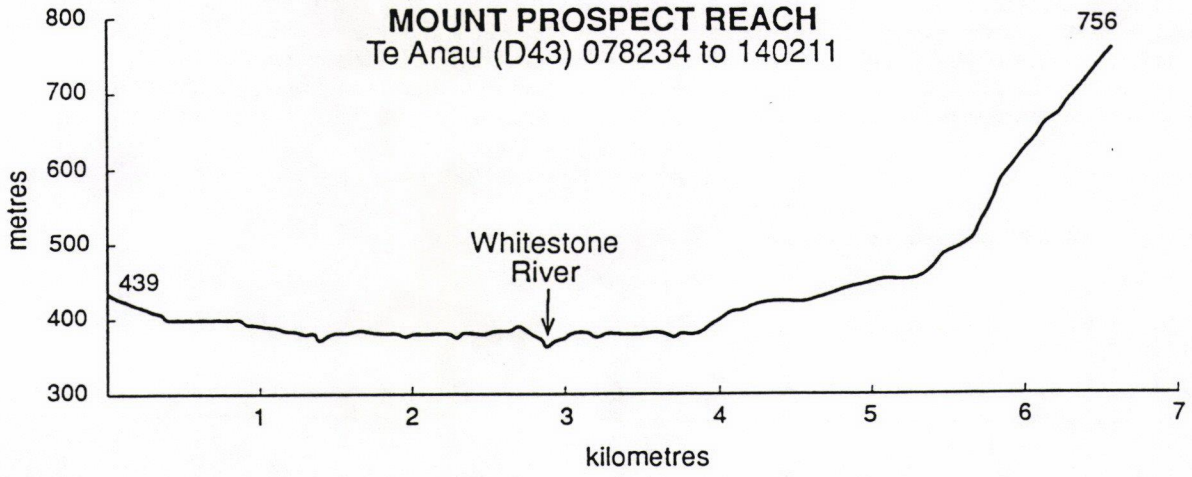
0 1 2 km

LEGEND

Road
500 Contours
Terrace riser
Creeks / rivers
Cross section
WS4 Sample location
Reach margin
Catchment margin

VALLEY CHARACTERISTICS

Valley cross section



Valley setting

Broad valley with remnant upper terraces at its margins. Valley is set between Te Anau Hill and Margin Forest on the right bank, and the foothills of Mount Prospect on the left bank.

Character and extent of Valley flat

Fairly uniform at about 1.5 km wide. This shallow surface is differentiated into a channelized zone by stop banks. The channel has no 'natural' division across the flats, and former abandoned channel courses extend across the valley.

Terrace character

Left Bank : A discontinuous upper terrace, about 80 m above the present channel, is noted upstream of Kakapo road bridge (from GR 132246 to 124233). High remnant terraces are also observed downstream. No lower terraces are evident, indicating the ease with which the channel could shift over the valley flats if the stop banks were not in place.

Right Bank: Channel-marginal terrace upstream of Kakapo Road bridge is about 10 m above the channel. This discontinuous surface is about 200 m wide adjacent to the bridge. No upper terraces are evident.

Extent and character of Alluvial flat

Active alluvial flats are constrained by stop banks to about 200-300 m wide; otherwise the flats would extend to the valley-margin. The channellised zone between the stop banks has a hummocky surface. Abandoned bends of secondary channels indicate that alluvial flats are readily reworked at high discharge stages. Areas of extensive sand accumulation are evident, such as immediately upstream of bedrock constriction on the right bank at Fred Burn confluence.

Degree and character of channel constriction

Alluvial flats are confined by stop banks. Within this area the river has adopted a 'channelized zone' about 80-100 m wide. This gives a ratio of available alluvial flats to active channel zone of around 4:1. The channel switches position readily within the channelized zone; indeed, this zone itself occasionally abuts against stop banks. Localised bedrock constraint occurs immediately downstream of Fred Burn confluence (GR 118241).

Character and impact of tributary streams

An unnamed right bank tributary forms the downstream margin of Mount Prospect reach (GR 099213). This stream, along with two other right bank tributaries upstream of Kakapo Road bridge (Fred's Burn and an unnamed tributary, with confluences at GR 118240 and 115239 respectively), drain relatively large catchments, but they flow for some distance over the valley flats prior to joining Whitestone River. The low slopes of these tributaries indicates that while they have transported substantial volumes of material in the past, they no longer supply large volumes of material to the Whitestone. The same can be said for a series of small left bank tributaries.

Surficial geology
Hummocky ridge-like topography in this area reflects regionally-tilted sedimentary strata and glacially-derived surficial materials. The ridged terrain is comprised primarily of Pliocene-Pleistocene sandstones, siltstones and conglomerates of Mount Prospect Formation. Glacially-derived deposits form discontinuous remnant terraces pinned several tens of metres above the left bank of Whitestone River.

Vegetation
Valley sides/terrace risers: Valley sides are partially covered by beech forest, with a good cover of hard and silver tussock. Terrace risers have a cover of grasses (brown top) with scattered manuka (some recently burnt off) and ferns in sheltered locations.

Alluvial flats/Bank/Bars: Grasses (brown top, cutty and occasional tussock) and sedges, with matagouri, coprosma, poplars, willows, sweet thorny briar (rosehip), lupins, dock (rumex) and other exotic weeds.

Land use
Pasture.

Direct human impacts
Numerous management works in the guise of 'river improvement' have been emplaced in an irregular, largely unstructured manner, including:
i) The channellised zone itself is defined by 2-3 m high stop banks.
ii) Diversion channels at the upstream and downstream ends of the reach.
iii) Groynes, planted willows and mounded gravels within stop banks deflect flow towards the channel, serving to protect the stop banks. For example, at the head of the reach, flow has been constrained into a smaller channelized zone within the stop banks, with planted willows and rip-rap protecting the left stop bank.
iv) Kakapo Road bridge is protected by rip-rap consisting of angular boulders 1-2 m in width.

CHANNEL CHARACTERISTICS

Number of channels
Upstream of Kakapo road bridge, Mount Prospect reach is characterised by two or three channels. Downstream of the bridge Whitestone River is predominantly single-channelled, with occasional division of bar surfaces and riffles by chute channels. Few side channels are evident in the lower part of the reach.

Channel geometry
Relatively high width:depth of approximately 15:1, with shallow expansive flow across the channel. Numerous riffles indicate the relatively steep grade, but few pools are evident in the upstream part of Mount Prospect reach, as the pool-riffle sequence has been distorted by rip-rap both at the head of the reach and immediately upstream of Kakapo Road Bridge. The bar sequence within the diversion channel has yet to stabilise, resulting in an irregular channel geometry.

Sinuosity
The channelized zone is relatively straight, but the channel itself alternates from side to side with low to moderate sinuosity. No tight bends are observed, as flow is aligned down-valley with only a limited cross-valley component. This channel alignment differs significantly from the pattern of meander loops abandoned following construction of the straighter diversion channels, as evidenced at the upper and lower ends of this reach.

Lateral stability of channel(s)
The channel shifts with relative ease within the channelized zone, with significant active gravel surfaces. However, the flats within the stop banks appear relatively stable, with little evidence of aggradation. Extensive gravel sheets are common on the inside of bends, while concave banks at flat margins are locally eroding opposite lateral and point bars.

Bar type and scale
The chaotic transition in bar styles over very short distances attests to the disequilibrium nature of this reach. Upstream of Kakapo road bridge, Mount Prospect reach is characterised by a wide range of bar styles, with extensive gravel surfaces. Regular bar types are seldom observed; rather, the channel appears to switch position within the channelized zone giving little apparent order to the sediment distribution. In general, laterally accreting forms prevail over downstream accreting forms, although diagonal (down-riffle) forms are common. Many bars have discrete lobes of

finer clasts on their surfaces, and sands are abundant. In general, bar surfaces are irregularly sorted with little textural organisation.

Adjacent to Kakapo road bridge, alternating lateral bars are dominant. These frequently form as extensions of riffles which extend across-channel. Bars are typically up to a few hundred metres long, but are only a few tens of metres wide. These bars appear to be translating downstream rather than migrating laterally, as gravels are funnelled down the channelized zone rather than being dispersed onto the channel-marginal flats. This pattern is not maintained throughout the reach, however, as a series of point bars have formed at the head of the diversion channel. These bars are less laterally stable than upstream lateral bars, and one of the bends has breached the former right bank. This bar is now dissected by chute channels at various topographic levels. In this area the active gravel area is significantly wider than upstream (locally up to 100 m). This has mid-channel bar features downstream, with lobes of fine gravels over their surface.

Bed/Bank character (extent and materials)

Bar surfaces are moderately imbricated at the head of the reach, with discrete lobes of finer grained materials draped across bar surfaces. In some sections the river bed is sandy and very loose. Banks are typically about 1 m high and grassed. Immediately upstream of Fred Burn confluence, up to 70 cm of sand is draped in an extensive sheet over the right bank. Banks are locally protected by rip-rap, while willows have been planted at the margins of channel bends in the diversion channel. In the lower section of the diversion channel the banks of the active channel zone are poorly defined.

Flow character

Uniform flow with occasional white water over riffles. Flow is too shallow for development of boils and other turbulent structures.

SAMPLE SITE CHARACTERISTICS

Sample number: **WH2** Analysts: GB, SB, JW

Grid reference: Te Anau Sheet (D43), 126244

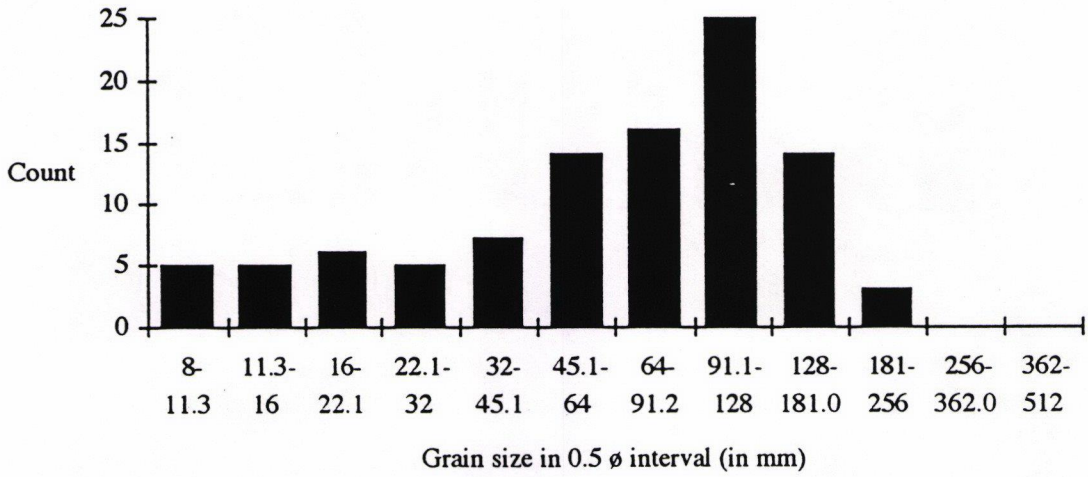
Sample type: 2 x 50 m @ 1.0 m interval

Bar type: Head of abandoned channel on large bank-attached compound bar.

Sample position on bar: Across head of abandoned channel at bar head.

'Particle characteristics'

Grain size distribution, Whitestone River (WH-2), Mount Prospect reach



D95	151 mm		
D84	129 mm		
D50	75 mm	Mean	79.12 mm
D16	22 mm		
D5	10 mm		

Sorting: 49.58 mm. Poor.

Packing arrangement: Relatively loose, jumbled surface with no imbrication. Barely winnowed, with sands evident a few metres from the water's edge.

Shape: Subrounded to rounded; blocky

Lithology: Mixed, with large proportion of greywacke.

Other characteristics: Bar surface has sparse vegetation cover, with grass, clover, and *Raoulia australis*, along with occasional large clumps of vegetation stranded atop gravels (mainly grasses). Alluvial flats are covered by grasses, including red tussock and fescu tussock, along with thistles. There is much open gravels, with scattered herbaceous weeds - *Epilobium*, *Plantago*, clover, *Raoulia australis*, rumex (dock), stranded clumps of grass and some lupin and briar (ie woody plants).

