CHANNEL ADJUSTMENTS ALONG WAIAU RIVER, 1946-1992: ASSESSMENT OF THE IMPACTS OF FLOW REGULATION

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Brief

1) To characterise channel adjustments of Waiau River between 1946-1992 from series of air photograph runs.

2) To account for the spatial variability of channel adjustments.

3) To assess the relationship between flood history and channel adjustments.

4) To evaluate the role of flow regulation associated with Manapouri Power Scheme on channel adjustments along Waiau River between Lake Te Anau and Te Waewae Bay.

Summary

1) Overview of project

This report documents the nature and rate of channel adjustments along Waiau River between 1946-1992, as determined from a series of air photographs. Flow regulation since 1969, associated with the Manapouri power scheme, has reduced mean flow of Waiau River from 560 m^3s^{-1} pre-regulation to around 140 m^3s^{-1} post-regulation. Since the air photo record predates flow regulation in 1969, and discharge data have been collected since 1964, impacts of flow regulation on channel adjustments can be assessed in relation to river responses to flood events.

2) Channel responses to flow regulation: Theoretical expectations

Over periods of tens of years, channel shape is fashioned by mean discharge and sediment supply to an "equilibrium condition". The channel modifies its boundaries as flow conditions change, and sediments are moved through the channel, oscillating around a characteristic form. Change in river discharge, associated with either natural runoff variability or flow regulation, modifies the equilibrium channel character. Reduced flow levels are accommodated by changes to channel width, depth or flow velocity at any particular channel cross-section, although other variables, such as water surface gradient, bed roughness, and bed shear stress may also be adjusted. Channel responses to a modified discharge regime may be highly complex, with significant local variability and lagged responses. Sections downstream of the regulation structure become incised. Materials from this zone move downstream as bedload pulses. Relative increase in flow and sediment supplied by tributaries may result in channel changes at, and immediately downstream of, confluence zones. Because the regulated flow can no longer rework these deposits, the main channel becomes constricted. The rate at which a new equilibrium position is attained post-regulation is determined by local conditions, such as bed-material size, bank-material cohesion and valley slope, and the frequency of competent flows and tributary inputs.

3) Hydrological summary

Waiau River has a catchment area of about 8,200 km^2 and receives most of its water from Fiordland National Park. Two significant lakes in the headwaters, Lakes Te Anau and Manapouri, act as regulatory controls on rate of supply of runoff to the river. In general, upper catchment streams are in wet zones (up to 8000 mm/year rainfall), whereas lower catchment streams are in quite dry areas (commonly around 1000 mm/year). Together Lake Te Anau and Manapouri catchments cover 55 % of Waiau catchment area, but contribute 78 % of total 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. Full-scale generation did not begin until early 1973. Lake Te Anau Control Structure was commissioned in July 1974 and Lake Manapouri Control Structure (Mararoa Weir) was commissioned in November 1976. Prior to commissioning of the permanent Manapouri Lake Control Structure, a temporary weir was placed across the river in February 1970.

Water level recorders at Tuatapere commenced in late July 1964, some five years before water was first diverted out of Lake Manapouri to Deep Cove. Mean flow 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 from 1973 to 1991 inclusive were 137 m^3s^{-1} and 62 m^3s^{-1} respectively. In nearly all floods at Tuatapere post-control, 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 flood of record, in January 1984, when a 'normal' amount of water was coming from Lake Manapouri and October/November 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 had a return period of around 200 years. The October/November 1988 event was the most significant flood on record in Upper Waiau (Wairoa), when discharges in excess of 1000 m^3s^{-1} were maintained for several days between Lakes Te Anau and Manapouri.

4) Methods

Seventeen sets of aerial photographs, at scales ranging from 1:7,920 to 1:67,000, were used to compile the record of channel adjustments along Waiau River. Base maps were produced at a scale of 1:12,000 from the 1992 air photograph run. They comprise the channel outline discerned from visible banks and vegetated margins, and a series of fixed points, such as major terraces, roads, bridges, buildings and fences. The fixed points were then used to control the positional placement of the river outline plot for each of the additional photographic coverages. Vegetated margins were used to determine channel position, rather than the outline of gravel bars, as the shape of the latter are too dependent on flow stage at the time of photography. Photographs used to characterise channel adjustments for each reach are summarised below.

4.1) Measurement of channel adjustments

For those reaches in which significant channel adjustments were recorded, detailed measurements of areas of erosion and deposition were determined from consecutive air photograph runs. The large number of air photograph runs, along with the detailed methods of analysis employed in this study, enabled fine resolution assessment of channel adjustments. In total, almost 3,000 areal measurements of channel adjustment were made. Separate analysis of the banks and the within-channel zone enabled differentiation of permanent changes along banks from transitory within-channel behaviour. Field measurements of bank height were determined at nine sites of continual erosion so that volumetric estimates of material removed could be derived.

Air photograph runs used for each river reach

Reach name	Year of photography													
	46-48	54-57	63-65	69	74	75	77	78	80	82	84 (i)	84 (ii)	85	89	92
Wairoa (Upper Waiau)		X	X				X								X
Pearl Harbour		X													X
Duncraigen		X													X
Redcliff		X		X						X				X	X
Blackmount-Mangapiri	X	X								X					X
Wairaki	X		X	X	X			X	X	X	X	X		X	X
Motu	X														X
Lill Burn	X		X	X	X		X		X	X	X	X		X	X
Clifden Suspension bridge	X														X
Downstream o'Clifden	X		X	X	X		X	X	X	X	X	X		X	X
Hagen Road	X														X
Orauea	X														X
Tuatapere	X		X	X	X	X	X	X	X	X	X		X	X	X

4.2) Limitations to methodological approach

1) Analysis was restricted to changes is channel outline and does not refer to changes in bed elevation. No account of bank height was taken other than at the nine selected sites of bank erosion. Since areal estimates of channel adjustment have been used consistently throughout this report, comparative analyses of change over time are valid.

2) Areal estimates of channel changes are proportionally greater over shorter photographic intervals as the resolution of adjustments is greater. The longest period between photographs (1946-1963), which was coincident with the highest discharge levels pre flow regulation, has the least detailed analysis of areal adjustments. Measurements of channel change in this interval are certainly underestimated relative to other photographic intervals.

3) Hydrological data are restricted to the period since July 1964, whereas the documented history of channel adjustments dates back to 1946. No surrogate analysis of the rainfall record before 1964 has been undertaken.

5) Summary channel adjustments in each reach over the period of record

Initial analysis of channel adjustments compared channel alignments from the oldest air photographs, which date to 1946, 1954 or 1957 for differing river reaches, with the 1992 air photograph run.

5.1) Wairoa (Upper Waiau) reach

In Wairoa reach, which extends between Lakes Te Anau and Manapouri, Waiau River is deeply incised into lake and glacial outwash deposits and has an imposed, laterally stable condition. The only channel adjustments evident between 1957-1992 were:

a) Construction of Lake Te Anau Control Structure,

b) Trimming of the bend upstream of Kepler Track footbridge,

c) Abandonment of a tight gooseneck meander at the confluence with Forest Burn,

d) Lateral expansion (up to 50 m) of three bends immediately upstream of Lake Manapouri, and

e) Extension of the delta front into Lake Manapouri.

5.2) Pearl Harbour reach

Pearl Harbour reach is an incised, low sinuosity section of Waiau River between Pearl Harbour and Mararoa Weir. At low discharge stages this reach is essentially an extension of Lake Manapouri. Sites of trimming between 1957-1992 were restricted to the right bank immediately downstream of Lake Manapouri, the big bend 4 km upstream from Lake Manapouri Control Structure, and along each bank at the downstream end of the reach. Maximum extent of bank erosion, measured perpendicular to flow direction, was less than 25 m. Significant channel adjustments at Waiau/Mararoa confluence were artificially induced.

5.3) Duncraigen (or Excelsior) reach

Duncraigen reach extends from Manapouri Lake Control Structure to Waiau/Whare confluence. Adjustments in this single-channelled, almost straight reach are constrained by fluvioglacial terraces.

5.4) Redcliff reach

Redcliff reach extends from just upstream of Whare Creek to the margins of Blackmount Forest. The valley widens considerably in this reach. As the extent of alluvial flats increases down-reach, so does the width of active gravel surfaces. The channel divides from a single channel at the reach head to four or five channels downstream of Redcliff Creek. Compound point bars are transitional downstream to a sequence of alternating bank-attached compound bars and dissected islands. Large complex bars have formed as the channel divides downstream of Redcliff confluence.

Between 1957-1992 the right bank of Waiau River opposite Whare Creek eroded, while the left bank of Whare Creek shifted downstream. Between Whare and Redcliff Creek confluences Waiau River became less multichannelled, as islands became bank-attached. Redcliff Creek moved almost 50 m to the south at the confluence zone, modifying bars in Waiau River. Complex changes took place downstream of Redcliff Creek, where significant within-channel deposition and channel realignment occurred. The compound point bar on the left bank was extensively modified, as was a bank-attached bar on the opposite bank.

5.5) Blackmount-Mangapiri reach

Blackmount-Mangapiri reach is characterised by a laterally constrained single channel with a broadly sinuous outline. Alluvial flats are limited and within-channel deposition was restricted to compound point bars in Blackmount and Waicoe subreaches and a series of alternating bars at the downstream end of the reach. Channel adjustments between 1948-1992 were restricted to negligible channel trimming or occasional deposition at channel margins, although some adjustments occurred at compound point bars.

5.6) Wairaki reach

Downstream of Blackmount-Mangapiri reach Waiau Valley widens significantly, with extensive terrace sequences adjacent to Wairaki and Dean Burn confluences. As the river emerges from Mangapiri subreach it is concentrated in a single channel which switches from side to side within the valley/alluvial flats, eroding concave banks and depositing point bars on the inside of bends. Although generally more than several hundred metres wide, alluvial flats are

fragmentary and switch from valley side to valley side. Sediment inputs from Wairaki River and Dean Burn have produced a series of bars and riffles, with bank-attached compound bars dissected by chute channels. Pronounced lateral instability is evident. At the downstream limit of the reach, Waiau River is pinned into a single channel against bedrock at Motu Bush. Immediately downstream of this point there are two alternating bank-attached compound bars.

In 1946 flow in the bend at the head of Wairaki reach was divided, with a couple of chute channels evident, but by 1992 flow was confined to a single channel. The bend immediately upstream of Wairaki confluence experienced significant lateral expansion between 1946-1992. The pattern and rate of bend migration may be related to changes in the configuration of Wairaki River, as pronounced channel changes in the pattern of bars and islands were evident immediately downstream of Wairaki confluence.

5.7) Motu reach

Motu reach is a short, single-channelled, almost straight reach which is pinned between extensive terraces of Otahu Flat to the east and Motu Bush to the west. No channel changes were evident between 1947-1992.

5.8) Lill Burn reach

Lill Burn reach is constrained by bedrock at its upstream and downstream limits, adjacent to Motu Bush and Clifden respectively. Alluvial flats are continuous and > 1 km wide, presenting great opportunity for the channel to modify its planform. This is a similar condition to Wairaki reach, with distinct downstream variability in the character of within-channel sedimentation. At the head of the reach, flow is deflected around alternating bank-attached compound bars. Moving down-reach, side and chute channels are more prominent, and within-channel sedimentation is pronounced adjacent to Lill Burn confluence. Downstream of Lill Burn confluence the channel is laterally unstable, and flow divides around a series of large within-channel bars. At the downstream end of the reach there is a tight bedrock-constrained bend, with a prominent compound point bar.

Between 1947-1992 flow became concentrated into fewer channels in Lill Burn reach. Lill Burn itself shifted position at Waiau confluence, affecting the pattern of erosion and deposition downstream.

5.9) Clifden Suspension Bridge reach

Clifden Suspension Bridge reach is a short, single channelled reach with prominent limestone cliffs on both banks. There are no alluvial flats or bars, and hence no opportunity for channel adjustments to occur.

5.10) Downstream o'Clifden reach

Downstream o'Clifden reach occupies a lowland setting, with gentler valley slopes and fewer high terraces than upstream. Lateral and bank-attached compound bars at the reach head are transitional downstream to longitudinal and mid-channel compound bars, with dissected point bars on the inside of tight bends. This pattern of bars is associated with the tightest, most freely-migrating bend in the study area. Between 1947-1992 the bend expanded by up to 350 m, with concomitant within-channel deposition.

5.11) Hagen Road reach

In Hagen Road reach flow is confined into a roughly straight, single channel, as the left bank abuts against bedrock. Alluvial flats are < 300 m wide. There were no discernible adjustments between 1947-1992.

5.12) Orauea reach

Orauea reach extends from 1.5 km upstream of Orauea confluence to Tuatapere, where the river is confined by bedrock. Alluvial flats are more extensive upstream of Orauea confluence, but the channel is relatively stable and bar types are restricted to alternating bars. The river is generally single-channelled and moderately straight. Between 1947-1992 a secondary channel was abandoned upstream of Orauea confluence, but channel adjustments were otherwise trivial.

5.13) Tuatapere reach

This lowland reach extends from Tuatapere to the river mouth. Alluvial and valley flats are more extensive than elsewhere, as terraces are set back further from the river. However, the channel abuts against bedrock at a couple of locations. The active channel zone is broad, and flow is divided two or more laterally unstable channels. Within-reach variability in bar type is pronounced. At Tuatapere, Waiau River is constrained by terraces into a single-channelled, almost straight configuration. Downstream of this constraint the channel moves laterally, and deposition occurs in the form of a bank attached compound bar. Beyond this bar the main channel divides around a major mid-channel compound bar. Downstream of this point, flow is concentrated into one primary channel with a series of compound point bars. The channel widens considerably at the river mouth, with concomitant mid-channel deposition.

Tuatapere reach experienced the most complex pattern of channel changes along Waiau River between 1946-1992. Significant within-reach variability in channel adjustments was evident, as erosion zones migrated downstream. Channel multiplicity was reduced and the channel adopted a more sinuous outline, especially in the lower 4 km. The mouth of the river moved to the west, possibly associated with morphologic changes to the barrier system.

5.14) Summary assessment of channel character and changes along Waiau River

A distinct pattern in river reaches is discernible along Waiau River, with an alternating sequence of bedrock/terrace constrained reaches and less constrained reaches with multi-channelled planform geometries. This pattern of reaches acts as the primary control on the character of channel adjustments. Channel adjustments between 1946-1992 are summarised in the table below.

In Wairoa and Pearl Harbour reaches, Waiau River has an imposed, low to moderate sinuosity planform. Downstream of Mararoa Weir there are six more reaches which are laterally constrained: 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). Channel adjustments in these laterally confined reaches has been restricted to localised trimming or flow realignment around compound point bars.

Summary channel changes in each reach in the period of photographic record

Reach	Photograph interval	Summary channel adjustments
Wairoa	1957-1992	Channel marginal trimming; cut-off gooseneck meander at Balloon Loop
Pearl Harbour	1957-1992	Negligible changes
Duncraigen	1957-1992	No planform changes, but notable incision
Redcliff	1954-1992	Abandonment of secondary channels and attachment of mid-channel compound bars upstream of Redcliff confluence; shift in position of Redcliff Creek at the confluence zone; significant channel adjustments downstream of the confluence, with bar attachment and channel realignment
Blackmount-Mangapiri	1948-1992	Negligible changes other than in compound point bars and adjacent to Waicoe confluence
Wairaki	1947-1992	Abandonment of a secondary channel at the reach head. Expansion of a compound point bar and adoption of a more sinuous outline upstream of Wairaki confluence, with associated erosion of concave banks. Change in alignment of Wairaki River at the confluence and significant modification of Waiau River immediately downstream.
Motu	1947-1992	No change
Lill Burn	1947-1992	Attachment of a mid-channel bar to the left bank upstream of Lill Burn and significant erosion of this bank opposite Lill Burn confluence. Pronounced shifts in the position of Lill Burn, which has adopted a more sinuous outline and has cut a new channel to the south at Waiau confluence. Numerous channels have been abandoned downstream of Lill Burn, as bars have expanded considerably. This has resulted in significant channel realignment.
Clifden	1947-1992	No change
Downstream o'Clifden	1947-1992	Significant lateral expansion of a tight bend, with up to 350 m of erosion. Associated within-channel bar development and channel realignment.
Hagen Road	1947-1992	No change
Orauea	1947-1992	Negligible channel adjustments other than abandonment of a chute channel upstream of Orauea confluence.
Tuatapere	1946-1992	Complex sequence of adjustments. Channel multiplicity reduced and sinuosity increased. Focal points of erosion in concave banks migrated downstream. A mid-channel bar complex at the head of the reach became more stable, while a series of compound point bars developed in the lower 4 km of the reach.

Channel adjustments between 1946-1992 were restricted to reaches where the river has space to adjust laterally, namely: Redcliff, Waicoe, Wairaki, Lill Burn, Downstream o'Clifden, Orauea and Tuatapere. Channel changes were localised at confluence zones in Waicoe and Orauea reaches, but were much more significant in Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere reaches. Subsequent detailed analysis of channel adjustments was restricted to Wairoa, Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere reaches. Up to thirteen sets of air photographs were analysed in these reaches. Although the time intervals considered pre- and post-regulation are roughly equal, only three sets of air photographs pre-dated flow regulation.

6) Floods and channel adjustments

Daily discharge data from Tuatapere and Sunnyside gauging stations were used to evaluate the relationship between hydrologic regime and channel adjustments. Counts were made to determine the number of days on which 50 m^3s^{-1} discharge intervals were exceeded for each photographic interval. Flood peakedness was assessed from plots of daily discharge levels for each event > 800 m^3s^{-1}. Relative flow contributions from the upper and lower Waiau catchments were determined for individual flood events by comparison of discharge levels at Tuatapere and Sunnyside. The flood history for the differing air photograph intervals is summarised below.

Flood events in the main periods of air photograph record

Date	Summary flood record	
	Upper catchment	*Lower catchment*
1964-1969	Twenty events exceeded 800 m^3s^{-1}, and five events exceeded 1200 m^3s^{-1}. On nine occasions flow levels > 800 m^3s^{-1} were sustained for 10 days or longer. Highest discharge recorded was 1737 m^3s^{-1}.	
1969-1974	Seven events exceeded 800 m^3s^{-1}, two of which extended for > 10 days and attained discharges > 1200 m^3s^{-1}. Highest discharge recorded was 1389 m^3s^{-1}.	
1974-1978	Two events exceeded 800 m^3s^{-1} neither of which extended for > 10 days. Maximum discharge was 1168 m^3s^{-1}.	One event exceeded 800 m^3s^{-1}. This lasted for one day with a maximum discharge of 878 m^3s^{-1}.
1978-1980	One event exceeded 600 m^3s^{-1} at Sunnyside, but did not exceed 800 m^3s^{-1} at Tuatapere.	Three, short duration flood events exceeded 800 m^3s^{-1}. Maximum recorded discharge was 1240 m^3s^{-1}.
1980-1982	Three of the five events which exceeded 600 m^3s^{-1} at Sunnyside were short-lived upper catchment events. One of these was a peaked event which had a discharge of 1357 m^3s^{-1}. This event reflected runoff contribution throughout the catchment. The two other events were relatively low discharge events.	Two one-day events with discharge levels < 1000 m^3s^{-1} occurred.
1982-1984	The two largest floods on record in January 1983 and January 1984 both reflected runoff contribution from throughout the catchment and attained discharges of 1571 m^3s^{-1} and 2182 m^3s^{-1} respectively. Both events were peaked and short-lived. Discharges > 1200 m^3s^{-1} were only maintained for 2 days, although the January 1983 event sustained discharge levels > 800 m^3s^{-1} for 17 days. There were two further upper-catchment events in this interval. One event exceeded 1000 m^3s^{-1} and sustained discharge > 800 m^3s^{-1} for 8 days.	Two one-day events > 800 m^3s^{-1} occurred.
1984-1989	Four upper catchment events were recorded, three of which exceeded 1000 m^3s^{-1}. While the first two of these events were 2-day events, the third event, in October/November 1988, maintained discharge levels > 1200 m^3s^{-1} on 16 days, while levels > 800 m^3s^{-1} were maintained for 29 days. Maximum recorded discharge was 1484 m^3s^{-1}.	Three events > 800 m^3s^{-1} were dominated by runoff contribution from the lower catchment. While two of these events had peak discharge < 1000 m^3s^{-1}, the third event in March 1987 was a peaked event with a maximum discharge of 1310 m^3s^{-1}. All three events lasted 2 days or less.
1989-1992	No upper-catchment events were recorded.	Two lower catchment events were recorded. Both events lasted less than 2 days and had peak discharges > 1000 m^3s^{-1}. Maximum discharge was 1237 m^3s^{-1}.

6.1) Floods and channel adjustments in Wairoa reach

Channel adjustments in Wairoa reach were negligible between 1957-1965 and 1965-1977, when discernible changes were restricted to erosion adjacent to Balloon Loop. Erosion and deposition were much more substantive between 1977-1992 when significant trimming took place, especially in Yerex, Rainbow, Balloon Loop and Downstream of Boulder reaches. Erosion almost certainly reflected the high discharge events in the 1980's, which are amalgamated between 1977-1992 in this analysis. It is likely that a significant proportion of bank trimming occurred during the October/November 1988 flood when discharge levels > 1000 m^3s^{-1} were maintained for several days.

6.2) Floods and channel adjustments in Lower Redcliff reach

The most dramatic feature of the erosion/sedimentation regime in Lower Redcliff is the shift from erosional dominance before 1969 to depositional dominance between 1969-1982. This clearly reflects flow regulation impacts in the first reach downstream of Lake Manapouri Control Structure in which Waiau River has space to adjust. Erosion rates were

rapid between 1954-1969, especially in the within-channel zone. Erosion was also prominent along the left bank bar complex downstream of Redcliff confluence. As mean flow was drastically altered following flow regulation, deposition became pronounced along banks, as the channel contracted and mid-channel bars became bank-attached. The erosion rate was exceptionally low between 1969-1982.

Between 1982-1989 channel adjustments were relatively trivial, although some erosion occurred along margins of the left bank complex downstream of Redcliff confluence. The suggests that the high discharge events of the 1980's were surprisingly ineffective, although within-channel deposition was negligible. Associations between areal channel adjustments and the flood regime were complex, although rate of erosion between 1982-1989 did exceed that between 1969-1982. Erosion rates were higher, however, between 1989-1992, when discharge levels > 1250 m^3s^{-1} were never exceeded. High erosion rates between 1989-1992 may reflect sediment availability following flood events in the 1980's associated with tributary flows from Redcliff Creek. Rate of deposition was highest in this interval, when a former mid-channel bar became attached to the left bank upstream of Redcliff confluence.

6.3) Floods and channel adjustments in Wairaki Reach

A major switch in the erosion/deposition balance occurred between 1969-1974 in Wairaki reach, when erosion exceeded deposition by a ratio of over 5:1. Other than occasional units adjacent to the right bank, deposition was largely restricted to the within-channel zone. Deposition continued to dominate over erosion throughout the 1970's. The shift to depositional dominance between 1969-1974 reflected changes to the discharge regime associated with flow regulation. Relative change in mean flow was more dramatic in this period than at any other stage, as the proportion of days with discharge levels > 500 m^3s^{-1} was reduced from 46.9 % of days between 1964-1969 to just 19.4 % of days between 1969-1974. The flow no longer had the capacity to move the extensive volumes of material that it was previously able to, and extensive within-channel deposition occurred. This effect was exaggerated by the lack of major flood events between 1969-1974.

In the period before flow regulation there was pronounced variability in the distribution of deposition and erosion in Wairaki reach. Between 1947-1963 erosion was prominent along the right bank and in the within-channel zone upstream of Wairaki. At the confluence zone and in the 2 km reach downstream deposition greatly exceeded erosion. Erosion and deposition were also localised between 1963-1969. Upstream of Wairaki confluence there was significant deposition on the complex point bar at the reach head, while King-Allen bend eroded. Downstream of Wairaki confluence there was extensive deposition adjacent to the right bank, but erosion and deposition were roughly balanced in the within-channel zone. Downstream of the bedrock constriction erosion was pronounced along the left bank and in the within-channel zone.

Negligible changes were evident between 1974-1978. Rates of erosion and deposition increased between 1978-1980, but deposition continued to prevail overall. Notable erosion occurred along the left bank at Wairaki confluence and along the right bank downstream of the confluence. Deposition was prevalent on compound point bars upstream of Wairaki confluence and in the within-channel zone. Rate of erosion was higher between 1978-1980 than at any other stage during the 1970's. The lower catchment flood in May 1979 induced much greater adjustments than would be

expected for an event of its magnitude. Rates of erosion and deposition between 1980-1982 were notably lower than between 1978-1980. Negligible erosion occurred, and deposition was restricted to the compound point bar at the reach head and in the within-channel zone at Wairaki confluence.

The two floods of record in January 1983 and January 1984 almost completely redressed the depositional dominance evident throughout the 1970's. Indeed, these events exerted more extensive channel adjustments in Wairaki reach than anywhere else along Waiau River, as the channel zone was flushed out and large areas of alluvial flats downstream of Wairaki confluence were inundated. Channel width-depth ratio was reduced and numerous secondary channels were reactivated. While erosion was extensive along banks, King-Allen bend did not erode. Channel recovery following the January 1984 flood was dramatic, and by June 1984 much of the land previously eroded had been replaced. Deposition was especially pronounced along the left bank and in the within-channel zone.

In contrast to the dominant impact of the floods of record between 1982-1984, the sustained high discharge conditions in October/November 1988 were less effective in bringing about channel adjustments in Wairaki reach than was evident elsewhere along the river. Indeed, extent of erosion between 1984-1989 was one-sixth that recorded between 1982-1984 and erosion only marginally exceeded deposition. Extensive erosion occurred at King-Allen bend and in the within-channel zone, while deposition was pronounced along the left bank upstream of Wairaki confluence and in the within-channel zone at, and immediately downstream of, Wairaki confluence. The erosion/deposition balance was maintained along the banks between 1989-1992, but erosion was dominant in the within-channel zone. Erosion was primarily restricted to the left bank upstream of Wairaki confluence and to the right bank and within-channel zones downstream of Wairaki confluence. Deposition was most substantial along the right bank downstream of Wairaki confluence. Between 1989-1992 considerable erosion resulted from events of relatively low discharge, as there were only 3 days $> 1000\ m^3s^{-1}$.

6.4) Floods and channel adjustments in Lill Burn reach

Between 1947-1963 there was pronounced spatial variability in the distribution of erosion and deposition in Lill Burn reach. The left bank was predominantly erosional, especially upstream of Lill Burn confluence, while the right bank was mainly depositional. Rates of activity were much greater downstream of the confluence. Rates of erosion and deposition were much higher between 1963-1969 than between 1947-1963. Erosion was dominant along the left bank, deposition was dominant along the right bank, and erosion and deposition were crudely balanced in the within-channel zone.