Sample number: **WS1** Analysts: AB, BA

Grid reference: Te Anau Sheet (D43), 112233

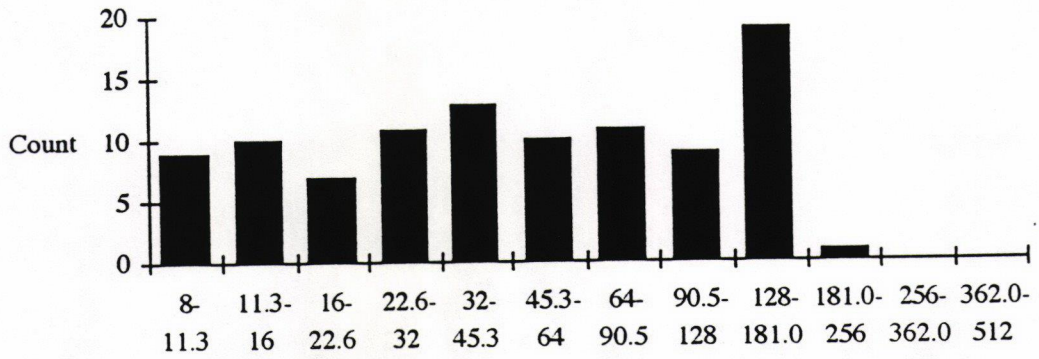
Sample type: 2 x 25 m @ 0.5 m interval

Bar type: Unit lateral bar with a dissected riffle and small mid-channel bar at its head. Influxes of finer gravel sheets are evident down-bar. The bar surface has been modified at its tail, associated with the bridge.

Sample position on bar: Extends from the riffle at the bar head, about 5 m from the water's edge.

'Particle characteristics'

Grain size distribution, Whitestone River (WS-1), Mount Prospect reach



D95	175 mm		
D84	135 mm		
D50	45 mm	Mean	68.76 mm
D16	15 mm		
D5	10 mm		

Sorting: 59.52 mm. Very poorly sorted, ranging from b max of 300 mm down to fine gravel/coarse sand (see histogram above). A mud drape has recently been washed over much of the bar surface.

Packing arrangement: Moderately imbricated, well-packed gravels with many partially-buried clasts. A high percentage o fines are trapped beneath these one or two-layer thick, larger clasts. Surface is winnowed down to 10 mm.

Shape: Subrounded to rounded; blocky

Lithology: Mixed.

Other characteristics: No down-sample variation noted. Bar is only sparsely vegetated by grasses and exotic weeds.

Whitestone River Photo 12, Mount Prospect Reach
View downstream of rip-rapped left bank at the head of Mount Prospect reach. Note the prominent riffle and pool in the foreground and the predominance of bank-attached bars.
17.07.93 WH 3/7A Te Anau (D43) 1:50,000, GR 145257



Whitestone River Photo 13, Mount Prospect Reach
Channel constriction at the head of Mount Prospect reach. Gravels have been mounded to narrow the active channel zone, and series of crack willows have been planted to 'protect' the right stop bank (photo taken looking upstream at GR 143257).
17.07.93 WH 3/6A Te Anau (D43) 1:50,000, GR 143257



Whitestone River Photo 14, Mount Prospect Reach
Constrained channel section at head of Mount Prospect reach, looking downstream. Note the shallow, wide channel, with minimal differentiation of depositional units of similar grain size. This indicates the disturbed nature of the channel bed at this site.
17.07.93 WH 3/5A Te Anau (D43) 1:50,000, GR 143257



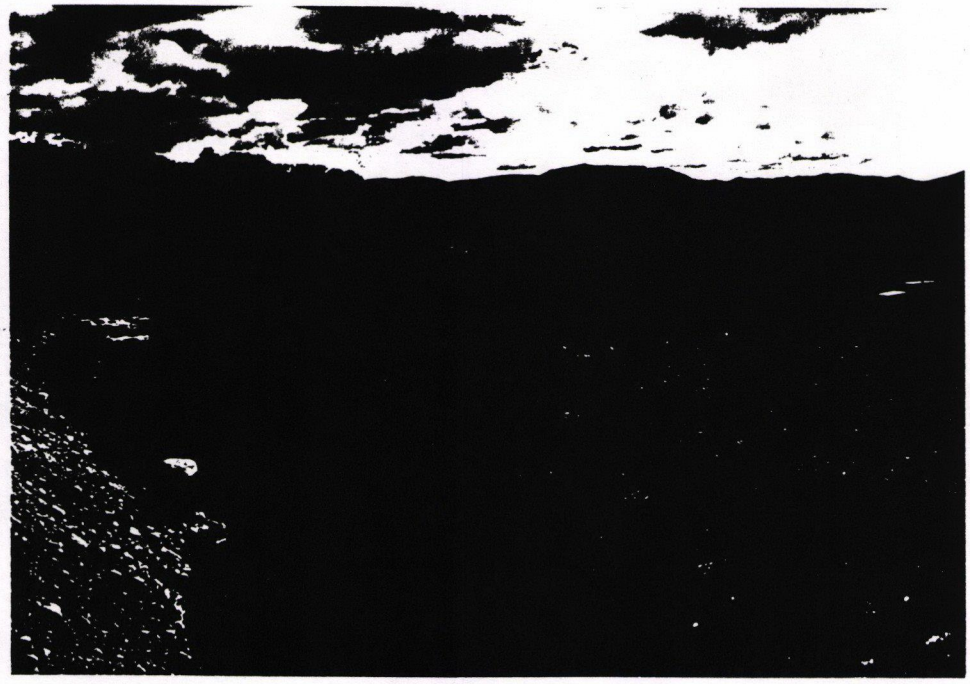
Whitestone River Photo 15, Mount Prospect Reach
Extensive gravel surfaces within the channelized zone, immediately upstream of Fred Burn confluence. The channel locally abuts against bedrock at this point.
17.07.93 WH 3/4A



Whitestone River Photo 16, Mount Prospect Reach
Immediately downstream of Fred Burn confluence bank-attached and within-channel bars are evident, along with abandoned channel courses. The exposure of Mount Prospect Formation on the ridge in mid-photo is about 3 km downstream of Kakapo Road Bridge in Moat Creek reach.
17.07.93 WH 3/3A



Whitestone River Photo 17, Mount Prospect Reach
View upstream of Mount Prospect reach, taken from the right bank terrace immediately upstream of Kakapo Road Bridge. Note the sequence of alternating bars, with flow division around the bar head riffle in mid-photo. Sample site WS1 was located downstream of this riffle. Large boulders have been placed within the channel to inhibit bank erosion and protect the bridge. The fringes of Margin Forest are evident on the left hand side of the photograph.
20.01.93 WH 2/7 Te Anau (D43) 1:50,000, GR 113234



Whitestone River Photo 18, Mount Prospect Reach
View downstream showing the riffle-lateral bar transition at sample site WS-1.
17.07.93 WH 3/2A



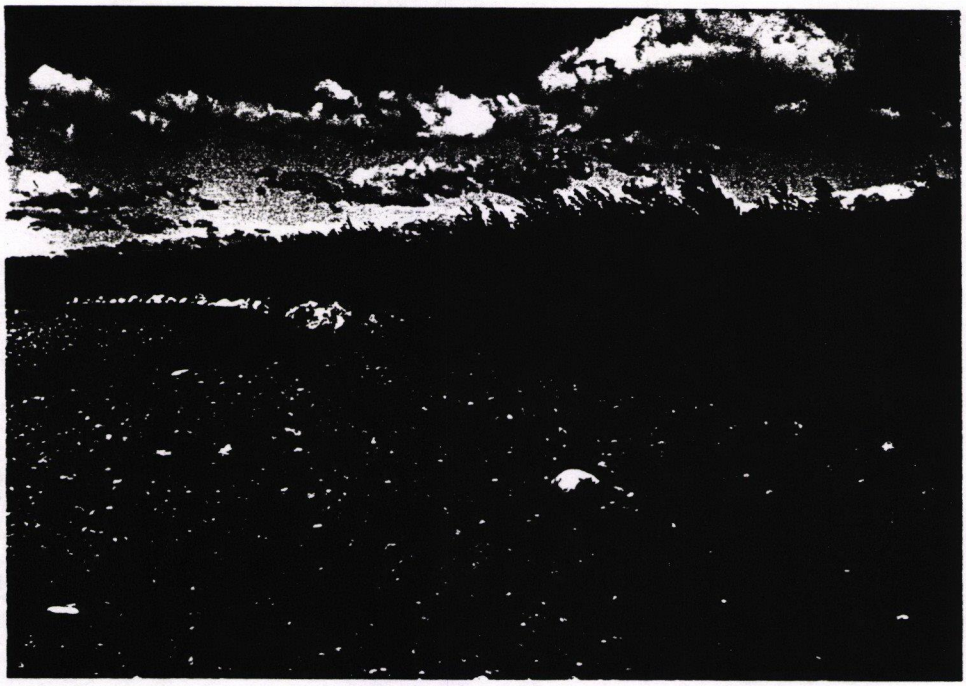
Whitestone River Photo 19, Mount Prospect Reach
Sample site WS1, located downstream of a riffle on a lateral bar. Note the eroding terrace on the outside of this broad bend.
20.01.93 WH 1/10 Te Anau (D43) 1:50,000, GR 112238



Whitestone River Photo 20, Mount Prospect Reach
View of Mount Prospect reach looking downstream from Kakapo Road Bridge. Note the shallow banks and the stop bank in front of the buildings on the left hand side of the photo.
20.01.93 WH 1/2 Te Anau (D43) 1:50,000, GR 112234



Whitestone River Photo 21, Mount Prospect Reach
Tiered and pole planted willows and boulder rip-rap at the outside of a bend at GR 112232.
20.01.93 WH 2-8 Te Anau (D43) 1:50,000, GR 112232



Whitestone River Photo 22, Mount Prospect Reach
Straight diversion channel of Whitestone River a few hundred metres downstream of Kakapo Road Bridge.
20.01.93 WH 2-9 Te Anau (D43) 1:50,000, GR 108228



Whitestone River Photo 23, Mount Prospect Reach
Less constrained channel conditions beyond the straight diversion channel described above. Active gravel surfaces are locally extensive.
20.01.93 WH 2-10 Te Anau (D43) 1:50,000, GR 105225



Whitestone River Photo 24, Mount Prospect Reach
Note the abrupt change in channel character at the downstream end of Mount Prospect reach, where the channel adopts a more sinuous course with less active gravel surfaces. This transition is a direct, human-imposed condition associated with river management works. Note also the smaller sinuous thread of a tributary channel on the left bank alluvial flats. Flow direction is from left to right.
16.01.93 GBF1/15