A pronounced shift in erosion:deposition balance in Lill Burn reach was induced by flow regulation. While erosion and deposition were crudely balanced between 1947-1969, rate of deposition exceeded rate of erosion by over 6 times between 1969-1974. Channel response to the change in mean flow was dramatic and rapid. Deposition was dominant throughout the entire reach, other than along the left bank downstream of Lill Burn confluence, where erosion was induced when substantial within-channel deposits pushed Waiau River against the opposite bank. High rates of deposition were maintained throughout the 1970's, other than between 1977-1980 when the May 1979 flood induced anomalously high erosion at, and downstream of, Lill Burn confluence. A stark turnaround in process activity was

evident between 1978-1980 and 1980-1982. In the latter period deposition rates were significantly higher, and ratios of deposition:erosion of around 10:1. Deposition was particularly pronounced along the right bank at Lill Burn confluence and in the within-channel zone downstream.

The two floods of record between 1982-1984 induced erosion and channel reactivation occurred throughout Lill Burn reach, as Waiau River realigned. High rates of erosion during the floods of record were evident along the left bank upstream and downstream of Lill Burn confluence, along the right bank at Lill Burn confluence, and in the within-channel zone downstream of Lill Burn. Channel recovery between February-June 1984 was particularly effective along the left bank upstream of Lill Burn confluence, and in the within-channel zone downstream of Lill Burn confluence. In both instances secondary channels which had been reactivated between 1982-1984 flood were largely abandoned. Deposition was dominant throughout the reach.

Between 1984-1989 the ratio of erosion:deposition was tilted towards erosion, especially at Lill Burn confluence where the tributary cut a straight course to the trunk river. This brought about further erosion of the left bank of Waiau River. Substantial erosion also occurred in the within-channel zone, as the main channel of Waiau River became better defined and eroded the left bank compound point bar at the downstream end of Lill Burn reach. Between 1989-1992 the erosion/deposition balance reverted to a dominantly depositional regime. Deposition was particularly pronounced along the right bank at the confluence zone and in the within-channel zone downstream of Lill Burn confluence where a secondary channel was abandoned.

In summary, channel adjustments were especially prominent downstream of Lill Burn confluence, while anomalously high erosion rates during relatively low magnitude floods resulted from shifts in the position of Lill Burn (eg. 1977-1980). Extents of erosion were roughly equal between 1982-1984 and 1984-1989. In both instances erosion was dominant adjacent to the banks while deposition was relatively trivial, indicating the flushing nature of the January 1984 flood and the period of sustained high discharge in October/November 1988. The sustained high flow levels in late 1988 were more effective in erosional terms in Lill Burn reach than in Wairaki reach, while the extent of deposition was notably lower. This implies that the channel was more effectively flushed in Lill Burn reach, possibly associated with the pattern of flow realignment and within-channel sedimentation following flow regulation. February-June 1984 and 1989-1992 were periods of unusually high rates of activity, probably associated with reworking of deposits following the floods in the preceding intervals.

6.5) Floods and channel adjustments in Downstream o'Clifden reach

Extent of erosion and deposition in Downstream o'Clifden reach were greatest in the period prior to flow regulation. Waiau River effectively maintained an equilibrium condition between 1947-1969, in which erosion of the concave bank was balanced by within-channel deposition. Deposition increased markedly in the period following flow regulation, while the rate of erosion decreased. However the shift to a predominantly depositional regime was not as dramatic as observed in Wairaki and Lill Burn reaches. Rate of deposition between 1969-1974 was only marginally greater than that before 1969. Erosion continued along the concave bank despite the greatly reduced mean flow between 1969-1974. Deposition was dominant along the left bank and in the within-channel zone. Rate of deposition between 1974-1977

actually exceeded the rate between 1969-1974. Negligible channel changes were evident between 1977-1978. While erosion continued to dominate along the right bank between 1978-1980, deposition was dominant along the left bank and in the within-channel zone. Substantive within-channel deposition occurred between 1980-1982, but erosion continued along the right bank.

The pattern of depositional dominance was modified during the high discharge intervals in the 1980's, although rapid channel recovery followed the erosional phases induced by the major floods in January 1983 and January 1984 and the period of sustained high discharge in October/November 1988. In contrast to the laterally unconfined reaches upstream, extent of erosion between 1984-1989 was actually greater than between 1982-1984, especially along the right bank. However, rate of erosion was greater between 1982-1984 than any other interval. The reversal in trend of the erosion/sedimentation balance was most pronounced in the within-channel zone, where deposits were efficiently flushed. The negligible area of deposition between 1984-1989 contrasted starkly with Wairaki and Lill Burn reaches. Deposition was dominant between February-June 1984 and 1989-1992 as materials were reworked and the channel contracted during low discharge conditions. While channel recovery was pronounced between 1989-1992, substantive erosion continued along the right bank and in the within-channel zone.

6.6) Floods and channel adjustments in Tuatapere reach

Tuatapere reach is the longest and most alluvial reach along the course of Waiau River. Erosion and deposition were balanced in summary terms prior to flow regulation, although erosion was dominant along banks and deposition was dominant in the within-channel zone between 1946-1969. Erosion was focussed along the left and right banks alternately, reflecting the broadly sinuous nature of the channel zone. Erosion was particularly severe along the left bank in mid-reach and along the right bank immediately at the river mouth. Deposition rate was highest in the within-channel zone.

A dramatic shift in the erosion and sedimentation regime occurred between 1969-1974, when extent of deposition was 5 times that of erosion. While rate of erosion between 1969-1974 was roughly half that recorded between 1963-1969, rate of deposition increased by almost 3 times. Deposition was dominant throughout Tuatapere reach, especially in the within-channel zone. Erosion was localised, and was especially pronounced along the left bank in mid-reach. Although this transition clearly reflected the impact of flow regulation, 1969-1974 was also with a period of infrequent moderate-high magnitude floods. For example, 0.7 % of days between 1964-1969 had discharge levels > 1250 m^3s^{-1} compared to just 0.25 % of days between 1969-1974.

Negligible channel adjustments were evident between 1974-1977, although deposition dominated over erosion. Deposition continued to dominate over erosion between 1977-1978, 1978-1980 and 1980-1982. Although high discharge events were infrequent throughout this period, erosion recurred along the left bank in midreach and along the right bank upstream of the river mouth. This reflected the ability of Waiau River to rework its boundaries under relatively low magnitude, high frequency events in Tuatapere reach. Floods of record between 1977-1978, 1978-1980 and 1980-1982 were 878 m^3s^{-1}, 1240 m^3s^{-1} and 1357 m^3s^{-1} respectively. Less than 0.5 % of days had discharge levels > 750 m^3s^{-1} in each interval. However, between 1978-1980 and 1980-1982 there were 6.7 % and 7.8 % of days

with discharge levels > 500 m^3s^{-1}. Accordingly, it is inferred that most erosional reworking in Tuatapere reach between 1977-1982 occurred at discharge levels between 500-750 m^3s^{-1} (ie. flow levels marginally above the mean flow prior to regulation). It must be remembered, however, that deposition was clearly dominant in each of these intervals.

The erosion/deposition balance shifted markedly towards erosion between 1982-1984, when erosion exceeded deposition by a ratio of over 5.5:1. Erosion was dominant throughout Tuatapere reach, especially along the left bank and in the within-channel zone. A notable shift occurred in the location of erosion along banks. At the reach head erosion was dominant along the left bank, whereas between 1946-1963 erosion had been dominant along the right bank. A similar shift in location of erosion occurred 4 km upstream from the river mouth, where erosion shifted from the left bank in 1946 to the right bank in 1984. This transition reflected the downstream shift in the pattern of bends.

Instability induced by the floods of record in January 1983 and January 1984 was maintained between 1984-1985. Erosion continued to dominate over deposition, although this was a period of low magnitude floods with just one event > 800 m^3s^{-1}. However, 7 % of days maintained discharge levels > 500 m^3s^{-1} between 1984-1985, confirming the capability of flow levels between 500-800 m^3s^{-1} to induce erosion in Tuatapere reach. Between 1984-1985 over 80 % of this erosion occurred in the within-channel zone, especially at the reach head and immediately upstream of the river mouth. Rate of deposition was high along the left bank at the river mouth, while erosion continued along the right bank. This reflects the gradual westward shift in the position of the river mouth over the period of record.

In contrast to other laterally confined reaches, where the highest rate of bank erosion occurred between 1982-1984, bank erosion in Tuatapere reach was most rapid between 1985-1989. This largely reflected the shift in channel alignment, as a more sinuous outline was adopted in the 4 km reach upstream of the river mouth. Erosion was especially severe along the left bank at the reach head and along the right bank in mid-reach. In both instances erosion was located on the opposite bank between 1946-1963. Erosion was particularly active in the within-channel zone, as flood channels dissected the large bar complex near the reach head. Deposition was also extensive between 1985-1989, as compound bars developed on the inside of bends and secondary channels were abandoned. The relatively high percentage of days with discharge levels > 800 m^3s^{-1} between 1985-1989 induced major erosional and depositional activity throughout this lowland reach.

Between 1989-1992 deposition was 3 times more extensive than erosion, especially in the within-channel zone. Only four days had flow levels > 800 m^3s^{-1}, and discharge exceeded 1200 m^3s^{-1} on just one of these days. However, discharge was > 500 m^3s^{-1} on 24 days (2.3 % of total days) suggesting that substantial erosion and deposition occurred at discharge levels between 500-800 m^3s^{-1}.

6.7) Comparative assessment of flood effectiveness along Waiau River

Proportions of erosional and depositional activity that occurred in each time interval in the four laterally unconfined reaches are presented in the table below.

Proportion of erosion and depositional activity over differing photographic intervals

	Wairaki	*Lill Burn*	*Downstream o'Clifden*	*Tuatapere*
Total erosion (%)				
1963-1969	13.6	16.1	19.0	15.8
1969-1974	3.2	4.5	9.7	7.7
1974-1978	1.2	2.0	5.3	5.6
1978-1980	10.6	8.4	4.0	2.9
1980-1982	2.1	2.7	7.6	4.6
1982-1984	50.2	32.1	20.0	17.1
1984-1984	6.0	4.4	0.4	
1984-1985				10.3
1984-1989	7.4	24.3	25.6	
1985-1989				32.1
1989-1992	5.8	5.5	8.6	3.9
Bank erosion (%)				
1963-1969	12.1	9.4	30	20.0
1969-1974	2.5	6.5	7.6	10.6
1974-1978	1.4	1.8	2.2	4.9
1978-1980	15.5	5.4	4.8	4.1
1980-1982	2.5	2.8	10.2	4.9
1982-1984	54.3	37.8	13.1	12.8
1984-1984	3.8	3.9	0.8	
1984-1985				4.2
1984-1989	3.4	27.5	22.9	
1985-1989				35.0
1989-1992	4.5	4.8	8.5	3.5
Total deposition (%)				
1963-1969	8.8	13.2	14.4	12.3
1969-1974	18.9	24.4	19.9	31.3
1974-1978	7.6	7.6	19.1	11.8
1978-1980	17.4	3.1	13.3	11.3
1980-1982	7.1	14.7	11.7	5.1
1982-1984	0.7	0.6	0.4	2.4
1984-1984	30.5	17.1	9.1	
1984-1985				3.4
1984-1989	5.5	6.8	2.7	
1985-1989				13.1
1989-1992	3.4	12.4	9.3	9.2
Erosion:Deposition				
1963-1969	1.30	1.04	0.95	1.00
1969-1974	0.14	0.16	0.35	0.19
1974-1978	0.13	0.22	0.20	0.37
1978-1980	0.51	2.35	0.21	0.20
1980-1982	0.25	0.16	0.47	0.71
1982-1984	58.08	45.66	33.06	5.56
1984-1984	0.17	0.22	0.03	
1984-1985				2.34
1984-1989	1.15	3.02	6.82	
1985-1989				1.91
1989-1992	1.43	0.37	0.67	0.33

Perhaps the most telling statistic that reflects changes in the erosion and sedimentation regime of Waiau River over the period of record is the ratio of erosion:deposition. While erosion and deposition were roughly balanced between 1963-1969, a profound shift occurred between 1969-1974, associated with the impacts of flow regulation. The shift to depositional dominance between 1969-1974 was marked by proportion of deposition roughly twice those recorded between 1963-1969. Indeed, between 1969-1974 and 1974-1978 deposition outstripped erosion by a ratio of at least 3:1 in all reaches. Erosion rates were selectively higher in the lowland Downstream o'Clifden and Tuatapere reaches

between 1969-1974, reflecting the greater erosional effectiveness of discharge levels above 500 m^3s^{-1} in more alluvial reaches. Although high deposition rates were maintained throughout the 1970's, the peak depositional interval differed among the four reaches. In Wairaki reach deposition was relatively high in 1978-1980, in Lill Burn reach deposition was relatively high between 1980-1982, in Downstream o'Clifden reach deposition rate diminished consistently in the three intervals following 1969-1974, whereas in Tuatapere reach the relative proportion of deposition was notably greater between 1969-1974 but remained high between 1974-1978 and 1978-1980. These differences reflect sediment movement through the system, induced in large part by tributary sediment supply.

The anomalous erosion:deposition ratio in Lill Burn reach between 1978-1980, and the disproportionately high proportion of bank erosion that occurred in Wairaki reach in this interval, seemingly reflect the flood in May 1979. This short lived event had a maximum discharge of 1240 m^3s^{-1}, but discharge at Tuatapere was > 600 m^3s^{-1} higher than at Sunnyside. Erosion was localised at, and immediately downstream of, confluence zones. This suggests that tributary catchments were highly active during this peaked lower catchment event. In contrast to these high rates of erosional activity in Wairaki and Lill Burn reaches between 1978-1980, negligible changes were evident in Downstream o'Clifden and Tuatapere reaches.

A pronounced switch to erosional dominance occurred in association with the two floods of record in January 1983 and January 1984. In all four reaches the rate of erosion was greatest between 1982-1984, when the channel was flushed and low deposition rates resulted. Ratio of erosion:deposition was notably lower in Tuatapere reach, where the 1982-1984 interval includes the phase of rapid channel recovery that was evident in the three other reaches between February-June 1984. The relative significance of erosion between 1982-1984 decreased downstream, from > 50 % of total erosion in Wairaki reach to < 20 % in Tuatapere reach.

Significant erosion occurred in Wairaki and Lill Burn reaches between February-June 1984. Adjustments along the lower courses of these tributary systems resulted in significant reworking of deposits in Waiau River. Reworking was much less evident in Downstream o'Clifden reach. No discharge levels > 500 m^3s^{-1} were experienced during this interval. Between 1984-1985 significant erosion occurred in Tuatapere reach, as a series of relatively low magnitude events reworked large volumes of material.

In contrast to the pattern of upstream dominance in the effectiveness of floods between 1982-1984, an opposite downstream trend was evident for geomorphic effectiveness of the sustained high discharge levels in late 1988. The interval between 1984-1989 accounted for > 30 % of total erosion in Tuatapere reach, at rates equivalent to those between 1982-1984, but accounted for < 10 % of erosion in Wairaki reach. The high proportion of total erosion in Lill Burn reach between 1984-1989 reflected the shift in course of the tributary at the confluence zone. Extensive deposition also continued in Tuatapere reach during this interval.

Associated with the lack of sustained or high magnitude events between 1989-1992, Waiau River reverted to a predominantly depositional regime. There were just four days on which discharge exceeded 800 m^3s^{-1}. High deposition rates may be associated with the large volumes of material made available for reworking by the major flood

events of the 1980's. Wairaki River effectively shifted to the north in the confluence zone during this interval, inducing substantive erosion downstream. This was probably associated with two peaked lower catchment events in February and August 1991.

6.8) Bank erosion rates and their relationship to the discharge record.

Nine sites were selected for detailed analysis of bank erosion over the period of photographic record. Field measurements of bank heights at these sites enabled estimates of volumes of removed material to be determined. Proportions of total material eroded from these sites during differing photographic intervals are presented below.

Percentage volume of material eroded from selected sites of bank erosion during differing photographic intervals (Sites 1-9 are listed below)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
1963-1969	70.2	4.3	51.9	3.2	33.8	29.2	33.0	-	49.8
1969-1974	15.7	-	23.6	20.3	5.8	-	25.1	-	6.3
1974-1978	-	-	9.0	0.8	-	-	6.3	9.2	-
1978-1980	-	-	12.1	-	5.8	-	1.8	4.6	8.6
1980-1982	-	2.8	3.4	2.5	10.4	-	6.3	4.6	-
1982-1984	-	91.8	-	14.1	9.1	12.4	2.5	32.1	2.3
1984-1984	-	-	-						
1984-1985						19.7	6.1	24.8	1.4
1984-1989	10.7	1.1		57.0	27.3				
1985-1989						8.0	18.8	16.5	31.7
1989-1992	3.3	-	-	-	7.8	30.7	-	8.3	-

Sites at which volumetric bank erosion was assessed

Site 1	King-Allen bend in Wairaki reach
Site 2	Left bank downstream of Wairaki confluence
Site 3	Left bank opposite Lill Burn confluence
Site 4	Left bank downstream of Lill Burn confluence
Site 5	Right concave bank in Downstream o'Clifden reach
Site 6	Right concave bank at Carr's property, Tuatapere reach
Site 7	Left bank in Carr's to Mid-break subreach, Tuatapere reach
Site 8	Right bank in Downstream of Bend break subreach, Tuatapere reach
Site 9	Right bank at the river mouth, Tuatapere reach

Pronounced variability in the temporal distribution of bank erosion reflects differing phases of bend evolution, from initiation through expansion to migration. In five of the nine sites studied, erosion rates were highest in the period before flow regulation (1963-1969). Of the remaining sites, one example did not commence eroding until 1974-1978 (site 8), one site experienced negligible erosion until the floods of record between 1982-1984 (site 2), and sites 4 and 6 experienced anomalous erosion histories. At site 4, along the left bank downstream of Lill Burn confluence, erosion was prominent between 1969-1974 as a bend developed, but by far the greatest proportion of erosion took place between 1984-1989 as Waiau River shifted towards the left bank and straightened, destroying the bend. At site 6, along the right concave bank 1 km downstream of Tuatapere, erosion was prominent between 1963-1969 and 1989-1992. While the former interval is readily explained as bend expansion during a period of relatively high discharge levels, the high erosion rate between 1989-1992 is perhaps best explained by local flow concentration associated with within-channel sedimentation.

Erosional impacts of the major floods of record and the period of sustained high discharge between 1982-1989 were relatively subdued. Sustained high discharge levels, such as those evident pre-regulation and in the immediately following regulation (1969-1974), were more effective erosive events. The only other intervals which accounted for > 10 % of total bank erosion were 1978-1980 at site 3 and 1980-1982 at site 5. Erosion at these sites probably reflected the peaked flood events in May 1979 and August 1980 which had maximum discharges of 1240 m^3s^{-1} and 1357 m^3s^{-1} respectively.

Four factors are seen to account for the spatial variability in the effectiveness of flood events, namely:

(i) The width of the active channel zone, which broadens considerably downstream.

(ii) Tributary confluence configuration, which induces markedly variable flood responses.

(iii) The "condition" of the river system and its relationship to sequences of flood events. In transport-limited systems such as Waiau River, the sequence and magnitude of floods will determine how much material is able to be moved, or how "flushed-out" the channel may be.

(iv) Stage of bend evolution, channel alignment and the pattern of within-channel deposition. Along Waiau River rate of retreat of concave banks was greatest just after bends initiated, and cannot be tied directly to the flood regime. For example, the right concave bank at the head of Tuatapere reach experienced the highest rate of bank retreat between 1946-1963, whereas the left bank in mid-reach and the right bank 2 km upstream of the river mouth experienced maximum rates of bank retreat between 1963-1969 and 1982-1984 respectively. Localised bank retreat may reflect sediment accumulation in the within-channel zone and associated flow deflection, for example,. erosion of the right bank 1 km downstream of Tuatapere between 1989-1992.

7) Regulation impacts on channel adjustments along Waiau River

Regulation impacts on the erosion/sedimentation regime of Waiau River were determined by assessment of channel planform adjustments and changes in the erosion/deposition regime.

7.1) Impacts of flow regulation on channel adjustments in Wairoa reach

While adjustments to channel alignment were negligible in Wairoa reach, significant trimming of banks occurred at selected locations, especially in Rainbow, Boulder and Downstream of Boulder subreaches. Rates of bank erosion increased since the construction of Lake Te Anau control structure.

7.2) Impacts of flow regulation on channel adjustments in Lower Redcliff reach

The most dramatic change in erosion/sedimentation regime in Lower Redcliff reach since 1969 has been the eight-fold increase in the rate of deposition adjacent to banks compared to the period before 1969. Channel contraction was the primary morphologic response to altered mean flow, with > 30 % reduction in width of the active channel zone upstream of Redcliff between 1969-1992. Number of channels decreased between 1969-1992 as former mid-channel bars became bank-attached and the braided index upstream of Redcliff decreased by over 67 %. Associated with these changes was an increase in sinuosity, as Waiau River adopted a better-defined sequence of bends around larger bar complexes. Increase in sinuosity was especially evident downstream of Redcliff, where sinuosity increased from 1.34 to 1.41.

Rates of erosion and deposition downstream of Redcliff were roughly double those observed in a similar length of river upstream of Redcliff confluence. This indicates the critical role played by tributary inputs of flow and sediment, and the increase in width of the active channel zone. Summary erosion rate decreased by around 50 % after 1969 in both subreaches, whereas deposition rate increased by over 5 times upstream of Redcliff and over 3 times downstream of Redcliff. Changes in the erosion/sedimentation balance can be attributed more to relative increase in deposition rate rather than decrease in the rate of erosion.

Summary channel planform adjustments in the periods pre- and post regulation

Planform characteristic	1954/1957	1969	1992
Channel multiplicity			
Upstream of Redcliff	4	4	3
Downstream of Redcliff	4	5	4
Width of active channel zone (in m)			
Upstream of Redcliff	254	255	174
Downstream of Redcliff	367	376	360
Overall	*308*	*312*	*262*
Braided index			
Upstream of Redcliff	8.88	11.39	3.69
Downstream of Redcliff	14.76	16.83	14.81
Overall	*11.63*	*13.93*	*8.89*
Sinuosity			
Upstream of Redcliff	1.07	1.07	1.09
Downstream of Redcliff	1.33	1.34	1.41
Overall	*1.18*	*1.19*	*1.23*

7.3) Impacts of flow regulation on channel adjustments in Wairaki reach

Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	1947	1969	1992
Channel multiplicity			
Adjacent to left bank bar complex	3	1	2
King-Allen bend and confluence bend	6	?	3
Downstream of Wairaki confluence	6	5	2
Downstream of bedrock constriction	4	3	3
Width of active channel zone (in m)			
Adjacent to left bank bar complex	273	192	133
King-Allen bend and confluence bend	404	462	417
Downstream of Wairaki confluence	600	515	331
Downstream of bedrock constriction	281	288	196
Overall	*398*	*366*	*265*
Braided index			
Adjacent to left bank bar complex	10.4	n/a	1.5
King-Allen bend and confluence bend	21.4	n/a	10.5
Downstream of Wairaki confluence	20.1	8.0	6.9
Downstream of bedrock constriction	11.7	6.8	4.3
Overall	*14.0*	*n/a*	*4.9*
Sinuosity	1.12	1.12	1.14

Between 1947-1969 channel multiplicity decreased in each subreach of Wairaki reach. As the main channel became more prominent, numerous smaller bars amalgamated and the braided index decreased markedly. Overall sinuosity of remained constant. Change in width of the active channel zone was markedly variable within-reach, but overall decreased by about 8 %. As a compound point bar formed at the reach head, flow became concentrated and over 150 m of erosion occurred in King-Allen bend. Downstream of Wairaki confluence, many bars amalgamated between 1947-1969, but the width of the active channel zone remained roughly constant. The only exception to this was adjacent to Dean Burn confluence, where several bars stabilised and the width of the active channel zone decreased from over 900 m to < 300 m. The braided index decreased from over 20 to < 8.

Adjustments to channel planform were much more significant between 1969-1992 the between 1947-1969, but the general 'direction' of change was consistent. Channel multiplicity diminished greatly from 5 or more in 1969 to 3 or less in 1992, as numerous bars amalgamated. As the definition of the primary channel increased and secondary channels were abandoned, the braided index decreased significantly in all subreaches. Alluvial flats became more extensive, but the width of the active channel zone decreased from over 360 m in 1969 to 265 m in 1992, a reduction of > 25 %. In King-Allen bend, however, the active channel zone was wider in 1992 than it was in 1947, reflecting > 200 m of bend expansion. Channel sinuosity increased from 1.12 to 1.14 between 1969-1992.

Pronounced spatial variability was evident in the erosion and deposition regimes in subreaches upstream and downstream of Wairaki confluence before and after 1969. While a pronounced shift towards depositional dominance post-regulation was evidenced upstream of Wairaki, the reverse trend was observed downstream of Wairaki. The pattern of channel shifting at Wairaki confluence has played a significant role in determining this pattern of channel adjustments. Between 1947-1969 Wairaki River shifted to the south. This resulted in erosion of the left bank of Waiau River, while bars amalgamated along the right bank. Channel changes were especially prominent adjacent to Dean Burn confluence, which moved 600 m to the east as the bars immediately upstream of the confluence stabilised and became bank attached. As Wairaki River reverted to its northern position after 1969, Waiau River shifted over 200 m to the west and much of the amalgamated bar complex opposite Wairaki confluence was removed. A large linear bar complex was deposited adjacent to the left bank, as Waiau River cut a straighter course.

7.4 Impacts of flow regulation on channel adjustments in Lill Burn reach

Planform adjustments in Lill Burn reach between 1947-1992 were similar to those demonstrated in Wairaki reach. While rates of channel change were much greater after 1969, the direction of adjustments was set in train before 1969. This was reflected by the decrease in width of the active channel and reduction in the braided index between 1947-1969, and the associated increase in sinuosity. Between 1969-1992 bar complexes became bank-attached and Waiau River adopted a more sinuous course around compound point bars and bank-attached bars. Increase in sinuosity was much greater than evidenced in Wairaki reach. Between 1969-1992 the width of the active channel zone decreased from > 375 m to < 310 m, a reduction of almost 20 %. In the same interval the braided index decreased from almost 12 to < 8. These adjustments were especially prominent downstream of Lill Burn confluence.

Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	1947	1969	1992
Channel multiplicity			
Upstream of Lill Burn confluence	3	4	2
Downstream of Lill Burn confluence	5	5	5
Width of active channel zone (in m)			
Upstream of Lill Burn confluence	281	270	216
Downstream of Lill Burn confluence	525	460	383
Overall	*417*	*376*	*309*
Braided index			
Upstream of Lill Burn confluence	7.45	7.05	5.39
Downstream of Lill Burn confluence	19.21	16.48	9.92
Overall	*13.61*	*11.99*	*7.76*
Sinuosity	1.13	1.17	1.20

Between 1947-1969 Lill Burn shifted to the north at the confluence, with extensive deposition along the southern bank. Deflection of Lill Burn induced extensive erosion along the left bank of Waiau River, which increased in sinuosity and shifted almost 200 m to the east. A compound point bar developed along the right bank downstream of Lill Burn confluence and a series of bars along the right bank upstream of the bedrock constriction amalgamated.

Between 1969-1992 Lill Burn shifted 230 m to the south. While erosion continued along the left bank of Waiau River, rate and extent of bank retreat were much lower than between 1947-1969. The focal point of erosion was 1 km further downstream along the left bank. Erosion started immediately upstream of the bedrock constriction between 1947-1969. However, land loss was much more extensive at this site between 1969-1992. This reflected modification in the pattern of within-channel sedimentation and channel alignment downstream of Lill Burn. While the compound point bar downstream of Lill Burn confluence was trimmed, a large bar complex became attached to the right bank downstream. While channel realignment and within-channel sedimentation were dominant between 1947-1969, bar amalgamation and bank-attachment were prominent between 1969-1992.

7.5 Impacts of flow regulation on channel adjustments in Downstream o'Clifden reach

Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	1947	1969	1992
Channel multiplicity	5	6	4
Width of active channel zone (in m)	428	386	333
Braided index	9.38	9.04	6.19
Sinuosity	1.25	1.39	1.49

Channel changes in Downstream o'Clifden reach essentially describe expansion of the most freely migrating bend along the course of Waiau River. Bend expansion between 1947-1969 resulted in an increase in sinuosity from 1.25 to 1.39 Up to 210 m of bank retreat occurred along the concave bank, significantly increasing the width of the active channel zone. Numerous bars on the inside of the bend amalgamated, reducing the braided index, and the

compound point bar downstream of the eroding bend expanded laterally by almost 300 m. Channel adjustments between 1969-1992 followed the direction of change between 1947-1969. While sinuosity continued to increase between 1969-1992, rate of change was lower than that recorded between 1947-1969 (an increase of 7.2 % compared to 11.2 %). Summary rates of both erosion and deposition along the right bank were lower after 1969 than before 1969. The primary bend continued to tighten and translate downstream as erosion was focussed at the bend apex. Indeed, by 1992 flow was actually oriented diagonally up-valley at the downstream end of the bend. Number of active channels decreased between 1969-1992, as extent of braiding reduced and width of the active channel zone decreased from > 380m to 333 m.

7.6 Impacts of flow regulation on channel adjustments in Tuatapere reach

Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	**1947**	**1969**	**1992**
Channel multiplicity			
Tuatapere to mid-reach break	6	5	4
Mid-reach break to river mouth	8	6	4
Width of active channel zone (in m)			
Tuatapere to mid-reach break	521	521	403
Mid-reach break to river mouth	872	768	473
Overall	*678*	*632*	*434*
Braided index			
Tuatapere to mid-reach break	17.9	16.9	10.6
Mid-reach break to river mouth	32.6	24.3	10.0
Overall	*24.4*	*20.2*	*10.3*
Sinuosity			
Tuatapere to mid-reach break	1.09	1.12	1.07
Mid-reach break to river mouth	1.09	1.17	1.27
Overall	*1.09*	*1.14*	*1.15*

Tuatapere reach is divided into two sections, *Tuatapere to mid-reach* and *Mid-reach to river mouth*, defined by the mid-reach transition point beyond which sinuosity increases markedly. While the reduction in channel multiplicity, width of the active channel zone, and braided index in *Tuatapere to mid reach* following flow regulation are consistent with upstream reaches, the reduction in sinuosity is not! Mean width of the active channel zone was roughly constant between 1946-1969, but decreased from 520 m to 400 m between 1969-1992, while the braided index decreased from almost 17 km/km to < 11 km/km. Change in sinuosity reflected differences in the pattern of within-channel sedimentation and flow alignment between 1969-1992 compared to 1946-1969. The large mid-channel complex amalgamated in the period of record and between 1969-1992 a larger proportion of flow was redirected down the left bank channel. Bar amalgamation started between 1946-1969, and resulted in reduction of the braided index. Within-channel deposition and increase in width of the active channel zone was coincident with erosion along the right bank 1 km downstream of Tuatapere. In contrast, 500 m downstream of Tuatapere mid-channel bars became attached to the right bank between 1946-1969, reducing the width of the active channel zone. Erosion along the right bank 1 km downstream of Tuatapere was significantly reduced between 1969-1992, as the mid-channel bar complex stabilised and flow realigned down the left bank channel. In 1946 flow divided around a second large bar complex downstream of this point. By 1969 the right bank channel was a secondary feature, while substantial

erosion occurred along the left bank of Waiau River. Between 1969-1992 the right bank channel was completely abandoned and the active channel zone narrowed substantially. The primary channel became better defined and adopted a notably straighter course.

Planform adjustments in *Mid-reach to river mouth* subreach between 1946-1992 were more extreme than in any other reach along the river. While many of the changes in the 4 km reach upstream from the mouth were set in-train between 1946-1969, rates of change were much greater between 1969-1992. Channel multiplicity halved over the period of record, from 8 channels in 1946 to 6 in 1969 to 4 in 1992. Numerous bars amalgamated as the pattern of within-channel sedimentation shifted from a complex assemblage of within-channel bars in 1946 to larger, increasingly bank-attached bars in 1969. By 1992 a series of compound point bars had developed. The braided index decreased dramatically, from > 30 in 1946 to almost 25 in 1969, to just 10 in 1992, reductions of 25 % and almost 60 % respectively. As the sedimentation pattern altered, the width of the active channel zone decreased, and Waiau River adopted a more sinuous course. The active channel zone narrowed from over 870 m in 1946 to almost 770 m in 1969, but reduced significantly to < 475 m in 1992, reductions of almost 12 % and almost 40 % respectively. Sinuosity increased by over 7 % between 1946-1969 and 8.5 % between 1969-1992.

The shift towards a greater lateral component to channel adjustment clearly started prior to flow regulation, but the pattern of bends changed its alignment over the period of photographic record. 1.5 km upstream from the river mouth, flow was aligned towards the left bank in 1946, but was redirected towards the right bank in 1992 as a bend developed. Significant erosion also took place along the right bank at the river mouth, where width of the active channel zone increased from 650 m in 1946 to over 850 m in 1969 and 1992. Many of these adjustments in lower Tuatapere reach were likely associated with modifications to the gravel barrier system, as the river/coastal sediment budget responded to the altered flow regime of regulated Waiau River.

7.7) Comparison of rates of bank erosion pre- and post-regulation

The one component of this study that can be used to test the areal basis of channel adjustments that underlies some of this report's findings is the volumetric assessment of material removed from nine sites of continual bank erosion. Bank height at these with concave banks was measured in the field, such that realistic estimates of erosion could be determined by combination with measurements of areal extents of land loss from air photographs. Results of this analysis are presented in summary form before and after 1969 in the table below.

The primary findings of this study, which indicate a switch in erosion/sedimentation regime towards depositional dominance and reduction in the rate of bank erosion after 1969, are strongly supported by comparison of pre- and post-1969 estimates of material removed from the selected bank erosion sites. In six of the nine sites there was a decrease of > 30 % in the amount of material removed following flow regulation. Many of the adjustments previously reported have been associated with a change in mean flow. The history of bank erosion, however, is more likely associated with the history of extreme events. The reduced peakedness of major floods on Waiau River, as water is redirected to Deep Cove, has seemingly reduced the rate of material removal from bank erosion sites since 1969.

Summary comparison of volumetric removal of material at selected eroding bank, before and after 1969

	Volume of material removed (in $m^3 \times 10^5$)		
	Pre 1969	Post 1969	% Change
King-Allen bend, Wairaki	9.7	3.6	- 62.89 %
Left bank, Downstream of Wairaki confluence	11.62	11.68	+ 0.52 %
Left bank, Upstream of Lill Burn confluence	2.78	1.55	- 44.24 %
Left bank, Downstream of Lill Burn confluence	0.79	4.59	+ 481.01 %
Right concave bank, Downstream o'Clifden	1.49	1.02	- 31.54 %
Right bank, Carr's property, Tuatapere reach	3.9	0.97	- 75.13 %
Left bank, Carr's to mid-break, Tuatapere reach	4.6	2.64	- 42.61 %
Right bank, D/s of bend break, Tuatapere reach	0.21	1.52	+ 623.81 %
Right bank, river mouth	5.1	1.11	- 78.24 %

Notable reductions in volumetric removal of material were not evident at three sites. Approximately the same volume of material was removed from along the left bank downstream of Wairaki confluence between 1947-1969 and 1969-1992. The only sites at which volume of removed material was greater after 1969 were the left bank downstream of Lill Burn confluence and the right bank at the end of Downstream of Bend break subreach in Tuatapere reach. Erosion of banks downstream of major confluences is not a coincidental product of flow regulation. At both Wairaki and Lill Burn confluences the course of Waiau River was redirected as the flow and sediment regime were altered, such that localised erosion ensued. The greater rate of erosion of a concave bank near the river mouth reflected the increase in sinuosity as a sequence of bends migrated downstream.

Increases in the rate of erosion and deposition since 1969 largely reflect the greater detail that can be discerned from analysis of nine sets of photographs analysed since 1969 compared to just two sets of air photographs analysed prior to 1969. Assessment of rates of erosion at various concave banks has shown, however, that rates of erosion before 1969 were generally greater than after 1969, confirming many of the trends described for areal assessments of channel adjustments.

7.8) Summary impacts of flow regulation on the erosion/sedimentation regime along Waiau River

There was pronounced spatial and temporal variability in the pattern of channel adjustments along Waiau River between 1946-1992. Channel adjustments were negligible along most of the river course, as large sections of Waiau River are constrained by either bedrock or outwash terraces. Channel changes were restricted to those reaches in which the river has the space to shift laterally. Such reaches are relatively few in number, and major channel changes only occurred in Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere reaches. The first three of these reaches are coincident with tributary confluences, while the latter two reaches are in lowland settings.

Summary rates of erosion and deposition before and after flow regulation and channel planform adjustments following flow regulation are summarised in the tables below. In general, rates of erosion and deposition were crudely balanced prior to flow regulation. Immediately following flow regulation, however, Waiau River endeavoured to attain a new equilibrium condition. Deposition became dominant and the channel contracted. The width of the active channel zone decreased, as bars became bank-attached and secondary channels were abandoned. Accordingly, there was a reduction in

braided index and reduction in channel multiplicity. Sinuosity also increased, albeit marginally, although some subreaches straightened. Many of these planform adjustments were initiated in the period before flow regulation. Reduction in mean flow and amelioration of major floods associated with flow regulation have served to greatly increase the rate of channel adjustments along laterally unconfined reaches of Waiau River.

Summary channel adjustments before and after 1969: All reaches

	Erosion		%	**Deposition**		%
	Pre 1969	*Post 1969*	Change	*Pre 1969*	*Post 1969*	Change
	Areal adjustments in m^2/day			Areal adjustments in m^2/day		
Lower Redcliff	35.57	21.80	- 38 %	16.85	62.99	+ 274 %
Wairaki	69.79	182.13	+ 161 %	86.88	226.62	+ 161 %
Lill Burn	63.57	143.61	+ 126 %	77.84	174.57	+ 124 %
D/s o'Clifden	25.07	28.94	+ 15 %	34.33	42.27	+ 23 %
Tuatapere	110.46	142.54	+ 29 %	114.63	193.02	+ 68 %
TOTAL	**302.46**	**519.02**	**+ 72 %**	**330.53**	**699.47**	**+ 112 %**

Channel planform adjustments in laterally unconfined reaches after 1969

++ Major increase; + Increase; o Roughly constant; - Decrease; -- Major decrease

Reach	**Channel multiplicity**	**Width of active channel zone**	**Braided index**	**Sinuosity**
Lower Redcliff	o	-	-	+
Wairaki	-	- -	- -	+
Lill Burn	o	- -	- -	+
Downstream o'Clifden	-	- -	- -	+
Tuatapere (*1)	-	- -	- -	-/+

*1 Sinuosity in Tuatapere reach decreased in the upper half of the reach but increased upstream of the river mouth

Channel adjustments in the latter half of the 1970's were not as dramatic as changes evident between 1969-1974. A depositional regime prevailed, however, until major flood events between 1982-1984 induced substantial erosion along most of the river, although bank erosion was not as prevalent as expected. The channel zone was effectively flushed during these floods, but channel recovery between February-June 1984 was rapid. Impacts of the sustained high discharge condition in late 1988 differed significantly from reach to reach and even within-reach, as the erosion/sedimentation regime adjusted to local sediment availability, bar configuration and flow alignment in each subreach. Channel adjustments between 1984-1989 were most dramatic along the lower course of the river. Significant reworking of materials occurred between 1989-1992.

Theoretical knowledge suggests that adjustments in the erosion/sedimentation regime should be most pronounced immediately downstream of impoundment structures and will migrate downstream over time. Lower Redcliff zone, as such, is the most likely reach in which adjustments in the erosion and sedimentation regime will be observed, as this is the most upstream of the laterally unconfined reaches. This expectation is seemingly fulfilled along Waiau River, as modification from an erosional to a depositional regime was more pronounced in Lower Redcliff reach than elsewhere along the river. Indeed, Lower Redcliff reach was the only reach in which erosion rate diminished after 1969 and was the reach in which deposition rate increased most dramatically. Although summary rates of activity are suspect in

absolute terms, the ratio between erosion and deposition provides a suitable guide to changes in the erosion/sedimentation regime. ***The spatial distribution of erosion and deposition has varied markedly from subreach to subreach, and the timeframe over which erosion and deposition have dominated post flow regulation has been one of distinct phases in response to flood history. However, the statistical similarity of rate of change of erosional and depositional adjustments in Wairaki, Lill Burn and Downstream o'Clifden reaches is remarkable. In all three reaches there is less than 10 % variability in the relative rates of change of erosion and deposition after 1969. This suggests that whatever balance in erosion and deposition was evident before 1969, it was maintained or reestablished after 1969. In other words, the erosion and depositional regime was either never significantly affected by flow regulation in these reaches or an equilibrium condition has subsequently been regained.***

Beyond the impoundment structure the most sensitive sites for subsequent channel adjustments are tributary confluences. This is certainly the case along Waiau River, as channel adjustments have been pronounced at, and downstream of, Wairaki and Lill Burn confluences. The greater width of the active channel zone downstream of the convergence zone, combined with inputs of flow and sediment into this zone, have permitted extensive channel modifications. As the tributary shifts position at the confluence, zones of erosion and deposition in Waiau River have realigned. Tributary inputs have also modified the geomorphic effectiveness of lower magnitude floods, as lower catchment floods induce greater channel changes than events of equivalent magnitude from upper catchment runoff contribution.

The summary relationship between erosion and deposition in Tuatapere reach differs notably from other reaches described. Summary changes in erosion/sedimentation regime in Tuatapere reach after 1969 show a 30 % increase in rate of erosion and an increase of almost 70 % in rate of deposition. Given the magnitude of channel adjustments in this reach, this indicates a clear shift in regime towards depositional dominance. Adjustments have been markedly variable in the differing subreaches, reflecting the shift in the position of bends over the period of record. While erosion increased by > 45 % along banks and in the within-channel zone between 1947-1969, the increase in rate of erosion between 1969-1992 was almost entirely accommodated by erosion in the within-channel zone. This implies, in relative terms at least, that margins of Waiau River have stabilised after flow regulation.

Several factors could account for the apparent depositional imbalance in Tuatapere reach. This is the most alluvial reach along Waiau River, and may be most sensitive to change. As the lowland reach, it is the reach of sediment accumulation, and the sedimentation pattern may have been modified in association with flow regulation. A more likely explanation, however, is the nature of interaction between the river and the gravel barrier system. The 4 km subreach of Waiau River upstream of the river mouth has experienced the most dramatic change in planform style along the entire river course between 1946-1992. Channel adjustments have been especially pronounced since 1969, as the main channel has become better defined and the river has adopted a more sinuous outline. Changes to the rate of sediment movement through the lower course of Waiau River associated with flow regulation, possibly exaggerated by the modified sediment contribution from tributary catchments, may have changed the relationship between Waiau River

and its barrier system, such that the planform geometry of Tuatapere reach has responded to an altered set of boundary conditions. Such notions await further enquiry.

8) Implications and recommendations

(i) Areas of change in the past are the most likely areas of subsequent adjustment. Future channel changes are most likely to occur at tributary confluences or in the lowland reaches, especially the section upstream of the river mouth.

(ii) Bank erosion seemingly reflects sustained moderate to high flow levels, whereas flushing of the within-channel zone only occurs during major floods > 1500 m3s-1. Localised erosion downstream of tributary catchments was pronounced for lower catchment runoff events > 800 m3s-1. Discharge conditions between 500-800 m3s-1 were primarily depositional, although localised erosion continued in alluvial reaches. Lower discharge stages are almost entirely depositional or ineffective in mobilising gravels. Adjustments in channel condition associated with flow regulation have been relatively trivial, as regulation has primarily modified mean flow levels rather than the major flood peaks. Indeed, changes to the flood peaks themselves would have reduced flood impacts on channel character. No further action seems necessary to characterise planform changes. In terms of likely future changes, it is suggested that channel outlines be traced from air photographs taken every 10 years or following flood events > 2000 m3s-1. Analysis should be restricted to the primary tributary confluences and the lowland plain.

(iii) In Wairoa reach significant trimming of banks was observed in the period following flow regulation. While this has not been a focus of much study in this report, a monitoring program to assess rates of bank erosion to differing flow releases through Lake Te Anau Control Structure would be advisable.

(iv) A monitoring program is required to assess sediment build-up at the river mouth, determining the location, rate and character of materials that are accumulating and changes to the nature of material throughput to the gravel barrier system.

(v) Integrative catchment management plans must aim to work with the natural behaviour of the river. Since channel adjustments record modifications to the erosion/sedimentation regime of a river, they provide the dynamic context to which a wide range of other aspects of the riverine environment respond, such as water quality issues, fisheries and aquatic ecosystems/habitat concerns, recreational values, etc. As such, geomorphic assessment of controls on the character, rate, permanence and spatial variability of channel changes has enormous implications for river management and should be integrated into other reports produced within Waiau River Working Party..

Outline of report

This report uses a series of air photographs taken at differing intervals to characterise channel adjustments of Waiau River between 1946-1992. Analysis is restricted to changes in channel planform and alignment; no evidence of within-channel aggradation/degradation can be assessed. Channel changes are then related to the flood regime in the period of record. From this information the nature and rate of channel changes in the period prior to and following construction of Lake Te Anau and Lake Manapouri Control Structures are evaluated.

The outline of the report is as follows. Following the introductory statement (Section 1) a brief review of background literature on channel adjustments in response to flow regulation is provided (Section 2). Pertinent aspects of the regional setting are described in Section 3. In the first instance the geomorphic character of each reach is described and a series of base maps are provided. This is followed by an assessment of summary hydrologic characteristics of Waiau River.

Methods of air photograph analysis and assessment of channel adjustments are provided in Section 4. Given the highly variable character of channel adjustments from reach to reach, detailed analysis was restricted to those reaches in which adjustments were most pronounced, namely: Wairoa (Upper Waiau), Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden, Tuatapere. At nine sites of persistent bank erosion, bank height was measured in the field so that volumetric analyses of material removal could be provided and compared over differing time intervals. In most cases, ten or more sets of air photographs were analysed for each reach, with two prior to flow regulation and eight or more following regulation.

The results section of the report is separated into two main components (Sections 5, 6 and 7). Section 5 provides summary assessment of channel adjustments for each reach of Waiau River between 1946-1992. This information is used to determine those reaches which have experienced negligible channel changes. These reaches are eliminated from subsequent more detailed analysis. In Section 6 detailed analysis of channel adjustments is performed for each reach which experienced significant channel adjustments. Areal estimates of channel adjustment are provided in terms of erosion and deposition along banks and in the within-channel zone. The summary nature of changes through time are summarised at the end of each section. Volumetric analysis of erosion along various banks is characterised for various bank locations.

A brief summary of flood events in each photographic interval is presented in Section 7. This is followed by detailed analysis of the relationship between channel adjustments and flood history in each reach. At the end of Section 7 the method of analysis is inverted, and the impacts of individual floods, or sequences of floods, is evaluated for all laterally unconfined reaches. In Section 8 impacts of flow regulation are isolated from the flood history. role of flow regulation. Finally, channel adjustments along Waiau River is summarised in section 9, and implications are considered.

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9.0 Summary and implications

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1.0 Introduction

This report documents the nature and rate of channel adjustments along the course of Waiau River between 1946-1992. This record has been compiled from a series of aerial photographs flown over western Southland and Fiordland by NZ Aerial Mapping, supplemented by photo runs taken along the course of the Waiau River by Southland Regional Council and Waiau River Working Party. Flow regulation associated with the Manapouri power scheme has reduced mean flow of Waiau River from over 500 m^3s^{-1} to around 100 m^3s^{-1} (Riddell et al., 1993). Since the air photo record predates flow regulation in 1970, and discharge data have been collected since 1964, impacts of flow regulation on channel adjustments can be assessed in relation to river responses to flood events.

Waiau River is characterised by an alternating sequence of bedrock/terrace constrained reaches and less constrained reaches (Brierley, 1992; 1993). Adjustments in channel configuration have been restricted to those reaches where the river has space to adjust laterally or reaches where there are significant inputs of sediment from tributary catchments. These reaches are generally coincident. In laterally confined reaches analysis of channel adjustments was restricted to comparison of the earliest available photographs (usually 1946-1948 or 1954-1957) with the 1992 air photograph run. Indeed, this analysis was completed for the entire length of Waiau River between Lake Te Anau and Te Waewae Bay. Figures documenting channel adjustments are compiled on a reach by reach basis. Up to thirteen sets of air photographs were then analysed for those reaches in which significant channel adjustments took place, namely: Wairoa, Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere reaches. Three air photograph runs pre-dated flow regulation, but the intervals of time considered pre- and post-regulation are roughly equal (ie. air photograph coverage is greater in the 20 year interval post-regulation).

Air photograph analyses were completed by Keith Fitchett, Senior Technical Officer in the Department of Biogeography and Geomorphology at the Australian National University. Co-ordination of the project, interpretations of channel adjustments, and assessment of the impacts of flow regulation were completed by Dr Gary Brierley, Lecturer in the School of Earth Sciences at Macquarie University.

Analysis was restricted to photogrammetric assessment of channel configuration and planform, ie. the outline of the river in plan view, and no assessment was made of the aggradational/degradational regime and its spatial variability. Almost 3,000 measurements of channel adjustment were completed. Comparison of areal adjustments of erosion and deposition was first used to determine the character of channel changes over time, especially in terms of channel multiplicity and sinuosity. Nine sites of continuous erosion were selected to assess erosion rate over time. Bank heights were determined at these sites so that volumetric estimates of removed material could be derived. Assessment of areal adjustments in each subreach, along with the bank erosion data, allowed assessment of the impacts of flood regimes on the character and rate of channel adjustments between differing photographic intervals. This provided the context for assessment of the role of flow regulation on the morphologic character of Waiau River.

2.0 Background information

> *"The study of river channel changes, in the broadest sense of the term, is no less than the study of equilibrium channel behaviour and the nature of excursions from those equilibrium conditions"*
> (Hickin, 1983, p61).

> Channel change below dams (and other flow regulation structures) *"requires the readjustment of the channel morphology from one quasi-equilibrium state to another, in response to a change in process regime which can be imposed by the impoundment"*
> (Petts, 1984, p118).

2.1 River style, channel changes and management implications

Geomorphic assessment of controls on the character, rate, permanence and spatial variability of channel changes has enormous implications for river management. Channel adjustments record modifications to the erosion/sedimentation regime of a river. As such, they provide the dynamic context within which a wide range of other factors respond, such as water quality issues, fisheries and aquatic ecosystems/habitat concerns, recreational values, etc. Increased recognition of the need to understand long-term river behaviour and its management implications, along with the changing sense of landscape aesthetic, have ensured that imposed design-structure 'solutions' to river management problems (what used to be called river *improvement*) are less socially acceptable than they used to be. Alternative strategies that work with the natural behaviour of the river are increasingly attractive and practical outcomes of integrative catchment management plans.

2.2 Channel changes: An overview

Much research has focussed on river responses to floods of differing magnitudes, testing the notion proposed by Wolman and Miller (1956) which suggested that most geomorphic work is performed by flood events which occur relatively frequently; in particular bankfull discharge (eg. summaries by Gregory, 1977; Hickin, 1983; Petts, 1989; Hooke and Redmond, 1992). However, geomorphic effectiveness of floods varies markedly in differing environmental settings, and there has recently been a switch towards re-emphasis of the role of extreme (catastrophic) events on river character (eg. Wolman and Gerson, 1978; Mayer and Nash, 1987; Baker et al., 1988; Beven and Carling, 1989). Indeed, it is contended that in some circumstances river style is a product of the history of extreme events and the river is unable to adjust its form during the intervening phases between floods. This is termed nonequilibrium river form (Stevens et al., 1975).

A geomorphic approach to channel changes endeavours to understand controls on form/process associations over timescales ranging from individual events which may last a matter of seconds, to lagged adjustments which may occur over tens, hundreds or thousands of years. Any change in environmental control (such as particle size or quantity, slope, or flow regime) may bring about adjustment in channel style. This is referred to as *channel metamorphosis* (Schumm, 1969). Adjustments to the internal geometry of rivers can be accommodated by changes to either flow geometry or channel geometry. In adjusting flow geometry a balance must be attained between continuity of discharge, flow resistance, and sediment transport. By definition, any change in river discharge is accommodated by adjustments in

width, depth or velocity at any particular channel cross-section. Other variables, such as water surface gradient, the roughness and friction factor, and bed shear stress may also be adjusted to accommodate this change.

There are at least four degrees of freedom for adjustments to channel geometry:

(i) Cross-sectional form (ie. channel shape)

(ii) Bed configuration

(iii) Channel planform

(iv) Down-valley changes, namely channel gradient and the longitudinal profile (Knighton, 1984:89).

Channel geometry is fashioned by mean discharge and sediment load over long time periods to an "equilibrium condition". Change to boundary conditions will bring about changes in channel form and the relationship between the channel(s) and their adjacent floodplain. One such imposed change is flow regulation.

Channel adjustments following flow regulation may not be immediate, and the character of channel changes will continue to be affected by the subsequent flood history. The challenge to geomorphologists is to unravel those changes induced by human activity from those brought about by the natural range of river activity. This can only be achieved using lengthy records of channel changes. For example, the impacts of flow regulation on channel adjustments can only be reliably inferred by examination of channel responses to similar flood events prior to and following regulation. This is complicated further, however, by the specific timing of a flood event, and the patterns of channel adjustments associated with a particular sequence of flood events.

2.3 Impacts of flow regulation on channel character

Although natural river systems are rarely, if ever, in a true state of equilibrium, erosion and deposition will balance over several years to maintain stability (Petts, 1984, p142). Upstream impoundment disrupts this natural process pattern and may induce changes in channel morphology. Schumm (1969) summarised likely adjustments to reduced discharge in the following expression:

$$Q^- = w^-, d^-, L^-, s^+$$

where,

Q = discharge,
w = width,
d = depth,
L = meander wavelength, and
s = slope

In other words, a reduction in discharge is generally accommodated by a reduction in width, depth and meander wavelength but an increase in channel bed slope. The channel downstream of the regulation structure contracts and incises into its bed. One of the secondary products of reduced discharge is an imposed reduction in sediment load and the

competence of the channel to carry materials of equivalent calibre. This reduction in sediment size, Q_w, also induces an adjustment in channel morphology, wherein:

$$Q_w^- \approx w^-, d^-, L^- / s^+$$

It is clear from these relationships that flow regulation generally induces constriction in channel geometry, reduction in meander wavelength, and increase in channel bed slope. In general, however, river responses to flow regulation and sediment abstraction are complex and channel adjustments vary both spatially and temporally.