REACH NAME: MOAT CREEK REACH

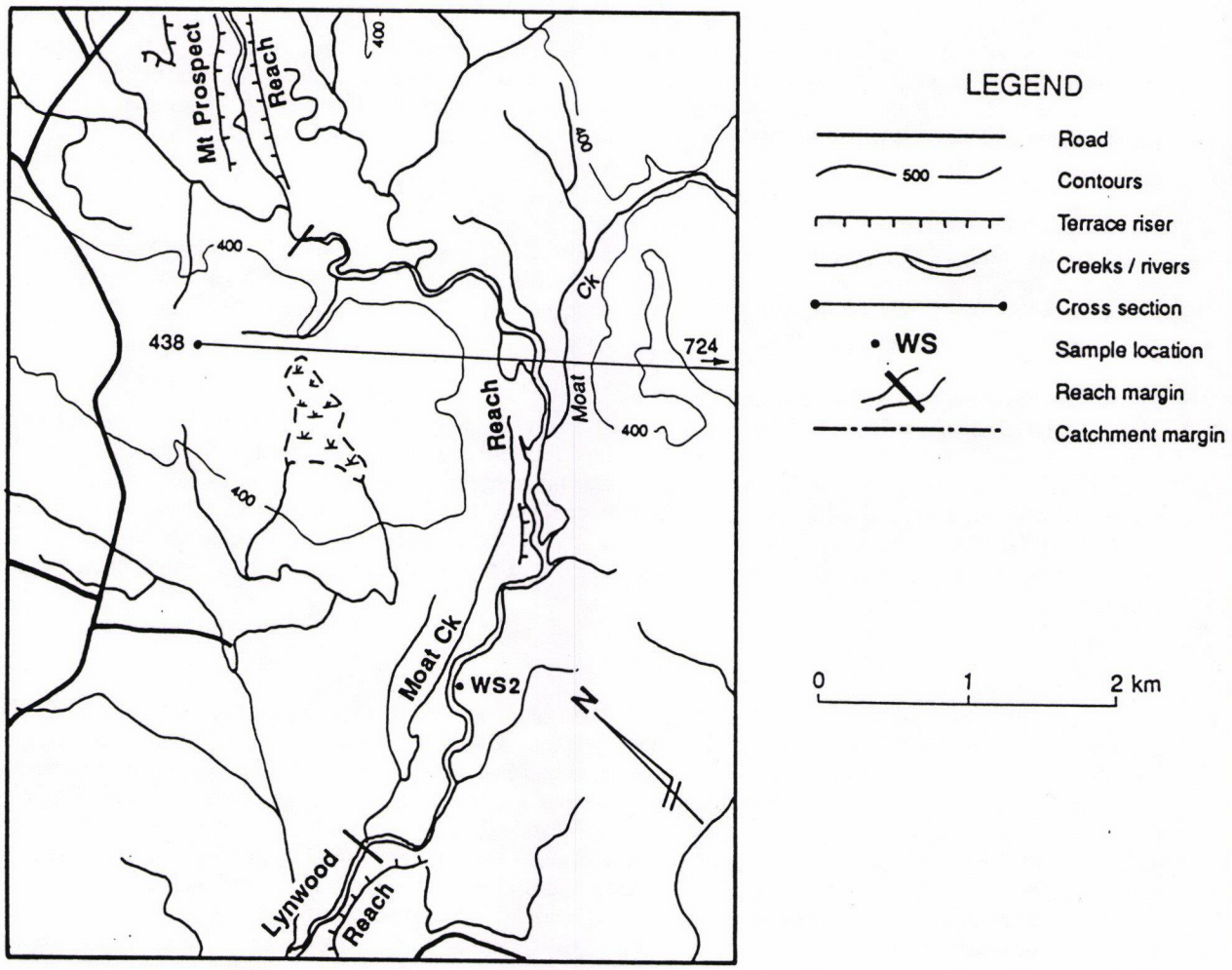
Geographic description of reach

Moat Creek reach extends from the downstream end of a diversion channel through a reach with cliffs of well-bedded grey-coloured tilted outwash materials to a laterally constrained section. The reach is characterised by a well-defined moderately sinuous channel. Stop bank constraints are less imposing than upstream, and alluvial flats are more extensive, but active gravel surfaces are less prevalent. Occasional side channels and abandoned channel courses are evident on the alluvial flats.

Analysts: GB, AH, BJ Date of Analysis: 20.01.93

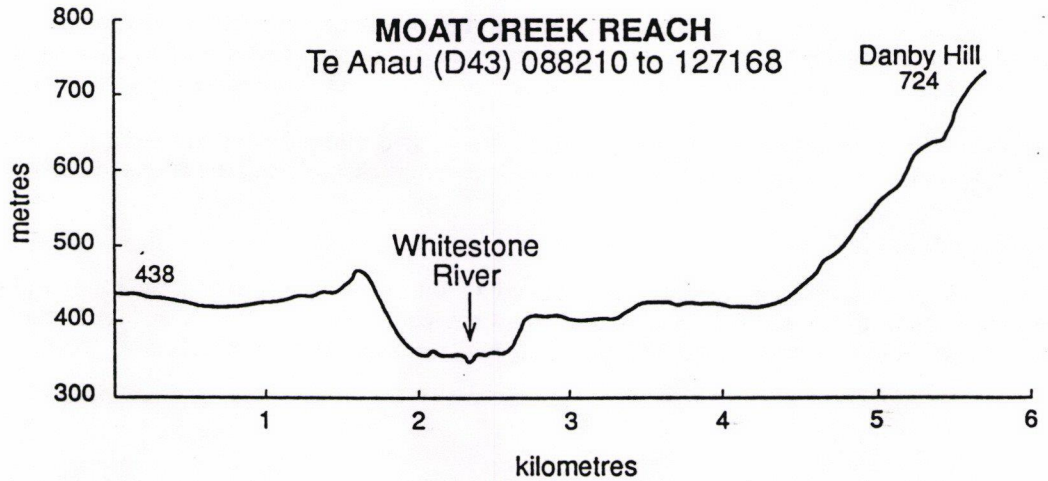
Grid co-ordinates of reach: Te Anau (D43) 1:50,000, 099210 to 073178

Moat Creek reach Base Map:



VALLEY CHARACTERISTICS

Valley cross section



Valley setting
Broad valley with discontinuous eroding 100 m high cliffs of Prospect Formation. This bedrock forms a ridged terrain on the right bank of Whitestone River. Several shallow angle fans are evident on the left bank (eg Moat Creek Fan at the base of Mount Prospect).

Extent of Valley flat
Valley flats narrow from about 1.5 km at the reach head to about 500-800 m adjacent to Moat Creek confluence. Beyond this point flats are constrained by bedrock for about 2 km, but at the downstream end of the reach, adjacent to Talbot Road, the valley broadens once more.

Terrace character
Discontinuous, perched upper terraces are evident on both banks, but lower terraces are barely evident. Deposits that made up left bank terraces must have been removed prior to emplacement of the fans.

Extent and character of Alluvial flat
Given the limited presence of stop banks, alluvial flats are less constrained than upstream, and the channel is able to shift over the entire valley bottom. However, there is no evidence of erosion at the toes of the left-bank fans. Numerous side channels and abandoned former courses are evident on the alluvial flats. Abandoned channels on the right bank at the downstream end of the reach still hold water and form duck-shooting ponds.

Degree and character of channel constriction
Although the valley is narrower than upstream, Whitestone River is scarcely confined in Moat Creek reach. However, the channel locally abuts and erodes grey bedrock cliffs. Banks are typically just 1-2 m high. Active gravel surfaces are quite extensive in the narrowest section of the reach, between eroding bedrock cliffs and Moat Creek fan.

Character and impact of tributary streams
Shallow angle fans have formed at the valley margin as the unnamed stream from Mount Prospect and Moat Creek overflow into Whitestone Valley. Although these fans are barely active, their morphology indicates that they have not been reworked since they formed their fan-shape. The unnamed right-bank tributary at the head of the reach does not appear to have induced any adjustments in channel configuration; rather, this reach transition is associated with widening of the channel-zone associated with the termination of the upstream diversion channel and stop banks. Other than these tributaries, Whitestone River is also joined by a series of drainage ditches, which exert minor, if any, impact.

Surficial geology
Regionally-tilted well-bedded grey-coloured outwash form a massive 100 m high cliff face at GR 103199. The upper surface is hummocky and forms a generally ridged terrain. The exposure is made up of compacted clast-supported gravels, typically ranging in size up to 100 mm, with occasional sandy lenses. Gravels are tilted in some exposures, but appear roughly horizontal in others. This sequence of greywacke gravel set in a lightly cemented sandy matrix, with discontinuous sand lenses and some sand and silt beds, is the type section for the Prospect Formation (McKellar, 1973). This Miocene to Quaternary formation always occurs beneath the oldest Quaternary till units, and extends along the entire lower course of Whitestone River. Discontinuous drapes of glacial till and reworked glacially-derived deposits mantle the landscape, with a series of glacial advances evident. A large proportion of these deposits were reworked to form large outwash plains at the downstream margins of ice lobes. Subsequent river incision has effectively flushed these gravels downstream, and only remnant terrace sequences remain in Moat Creek reach.

Vegetation
Valley side/flats: Dense coprosma (with creepers) and matagouri covers the extensive, discontinuous terrace riser. The large size of the matagouri here, and on the scree slope at the downstream end of the first right bank bedrock exposure, indicates that these surfaces have been stable for some time. Less beech forest is evident compared to upstream.

Alluvial flats/Bank/Bars: Grasses, with coprosma, willows, sweet thorny briar (rosehip), monkey mush (mimulus), hebe (koromiko), wild spaniard, lupins and exotic weeds cover the channelized zone of this reach.

Land use
Pasture predominates, although there is a pine plantation on the left valley side at the lower end of the reach. The downstream end of this reach is characterised by low-lying ponds along a former abandoned course of the river, with anglers access. Ponds are used for water fowl-hunting with mai mais (eg Hacienda Hut).

Direct human impacts
Stop banks are discontinuous along Moat creek reach and channel modifications are significantly less than upstream. Exceptions include an excavated channel cut-off on a large bend at the head of the reach (GR 104200) and a channel cut-off bend at the downstream end of the reach. Planted willows are intended to prevent bank erosion in the latter bend and at other locations within-reach. Most drainage ditches on flats have been artificially straightened.

CHANNEL CHARACTERISTICS

Number of channels
Primarily single-channelled, with occasional chute cut-offs.

Channel geometry
Although channels have a moderately high width:depth, the thalweg is better-defined than upstream. The channel narrows down-reach. Channel geometry is much more irregular around dissected point and compound bars.

Sinuosity
Moderate to high, with well-developed bends. Smaller tributaries on the flats also have sinuous outlines. These contrast starkly with straight diversion channels in the upstream and downstream reaches. A dry cut (runner) has been dug to redirect flow in an upper bend (GR 104200) and at the downstream end of the reach. Several abandoned courses of the river are evident on the alluvial flats. The sinuosity of the bends in these abandoned channels is roughly consistent with that of the present channel in this reach.

Lateral stability of channel(s)
The channel is laterally eroding throughout most of the reach. Banks are relatively shallow, and the channel locally abuts against bedrock cliffs. Despite this activity, the channel has not reworked Moat Creek and other left bank fans. This may reflect the presence of a channelized zone on the alluvial flats.

Bar type and scale
The extent of active gravel surfaces is quite variable down-reach. Active gravel surfaces are primarily restricted to the inside of bends. Moving down-reach, point bars become more dissected, reflecting a more complex history of channel shifting. In the lower half of the reach the lateral component of channel/bar migration is less pronounced, and there is a greater downstream component to channel movement. The dissected bar at GR 089183 has thick sheets of loose fine gravels at its tail, and a distinct mud drape. The point bar immediately downstream of GR 089193 has a considerably wider active gravel surface. In some instances dissection of riffles at the bar head results in small-scale mid-channel bars. Broader bends are characterised by complex point bar assemblages. Adjacent to some of the abandoned loop sections the bar pattern has yet to stabilise, and the active gravel surfaces and alluvial flats are dissected by channels of various scale, producing compound bar features. Diversion channels at the downstream end of the reach have greatly altered the 'natural' bar type, with development of lateral bars and some sedimentation at the outside of meander bends (possibly reflecting infill following cut-off development).

Bed/Bank character (extent and materials)
Banks are poorly defined and relatively shallow (< 1 m high). Bank undercutting is common throughout the reach. A riffle at the head of the small diversion channel that cuts off the bend at GR 104200 is aligned towards the inner bank, and is actively eroding the inside of the bend.

Bar surfaces are not especially packed, although occasional imbrication attests to the relatively high flow energy at high discharge stages. Bar surfaces are not winnowed, with mud drapes evident. Sand sheets have accumulated on flats adjacent to the channel, reflecting waning stage deposits from floods. The bed shows no indication of incision and may actually be aggrading. Conglomeratic gravels from the cemented outwash exposure at the head of the reach are clearly mobile and are actually accumulating on the point bar downstream. Extensive sheets of moderately well sorted gravels (up to 100 mm wide) are noted on compound point bar surfaces. Local within-channel sedimentation may be reducing channel capacity.

Flow character
Uniform flow with riffles that extend across the entire channel. Occasional deeper pools are noted at the outside of eroding bends. Riffles become less pronounced down-reach. Flow character is more irregular in modified channel subreaches.