The extreme form of flow regulation is that associated with dam construction. According to Williams and Wolman (1984), the primary downstream impacts of dams on rivers are:

(1) Change in the flow regime and sediment load of the river downstream. This usually entails a decrease in both
   (i) the magnitude, frequency and duration of flood flows, and
   (ii) the quantity and calibre of the sediment load (Erskine, 1985).
(2) Degradation and armouring of the bed surface in the sediment-starved reach immediately below the dam.
(3) Aggradation where tributaries supply sediment to the main regulated channel.
(4) Change in channel shape, which may contract, locally widen, or remain stable.
(5) Increase in vegetation within and along the channel.

While such impacts constitute the extreme responses to flow regulation, channel adjustments associated with a modified flow regime can be expected to occur *in the same direction* as those changes outlined above. In this brief overview, impacts of flow regulation on channel character are differentiated into two components, namely changes in the aggradational/degradational condition and adjustments to channel morphology and planform.

2.3.1 Impacts of flow regulation on the erosion/sedimentation regime

Flow regulation structures commonly act as highly efficient sediment traps such that flow downstream is sediment-starved and thus has a greater ability to incise into the previous channel bed (degradation). Over time the erosional front of the scour zone moves down-channel. Migration rate and final length of the degradation zone can be related to variations in flow, bed-material size and topography (Petts, 1984). Degradation persists until the reduction of slope and the increase in channel bed roughness reduce the velocity below the threshold for sediment transport. In general, degradation downstream of dams is fastest after closure and gradually slows with time (Williams and Wolman, 1984).

Regulated flows may be no longer competent to transport the sediments but can winnow the finer materials away. This results in the channel having a gravel lag or armoured surface (Bray and Church, 1980). This effect is generated closest to the regulation structure. Propagation of this effect downstream depends on flow regime and sediment supply. Armour is important in determining channel morphology as it can govern the depth of degradation and channel slope.

Local channel degradation and armouring are only the most immediate geomorphological impacts of flow regulation (Petts, 1979). Changes to flow regime modify the capacity of the river to move its bedload. Adjustments in one reach induce channel changes elsewhere. Sections downstream of the degradation zone will experience periods of aggradation as bedload pulses migrate downstream. Changes to channel morphology result in redistribution of bank and floodplain sediments. Sediment supply from tributaries into a regulated channel may result in rapid channel changes, as the main channel is constricted at the confluence because the regulated flow can no longer rework these deposits (Petts, 1984, p133). Variations in the quantity and calibre of sediment load between tributaries and their downstream position may play a major role in the explanation of the rate and magnitude of channel adjustment to flow regulation (Petts, 1979). Unlike degradation, however, the effects of aggradation are generally much slower, requiring the introduction and/or redistribution of sediments (Petts, 1979). Usually post-regulation deposits are finer-grained materials due to the abstraction of bedload and reduction in competence, so that a narrower, higher velocity stream is formed with a capacity equal to that of the regulated stream (Petts, 1979). Channel adjustments that provide for the downstream transmission of sediment may take anywhere up to hundreds of years (Petts, 1984, p136).

2.3.2 Impacts of flow regulation on channel morphology

If process changes brought about by flow regulation are of sufficient magnitude they can induce changes in channel form. Some broad patterns can be observed in the morphological consequences of flow regulation as erosion and/or deposition zones migrate to restore morphological equilibrium along differing sections of the channel (Petts, 1984, p118). If channel geometry is in equilibrium with a peak discharge of a particular size and recurrence interval, flow regulation will likely result in a decrease in channel capacity (Gregory and Park, 1974). Regulated releases are often incompetent to transport bed material or erode banks and significant channel contraction results (Erskine, 1985, p207). Vegetation may play a critical role in this process, as it stabilises the bed and can act as a sediment trap resulting in aggradation and the formation of a new floodplain (Williams and Wolman, 1984:39). Riparian vegetation may also modify the magnitude and frequency of effective events (Petts, 1984). However, channel width downstream of a flow regulation structure does not always decrease following impoundment, and Williams and Wolman (1984) suggest reasons why channel width may increase downstream:

(i) Decreased sediment loads may enhance erosive capacity,

(ii) There may be a decline in volume of sediment brought to, or near, the banks,

(iii) Diurnal flow fluctuations may cause consistent bank wetting promoting erosion, and

(iv) Rapid changes in flow releases may cause the river position to wander.

Channel morphologic responses to a modified discharge regime may be highly complex, with significant local variability of channel adjustments and lagged responses. Long-term variations of channel response along a regulated river can be correlated to differences of controls operating within an individual reach such as bed-material size, bank-material cohesion or valley slope. These local-scale factors interact to produce a unique adjustment to impoundment (Petts, 1984, p143). The rate at which a new equilibrium position is attained will relate to these local conditions and to

the frequency of competent flows and tributary inputs. The time-lag before channel change is initiated varies between rivers and within individual reaches. For example, larger impoundment structures may induce longer lag times than smaller ones as they have a greater impact on the frequency of competent discharges (Petts, 1980, p328). Also, the probability of channel response being initiated within a given period will increase downstream due to the increase in frequency of competent discharges.

2.4 Summary assessment of flow regulation impacts on channel character

There is a complex response of channels to upstream impoundment. Changes of channel morphology at individual locations will affect the reaches above and below it and thus a complex sequence of interactions between fluvial processes and channel morphology should be expected (Petts, 1980, p329). Degradation is the dominant process of adjustment in the reach immediately downstream of the flow regulation structure. Further downstream the differential erosion and redistribution of channel and floodplain sediments, along with the introduction of sediments from tributary sources, facilitate channel morphologic response associated with the 'new' interaction between the regulated flow and the altered sediment load (Petts, 1980). The long term readjustment of channel morphology throughout the length of the river system will result in considerable reduction in sediment yield, particularly where vegetation encroachment within and around the channel is significant (Petts, 1979). This complexity of response ensures that channel adjustments will vary on a reach by reach basis.

3.0 Regional overview

Waiau River occupies a broad valley between Fiordland Mountain Complex and Takitimu and Longwood Ranges. The catchment area of about 8,200 km^2 receives most of its water from Fiordland National Park. Fiordland is characterised by high intensity precipitation throughout the year, with significant snow fall in winter. Precipitation variability is great, with average falls of around 4,500 mm, but some areas have precipitation totals in excess of 8,000 mm. There are two significant lakes in the headwaters of the catchment, Lakes Te Anau and Manapouri. Fiordland is an area of high inaccessible mountains characterised by steep slopes and glacially excavated valleys. Relief ranges from sea level to 2,700 m. Regional geology is largely composed of metamorphics (Cambrian-Ordovician schists and gneisses), although plutonics are common. In contrast, the lower part of Waiau Valley is characterised by tilted sedimentary strata including marine sediments, limestones and mudstones. Once extensively forested, Waiau catchment has a modified vegetation cover, consisting of 35% indigenous vegetation (shrub, forest and tussock) and 65% exotic vegetation (mainly pasture). Some small areas of remnant forest, shrub and tussockland remain, with limited wetlands.

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. Mountains in Fiordland create a rainshadow effect which result in average precipitation totals in Waiau Valley of around 1,100 mm, but rainfall totals are significantly greater to the west and south. 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.

Abundant gravels are supplied to Waiau River along its entire course, as the river reworks alluvial flats and terraces. Waiau River has adopted a route to the sea with considerable lateral constraints imposed by bedrock topography. Only in the lowland plains beyond Tuatapere can the river be described as truly alluvial. Although discharge variability is not extreme in global terms (see McMahon et al., 1992), Waiau River has experienced several significant flood events in historical times which have induced dramatic morphologic response. These adjustments have been constrained, however, by terraces and bedrock, which give the river little opportunity for wholesale shifts of position.

3.1 Hydrological summary

The following hydrological information is summarised from the WRWP report by Riddell et al. (1993).

3.1.1 Catchment characterisation

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. Although the lower part of the catchment (downstream of Sunnyside)

is drier than Te Anau and Manapouri catchments, it is of significance in flood events because there is no lake storage to dampen the peaks.

3.1.2 Rainfall variability

Channel adjustments along Waiau River must be placed in context of natural discharge variability. The seasonal pattern of inflows to river systems corresponds to the seasonal rainfall distribution. Generally inflows are lowest in the winter (June to August) and highest in Spring (October and November).

Mean inflow to Lake Te Anau was 7.5 % greater in the period since 1970 than in the period prior to implementation of Manapouri power scheme. Average flows were much higher than normal between 1982-1984 and 1987-1988 due mainly to floods in January 1983 and 1984 and October/November 1988. However 1974 and 1976 had the lowest annual inflows on record.

3.1.3 Operation of Manapouri power scheme

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 on 14 September 1969 although full-scale generation did not begin until early 1973. Lake Te Anau Control Structure was commissioned in July 1974 and Lake Manapouri Control Structure (Mararoa Weir) was commissioned in November 1976. Manapouri Lake Control Structure dammed the Waiau River below the confluence of Waiau and Mararoa Rivers. Prior to commissioning of the permanent Manapouri Lake Control Structure a temporary weir was placed across the river in February 1970. In large floods Mararoa flow is likely to completely suppress outflow from Lake Manapouri and even to flow back into Manapouri in addition to flowing down lower Waiau. The diversion of turbid flood waters into Lake Manapouri was unsightly so the control gates were opened whenever Mararoa was in flood and the majority of the turbid water was discharged down Waiau River. In late 1987 Mararoa River was diverted into a 'cut' in an attempt to reduce gravel deposition in the headpond upstream of Manapouri Lake Control Structure.

3.1.4 Flow contribution from Mararoa Catchment

Mean outflow from Lake Manapouri pre control (1932-1969) was 406 m^3s^{-1} while the mean post control (1970-1991) discharge was 435 m^3s^{-1}. The difference was essentially made up by flow diverted from Mararoa River, which had a mean flow during the period of record (since 1976) of 34.5 m^3s^{-1}. Mean flow through Manapouri Lake Control Structure (Mararoa Weir) from 1969-1991 inclusive was 99 m^3s^{-1} , but median flow was actually zero, as the gates were closed at all stages other than during floods. Between 1969-1991 outflow from the control structure occurred less than 40 % of the time.

3.1.5 Flow regulation along Waiau River at Tuatapere

Catchment area of Waiau River at Tuatapere is 8134 km^2, of which 2341 km^2 is downstream of Manapouri Lake Control Structure. Water level recorders at Tuatapere commenced in late July 1964, some five years before water was first diverted out of Lake Manapouri to Deep Cove. Mean flow 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 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.

3.1.6 Peakedness of flood events

In nearly all floods at Tuatapere post-control, the flow of water from Manapouri into lower Waiau River has generally 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, it seems that without Manapouri power station discharging water to Deep Cove they would have been even larger.

3.1.6.1 1984 Flood event

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. Peak release through Manapouri Lake Control Structure (Mararoa Weir) during the 1984 flood was only 1146 m^3s^{-1} (27 January, 1984). Maximum recorded discharge at Sunnyside was 2021 m^3s^{-1}.

3.1.6.2 Sustained high flow levels in late 1988

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. 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. Maximum flow through Manapouri Lake Control Structure (Mararoa Weir) occurred on 4th November 1988 (1470 m^3s^{-1}). In contrast, peak release during the 1984 flood was only 1146 m^3s^{-1}. At Sunnyside the October/November 1988 flood event was the second largest flow (1464 m^3s^{-1}). Discharge levels above 1000 m^3s^{-1} were maintained at Tuatapere for 22 out of 23 days.

3.2 Geomorphic characterisation of each reach

The nature of channel adjustments in each reach is constrained in large part by the physical characterisation of that reach. In this section the geomorphic character of all reaches of Waiau River from Lake Te Anau to Te Waewae Bay is briefly summarised from reports completed for WRWP by Gary Brierley (1992 and 1993). Base maps are presented for each reach, indicating the position of numerous reference points used in the subsequent channel adjustments work.

3.2.1 Wairoa (Upper Waiau) reach

Wairoa reach extends between Lakes Te Anau and Manapouri (Figure 3.1). This is an area of steep hilly terrain. Most of the right bank is marginal to beech forest in Fiordland National Park. The valley broadens down-reach, from roughly 2 to 6 km. The river is deeply incised into lake and glacial outwash deposits and has an imposed laterally stable condition. Alluvial flats are non-existent other than discontinuous surfaces 1-2 m above the present channel on the insides of bends. Wairoa reach is single channelled, other than local division around dissected point bars, adjacent to the large bank-attached compound bar opposite Balloon Loop, and in gravel accumulations immediately downstream of eroding terraces. The channel bed is composed of coarse-gravels throughout the reach.

The primary human impact on Wairoa reach is the flow control structure at the outlet of Lake Te Anau. At the time of construction the channel immediately downstream of this structure was deeply scoured. Other impacts which have affected the local sediment regime include gravel extraction on the large bar at Balloon Loop, and dynamiting of the gooseneck at Balloon Loop in 1965.

WAIROA (Upper Waiau)

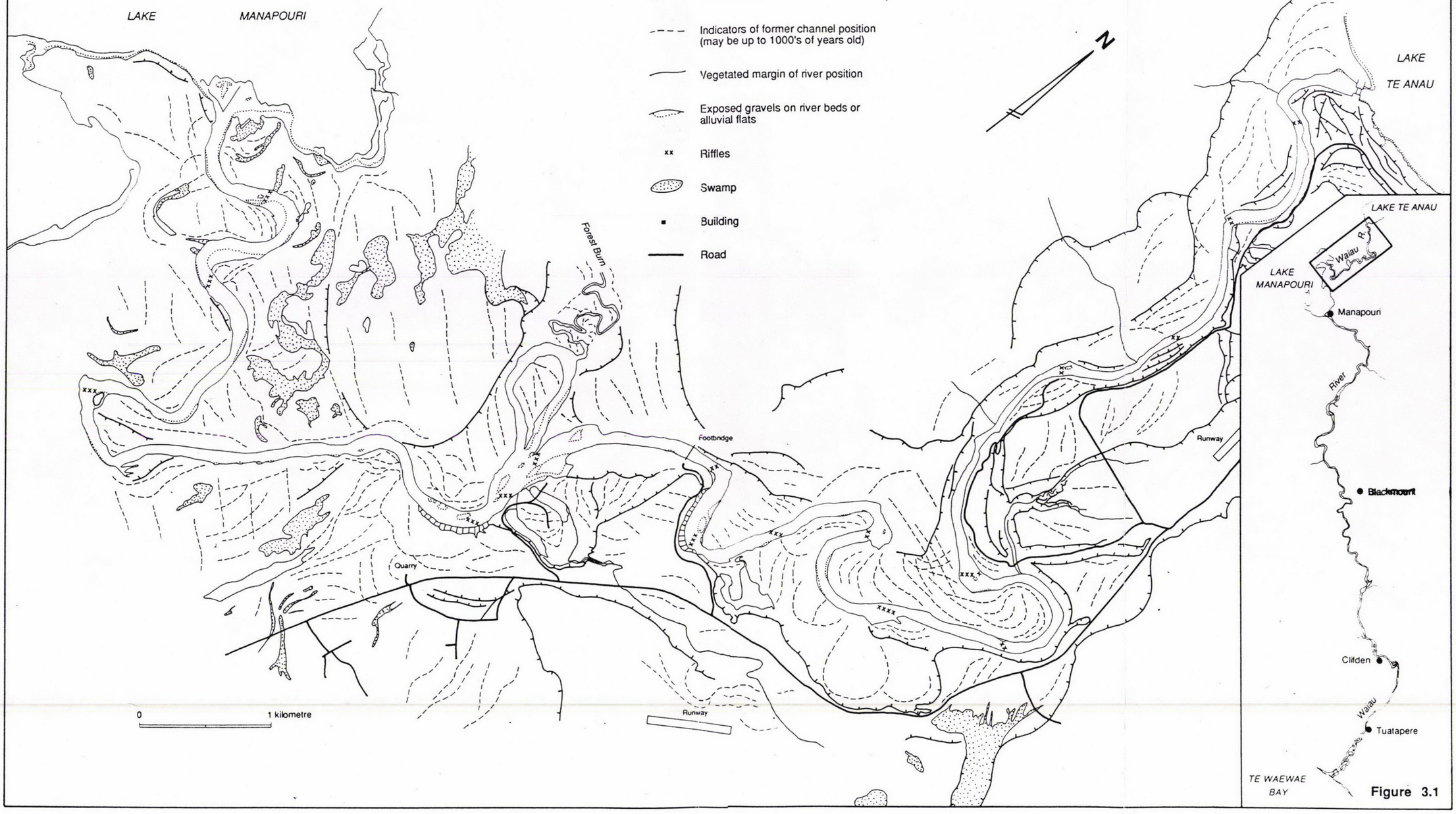


Figure 3.1

3.2.2 Pearl Harbour reach

Pearl Harbour reach is a single-channelled, low sinuosity section of upper Waiau River between Pearl Harbour and Mararoa Weir (Figure 3.2). In this reach Waiau River has cut a groove into lake deposits leaving a prominent upper terrace surface with a series of small, discontinuous lower surfaces adjacent to the channellised zone. Valley flats are primarily restricted to the northern side of the river, where they extend to > 4 km wide. Alluvial flats are virtually non-existent. At low discharge stages this reach is essentially an extension of Lake Manapouri.

Direct human impacts on channel form are evident at both ends of the reach. Angular boulders have been placed at the outlet/entrance of Lake Manapouri, whereas flow control gates and a high lake-level spillway have been built immediately downstream of Waiau/Mararoa confluence. Following flow impoundment behind Manapouri Lake Control Structure (Mararoa Weir), a delta has grown at the confluence. In order to maintain inputs of clean water to Lake Manapouri, a series of diversion channels have been constructed at Mararoa confluence.

3.2.3 Duncraigen (or Excelsior) reach

Duncraigen reach extends from Manapouri Lake Control Structure to Waiau/Whare confluence (Figure 3.3). This single-channelled, almost straight river reach has an imposed channel condition constrained by channel-marginal fluvioglacial terraces. There are virtually no alluvial or valley flats and gravel bars are restricted to small alternating lateral bars.

3.2.4 Redcliff reach

Redcliff reach extends from just upstream of Whare Creek confluence to the margins of Blackmount Forest (Figure 3.3). The valley is notably wider than in Duncraigen reach, with extensive valley and alluvial flats. Terraces are prominent on the left bank of the Waiau, while the right bank is pinned against the foothills of Paddock Hill. As the extent of alluvial flats increases downstream in Redcliff Reach, so does the extent of active gravel surfaces. The channel divides from a single channel at the head of the reach to four or five channels downstream of Redcliff Creek. The reach is broadly sinuous at its upstream end, with compound point bars. These are transitional downstream to a sequence of alternating bank-attached compound bars, with large, dissected islands in the channel. As the channel divides downstream of Redcliff confluence, large complex bars have formed.

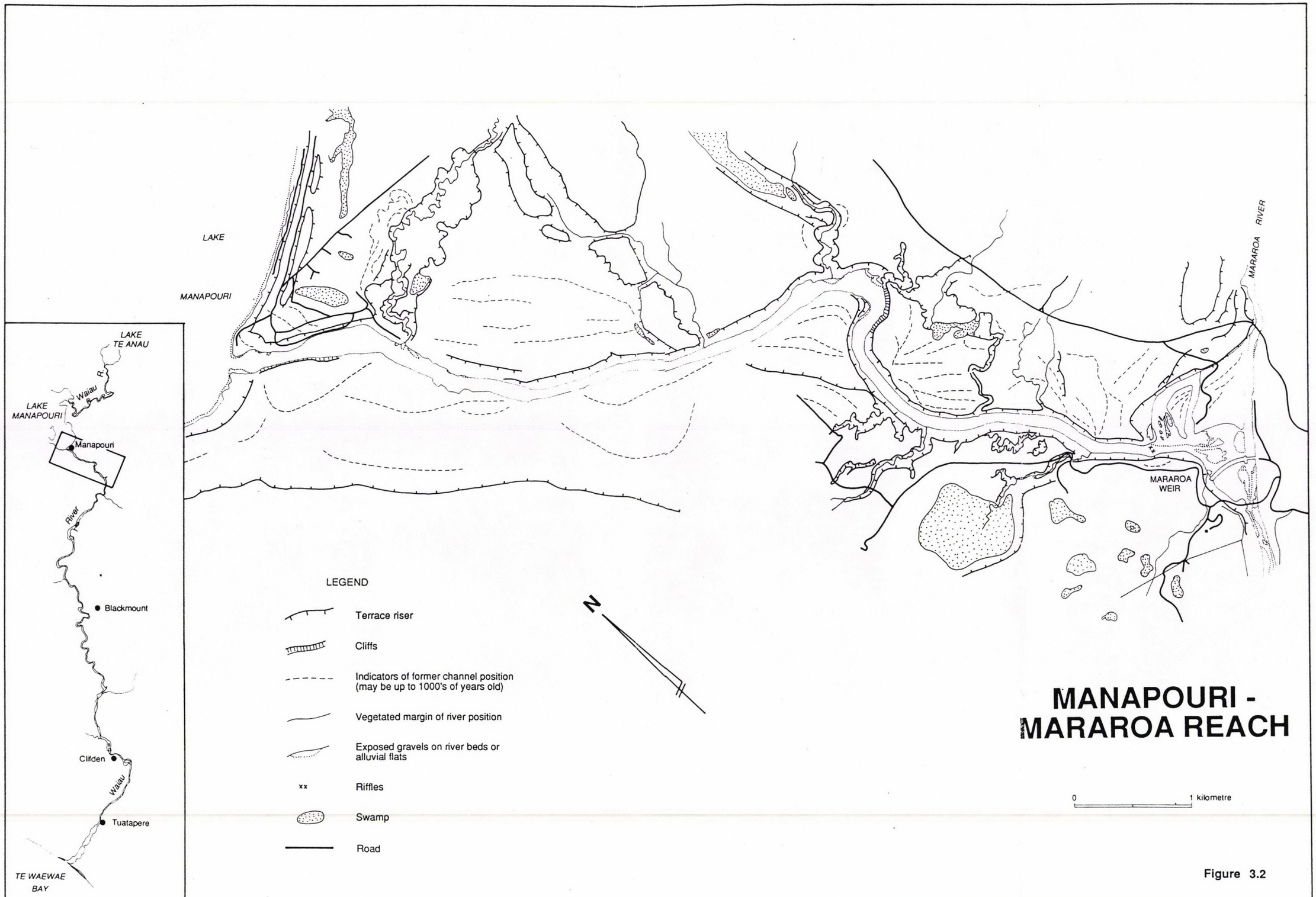

LAKE
MANAPOURI
MARAROA RIVER
LAKE
TE ANAU
Waiau R.
LAKE
MANAPOURI
Manapouri
River
Blackmount
Clifden
Waiau
Tuatapere
TE WAEWAE
BAY
MARAROA
WEIR
LEGEND
Terrace riser
Cliffs
Indicators of former channel position
(may be up to 1000's of years old)
Vegetated margin of river position
Exposed gravels on river beds or
alluvial flats
Riffles
Swamp
Road
N
MANAPOURI -
MARAROA REACH
0
1 kilometre

Figure 3.2

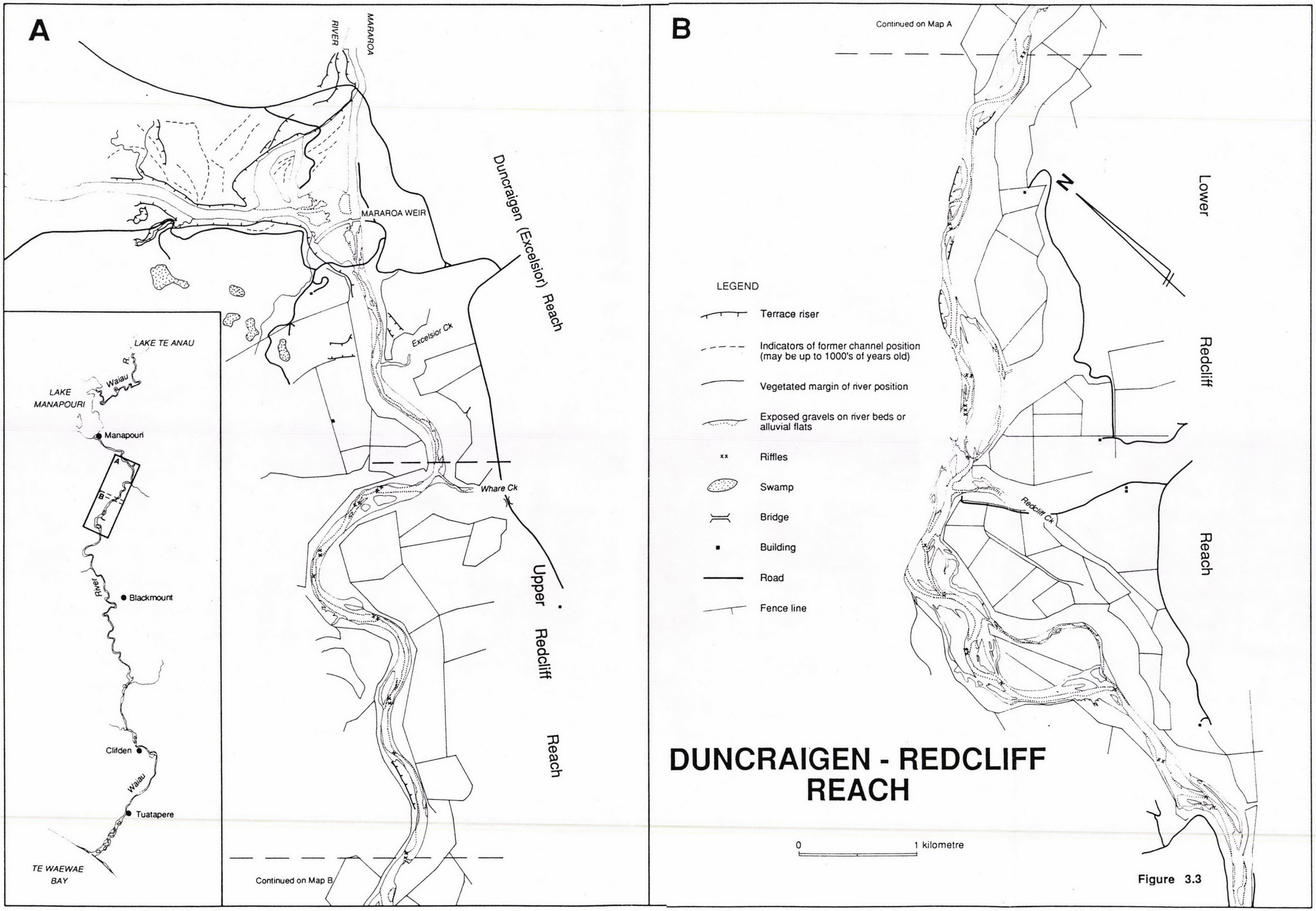

A
MARAROA RIVER
MARAROA WEIR
Duncraigen (Excelsior) Reach
Excelsior Ck
Whare Ck
Upper Redcliff Reach
Continued on Map B
LAKE TE ANAU
Waiau R.
LAKE MANAPOURI
Manapouri
A
B
Waiau River
Blackmount
Clifden
Waiau
Tuatapere
TE WAEWAE BAY
B
Continued on Map A
LEGEND
Terrace riser
Indicators of former channel position (may be up to 1000's of years old)
Vegetated margin of river position
Exposed gravels on river beds or alluvial flats
Riffles
Swamp
Bridge
Building
Road
Fence line
N
Lower Redcliff Reach
Redcliff Ck
DUNCRAIGEN - REDCLIFF REACH
0
1 kilometre

Figure 3.3

3.2.5 Blackmount-Mangapiri reach

Blackmount-Mangapiri reach is characterised by a laterally constrained single channel with a broadly sinuous course (Figure 3.4). Alluvial flats are limited and within-channel sedimentation is restricted to compound point bars in Blackmount and Waicoe subreaches and a series of alternating bars at the downstream end of the reach. On the left bank downstream of Waicoe Creek, and on the inside of the tight bend opposite Makarewa stream, there are areas of flat land which taper around the bends 2 m or so above present mean flow level. These surfaces may reflect within-reach degradation.

3.2.6 Wairaki reach

Downstream of Blackmount-Mangapiri reach Waiau Valley widens significantly, with a series of extensive terrace sequences adjacent to Wairaki and Dean Burn confluences. Wairaki reach extends from a point bar 2 km upstream of Wairaki confluence to a bank-attached compound bar downstream of Broadlands Bush (Figure 3.5). As flow emerges from Mangapiri subreach it is concentrated in a single channel which switches from side to side, eroding the outside (concave) bank and depositing large point bars on the inside of the bends. Although generally more than several hundred metres wide, alluvial flats are fragmentary and switch from valley side to valley side. Discrete sediment inputs from Wairaki River and Dean Burn have resulted in within-channel sedimentation and flow division around a series of bars and riffles. Bank-attached compound bars have been dissected by chute channels. Pronounced lateral instability is evident. At the downstream limit of the reach, at the head of Otahu Flat, Waiau River is pinned into a single channel against bedrock at the western valley margin (Motu Bush). Immediately downstream of this point there are two alternating bank-attached compound bars.

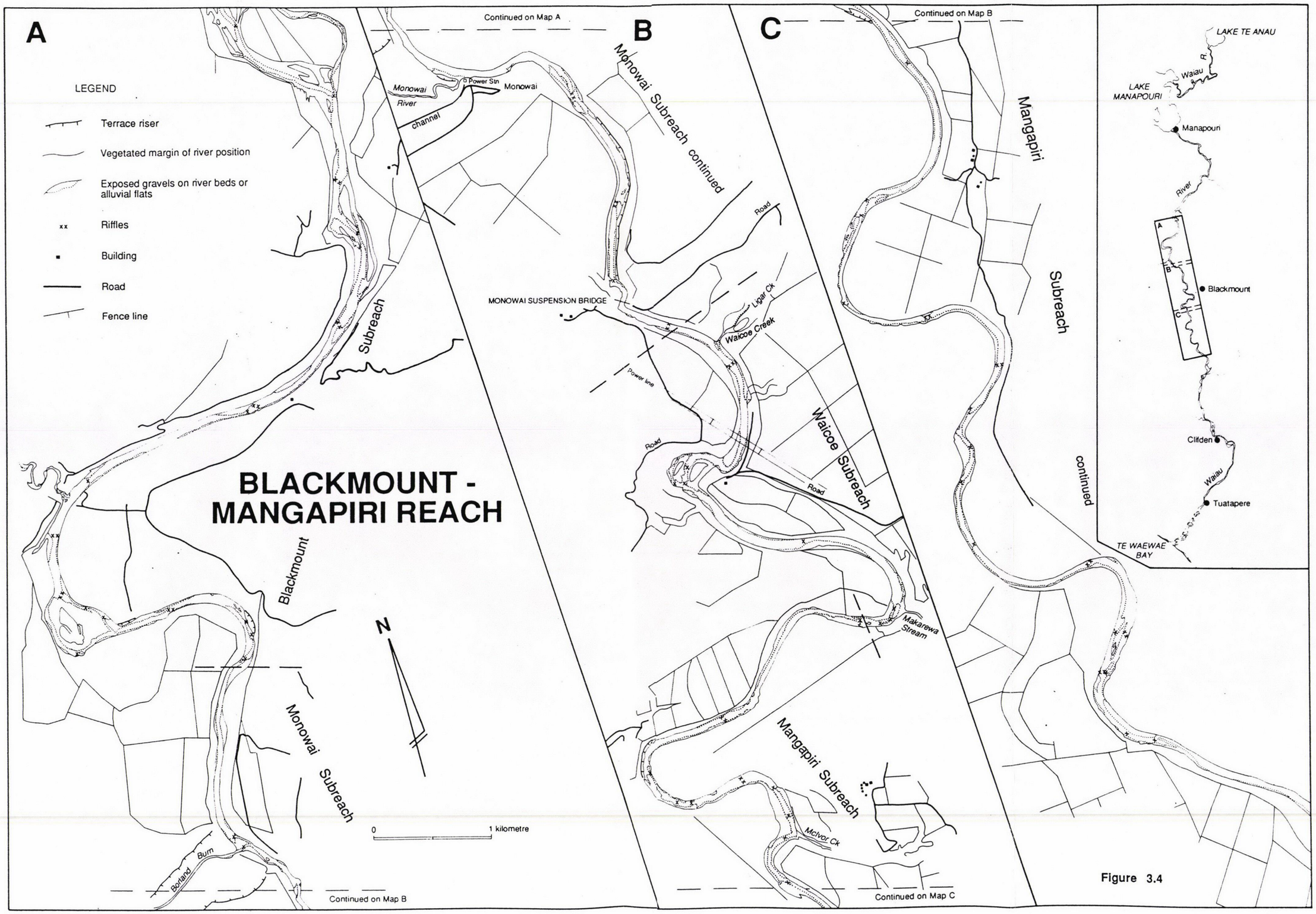

A
B
C
LEGEND
Terrace riser
Vegetated margin of river position
Exposed gravels on river beds or alluvial flats
Riffles
Building
Road
Fence line
BLACKMOUNT - MANGAPIRI REACH
Continued on Map A
Continued on Map B
Continued on Map C
Monowai Subreach
Monowai Subreach continued
Mangapiri Subreach
Waicoe Subreach
Mangapiri Subreach continued
Monowai River
Monowai Power Stn
Monowai channel
MONOWAI SUSPENSION BRIDGE
Waicoe Creek
Ligar Ck
Power line
Road
Blackmount
Borland Burn
Makarewa Stream
McIvor Ck
N
0
1 kilometre
LAKE TE ANAU
Waiau R
LAKE MANAPOURI
Manapouri
River
Blackmount
Clifden
Waiau
Tuatapere
TE WAEWAE BAY

Figure 3.4

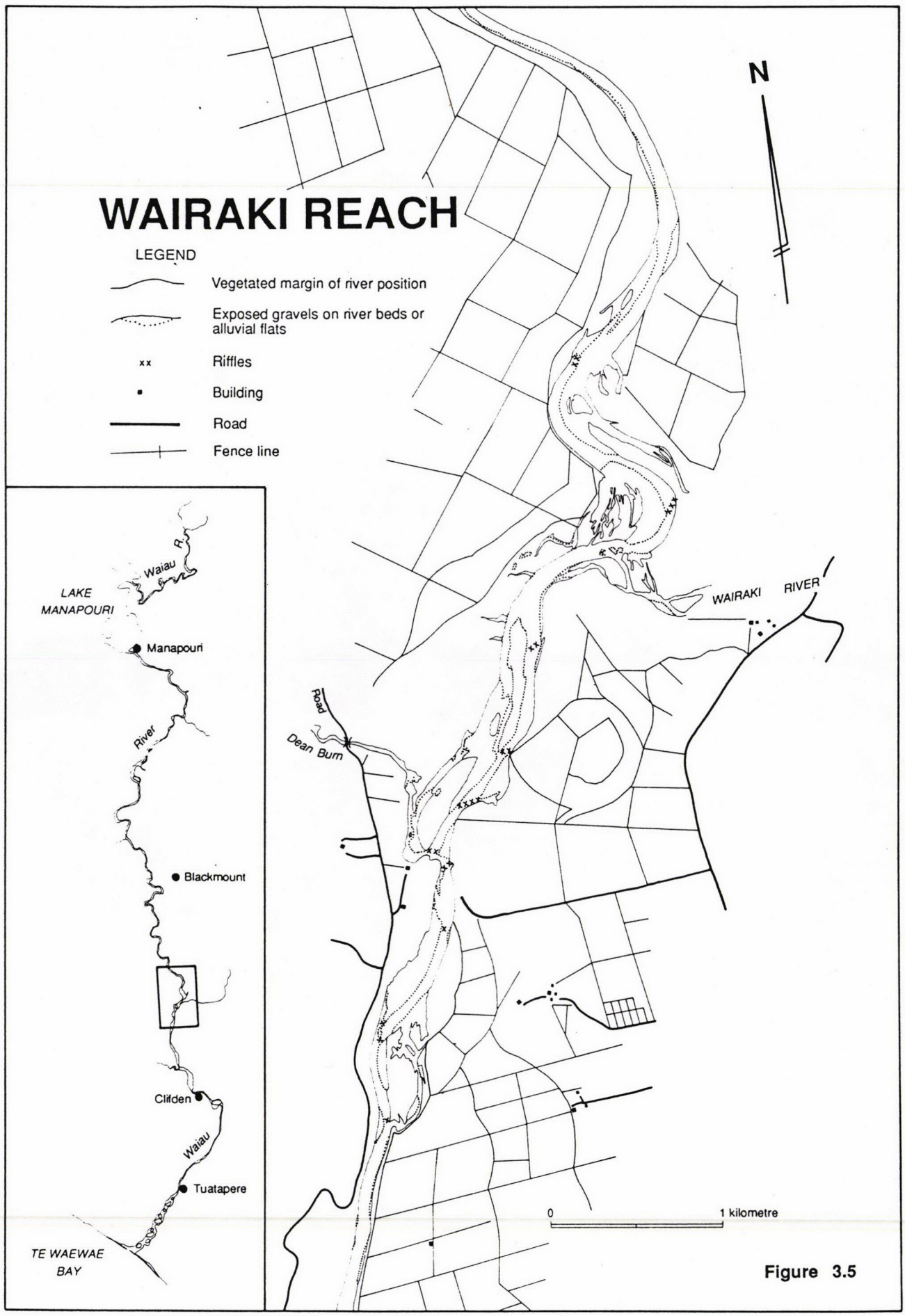

WAIRAKI REACH
LEGEND
Vegetated margin of river position
Exposed gravels on river beds or alluvial flats
Riffles
Building
Road
Fence line
N
WAIRAKI RIVER
Road
Dean Burn
0
1 kilometre
Waiau R.
LAKE MANAPOURI
Manapouri
River
Blackmount
Clifden
Waiau
Tuatapere
TE WAEWAE BAY

Figure 3.5

3.2.7 Motu reach

Motu reach is a short, single-channelled, almost straight reach which is pinned between extensive terraces of Otahu Flat on its eastern edge and Motu Bush on its western margin (Figure 3.6). While valley flats are up to 4.5 km wide, there are no evident alluvial flats and no within-channel sedimentation.

3.2.8 Lill Burn reach

Lill Burn reach is constrained by bedrock at its upstream and downstream limits, adjacent to Motu Bush and Clifden respectively (Figure 3.6). Alluvial flats and the lower terrace surface (4-5 m above mean flow level) are continuous and wide (> 1 km). Above this are unpaired flights of terraces which are particularly extensive on the left bank. Associated with the increased extent of alluvial flats is the greater capacity for the channel to adjust and modify its planform. This is a similar condition to Wairaki reach, with distinct downstream variability in the character of within-channel sedimentation. At the head of the reach flow is deflected around alternating lateral or bank-attached compound bars. Moving down-reach, side and chute channels are more prominent, and within-channel sedimentation is pronounced adjacent to Lill Burn confluence. The channel is laterally unstable in this subreach. Downstream of Lill Burn confluence flow divides around a series of large within-channel bars. At the downstream end of the reach there is a fairly tight bedrock-constrained bend, with a prominent compound point bar.

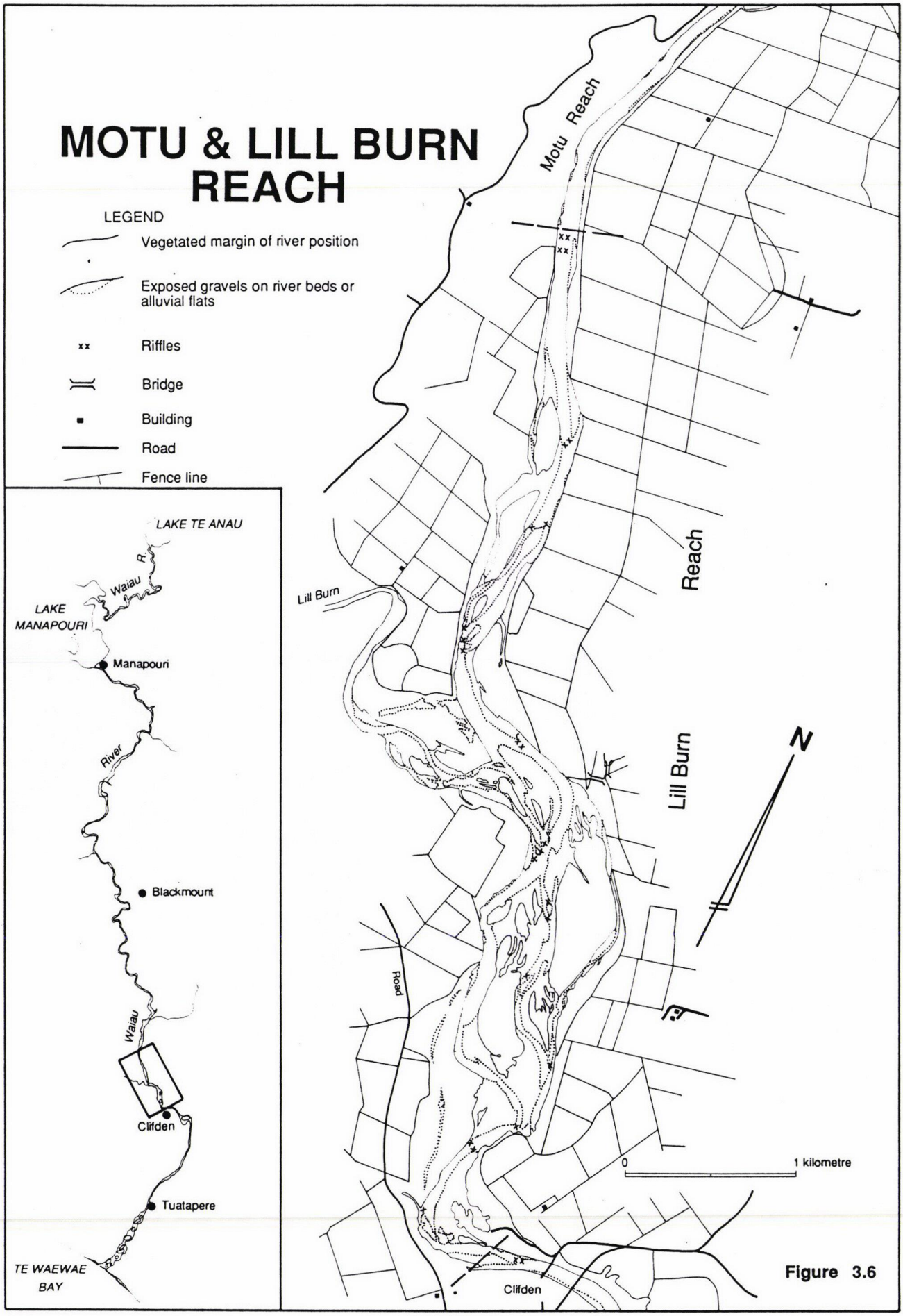

MOTU & LILL BURN REACH
LEGEND
Vegetated margin of river position
Exposed gravels on river beds or alluvial flats
Riffles
Bridge
Building
Road
Fence line
LAKE TE ANAU
Waiau R.
LAKE MANAPOURI
Manapouri
River
Blackmount
Waiau
Clifden
Tuatapere
TE WAEWAE BAY
Motu Reach
Lill Burn
Reach
Lill Burn
N
Road
0
1 kilometre
Clifden

Figure 3.6

3.2.9 Clifden Suspension Bridge reach

Clifden Suspension Bridge reach is a short, single channelled reach with no alluvial flats and no within-channel sedimentation. Prominent limestone cliffs are observed on both banks (Figure 3.7), with outwash terraces adjacent to the bedrock.

3.2.10 Downstream o'Clifden reach

Downstream o'Clifden reach extends for approximately 5 km from the limestone cliffs at Clifden (Figure 3.7). This is a lowland setting, with gentler valley-marginal slopes and fewer high terraces than upstream. Lateral and bank-attached compound bars at the head of the reach are transitional downstream to longitudinal and mid-channel compound bars, with dissected point bars on the inside of tight bends. This pattern of bars is associated with the tightest freely-migrating bend in the study area. The downstream section of the reach is characterised by within-channel sedimentation on bedrock-cored bars. Beyond this point flow becomes concentrated into a single channel, with bedrock at the base of both banks.

3.2.11 Hagen Road reach

Hagen Road extends for 4.5 km along the base of a ridge with Hagen Road atop (Figure 3.7). Valley flats are extensive (about 4 km wide) with pronounced terraces on the right bank. However the left bank is Papa bedrock and alluvial flats are laterally limited (< 300 m). Flow is confined into a roughly straight, single channel.

3.2.12 Orauea reach

In Orauea reach, which extends from about 1.5 km upstream of Orauea confluence to the bridge in Tuatapere, Waiau River has a moderately straight configuration and is predominantly single-channelled (Figure 3.7). Upper terraces are approximately 5 km wide. Tuatapere is located atop the third terrace level. Within-channel sedimentation is primarily associated with sediment input from Orauea confluence, which is coincident with a mid-channel bedrock step. The channel is confined by bedrock with terraces atop throughout the reach, although alluvial flats are more extensive in the short reach upstream of Orauea confluence. The channel is relatively stable and bar types are restricted to alternating bars.

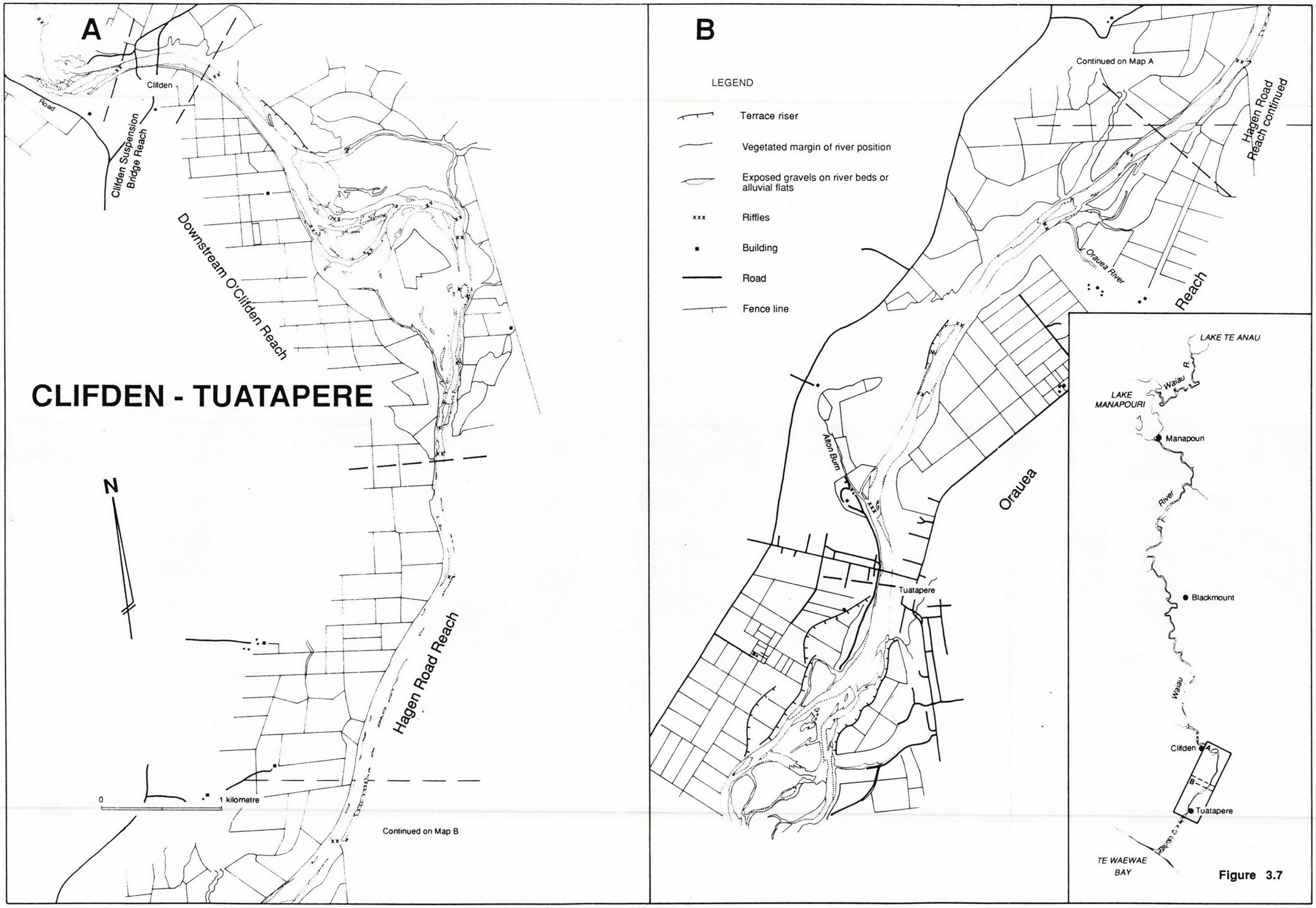

A
Clifden
Road
Clifden Suspension Bridge Reach
Downstream O'Clifden Reach
CLIFDEN - TUATAPERE
N
Hagen Road Reach
0
1 kilometre
Continued on Map B
B
LEGEND
Terrace riser
Vegetated margin of river position
Exposed gravels on river beds or alluvial flats
Riffles
Building
Road
Fence line
Continued on Map A
Hagen Road Reach continued
Orauea River
Reach
Alton Burn
Orauea
Tuatapere
LAKE TE ANAU
Waiau R.
LAKE MANAPOURI
Manapouri
River
Blackmount
Waiau
Clifden
Tuatapere
TE WAEWAE BAY

Figure 3.7

3.2.13 Tuatapere reach

This lowland reach extends from Tuatapere to the river mouth at Te Waewae Bay (Figure 3.8). Alluvial and valley flats are much more extensive than elsewhere, as terraces are set back further from the river. However, bedrock abuts against the channel at a couple of locations. Associated with the greater width of valley and alluvial flats in Tuatapere reach is a broad active channel zone. This active channel zone is aligned virtually straight between Tuatapere and Te Waewae Bay. Active gravel bars are more evident in this reach that at any point upstream. Flow divides two or more laterally unstable channels. Within-reach variability in bar type is pronounced.

At Tuatapere, Waiau River is constrained by terraces into a single-channelled, almost straight configuration. Downstream of this constraint the channel moves laterally, and deposition occurs on the inside bank in the form of a bank attached compound bar, which has a prominent side channel behind it. Immediately downstream of this bar the main channel divides around a major mid-channel compound bar. The character of gravel bars changes significantly downstream of this point, as flow is concentrated into one primary channel and a series of compound point bar features have developed. At the river mouth the channel widens considerably, with concomitant mid-channel deposition.