SAMPLE SITE CHARACTERISTICS

Sample number: **WS2** Analysts: AB, BA

Grid reference: Te Anau Sheet (D43), 085182

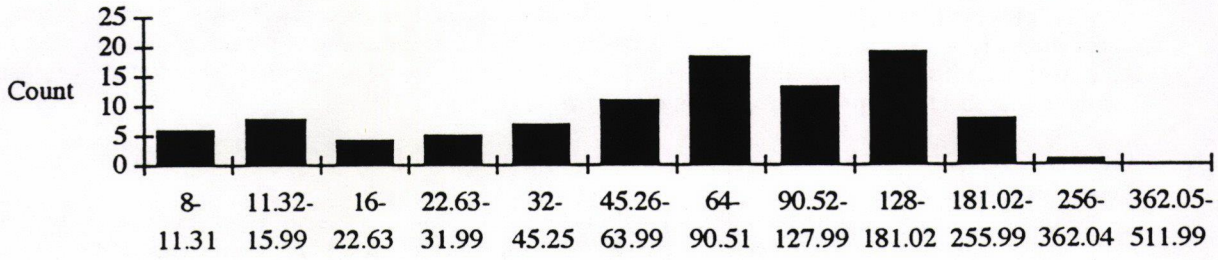
Sample type: 2 x 25 m @ 0.5 m interval

Bar type: Mid-channel bar, with riffles in both channels at the bar head. This bar seems to represent a single depositional unit with a finer grained unit at it's tail.

Sample position on bar: Down-bar from the left-side riffle, 1 and 2 m from the water's edge.

'Particle characteristics'

Grain size distribution, Whitestone River (WS-2), Moat Creek reach



Grain size in 0.5 ø interval (in mm)

D95	135 mm		
D84	100 mm		
D50	55 mm	Mean	63.15 mm
D16	25 mm		
D5	20 mm		

Sorting: 34.54 mm. Moderately poor, with smaller variation than sample WS1 (b max = 150 mm).

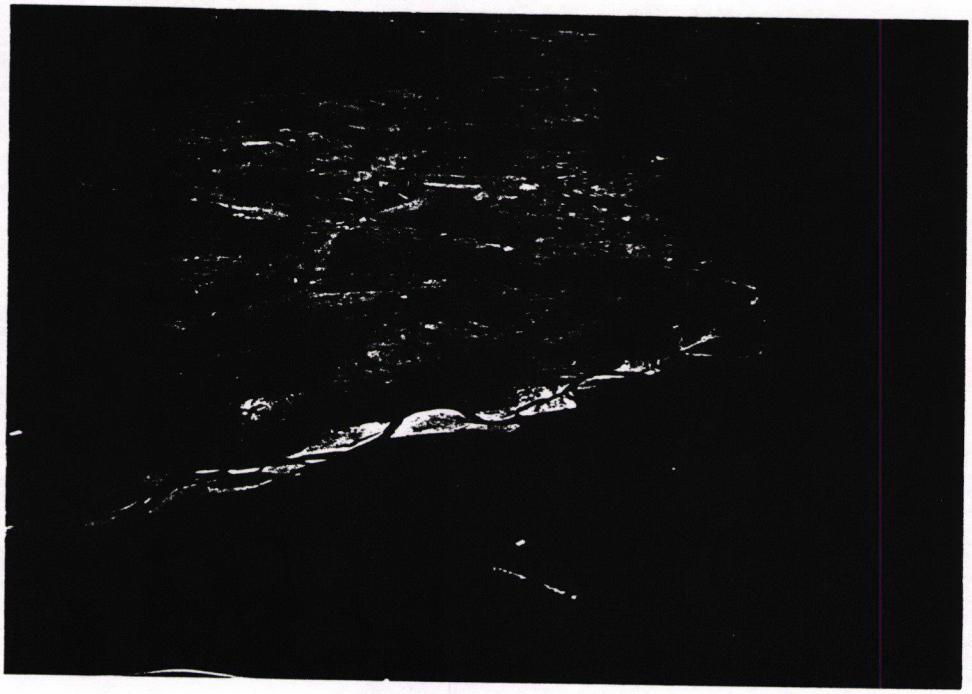
Packing arrangement: Moderately paved surface, which is generally well packed with few loose clasts. Clasts are moderately imbricated, and winnowed down to 20-25 mm. The surface layer of clasts 1-2 grains thick protects a subsurface of fine muddy-sand matrix.

Shape: Subrounded to rounded; predominantly blocky.

Lithology: Less mixed than sample WS1, with sedimentary rocks more prevalent.

Other characteristics: Sparsely vegetated surface. The smaller clast sizes at this site compared to sample WS1 may simply reflect the greater availability of finer gravels from eroding outwash cliffs.

Whitestone River Photo 25, Moat Creek Reach
Aerial view looking downstream at the transition zone from Mount Prospect to Moat Creek reach. The reach limit is at the end of the straightened channel section on the right hand side in mid-photo. Upstream of this point the channel has a well defined channelized zone with a large proportion of active gravel surfaces. Alluvial flats are constrained by stop banks. Moat Creek reach is characterised by a well defined, sinuous channel which locally divides at cut-offs in bends. Moat Creek itself has built a shallow fan of deposits on the left bank of Whitestone River.
16.01.93 GBF 1/14



Whitestone River Photo 26, Moat Creek Reach
View upstream of the upper end of Moat Creek reach. Note the extensive alluvial flats, with minimal terrace preservation, and the well defined meandering single channel.
20.01.93 WH 2-15 Te Anau (D43) 1:50,000, GR 103200



Whitestone River Photo 27, Moat Creek Reach
Eroding cliffs of greywacke gravel set in a lightly cemented matrix, with discontinuous sand lenses and some beds of sand and silt. This is the type section for the Pliocene-Pleistocene Prospect Formation, located near the head of Moat Creek reach.
20.01.93 WH 2-14 Te Anau (D43) 1:50,000, GR 105200



Whitestone River Photo 28, Moat Creek Reach
View downstream from eroding cliffs shown above. The 'chute' channel in the foreground is an artificial cut off, the right bank of which is eroding upstream of the lateral bar in mid photo. Note the different vegetation pattern on the shallow surface of Moat Creek on the extreme right hand side of the photo.
20.01.93 WH 2-11 Te Anau (D43) 1:50,000, GR 103200



Whitestone River Photo 29, Moat Creek Reach
Although banks remain relatively shallow in Moat Creek reach, channels are well defined and active gravel surfaces are not abundant. Alluvial flats, however, are extensive. This view shows Whitestone River, looking upstream, 1 km downstream of Moat Creek fan.
20.01.93 WH 2-19 Te Anau (D43) 1:50,000, GR 089183



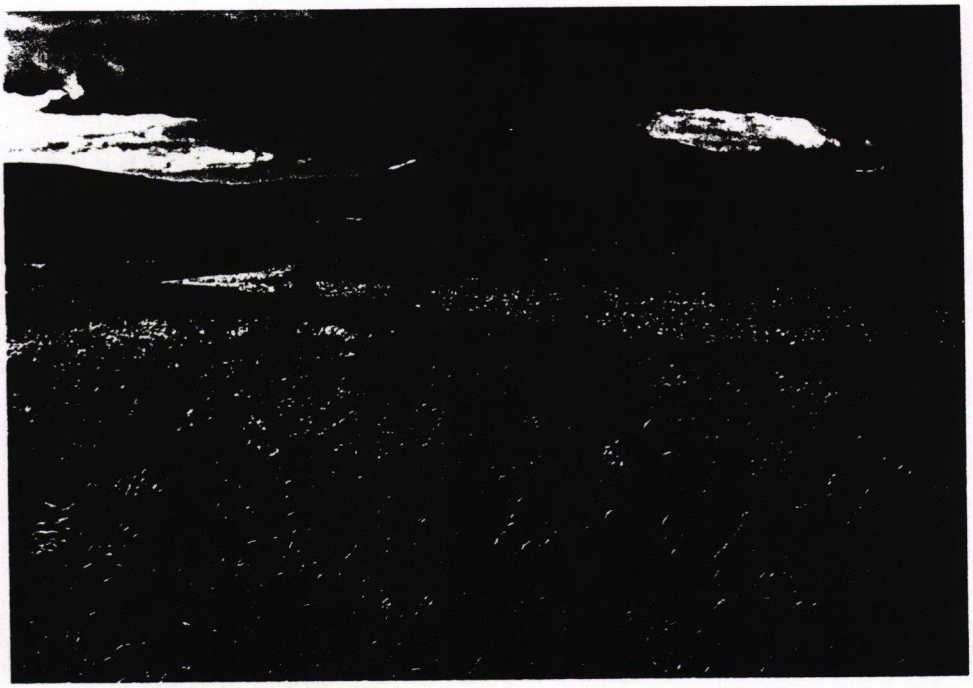
Whitestone River Photo 30, Moat Creek Reach
View upstream at sample site WS2. Note the local channel division at this site and the shallow, vegetated banks.
20.01.93 WH 1 4 Te Anau (D43) 1:50,000, GR 085182



Whitestone River Photo 31, Moat Creek Reach
Tilted sequences of grey-coloured greywacke gravels in a lightly cemented sandy matrix (Pliocene-Pleistocene Prospect Formation), exposed along the left bank of Whitestone River in Moat Creek reach, immediately downstream of sample site WS2.
20.01.93 WH 2-18 Te Anau (D43) 1:50,000, GR 089183



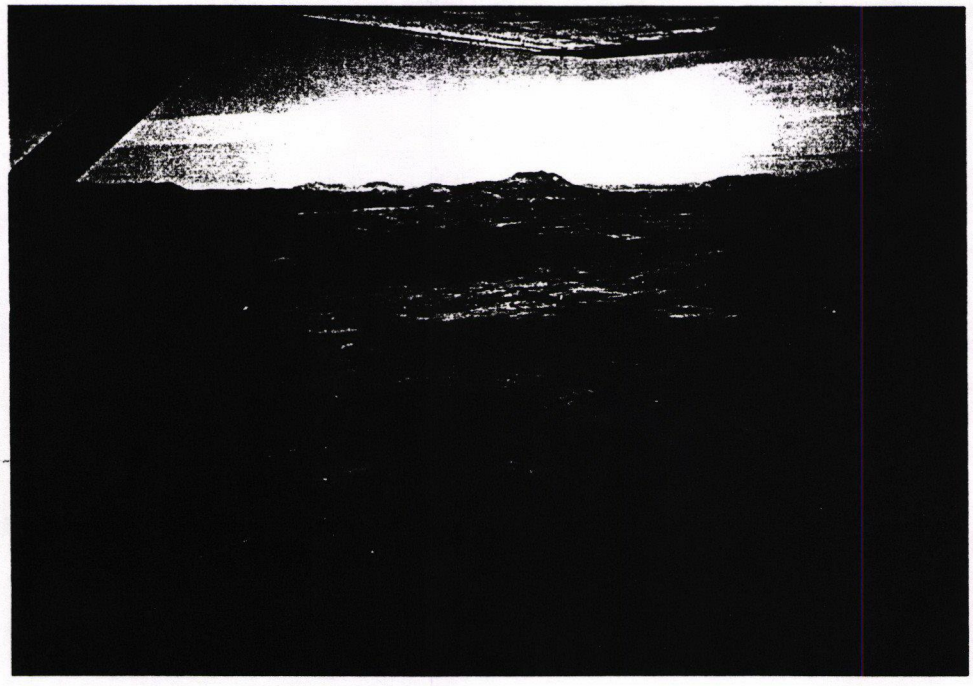
Whitestone River Photo 32, Moat Creek Reach
Active gravel surfaces become more abundant at the downstream end of Moat Creek reach. Note the tiered willows on the right bank (left hand side of photo), and the diversionary cut-off channel on the right hand side of the photo.
20.01.93 WH 2-20 Te Anau (D43) 1:50,000, GR 078177



Whitestone River Photo 33, Moat Creek Reach
Grey cliffs of the Prospect Formation on the left bank of Whitestone River at the downstream end of Moat Creek reach. Sample site WS2 was located on a small mid-channel bar in the bend on the left hand side of the photograph. Note also the lack of physiographic relief between Whitestone and Mararoa Rivers, and the Takitimu Ranges in the background.
16.01.93 GBF 1/13



Whitestone River Photo 34, Moat Creek Reach
The downstream end of Moat Creek reach. The reach divide to Lynwood reach is located at the head of the artificially straightened channel on the right hand side in mid-photo.
16.01.93 AHF 1/2



REACH NAME: LYNWOOD REACH

Geographic description of reach
Lynwood reach extends from the upstream end of a diversion channel a few kilometres beyond Talbot Road down to Mararoa confluence. Immediately downstream of the diversion channel at the reach head, Whitestone River abuts against cliffs of well-bedded grey-coloured tilted outwash materials on the right bank. Beyond this point the river flows through a less laterally constrained river section down to Mararoa confluence.