TUATAPERE REACH

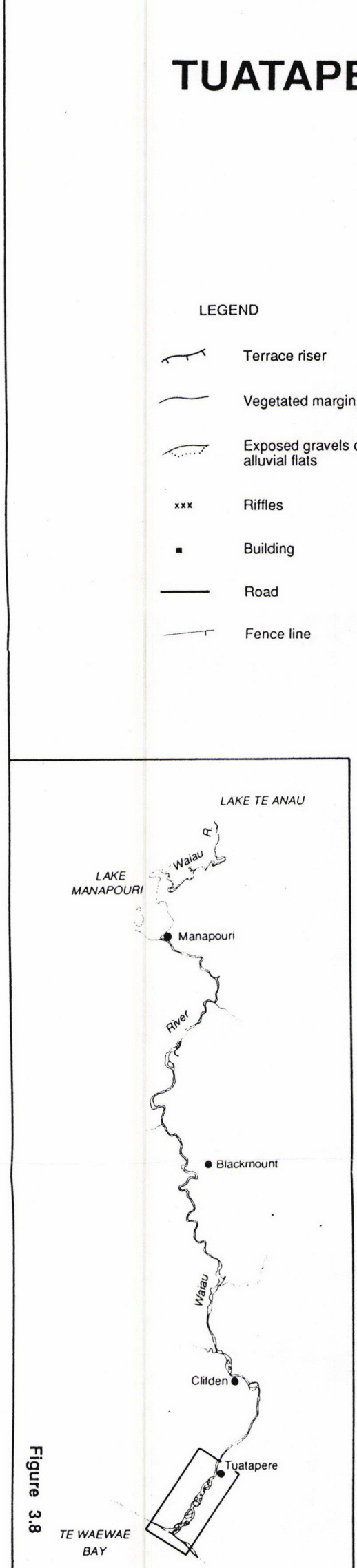
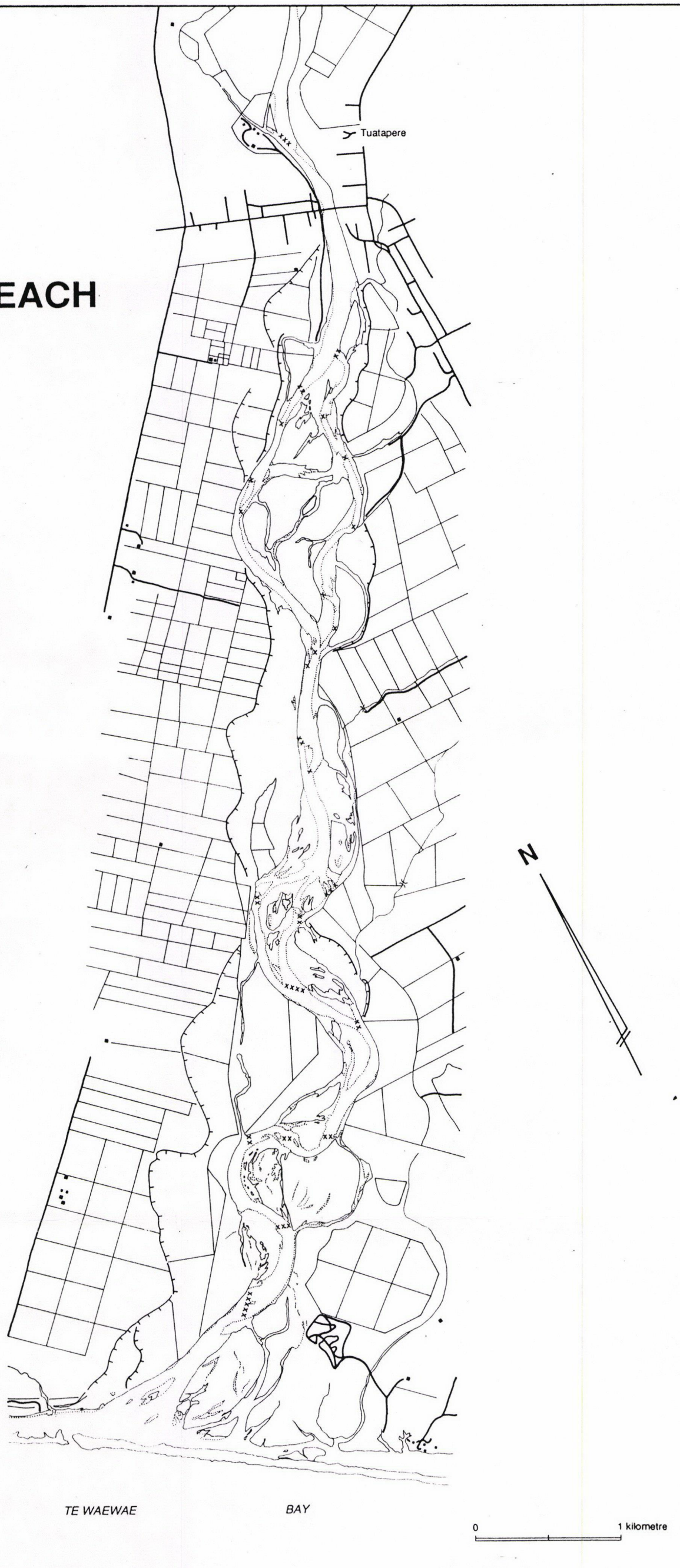


Figure 3.8



LEGEND

- Terrace riser
- Vegetated margin of river position
- Exposed gravels on river beds or alluvial flats
- xxx Riffles
- ■ Building
- Road
- Fence line

3.3 Summary assessment of channel character along Waiau River

A distinct pattern in river reaches is discernible along Waiau River, with an alternating sequence of bedrock/terrace constrained reaches and less constrained reaches with multi-channelled planform geometries. Upstream reaches (Wairoa and Pearl Harbour) have imposed channel conditions in which Waiau River has a low to moderate sinuosity, single-channelled outline. Six more reaches downstream of Mararoa Weir are laterally constrained: 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.

In laterally unconfined reaches (Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere) gravel bar types change down-reach in a systematic manner. As flow exits the upstream bedrock-confined reach, energy is concentrated within a single channel. Flow deflection beyond the lateral constraint results in deposition of bank-attached compound bars along the inside bank. Moving down-reach, channel competence is reduced as flow energy is dissipated over a broader area. Within-channel deposition occurs, typically as longitudinal, diagonal or mid-channel compound bars. In three of the four laterally unconfined reaches (Redcliff, Wairaki and Lill Burn), 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. At the reach head, bank-attached bars are transitional downstream to a large mid-channel compound bar. Beyond this bar, flow is concentrated into a single channel, and 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.

This geomorphic overview provides the context within which to assess channel adjustments between 1946-1992 from the air photograph record.

4.0 Methods

In the first stage of analysis, summary channel adjustments over the period of photographic record were assessed (Section 5). This preliminary analysis was used to determine those reaches in which more detailed photographic work was required. Seventeen sets of aerial photographs were used to compile the record of channel adjustments along Waiau River. Survey run numbers and the procedures used to undertake the air photograph analysis are summarised in Section 4.1. The procedure used to determine areal measurements of channel adjustments is described in Section 4.2. To convert these areal estimates to volumetric estimates of removed material, selected erosion sites were examined in the field to determine bank height and character.

Most of the hydrological work used in this report is derived from Riddell et al. (1993). However, in order to relate the hydrologic record to the sequence of channel adjustments, the flood history was determined for each photographic interval and the character of individual flood events was determined by comparison of daily discharge data from Sunnyside and Tuatapere (described in Section 4.3 and Section 7). Finally, methodological constraints of the adopted analytical procedure are summarised in Section 4.4.

4.1 Procedure employed in air photograph analysis

Seventeen sets of air photographs were used to compile the history of channel adjustments along Waiau River. There were nine differing scales of photograph, ranging from 1:7,920 to 1:67,000 (Table 4.1). The average scale for all coverages of about 1:24,000 is somewhat smaller than the preferred scale with which to resolve images; namely between 1:10,000 and 1:20,000. The 1965 coverage at 1:67,000 was at too small a scale to be of much use for detailed analysis.

The print quality of all sets of aerial photographs was excellent, although the 1969 coverage suffered from diffuse texture as a consequence of over-enlargement of the negatives. Most coverages complied with the standard for aerial photography mapping requirements, although six of the seven Southland Regional Council sets comprised sequential non-stereo photographs. These had variable forward laps which ranged from 3-70 % (the standard is 60%). Overlap ranged from 3-50 % in 1969 and 5-70 % in 1977. Variability of scale within some of the photograph sets was also apparent, probably associated with change in aircraft altitude during the photographic run. The plane also altered its direction of flight during photograph runs so as to remain above the river. This involved lowering one wing to an angle greater than 2 ° from the horizontal, thus exceeding the desirable tilt angle for vertical aerial photography.

Table 4.1 Air photograph runs available for analysis

Date of photo	Survey Number	Nominal scale of Prints used	Coverage
1946-1948	SN390	1:18,000	Stereo
28.01.1954	SN836	1:20,000	Stereo
15.02.1957	SN1020	1:44,000	Stereo
10.03.1963	SN1543	1:20,000	Stereo
18.03.1965	SN1723	1:67,000	Stereo
12.02.1969	SN2137	1:7,920	Mono
31.05.1974	AS 659	1:7,920	Mono
03.03.1975	SN3811	1:25,000	Stereo
25.02.1977	AS--	1:8,000	Mono
11.12.1978	SN5215	1:50,000	Stereo
14.04.1980	AS348	1:16,000	Mono
12.08.1982	AS550	1:16,000	Mono
07.02.1984	SN8317	1:50,000	Stereo
21.06.1984	AS608	1:8,000	Mono
08.10.1985	SN8541	1:25,000	Stereo
04.04.1989	AS787	1:16,000	Mono
14.04.1992	AS981	1:20,000	Stereo

Source code:
SN New Zealand Aerial Mapping Limited
AS Southland Regional Council

In the initial stage of analysis a 'standard' set of base maps was produced at 1:12,000 from the 1992 air photograph run for the entire length of the river from Lake Te Anau to Te Waewae Bay (Figures 3.1 to 3.8). This comprised the channel outline, which was discerned from visible banks and vegetated margins, and a series of selected fixed points, which included such things as nearby major terraces, roads, bridges, buildings and fences. The fixed points were then used to control the positional placement of the river outline plot for each of the additional photographic coverages. Vegetated margins were used to determine channel position, rather than the outline of gravel bars, as the shape of the latter are too dependent on flow stage at the timing of photography.

Channel position was determined using an Old Delft scanning stereoscope with magnification of 1.5 x and 4.5 x and an illuminated 2 x magnifier. This was supplemented by over 30 years experience in aerial photograph interpretation and related fieldwork (by Keith Fitchett). The adopted analytical procedure was similar to that used in other mapping exercises (Wasson et al., 1988; Yu et al., 1991). The stereoscope and magnifier were set-up alongside one another. The stereo scene being viewed was repeated by placing an enlargement at base map scale of the same scene from one photograph, together with an overlay of transparent drafting plastic, under the magnifier. The stereoscopically observed position of the Waiau channel was then carefully plotted in ink onto the overlay. When tracing the channel outline of the second and all subsequent coverages, the level of accuracy of the plot was enhanced by applying seven aerial photograph interpretation recognition elements (size, shape, tone, shadow, pattern, texture and site) to compare each location being mapped to the same stereo scene on the 1992 coverage. Where necessary, non-stereo photographs were viewed stereoscopically by pairing them with a view from another set. This technique was used by Fitchett (1987) to identify the source (before the event) and direction of movement (after the event) of a coral block from the reef-front onto the reef flat at Funafuti during hurricane Bebe in October 1972. Analysis of Waiau River photographs was

complicated by the necessity to sometimes view paired photographs of quite different scales. This severely limited the area that could be compared without readjustment of the relative positions of the photographs under the stereoscope.

Interpretation was also complicated by some photography being taken either in the early morning or late afternoon, as low angle sunlight across a high bank or dense forest crown adjacent to the channel sometimes resulted in from 1-100% of the river imaging in shadow, thus rendering all features invisible. Most problem shadows occurred above Clifden; for example just blow Manapouri on the 1969 set, and around Monowai Power Station on the 1992 set. Six of the twenty-six "sheets" of the 1977 set also contained clouds which obscured the view of the ground.

Analysis of channel adjustments along Waiau River was segmented into physically meaningful river reaches as indicated in Section 3. All figures were rescaled to fit on A3 paper. This required 3 x reduction from the scale at which the original base maps were compiled. In the first instance the earliest available photography for the entire river between Lake Te Anau and Te Waewae Bay was compared with the most recent (1992) photography. Results from this analysis, described in Section 5, were used to determine the number of additional air photograph runs required to reliably assess the nature and rate of channel changes. Detailed analysis of channel adjustments was restricted to Wairoa, Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere reaches. Photographs used to characterise channel adjustments for each reach are summarised in Table 4.2.

Table 4.2 Air photograph runs used for each river reach

	Year of photography														
Reach name	46-48	54-57	63-65	69	74	75	77	78	80	82	84 (i)	84 (ii)	85	89	92
Wairoa (Upper Waiau)		X	X				X								X
Pearl Harbour		X													X
Duncraigen		X													X
Redcliff		X		X						X				X	X
Blackmount-Mangapiri	X	X								X					X
Wairaki	X		X	X	X			X	X	X	X	X		X	X
Motu	X														X
Lill Burn	X		X	X	X		X		X	X	X	X		X	X
Clifden Suspension bridge	X														X
Downstream o'Clifden	X		X	X	X		X	X	X	X	X	X		X	X
Hagen Road	X														X
Orauea	X														X
Tuatapere	X		X	X	X	X	X	X	X	X	X		X	X	X

4.2 Measurement of channel adjustments

For those reaches in which significant channel adjustments were recorded between 1946-1992, detailed measurements of channel changes were assessed. This entailed analysis of the area of channel changes, both erosional and deposition, as indicated between consecutive air photograph runs. All figures of consecutive air photograph runs were doubled in scale using a photocopier (x 141 x 141). Enlarged figures of successive air photograph runs were divided into physically

meaningful river sections within each reach, usually on the basis of the pattern of bends, channel constrictions, or mid-channel bar complexes. Separate analysis of the banks and the within-channel zone enabled differentiation of permanent changes along banks from transitory within-channel behaviour. For example, eroding concave banks were examined in isolation, as were major within-channel compound bars.

On each copy of successive air photograph runs, zones of erosion and deposition were colour coded and separated into units along the banks and in the within-channel zone. Area of each adjustment unit was then measured using a digital planimeter. Area estimates less than 5,000 m^2 were determined by direct comparison by eye, using a 1,000 m^2 interval graph sheet. For reasons of reliability, and the vast number of measurements made (see below) only areas greater than 5,000 m^2 were determined using the digital planimeter. When using the digital planimeter, enough measurements were taken until three values within 5% of each other were determined. This usually entailed estimation to within several hundred m^2. The instrument was recalibrated on each day of measurement.

At various sites of continued erosion throughout the period of the photographic record field measurements of bank height and character were determined so that volumetric estimates of material removed could be derived. These field measurements were undertaken by Sue Bennett in May, 1993.

4.2.1 Comment on number of measurements of channel adjustment

The number of measurements of channel adjustments recorded for each reach during each photographic interval, as recorded in Table 4.3, is not a physically meaningful parameter but it does provide a guide to the extent of channel changes evident during each time slice.

Table 4.3 Number of measurements of channel adjustments recorded for each reach in which significant channel changes occurred

	Photographic interval																					
	46 - 63	57 - 65	54 - 69	63 - 69	65 - 77	69 - 74	74 - 75	74 - 77	75 - 77	74 - 78	77 - 78	78 - 80	69 - 82	80 - 82	82 - 84	84 - 84	84 - 85	82 - 89	84 - 89	85 - 89	77 - 92	89 - 92
Reach name																						
Wairoa		5			1																55	
Lower Redcliff			81										83					33				40
Wairaki	62			59		56				22		59		53	33	85			44			57
Lill Burn	94			99		56		74			??			43	14	88			41			84
D/s o'Clifden	35			37		22		29			11	16		38	7	39			18			42
Tuatapere	153			103		95	10		59		45	92		65	77		71			80		96

The lack of channel adjustments measured between 1957-1965 and 1965-1977 in Wairoa (Upper Waiau) reach indicates the limited channel adjustments that took place in these intervals, whereas between 1977-1992 a series of adjustments took place along the banks in Upper Waiau reach, as indicated by measurements of channel change at 55 locations.

Significant channel modifications took place in Lower Redcliff reach during each of the four intervals in the period of record. The large number of measurements in the short period 1989-1992 is proportionally greater than for the three preceding periods, indicating the much greater precision that can be attained when making assessments of areal adjustment from shorter time intervals. Air photo records determined from longer intervals record a composite of the changes that occurred in the intervening periods.

In Wairaki, Lill Burn and Downstream o'Clifden reaches significant channel adjustments were recorded in each of the air photo record intervals. For example, a large number of measurements were determined in the five month period following the January 1984 flood event, indicating rapid channel responses to major floods. In Lill Burn reach the number of measurements of channel adjustment was also high between 1963-1969 and 1989-1992. Given the relatively short length of river studied in Downstream o'Clifden reach the number of measurements of channel adjustments is particularly significant. Measurements of channel adjustments are high for each time interval in Tuatapere reach other than the short interval between 1974-1975. Indeed, this alluvial reach experienced dramatic changes throughout the period of air photograph record.

The short interval between air photograph runs, along with the detailed methods of analysis employed in this study, enabled fine resolution assessment of channel adjustments for each of the reaches described above. In total, almost 3,000 areal measurements of channel adjustment were made in compiling this report.

4.3 Assessment of hydrologic data

No detailed hydrological analysis was undertaken in this study, as the record of hydrologic modification to Waiau River has been amply considered in the WRWP report by Riddell et al. (1993). In Section 7, however, daily discharge data were used to evaluate the relationship between hydrologic regime and channel adjustments. In this analysis, the number of days that 50 m^3s^{-1} discharge intervals beyond 500 m^3s^{-1} were exceeded was determined for each photographic interval for each reach. This information was determined from the Tuatapere discharge record which dates back to 29.07.1964. This information is then used to assess the relationship between channel adjustments and flow regime. Assessment of flood peakedness was made by plots of daily discharge levels for each event > 800 m^3s^{-1} (presented in Appendix 5). Relative flow contributions from the upper and lower Waiau catchments were determined for individual flood events by comparison of discharge levels at Tuatapere and Sunnyside, where discharge measurements started on 11.02.1972. Flow contribution to individual floods and their peakedness was used to explain the spatial variability of river responses to floods of differing character.

4.4 Limitations to methodological approach

1) Analysis in this report is restricted to changes is channel outline and alignment, and does not refer to vertical changes in channel bed elevation to any degree. In other words, neither the aggradational nor the incisional response of the river to flow regulation are considered.

2) Channel adjustments within the interval of the photographic record are integrated over time. Inevitably, detailed assessment of rates of change is much easier over shorter periods, whereas in the earliest period of record (generally 1946-1963) numerous channel adjustments are simplified and minimised due to limitations of resolution. Accordingly, areal estimates of erosion and deposition in the within-channel zone are unreliable, as analysis is restricted to end points and intermediary stages can only be inferred and cannot be measured. Areal estimates of channel changes are proportionally greater over shorter photographic intervals. The longest period between photographs (1946-1963), which was coincident with the highest discharge levels (ie. pre flow regulation), has the least detailed analysis of areal adjustments and these measurements of channel change are certainly underestimated relative to other photographic time intervals.

3) Measurement of areas of channel adjustments is prone to gross misinterpretation in that it takes no account of bank height. The differences between areas of adjustment and the associated volume of materials deposited or eroded is conjectural indeed. As an example of this limitation, 80 m of channel expansion in a flood event which strips away vegetation along a 100 m bank section down to a depth of 0.5 m would give a volume of removal of 4,000 m^3, whereas just 0.5 m of bank erosion along a 100m section of 10 m high terrace would give a volume of removal of 5,000 m^3. Despite this obvious limitation, areal estimates of channel adjustment have been used consistently throughout this report, and this restriction has been considered in all assessments and interpretations. Although the adopted areal approach only approximates the volumetric reality of channel adjustments, the consistent application of this approach ensures that comparative analyses over time, at the very least, are valid.

4) In those instances in which bank heights were measured, they were only recorded down to water level. During an erosional event, however, the bank would erode to the depth of the adjacent channel. Accordingly, all volumetric estimates of bank erosion must be viewed as minimum estimates. For consistency the same procedure has been used throughout the study.

5) Hydrological data are restricted to the period following July 1964, whereas the history of channel adjustments documented in this report dates back to 1946. No surrogate analysis of the rainfall record has been undertaken in this report. One further constraint in the hydrological information used in this study is the lack of flow data from Upper Waiau (Wairoa) reach. Flow levels in this reach cannot be reliably related to flow characteristics in Lower Waiau at Sunnyside or Tuatapere.

5.0 Results

The results section of this report is divided into three components. In Section 5 summary channel adjustments in the overall period of air photograph record are described. From this, reaches of notable channel changes are discerned. These reaches form the focus for detailed analysis in Section 6. Channel changes are related to the hydrologic record in Section 7.

5.1 Descriptive analysis of summary channel adjustments, 1946-1992

Initial analysis of channel adjustments compared channel alignments from the oldest vertical air photographs, which date to 1946, 1954 or 1957 for differing river reaches, with the most recent (1992) air photograph run along the entire length of Waiau River from Lake Te Anau to Te Waewae Bay. The photographic inventory of channel changes has been split into eight river reach figures. Summary channel adjustments are characterised on a reach by reach basis in subsequent sections.

5.2 Summary channel adjustments 1957-1992: Wairoa (Upper Waiau)

The only channel adjustments evident between 1957-1992 in Wairoa (Upper Waiau) reach (Figure 5.1) were:

a) Construction of Lake Te Anau Control Structure,
b) Trimming of the bend upstream of Kepler Track footbridge,
c) Abandonment of a tight gooseneck meander at the confluence with Forest Burn,
d) Lateral expansion (up to 50 m) of three bends immediately upstream of Lake Manapouri, and
e) Extension of the delta front into Lake Manapouri.

Given the slow rate of channel changes evident in this reach, further analysis was restricted to the 1965 and 1977 air photograph run (Section 6.2).

5.3 Summary channel adjustments 1957-1992: Manapouri-Mararoa reach

Channel trimming between 1957-1992 was less evident in Pearl Harbour reach than for Wairoa reach (Figure 5.2). Sites of trimming were restricted to the right bank immediately downstream of Lake Manapouri, the big bend 4 km upstream from Lake Manapouri Control Structure (Mararoa Weir), and along each bank 2.5 km upstream from Mararoa Weir. Maximum extent of bank erosion, measured perpendicular to flow direction, was less than 25 m. Significant channel adjustments at Waiau/Mararoa confluence have been artificially induced. No further photographic analysis has been undertaken in this reach.

WAIROA (Upper Waiau)

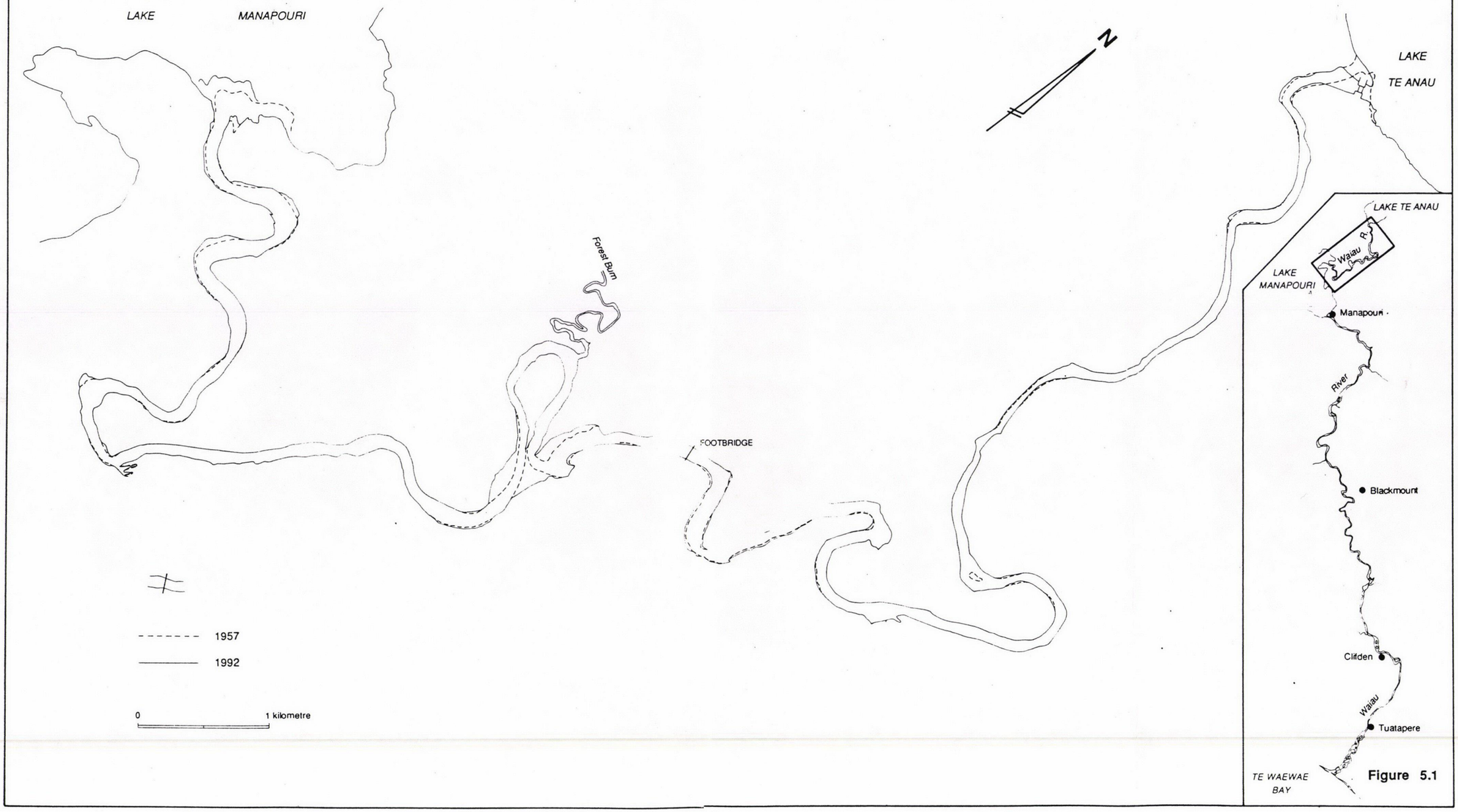


Figure 5.1

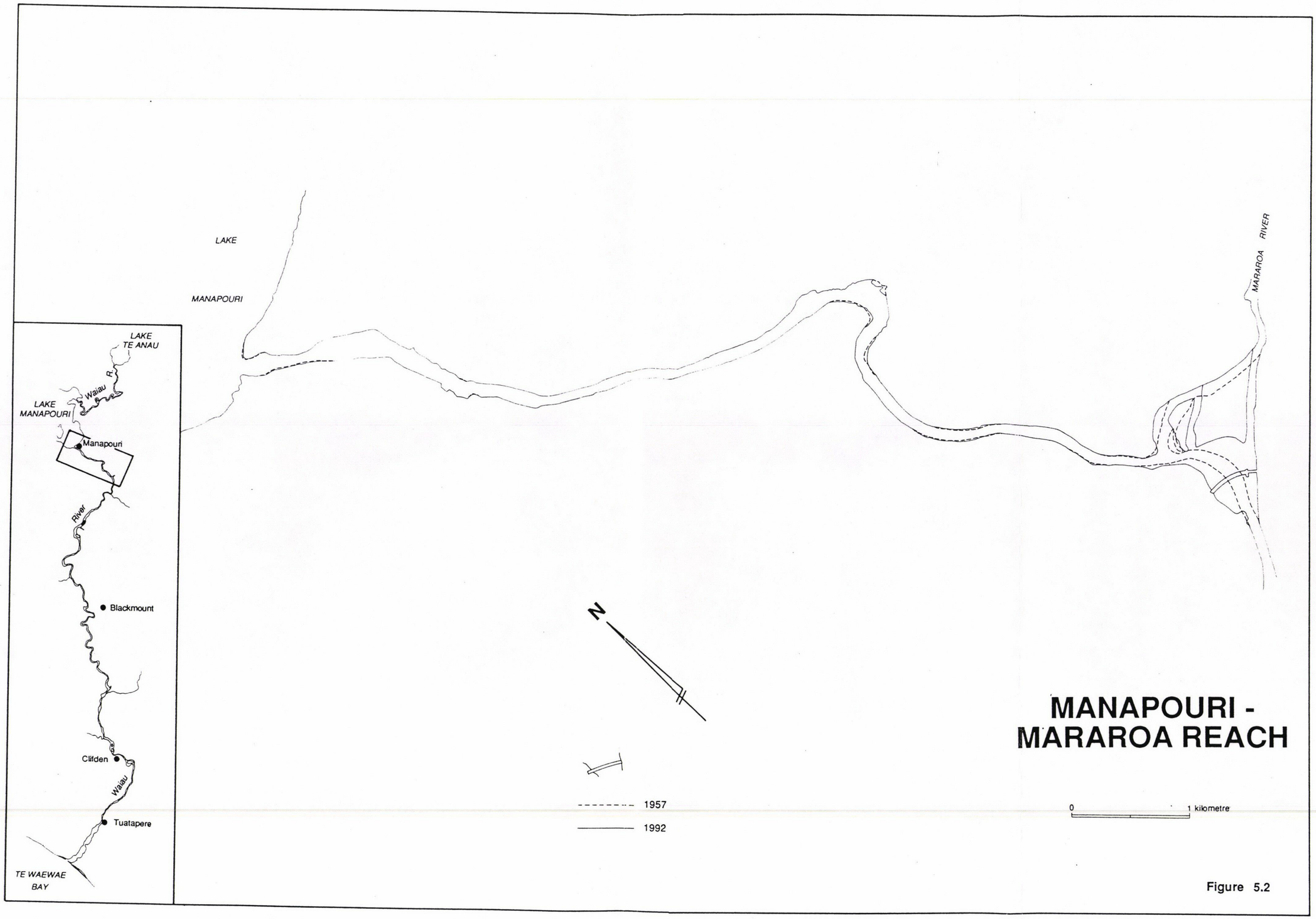

LAKE
MANAPOURI
MARAROA RIVER
LAKE
TE ANAU
Waiau R.
LAKE
MANAPOURI
Manapouri
River
Blackmount
Clifden
Waiau
Tuatapere
TE WAEWAE
BAY
N
1957
1992
MANAPOURI -
MARAROA REACH
0
1 kilometre

Figure 5.2

5.4 Summary channel adjustments 1957-1992: Mararoa-Redcliff reach

Channel adjustments between Lake Manapouri Control Structure (Mararoa Weir) and Blackmount over the period of available photographs (1954-1992) are shown on Figure 5.3. Duncraigen (or Excelsior) reach extends for approximately 2 km downstream from Mararoa Weir to Whare Creek confluence. In this reach Waiau River is laterally constrained by outwash terraces and bedrock, and is unable to modify its planform. However, incision would be expected immediately downstream of the control structure and in adjacent tributaries. These 'vertical' adjustments cannot be reliably discerned from the air photograph record, but field evidence certainly indicates that degradation has occurred in this short reach.

While lateral constraints limit channel adjustments in Duncraigen reach, potential for channel change is available in Redcliff reach where the valley and alluvial flats widen considerably. Between 1957-1992 slight modification in channel alignment took place at Whare Creek confluence. The right bank of Waiau River opposite Whare Creek eroded, while the left bank of Whare Creek shifted downstream as the confluence zone realigned.

Between Whare and Redcliff Creek confluences Waiau River became less multichannelled between 1957-1992, as islands became attached to the adjacent alluvial flats. A large compound point bar 2 km downstream of Whare Creek became attached to the right bank as a major chute channel was abandoned. This may reflect within-channel deposition, but more likely reflects channel incision. This degradational process not only reduced channel multiplicity but also changed channel alignment. Between 2.5-1.5 km upstream from Redcliff confluence a large mid-channel bar complex evident in 1957 had become attached to the left bank by 1992. Numerous small channels that dissected this former bar were abandoned.

Significant channel adjustments took place at Redcliff confluence between 1954-1992. Redcliff Creek moved almost 50 m to the south. This induced substantial modification of within-channel bars adjacent to Waiau River confluence. The bend downstream of Redcliff Creek experienced a complex history of channel changes, the specific sequence of which cannot be unravelled from the 1954 and 1992 photographs. The compound point bar on the left bank 500 m downstream of Redcliff confluence has been extensively modified, as has a bank-attached bar on the opposite bank. Significant within-channel sedimentation and channel realignment occurred.

Subsequent air photo analysis is used to evaluate the sequence and timing of channel changes in the lower half of this reach (Section 6.3).

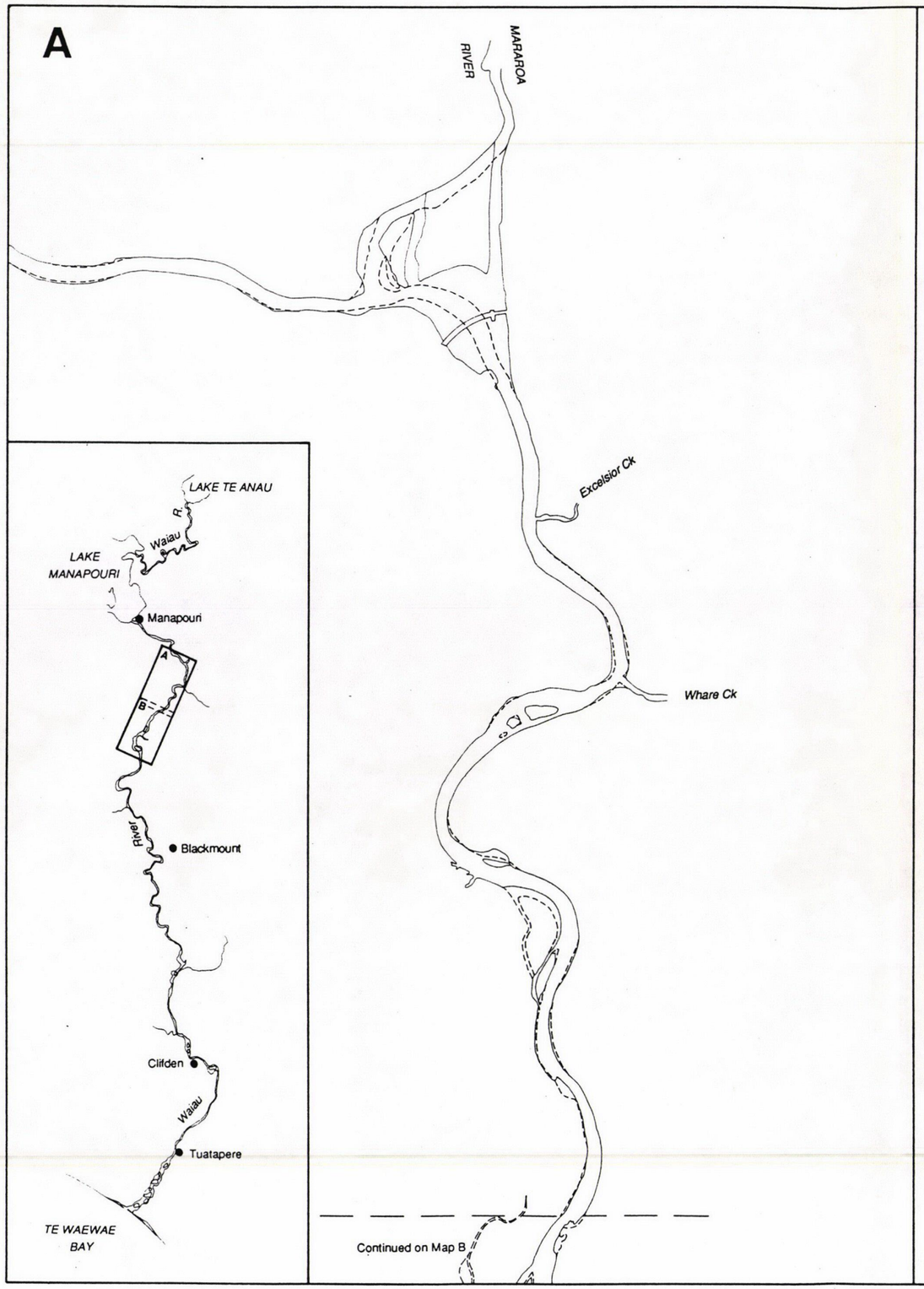

A
MARAROA RIVER
Excelsior Ck
Whare Ck
LAKE TE ANAU
R.
Waiau
LAKE MANAPOURI
Manapouri
A
B
River
Blackmount
Clifden
Waiau
Tuatapere
TE WAEWAE BAY
Continued on Map B
B
Continued on Map A
N
Redcliff Ck
1954
1957
1992
MARAROA - REDCLIFF REACH
0
1 kilometre

Figure 5.3

5.5 Summary channel adjustments 1948-1992: Blackmount-Mangapiri reach

Channel adjustments in Blackmount-Mangapiri reach between 1948-1992 have been restricted to negligible channel trimming or occasional deposition at channel margins, although some planform changes can be discerned on compound point bars (Figure 5.4). These limited modifications are scarcely surprising given that Blackmount-Mangapiri reach is a bedrock- or terrace-confined reach. The insignificant changes evident in this reach can be explained without reference to additional photographs.

5.6 Summary channel adjustments 1946-1992: Wairaki reach

The broad area of alluvial flats adjacent to Wairaki confluence presents the opportunity for significant channel adjustments to take place. In 1946 flow in the bend at the head of Wairaki reach was divided into a couple of chute channels, but by 1992 flow has become confined to a single channel (Figure 5.5). The bend immediately upstream of the Wairaki confluence experienced significant erosion and lateral movement between 1946-1992. The entire bend shifted downstream, in a process referred to as downstream translation. This process may be related to changes in the configuration of Wairaki River, as pronounced channel changes are also evident in the pattern of bars and islands immediately downstream of Wairaki confluence. The specific nature of erosion and deposition are analysed from all available air photographs in Section 6.4.

5.7 Summary channel adjustments 1947-1992: Motu and Lill Burn reaches

Motu reach, in the upstream section of Figure 5.6, is laterally confined by bedrock and river terraces. This reach experienced no channel changes between 1947-1992. Immediately downstream, however, significant changes occurred in Lill Burn reach. Between 1947-1992 flow became concentrated into fewer channels. Lill Burn itself migrated laterally and downstream at Waiau confluence. The manner of adjustments at this confluence has affected the local pattern of erosion and deposition downstream. The specific history of change is analysed is Section 6.5.

5.8 Summary channel adjustments 1947-1992: Clifden-Tuatapere

Nowhere in this preliminary analysis are the effects of lateral constraints on channel morphology better expressed than in Figure 5.7. Between 1947-1992 there were no discernible adjustments in the short and confined Clifden Suspension Bridge and Hagen Road reaches, whereas in Orauea reach a secondary channel was abandoned upstream of Orauea confluence. These adjustments are trivial when compared to expansion of the tight bend that constitutes Downstream o'Clifden reach, where up to 350 m of bank erosion occurred, with concomitant within-channel deposition. Timing of bank erosion of this bend is described in Section 6.6. No further air photograph analysis is undertaken for the remainder of this reach.

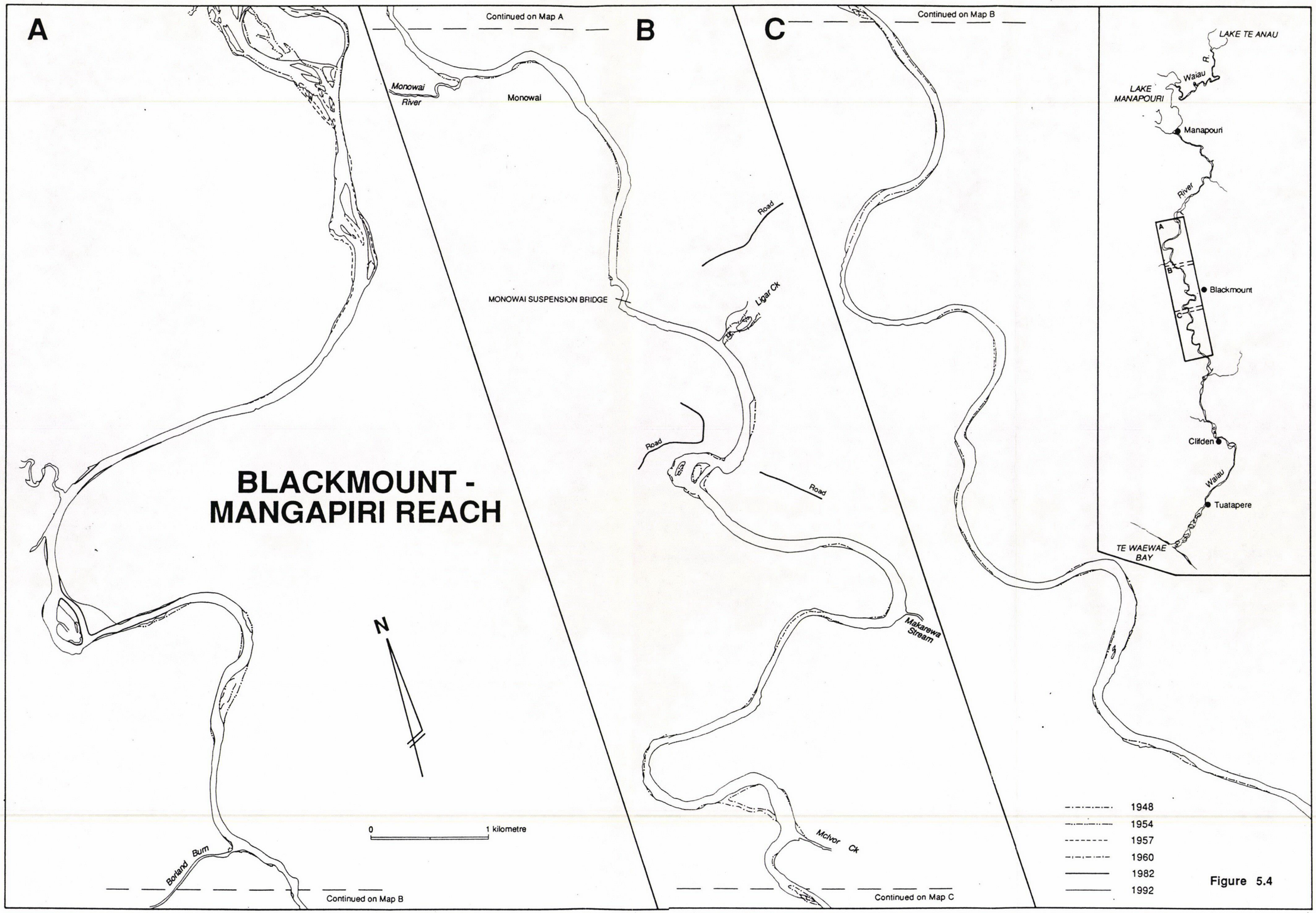

A
B
C
Continued on Map A
Continued on Map B
Continued on Map C
Monowai River
Monowai
MONOWAI SUSPENSION BRIDGE
Road
Ligar Ck
Road
Road
Makarewa Stream
McIvor Ck
Borland Burn
BLACKMOUNT - MANGAPIRI REACH
N
0
1 kilometre
LAKE TE ANAU
R.
Waiau
LAKE MANAPOURI
Manapouri
River
Blackmount
Clifden
Waiau
Tuatapere
TE WAEWAE BAY
1948
1954
1957
1960
1982
1992

Figure 5.4

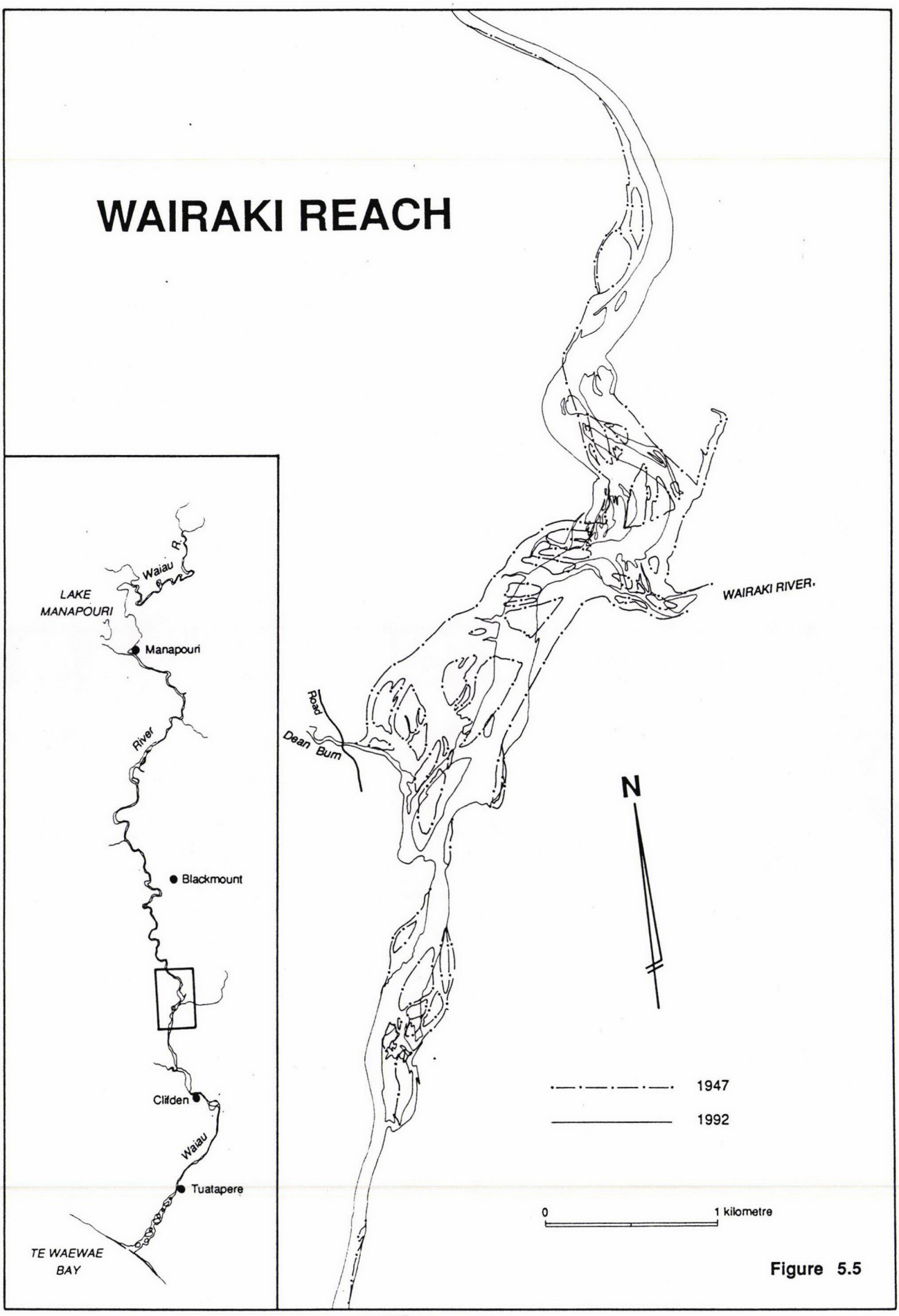

WAIRAKI REACH
LAKE MANAPOURI
Waiau R.
Manapouri
River
Blackmount
Clifden
Waiau
Tuatapere
TE WAEWAE BAY
WAIRAKI RIVER.
Dean Burn Road
N
1947
1992
0
1 kilometre

Figure 5.5

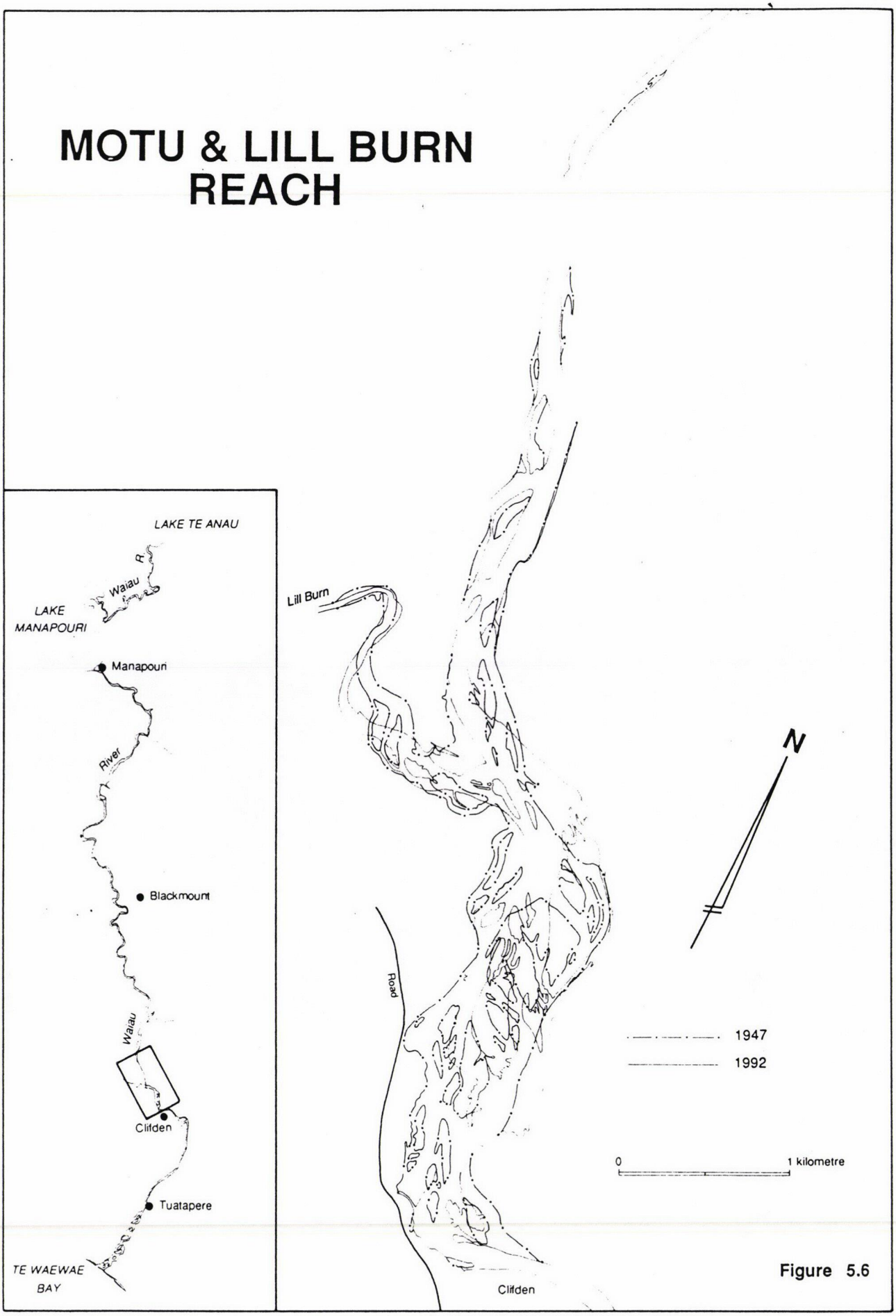

MOTU & LILL BURN REACH
LAKE TE ANAU
Waiau R.
LAKE MANAPOURI
Manapouri
River
Blackmount
Waiau
Clifden
Tuatapere
TE WAEWAE BAY
Lill Burn
Road
Clifden
N
1947
1992
0
1 kilometre

Figure 5.6

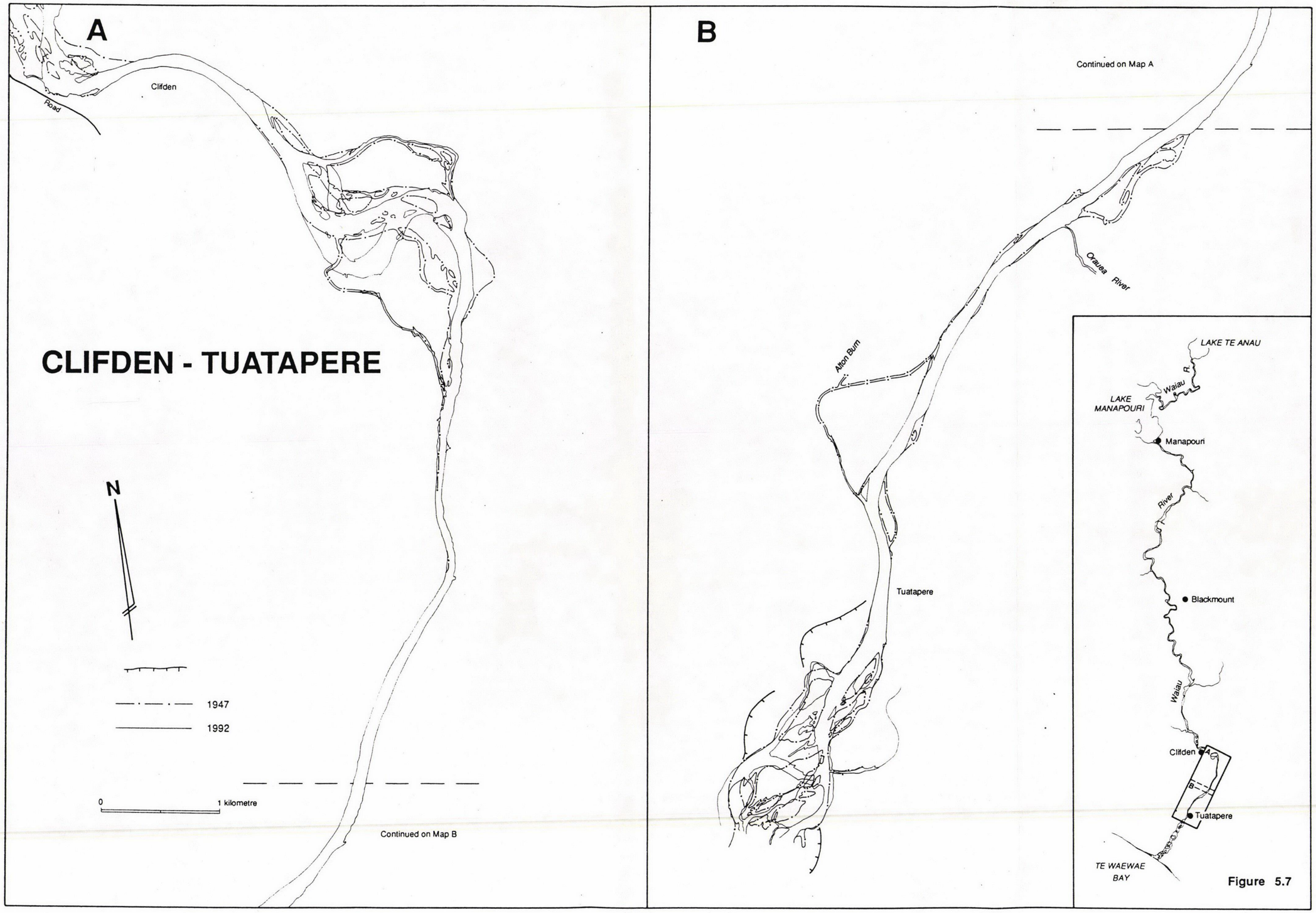
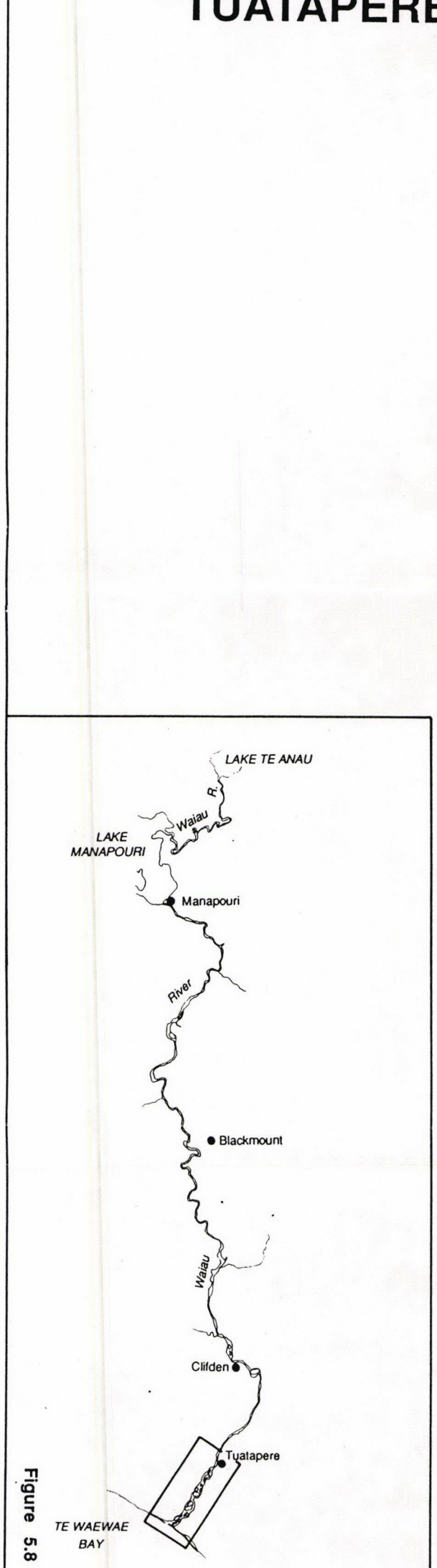

A
Clifden
Road
CLIFDEN - TUATAPERE
N
1947
1992
0
1 kilometre
Continued on Map B
B
Continued on Map A
Orauea River
Aton Burn
Tuatapere
LAKE TE ANAU
Waiau R.
LAKE MANAPOURI
Manapouri
River
Blackmount
Waiau
Clifden
A
B
Tuatapere
TE WAEWAE BAY

Figure 5.7

5.9 Summary channel adjustments 1946-1992: Tuatapere reach

Tuatapere reach experienced the most complex pattern of channel changes along Waiau River between 1946-1992. Indeed, the realignments and adjustments in the number of channels and their configuration are so complex that they cannot be unravelled from Figure 5.8, and the character and timing of changes requires more detailed analysis over shorter time intervals. Significant within-reach variability in channel adjustments has occurred, and some of the erosion zones appear to have effectively migrated downstream. Channel multiplicity has been reduced, and the channel has adopted a more sinuous outline, especially in the lower 4 km. The mouth of the river has moved significantly to the west, possibly associated with changes in the morphology of the gravel barrier system. The nature and timing of channel adjustments in Tuatapere reach are analysed in detail in Section 6.7.