The primary feature of Lynwood reach is the degree of human modification of the channel. A series of river engineering works have been implemented at various sites along the reach. In essence these measures have reduced the width of the active channel zone and imposed a straighter single-channelled configuration. The pattern of bars is highly irregular, and is seemingly in a state of adjustment to the altered channel condition. There is pronounced within-reach variability in channel character and the nature of the adjacent alluvial flats.

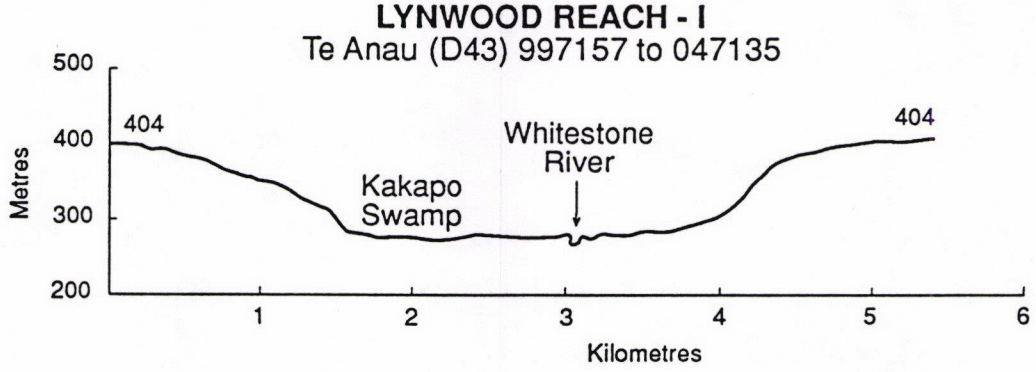
Analysts: GB, AH, BJ Date of Analysis: 20.01.93 and 21.01.93

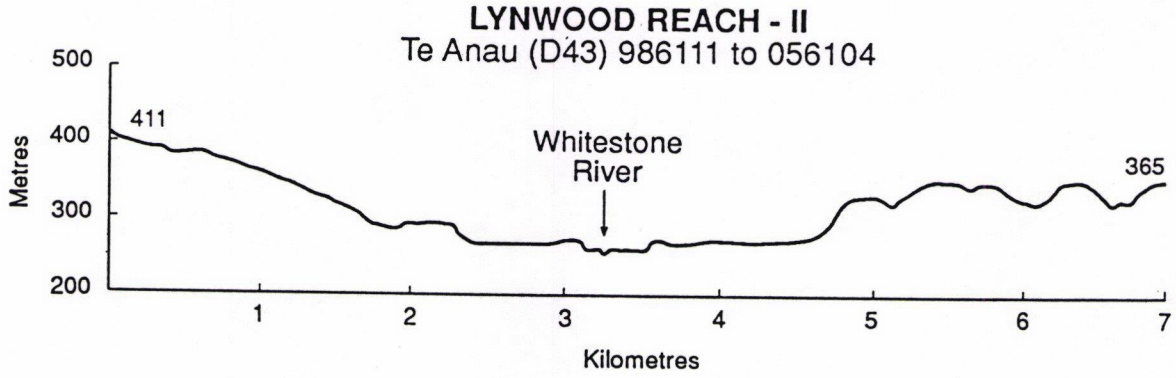
Grid co-ordinates of reach: Te Anau (D43) 1:50,000, 073178 to 003061 (Mararoa confluence)

Air photographs used: Southland Regional Council # 0963, 18.12.91

VALLEY CHARACTERISTICS

Valley cross section



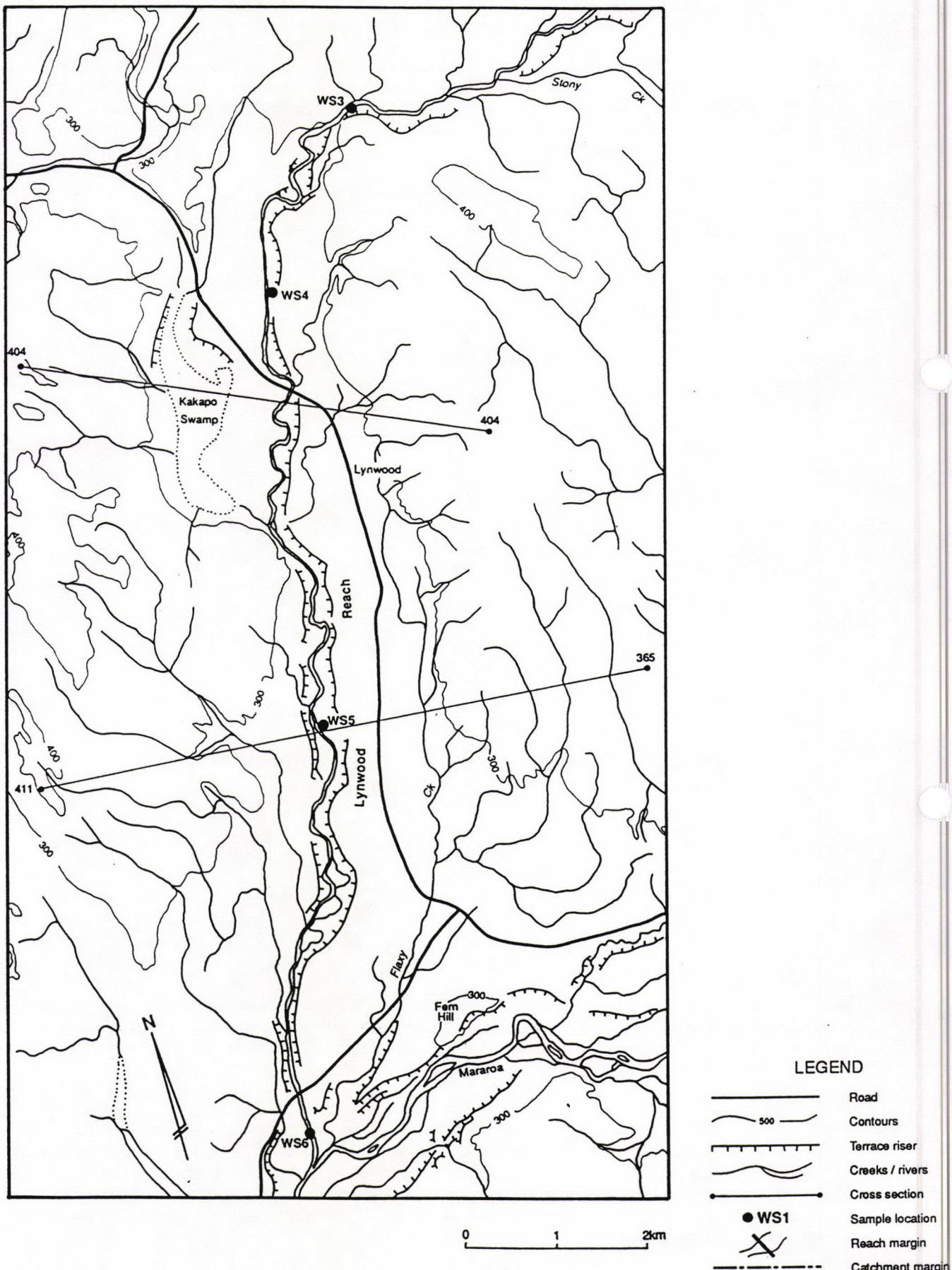


Valley setting
Broad valley with perched remnant high terraces. Surrounding relief is dominated by north-south aligned hummocky ridges composed of tilted sedimentary strata. Weaker, more erodible bedrock layers have been selectively reworked, and form the course of several meltwater channels. Kakapo Swamp infills one of these channels.

Extent of Valley flat
Valley flats are 600-800 m wide at the head of the reach. They widen considerably downstream of the bedrock constraint at GR 046176, and the valley maintains a fairly uniform width of 2-3 km adjacent to the head of Kakapo Swamp. Downstream of this point the valley narrows associated with right bank bedrock constraint (The Ramparts). Beyond this point the valley maintains a relatively uniform width of about 1.8 km, down to Mararoa River confluence. Adjacent to the confluence, which is also coincidental with Flaxy Creek, the valley widens to 2.5 km. Shallow angle fans are evident at valley margins.

Lynwood reach Base Map:

LYNWOOD REACH Te Anau (043) 1:50,000



Extent of Valley flat

Valley flats are 600-800 m wide at the head of the reach. They widen considerably downstream of the bedrock constraint at GR 046176, and the valley maintains a fairly uniform width of 2-3 km adjacent to the head of Kakapo Swamp. Downstream of this point the valley narrows associated with right bank bedrock constraint (The Ramparts). Beyond this point the valley maintains a relatively uniform width of about 1.8 km, down to Mararoa River confluence. Adjacent to the confluence, which is also coincidental with Flaxy Creek, the valley widens to 2.5 km. Shallow angle fans are evident at valley margins.

Terrace character

High perched terraces, about 60-80 m above the present channel position, are generally paired along large sections of the reach. These terraces become more discontinuous down-reach. Lower terraces are seldom evident, other than a remnant 4 m right bank terrace in a wider section of the valley at the reach head. Beyond GR 046076 this 4 m high terrace surface has a second right bank terrace about 3 m above it. Both terrace surfaces are distinctly hummocked reflecting the former channel complex of a braidplain. Distinct flights of terraces are restricted to the section just upstream of Mararoa confluence, where a series of right bank terraces have been preserved at approximately 2, 5, 10 and 18 m above the channel.

Extent of Alluvial flat

Other than the area adjacent to Kakapo Swamp, alluvial flats extend to the valley margin. Due to stop bank construction, however, flats are no longer active surfaces, but a large number of former channel surfaces are evident . At GR 043176, immediately downstream of the confined bedrock section at the reach head, the alluvial flats are about 500 m wide, with a stop bank defining a 150 m wide channelized zone. Channel width is about 20 m in channelized sections, whereas in less constrained sub-reaches channel width extends to 40-50 m wide over active gravel surfaces. Immediately upstream of Te Anau-Mossburn road bridge (GR 026146) the bed is incised 2 m beneath alluvial flats. Adjacent to the Te Anau-Mossburn road bridge the active zone of the alluvial flats is less pronounced. Mid-way between the highway bridge and the Mararoa confluence (GR 017109) numerous channel surfaces are evident, most of which are smaller, more sinuous features than the present channel.

Degree and character of channel constriction

Lynwood reach is characterised by a series of channelized sections in which flow is artificially constrained within stop banks. For example, breaching of two stop banks at the reach head in 1991 prompted channelization of an 800 m long section. The ability of former channels to shift is evident at GR 037174 where old meander scars are apparent on the alluvial flats. Other than in channelized areas, the active channel is able to shift laterally within 150 m wide stop banks. This gives a ratio of alluvial flat width to channel width of approximately 4:1, which is much lower than elsewhere. The channel abuts against bedrock at both the upstream end of the reach and 1.5 km downstream of Te Anau-Mossburn road bridge, adjacent to Kakapo Swamp (GR 019132).

Character and impact of tributary streams

Tributary streams that join Whitestone River in Lynwood reach drain small catchments with limited relief, and exert negligible impact on the character of the channel. These tributaries are extensively ditched on the alluvial flats, while their headwaters may be incised (eg Stony Creek). A small right bank tributary at the reach head has a sinuous lower course. Kakapo Swamp, which drains the largest subcatchment in this reach, acts as a buffer zone to sediment movement. A series of short right bank tributaries, which drain The Ramparts, join Whitestone River downstream of Te Anau-Mossburn road bridge. These tributaries flow for extensive distances down the alluvial flats prior to joining Whitestone River. The best example of this downstream deflection of flow is represented by Flaxy Creek, a left bank tributary which flows along the valley flats of Whitestone River from Lynwood and actually joins Mararoa River 250 m upstream of Whitestone-Mararoa confluence.

Surficial geology

Regionally-tilted sedimentary strata comprise thick sequences of greywacke gravel set in a lightly cemented sandy matrix, with discontinuous sand lenses and some sand and silt beds. These are part of the Miocene to Quaternary Prospect Formation (McKellar, 1973), which always occurs beneath the oldest Quaternary till units, and extends along the entire lower course of Whitestone River. Discontinuous drapes of glacial till and reworked glacially-derived deposits mantle the landscape, with a series of glacial advances evident. A large proportion of these deposits were reworked to form large outwash plains at the downstream margins of ice lobes. Subsequent river incision has flushed these gravels downstream, and only remnant terraces remain in Lynwood reach. At least four meltwater streams draining the Te Anau ice lobe combined along the lower course of Whitestone River. A series of moraines marking glacial advances, and their subsequent reworking by meltwater streams, produced the hummocky landscape with north-south oriented ridges (eg The Ramparts).

Vegetation

Valley side/flats: Pine trees on terrace surfaces at the reach head only act as windbreaks or shelter belts on ridge tops down-reach. No beech are evident. Coprosma, matagouri, remnant tussock, and grasses are dominant.

Alluvial flats/Bank/Bars: Well established willows, with localised recent pole-plantings (eg at head of reach). Grasses, exotic weeds and lupins are dominant, with occasional ferns on banks.

Land use

Pasture and deer farms. Pine plantations. Gravel extraction. Rural water supply pump (GR 043174).

Direct human impacts

Stop banks have been constructed along the channel throughout the reach. Moving down-reach, the following management practices were observed :

Between stop banks at the reach head there are series of dry cuts and diversion channels. Groynes have been constructed at the head of diversion channels and perpendicular to the main channel at the outside of bends (eg GR 028167). Layered and pole-planted willows have been implemented to prevent bank erosion in various bends. Beyond these bends the channel outline has been artificially straightened almost as far as Te Anau-Mossburn road bridge. Drainage ditches in tributaries and on flats have been artificially straightened.

Immediately downstream of a rip-rapped bend at GR 028167 the channel outline is adjusting to straightening. Localised pole plantings of willows and bulldozed gravel mounds are evident.

Upstream of Te Anau-Mossburn road bridge (GR 025153) gravels have been extracted from bar/flat surfaces. Extraction equipment has locally compacted gravel surfaces.

At Te Anau-Mossburn road bridge (GR 026146) the channel has been constricted by rip rap. Beyond the bridge, at GR 024144, extensive volumes of gravel have been removed from a bank-attached compound bar for use in the cement works. Immediately downstream of the gravel extraction works there is a major diversion channel of rectangular cross-sectional geometry (between GR 025143 and 024140). Incipient lateral bars are evident within this channel. Extensive willow plantings are evident down to GR 019132. An older diversion channel is evident upstream of this point.

At GR 024124 there is an abandoned meander loop, with extensive willows planted on its concave bank. The present channel short circuits this old loop. Similarly, at GR 023118 the channel has been diverted away from its old course, and the old course itself is now planted with willows.

At GR 022117 substantial willows at the outside of a bend have been cut and tied-in to stabilise the bank. 'Webb's' Diversion channel at GR 019116 has artificially realigned the channel towards the left bank stop-bank (ie away from the meander loop on the right bank). At GR 017109 'Stephenson's' Diversion channel has cut-off a broad right-bank meander. Layered willows have been emplaced at the downstream end.

Just upstream of Hillside-Manapouri road bridge (GR 005073) gravel extraction has taken place on a large bank-attached compound bar to take pressure off the outside of the bend by increasing channel capacity. Willows have been cut and tied-in along the outside of the bend to inhibit erosion.

Other comments

It appears that channel works in Lynwood reach have been driven by a range of site-specific motives with little regard for the overall channel condition and off-site consequences. Emplacement of a series of piecemeal river management measures has resulted in a channel condition which is out-of-phase with flow and sediment characteristics, such that the river is now in a semi-permanent state of adjustment. For example, beyond the end of the channelized zone at the reach head (GR 044174) there is a large gravel accumulation on a dissected point bar surface, with a couple of small diagonal channels. These straightened/channelized subreaches are in a state of adjustment in which an equilibrium cross-sectional geometry has yet to be attained. Their rectangular form acts to convey finer gravels through them relatively efficiently. This throughput of gravels associated with increased competency results in deposition downstream. The outer (willowed) bank was dry cut in 1992. Tiered willows now line the banks. Willows on the left bank at GR 043175 were actually planted pre-channelization - the plan was to protect the rural pumping station behind them, as the willows serve to stabilise banks. Many tiered willow plantings are evident. In some instances the pole planting itself may lead to bank destabilisation (eg on right bank downstream of the dry cut at the head of the reach).

CHANNEL CHARACTERISTICS

Number of channels

Generally single-channelled, though a number of secondary channels are evident as the channel divides over dissected active gravel surfaces, especially in bends. A few kilometres above Hillside-Manapouri Road bridge, between GR 016096 and 008083, there are a number of distributary channels of low width:depth and irregular sinuosity.

Channel geometry

Artificial channels typically have rectangular cross-sections, with uniform width:depth. These locally efficient, deeper-channelled subreaches alternate with sections of irregular cross-sectional channel geometry. Riffle spacing is inconsistent, as the channel adjusts its geometry to altered boundary conditions.

Sinuosity

Channel maintenance works have reduced the 'natural' sinuosity of the river. Meander scars on the alluvial flats beyond the stop banks attest to the much greater sinuosity of former Whitestone River. There is effectively only one subreach that is equivalent to this former channel alignment, namely the sequence of bends 2 km upstream of Te Anau-Mossburn road bridge (between GR 038174 and 028167). Lateral adjustment of this sequence of bends is now controlled by rip-rap and planted willows. In general the active channel zone is a series of straight sections, within which the main channel has low sinuosity.

Lateral stability of channel(s)

Lateral stability is locally variable. Moving down-reach the following characteristics were observed :

At the reach head, local instabilities are evidenced by reworking of flats, and some willows are now in mid-channel. Active, dissected gravel surfaces are several tens of metres wide. Downstream of GR 043175 the channel abuts against the older 4 m terrace which has a highly dissected surface. Substantial willows on the left bank fenceline suggest relative stability through this reach.

At GR 028167 the channel is laterally unstable within stop banks and is highly irregular down-reach. At GR 022117, roughly mid-way between road bridges, the channel condition is clearly imposed, although there is plenty of evidence to show significant channel adjustments in the past, with abandoned channels and irregular topography of the alluvial flats.

The pronounced local instability of the channel is demonstrated at GR 019106, where a meander loop has been abandoned and the channel has realigned down a former course. At the this point the active gravel surface is about 80 m wide, as the loop infills with finer gravels and sand lenses. At GR 016096 the outside of a bend has either been abandoned or the channel has been forcibly shifted.

Bar type and scale

Modifications to channel alignment and geometry have greatly affected bar type and distribution. The local availability of materials and extent of active gravel surfaces, set in the context of upstream channel alignment and position of stop banks, determine on-going channel adjustments in bar configuration.

In the straight channelized subreach at the head of Lynwood reach there is early stage development of alternate bars. Immediately downstream of this short channel (at GR 043175) there is a complex bar assemblage with lobes of loose fine gravels and a sand dune-field.

The chaotic assemblage of bars at GR 043176 has not had sufficient time to stabilise into a predictable downstream pattern. Incipient lateral bars in a diversion channel are transitional downstream to dissected gravel surfaces comprising reworked lateral bars, mid-channel and point bars. Individual depositional units that comprise the bar surfaces are of uniform character, but the assemblage of units is itself irregular, such that the overall grain size distribution is distorted. Abundant fine gravels have exceeded channel capacity, inducing localised erosion in places that would not be expected.

A riffle at the entrance to a bend at GR 037173 has a cluster of coarser gravels at its downstream end. Dry-cut channels adjacent to the highly-dissected point bar immediately downstream (GR 034168) are no longer dry. This bar has a thick sheet of fine gravels at its tail.

In the bend at GR 032167, a fine gravel sheet forms a mid-channel unit adjacent to the point bar head. This has redirected the thalweg towards the outside of the bend upstream of the apex. Golden willows have been planted adjacent to the misplaced erosion zone opposite the bar head, while rip-rap boulders (ex Duncraigen at a cost of $25,000) have been positioned opposite the bend apex, with more layered golden willows downstream.

Alternating point and lateral bars at GR 028167 are transitional downstream to chaotic bar assemblages with bank-attached and mid-channel compound features. Adjacent alluvial flats are largely reworked.

Upstream of Te Anau-Mossburn road bridge at GR 026146 is a large bank-attached compound bar that is being used as a source for gravel extraction. Incipient lateral bars are forming in the diversion channel downstream of the gravel extraction site (GR 025143). The pattern of lateral bars is better established in other diversion channels.

The bend at GR 022117 has a recent gravel sheet (b max 150 mm) with discrete finer gravel/sand lenses at the outside of the bend, but no point bar on the convex slope. This local instability has resulted in incipient lateral bar development downstream (ie immediately upstream of Webb's diversion channel).

Downstream of Stevenson's diversion channel (GR 017109) is a complex, highly dissected mid-channel compound bar that has formed in association with energy reduction as flow diverges downstream of a straightened channel.

At GR 016096 a compound point bar on the inside of a bend is transitional downstream to a mid-channel bar on a dissected riffle, with a lateral bar beyond.

By GR 008083 a distinct transition in bar type is noted, as bars translate downstream rather than laterally. Mid-channel bars are especially evident, and extend beyond Hillside-Manapouri road bridge, possibly indicating that this reach is a more efficient throughput subreach.

Bed/Bank character (extent and materials)

Other than when the channel abuts locally against stop banks, the banks are shallow (< 1 m) and locally undercut grassed surfaces. Channel bed conditions have been greatly altered by channel works, and the subsequent redistribution of gravels.

Upstream of the cliff-face near the head of the reach (GR 066177), the right bank of the channel is locally undercutting, with a 1 m high cut.

Downstream of the channelized section at GR 043175, early-stage lateral bars have developed. Immediately downstream of this actively reworked zone there is an extensive, highly dissected complex of fine gravels within series of broad bends (GR 034169). This unstable area has a series of willow plantings of different ages.

The broad bend at GR 043176 is highly active, with abundant mobile gravel sheets composed of small gravels. These are relatively well-sorted, with finer gravel/sand drapes. Larger clasts are notably absent, probably in response to material availability associated with terrace removal and the aggradational regime of the channel.

The bank-attached compound bar at GR 027165 has a poorly sorted surface with moderately packed gravels and occasional clasts up to 250 mm wide. This unit is distinctly coarser than active gravel sheets which are presently moving through the system as riffles. This coarser unit may represent the reworked pavement of a former channel bed.

At GR 025153 the bank is actively eroding around planted willows.

Just upstream of Te Anau-Mossburn road bridge there is 0.7 m sands atop shallow banks. At GR 026147 a break is evident in the left bank stop bank, although a larger stop bank is noted behind the channel-marginal bank.

At GR 022117 localised erosion on the inside of a bend indicates that within-channel sedimentation is destabilising the bed configuration.

Bed materials at GR 016096 are deficient of the finer gravel sheets observed upstream. However, this is only a localised phenomenon, as sheets of finer gravels are evident once more at GR 008083.

Adjacent to the bridge of Hillside-Manapouri Road (GR 004069), occasional large white boulders and large clasts of other lithologies form a basal pavement on the channel. Large sheets of finer clasts (up to 100 mm wide) are clearly active atop this pavement.

Flow character

Flow is uniform at the head of the reach. The riffle and pool spacing appears irregular, associated with the history of gravel reworking and the chaotic pattern of gravel bar assemblages. Gravel sheets attest to planar flow conditions during higher discharge stages. Dune surfaces are evident downstream of the bend apex of a point bar at GR 043175.

SAMPLE SITE CHARACTERISTICS

Sample number: **WS3** Analysts: AB, BA

Grid reference: Te Anau Sheet (D43), 042175

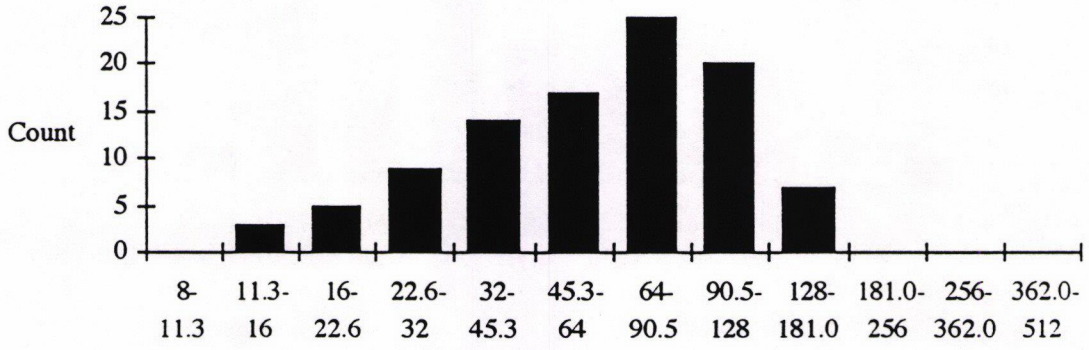
Sample type: 2 x 25 m @ 0.5 m interval

Bar type: Point bar with riffle at head, dissected at higher flow stages. Fine gravel/sand units at the bar margin and tail.

Sample position on bar: Downstream from the riffle, along the middle of the bar. Transects positioned about 7 and 5 m from the water's edge.

'Particle characteristics'

Grain size distribution, Whitestone River (WS-3), Lynwood reach



D95	135 mm		
D84	110 mm		
D50	65 mm	Mean	70.65 mm
D16	30 mm		
D5	20 mm		

Sorting: 36.21 mm. Moderately poorly sorted.

Packing arrangement: Paved, well-packed surface, with moderate to high degree of imbrication. Winnowed down to 20 mm.

Shape: Subrounded to rounded; blocky with a greater proportion of blades than observed upstream.

Lithology: More mixed population than upstream.

Other characteristics: No internal gradation noted. Bar surface is unvegetated. Some microtopography is noted, as depressions have formed around organic debris. Two distinct banks noted, the first is 0.5 m high and delimits the bar from the floodplain, the second 1 m high bank segregates coarse and fine gravel segments adjacent to the water's edge

Sample number: **WS4** Analysts: AB, BA

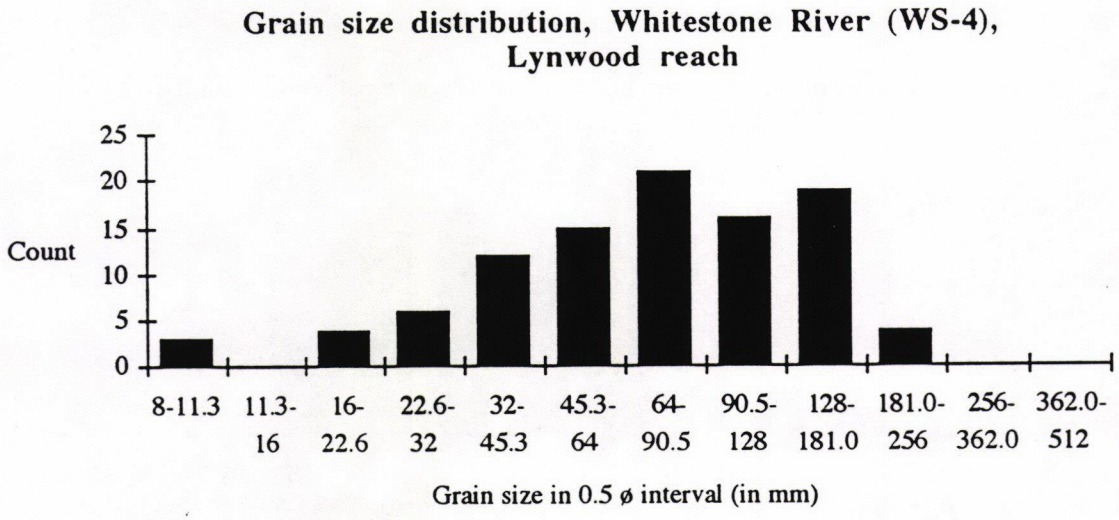
Grid reference: Te Anau Sheet (D43), 026157

Sample type: 2 x 25 m @ 0.5 m interval

Bar type: Point bar, continuous with a riffle at its head, with down-bar aligned depositional units and a well-defined chute channel. Many lenses of coarse/fine gravels evident.

Sample position on bar: In riffle at upstream end of bar. Transects were taken 7 and 5 m from the water's edge.

'Particle characteristics'



D95	170 mm		
D84	140 mm		
D50	75 mm	Mean	85.7 mm
D16	35 mm		
D5	20 mm		

Sorting: 48.97 mm. Poorly sorted.

Packing arrangement: No paving or imbrication in sampled area, but finer unit further downstream on bar is quite well paved and imbricated. Surface is quite well packed, with a rough microtopography. The percentage of loose gravels is greater than other samples taken along Whitestone River, but is still not very high.

Shape: Very blocky; subangular to subrounded.

Lithology: Mixed

Other characteristics: Vegetation is sparse, and restricted to a few primary colonisers. Bar surface appears to be recently reworked. Margins of depositional units are gradational rather than sharply defined.

Sample number: WS5 Analysts: AB, BA

Grid reference: Te Anau Sheet (D43), 108107

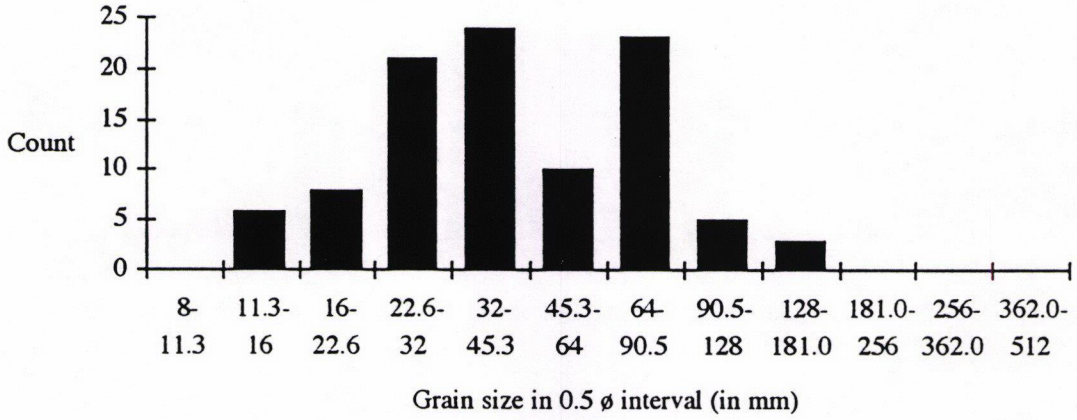
Sample type: 2 x 25 m @ 0.5 m interval

Bar type: Point bar formed in an avulsed channel (or flood chute). Fairly complex assemblage of depositional units on the bar surface, with 'alternating' sequence of coarse and fine units aligned down-bar. Some microtopography associated with organic debris.

Sample position on bar: Bar head samples, 3 and 7 m from the water's edge.

'Particle characteristics'

Grain size distribution, Whitestone River (WS-5), Lynwood reach



D95	100 mm		
D84	80 mm		
D50	45 mm	Mean	51.25 mm
D16	25 mm		
D5	15 mm		

Sorting: 30.44 mm. Moderately sorted bimodal distribution, with some well-sorted lenses of fine gravels.

Packing arrangement: Packed, regular surface, with finer gravels especially well-paved. A distinct finer-grained unit is evident beneath a 2-3 clast thick veneer. The bar surface is moderately imbricated, with few loose gravels. Winnowed down to 15 mm.

Shape: Blocky; subangular to subrounded.

Lithology: Mixed, with relatively high proportion of sedimentary-derived clasts.

Other characteristics: Very sparse vegetation, with occasional lupins, thistles. Sample site gravels are similar in character to those evident in eroding right bank. Bulldozers have recently been through this area of the river bed.

Sample number: **WS6** Analysts: AB, BA

Grid reference: Te Anau Sheet (D43), 1:50,000, 005064

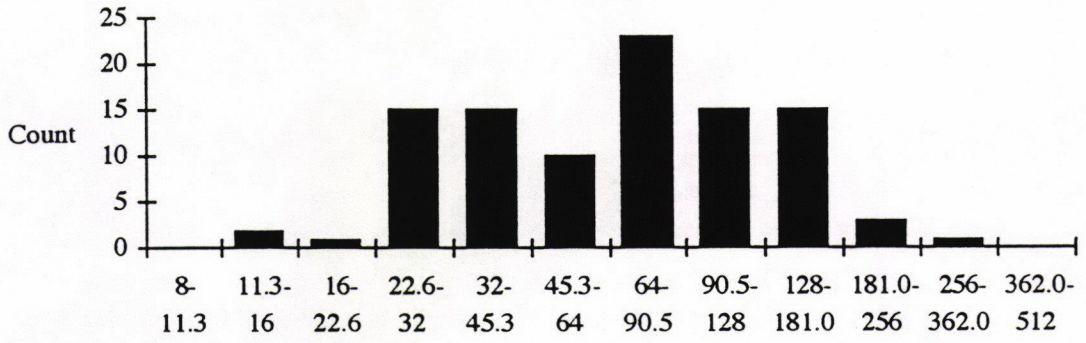
Sample type: 2 x 25 m @ 0.5 m interval

Bar type: Point bar immediately downstream of junction of two braid channels. Distinct riffle at the bar head. This bar has a relatively uniform surface other than a raised finer-grained vegetated surface at its margin.

Sample position on bar: Downstream of the riffle adjacent to the left bank at the head of the bar. Transects located 9 and 7 m from the water's edge.

'Particle characteristics'

Grain size distribution, Whitestone River (WS-6), Lynwood reach



D95	175 mm		
D84	130 mm		
D50	70 mm	Mean	80.15 mm
D16	30 mm		
D5	25 mm		

Sorting: 50.21 mm. Poor, as indicated by the spread in the histogram above.

Packing arrangement: No paving in the sampled area, but paving evident elsewhere on the bar (especially in the finer gravel fraction). Moderately packed, regular surface, with few loose clasts. High proportion of finer beneath 1-2 clast-thick laye . Low to moderate imbrication. Winnowed down to 10 mm.

Shape: Blocky; subrounded to rounded.

Lithology: Mixed, with increased proportion of white crystalline rock and conglomerates.

Other characteristics: No vegetation. Upstream of the sample site the channel bed has been considerably disturbed by gravel extraction. The large proportion of fines on the channel bed adjacent to the sample site may reflect this disturbance. Alternatively, these fine-grained deposits may reflect backing-up of suspended load deposits upstream of Mararoa confluence during floods.

Whitestone River Photo 35, Lynwood Reach
View upstream at the head of the artificially straightened channel that marks the upstream limit of Lynwood reach.
20.01.93 WH 2-22 Te Anau (D43) 1:50,000, GR 073178



Whitestone River Photo 36, Lynwood Reach
View downstream showing the artificially straightened channel at the head of Lynwood reach.
20.01.93 WH 2-23 Te Anau (D43) 1:50,000, GR 073178



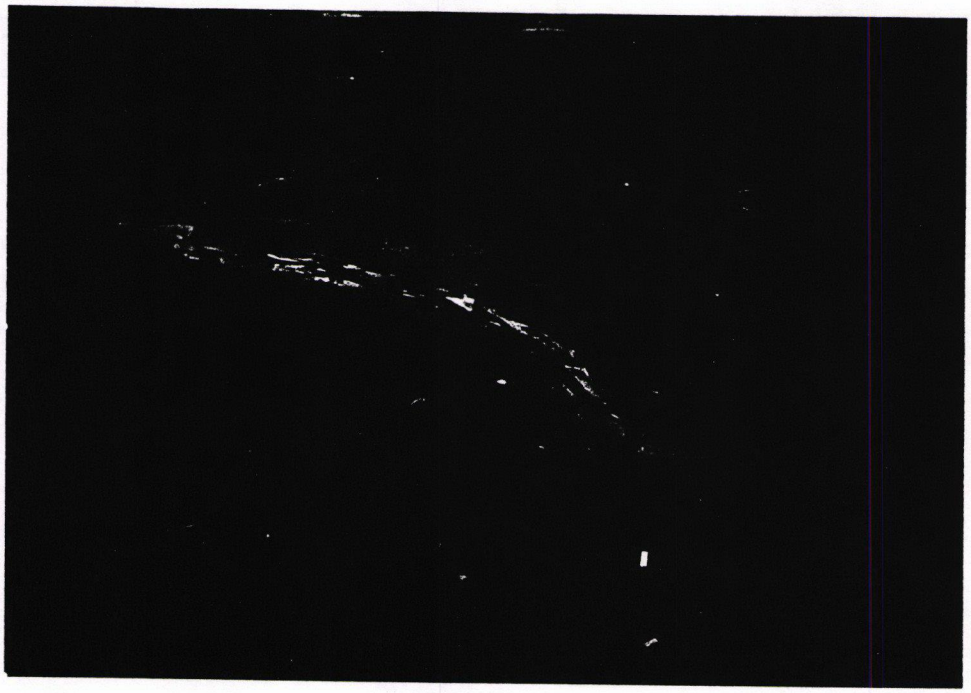
Whitestone River Photo 37, Lynwood Reach
Eroding cliffs at the downstream end of the artificially straightened channel at the head of Lynwood reach.
20.01.93 WH 2-24 Te Anau (D43) 1:50,000, GR 068177



Whitestone River Photo 38, Lynwood Reach
Within-channel sedimentation at the downstream end of the artificially straightened channel at the head of Lynwood reach. Note channel division over the shallow riffle and the willow in the deepest part of the channel.
20.01.93 WH 2-25 Te Anau (D43) 1:50,000, GR 068177



Whitestone River Photo 39, Lynwood Reach
The upstream end of Lynwood reach. Note the highly irregular and modified channel pattern, with artificially straightened segments, sections with alternating bars, areas of within-channel sedimentation, and different styles of side channel on alluvial flats. These various sections do not form a well defined or characteristic downstream sequence.
16.01.93 GBF 1/12



Whitestone River Photo 40, Lynwood Reach
Shallow, poorly defined channel of Whitestone River, viewed upstream from sample site WS3. Photograph is taken from the bend 1.5 cm above the white building on the upper photo.
20.01.93 WH 1-9 Te Anau (D43) 1:50,000, GR 042175



Whitestone River Photo 41, Lynwood Reach
Sample site WS3, looking upstream. This is a bank-attached bar in a sequence of alternating features. Note the irregular distribution of clasts and jumbled surface on the bar.
20.01.93 WH 1/16 Te Anau (D43) 1:50,000, GR 042175



Whitestone River Photo 42, Lynwood Reach
View downstream from sample site WS3. Note the sand drape and pioneer vegetation on the bar surface, and the willows planted at the outside of the bend.
20.01.93 WH 1/7 Te Anau (D43) 1:50,000, GR 042175



Whitestone River Photo 43, Lynwood Reach
Sequence of well-developed, dissected bends 2 km upstream of Te Anau-Mossburn road bridge.
16.01.93 GBF 1 10



Whitestone River Photo 44, Lynwood Reach
Bank erosion protection works on the bend in the middle of the upper photo.
21.01.93 WH 1-21 Te Anau (D43) 1:50,000, GR 032167



Whitestone River Photo 45, Lynwood Reach
Sample site WS4, looking upstream. Note the poor channel definition in this highly modified reach.
20.01.93 WH 1-10 Te Anau (D43) 1:50,000, GR 026157



Whitestone River Photo 46, Lynwood Reach
Lynwood reach of Whitestone River, immediately upstream of Te Anau-Mossburn road bridge. The channel is greatly modified in this subreach, and presently demonstrates a sequence of alternating lateral bars. Gravel extraction takes place on the bar in mid-photo.
16.01.93 GBF 1/9



Whitestone River Photo 47, Lynwood Reach
Highly dissected compound point bar immediately downstream of Te Anau-Mossburn road bridge. This is a major source of gravels for the adjacent cement works.
16.01.93 GBF 1/7



Whitestone River Photo 48, Lynwood Reach
The greatly modified channel of Whitestone River immediately downstream of Te Anau-Mossburn road bridge.
21.01.93 WH 1-28 Te Anau (D43) 1:50,000, GR 026146



Whitestone River Photo 49, Lynwood Reach
Whitestone River downstream of Te Anau-Mossburn road bridge. Note the broad sweeping sequence of bends. This configuration has been greatly modified by a series of straightened reaches.
16.01.93 GBR 1/8



Whitestone River Photo 50, Lynwood Reach
View upstream of one of the broad sweeping bends of Whitestone River downstream of Te Anau-Mossburn road bridge. The channel appears to have adopted a more sinuous course inset within the broad sweeping bend, accounting for the gravel bar in the foreground which has accumulated at the outside of the broad bend.
21.01.93 WH 1-30 Te Anau (D43) 1:50,000, GR 022117



Whitestone River Photo 51, Lynwood Reach
The modified, straightened course of Whitestone River between Te Anau-Mossburn road bridge and Hillside-Manapouri road bridge. Flow is from left to right.
16.01.93 GBF 1/6



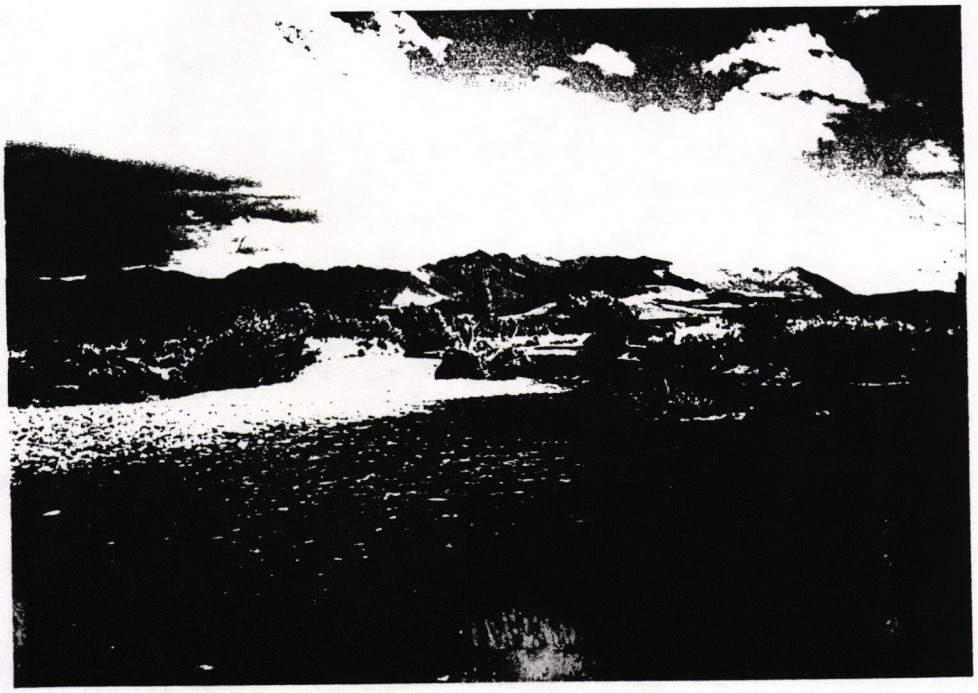
Whitestone River Photo 52, Lynwood Reach
The chaotic gravel surface in the disturbed channel section of Whitestone River. This photograph records the view downstream of the bar complex (4 cm from the right margin of the upper photograph).
21.01.93 WH 1-33 Te Anau (D43) 1:50,000, GR 017109



Whitestone River Photo 53, Lynwood Reach
View upstream at sample site WS5.
20.01.93 WH 1-13 Te Anau (D43) 1:50,000, GR 018107



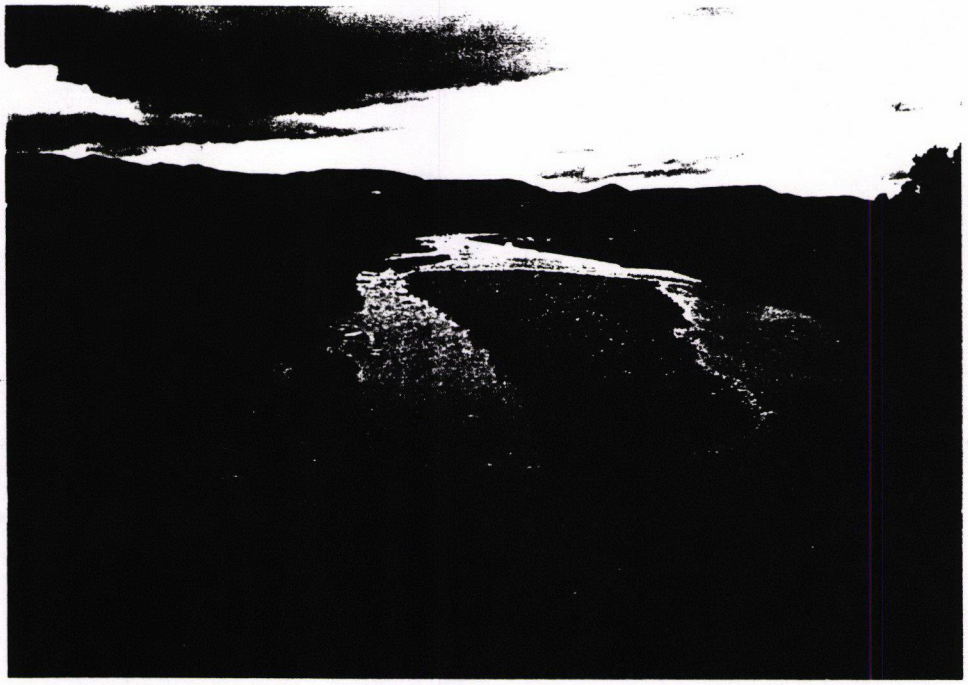
Whitestone River Photo 54, Lynwood Reach
Highly irregular channel geometry downstream of sample site WS5. Note the meandering bank and the large number of clumps of organic debris in the channel and on bar surfaces.
20.01.93 WH 1/14 Te Anau (D43) 1:50,000, GR 018107



Whitestone River Photo 55, Lynwood Reach
View downstream showing the highly disrupted channel configuration downstream of Webb's and Stephenson's diversion channels.
21.01.93 WH 1-35 Te Anau (D43) 1:50,000, GR 008083



Whitestone River Photo River 56, Lynwood Reach
View of Whitestone River upstream from Hillside-Manapouri road bridge. The large compound point bar in the background is used for gravel extraction. Note the occasional large white boulders within the channel.
21.01.93 WH 1-36 Te Anau (D43) 1:50,000, GR 004069



Whitestone River Photo 57, Lynwood Reach
View of Whitestone River downstream of Hillside-Manapouri road bridge. Note the extensive within-channel sedimentation. This large bar is composed primarily of fine (fist-sized) gravels.
21.01.93 AO 1/00 Te Anau (D43) 1:50,000, GR 005069



Whitestone River Photo 58, Lynwood Reach
View looking upstream at sample site WS6. Note the highly jumbled, poorly sorted bar surface.
20.01.93 WH 1/16 Te Anau (D43) 1:50,000, GR 005064



Whitestone River Photo 59, Lynwood Reach
Whitestone River downstream of sample site WS6. Site is located a few hundred metres upstream of Mararoa River confluence. Note the distinct sheet of fine gravels at the tail of the bank-attached bar in the foreground.
20.01.93 WH 1-17 Te Anau (D43) 1:50,000, GR 005064