TUATAPERE REACH



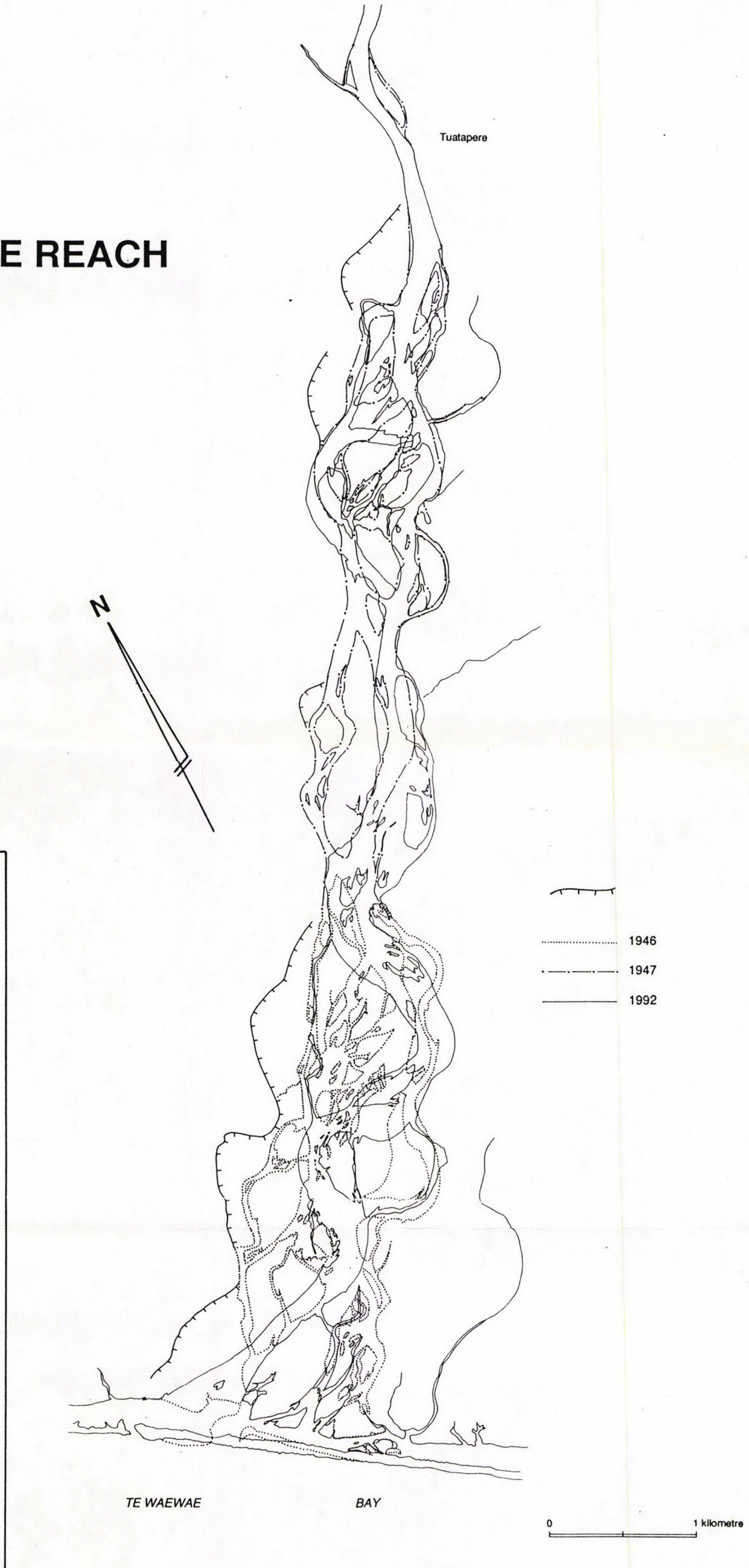


Figure 5.8

5.10 Summary of channel adjustments along Waiau River: 1946-1992

The extent and character of channel changes along Waiau River between 1946-1992 varies considerably from reach to reach (Table 5.1). Adjustments were restricted primarily to reaches where the river has space to adjust laterally or reaches where there were significant sediment inputs from tributary catchments. In most instances, these reaches are coincident. These effects operate to differing extents in seven reaches: Redcliff, Waicoe, Wairaki, Lill Burn, Downstream o'Clifden, Orauea and Tuatapere. Channel changes were extremely localised in Waicoe and Orauea reaches. Tuatapere reach experienced most channel adjustments, but significant changes were also evident in Wairaki, Lill Burn and Downstream o'Clifden reaches. Several islands in Redcliff, Lill Burn and Tuatapere reaches became bank-attached. Elsewhere along the river, channel changes were restricted to bank trimming. Along large sections of the river no modifications were evident over the period of record. Subsequent detailed analysis of channel adjustments is restricted to Wairoa, Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere reaches.

Table 5.1 Summary channel changes in each reach in the period of photographic record

Reach	Photograph interval	Summary channel adjustments
Wairoa	1957-1992	Channel marginal trimming; cut-off gooseneck meander at Balloon Loop
Pearl Harbour	1957-1992	Negligible changes
Duncraigen	1957-1992	No planform changes, but notable incision (degradation)
Redcliff	1954-1992	Abandonment of secondary channels and attachment of mid-channel compound bars upstream of Redcliff confluence; shift in position of Redcliff Creek at the confluence zone; significant channel adjustments downstream of the confluence, with bar attachment and channel realignment
Blackmount-Mangapiri	1948-1992	Negligible changes other than in compound point bars and adjacent to Waicoe confluence
Wairaki	1947-1992	Abandonment of a secondary channel at the head of the reach. Expansion of a compound point bar and adoption of a more sinuous outline upstream of Wairaki confluence, with associated erosion of concave banks. Change in alignment of Wairaki confluence and significant modification of Waiau River immediately downstream.
Motu	1947-1992	No change
Lill Burn	1947-1992	Attachment of a mid-channel bar to the left bank upstream of Lill Burn and significant erosion of this bank opposite Lill Burn confluence. Pronounced shifts in the position of Lill Burn, which has adopted a more sinuous outline and has cut a new channel to the south at Waiau confluence. Numerous channels have been abandoned downstream of Lill Burn, as bars have expanded considerably. This has resulted in significant channel realignment.
Clifden	1947-1992	No change
Downstream o'Clifden	1947-1992	Significant lateral expansion of a tight bend, with up to 350 m of erosion. Associated within-channel bar development and channel realignment.
Hagen Road	1947-1992	No change
Orauea	1947-1992	Negligible channel adjustments other than abandonment of a chute channel upstream of Orauea confluence.
Tuatapere	1946-1992	Complex sequence of adjustments. Channel multiplicity has been reduced and sinuosity has increased. Focal points of erosion in concave banks have migrated downstream. A mid-channel bar complex at the head of the reach has become more stable, while a series of compound point bars have developed in the lower 4 km of the reach.

6.0 Detailed air photograph analysis of selected reaches

Summary channel changes along the entire length of the trunk stream of Waiau River described in Section 5 indicated that channel adjustments were spatially discontinuous. In this section detailed analyses are carried out for those reaches which demonstrated significant channel adjustments between 1946-1992, namely Wairoa (Section 6.1), Lower Redcliff (Section 6.2), Wairaki (Section 6.3), Lill Burn (Section 6.4), Downstream o'Clifden (Section 6.5) and Tuatapere (Section 6.6). Up to thirteen sets of photographs were analysed for individual reaches, although the specific sequence (and date) of photographs was determined by availability (see Table 4.2). Although these photographs span the period of flow regulation, the number of photograph runs is inevitably greater for the past two decades.

6.1 Channel adjustments in Wairoa (Upper Waiau) reach

Four sets of air photographs were examined for Wairoa (Upper Waiau) reach dating from 1957, 1965, 1977 and 1992. In the analysis of channel changes Wairoa reach was split into eight subreaches as indicated on the 1:50,000 map sheet (Figure 6.1). Given the constrained nature of Wairoa reach, channel adjustments were restricted to erosion and deposition adjacent to banks. In subsequent sections analysis is split into left and right banks for each subreach. For presentation purposes the figures of channel changes in Wairoa reach are split into two (Figure 6.2 to 6.6).

6.1.1 Channel adjustments adjacent to Lake Te Anau Control Structure

Table 6.1.1 Adjacent to Lake Te Anau Control Structure, Left and right bank

		Areal adjustments (in m^2 x 1000)		Areal adjustments (in m^2/day)	
	# Days	Erosion	Deposition	Erosion	Deposition
Left bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-14.04.92	9825	26.83	2.00	2.73	0.20
Right bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-14.04.92	9825	0.00	13.67	0.00	1.39

No changes were evident at the outlet of Lake Te Anau between 1957-1965. However, construction of Lake Te Anau control structure induced direct modifications of channel form as the lake outlet was constricted and moved a hundred metres to the east. Some subsequent deposition occurred on the lake shore adjacent to the structure. Anecdotal evidence indicates that large volumes of basal gravels were excavated from the channel bed downstream of the control structure during construction. Modifications of the lake outlet and subsequent adjustments to the flow regime of Upper Waiau (Wairoa) have induced significant trimming of the channel marginal terraces downstream. These changes were associated with flood events in the 1980's, rather than in the period 1965-1977.

WAIROA (Upper Waiau)

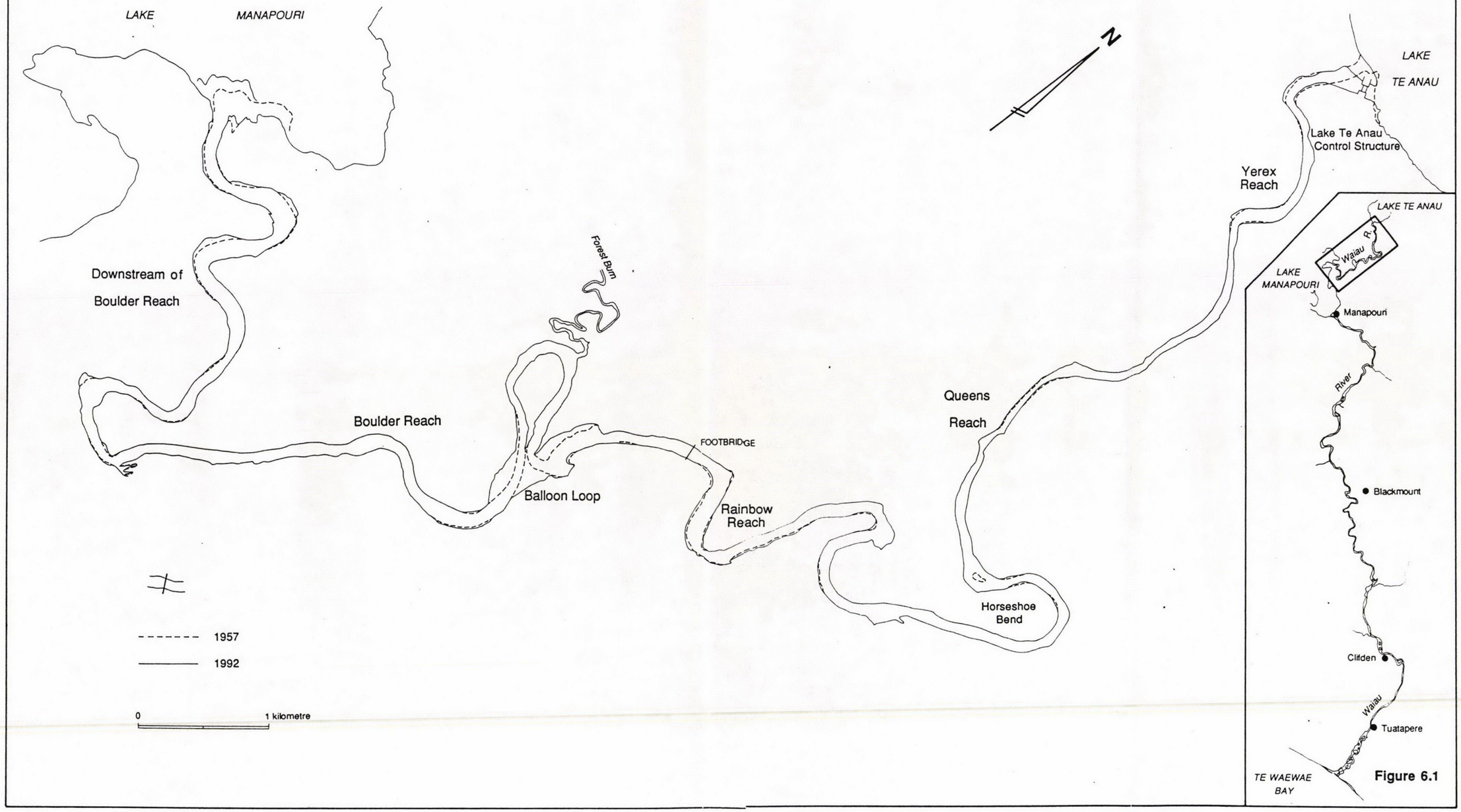


Figure 6.1

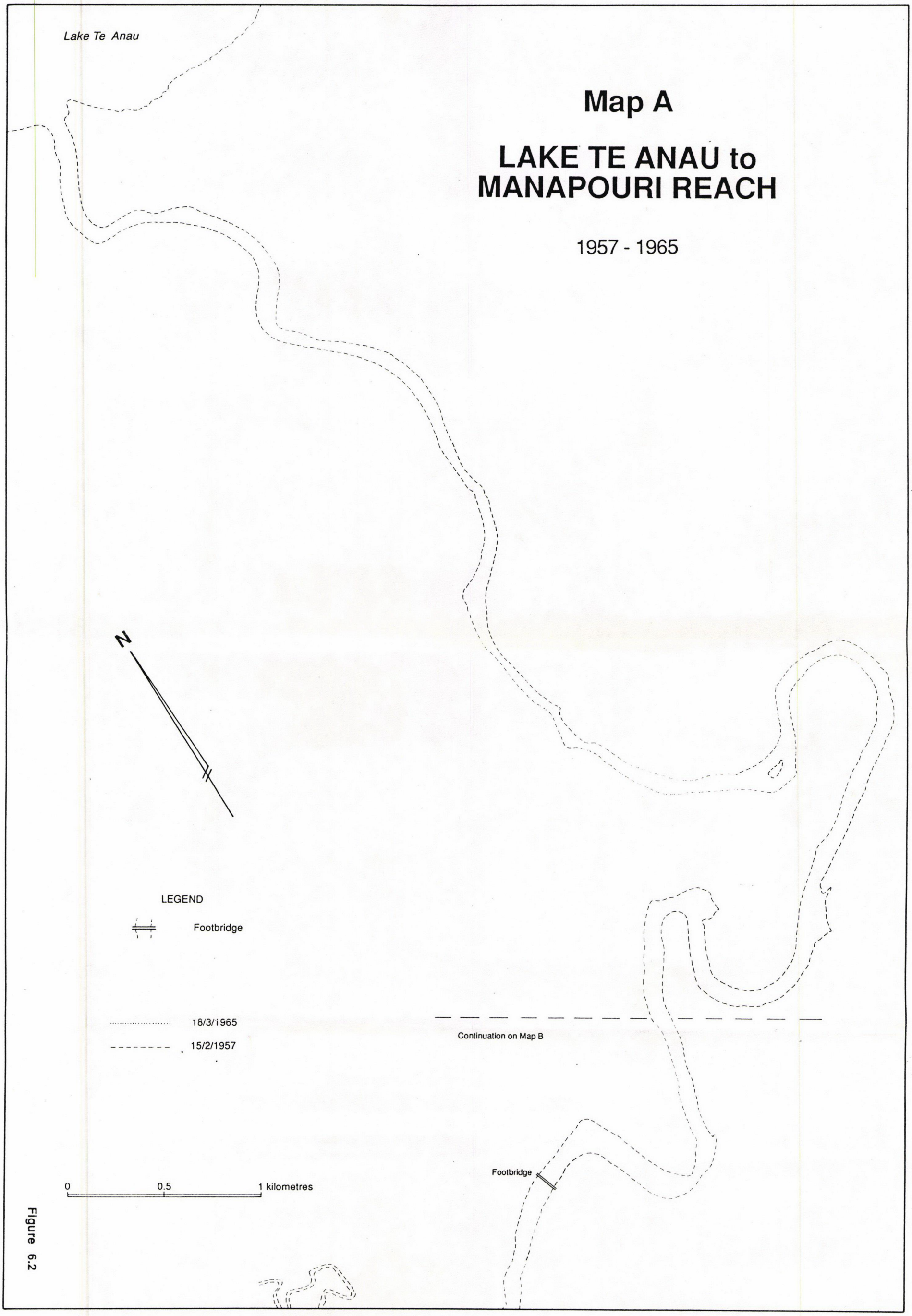

Lake Te Anau
Map A
LAKE TE ANAU to MANAPOURI REACH
1957 - 1965
N
LEGEND
Footbridge
18/3/1965
15/2/1957
Continuation on Map B
Footbridge
0
0.5
1 kilometres

Figure 6.2

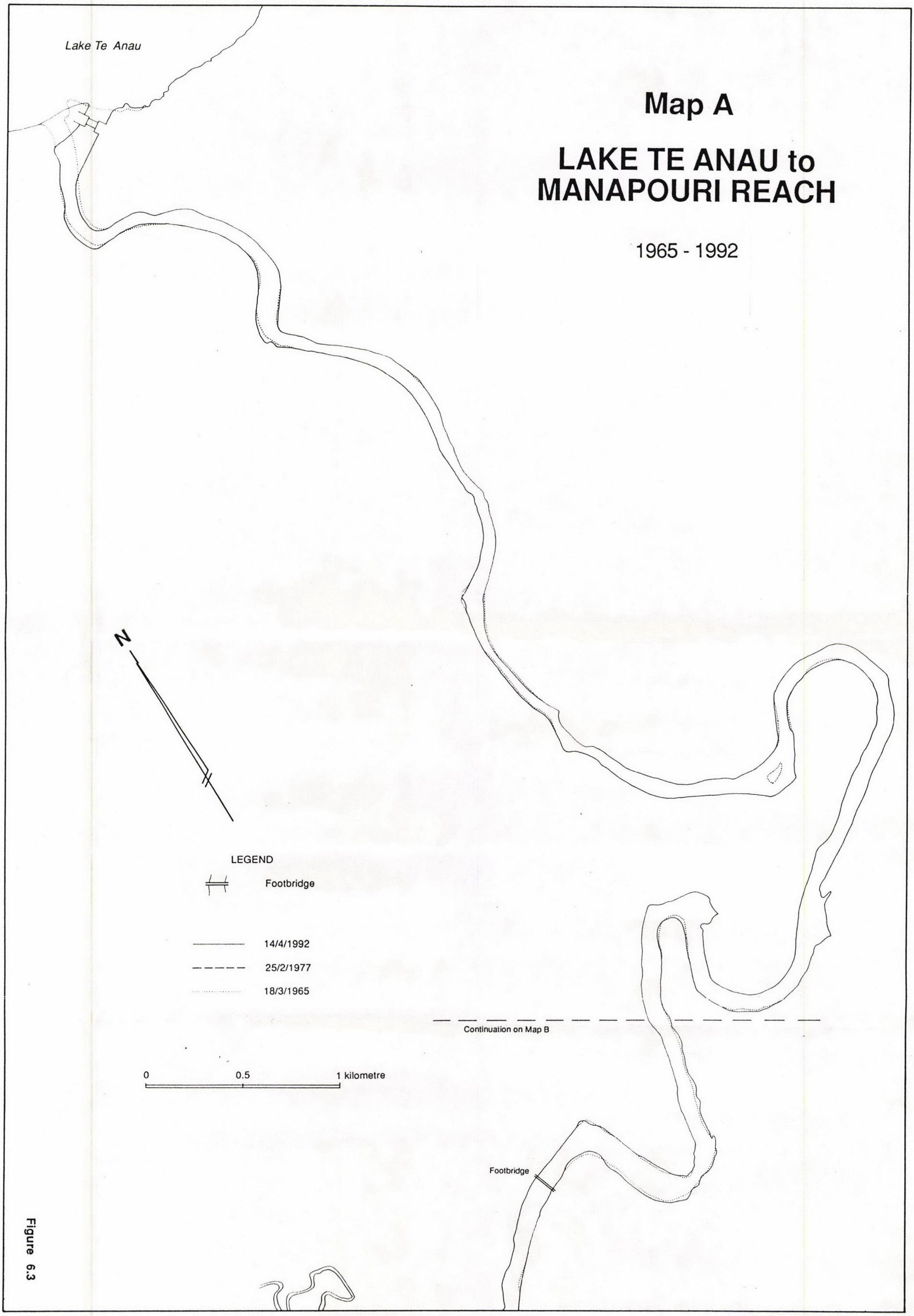

Lake Te Anau
Map A
LAKE TE ANAU to
MANAPOURI REACH
1965 - 1992
N
LEGEND
Footbridge
14/4/1992
25/2/1977
18/3/1965
Continuation on Map B
0
0.5
1 kilometre
Footbridge

Figure 6.3

Map B

LAKE TE ANAU to MANAPOURI REACH

1957 - 1965

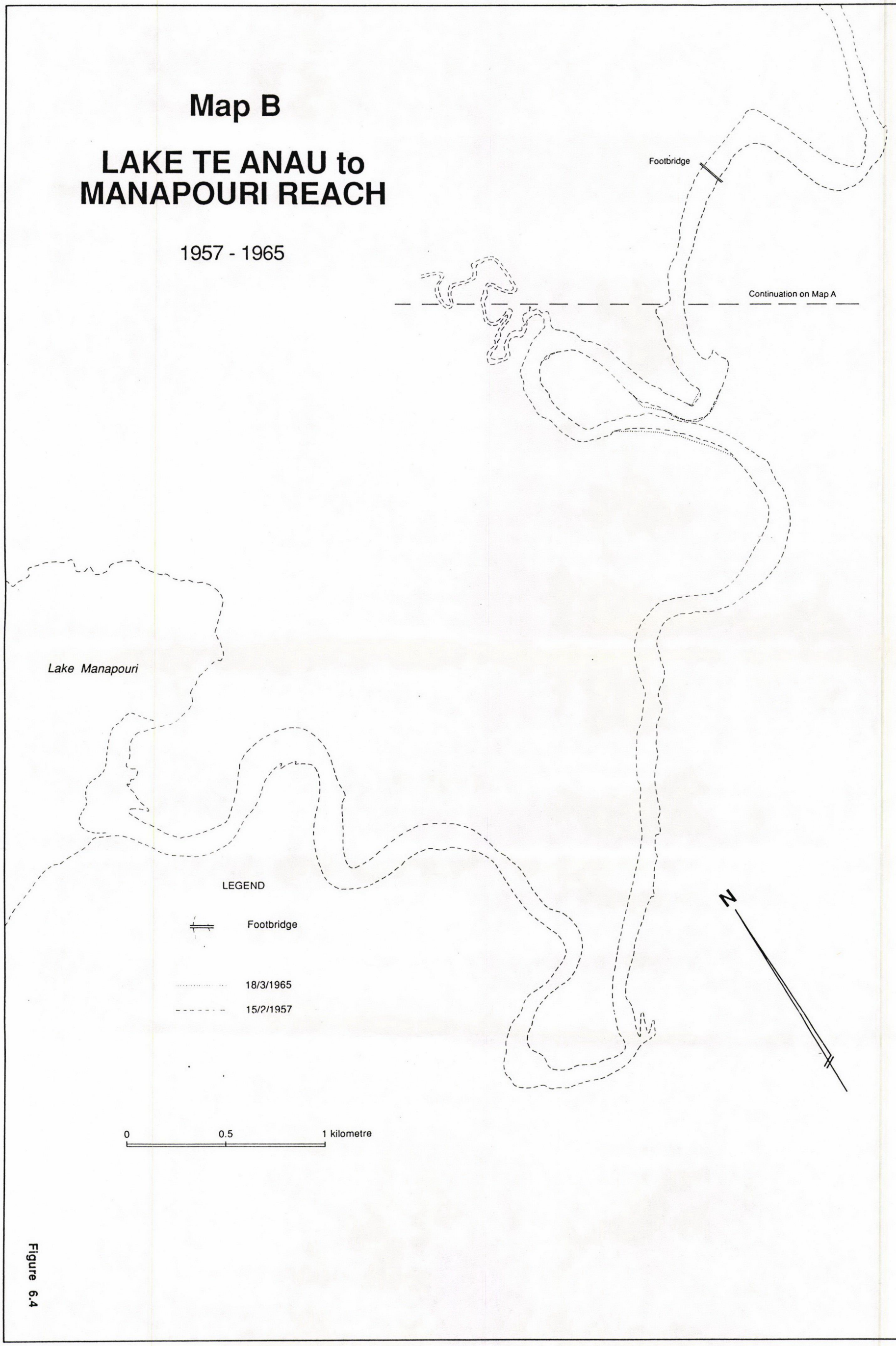


Figure 6.4

Map B

LAKE TE ANAU to MANAPOURI REACH

1965 - 1992

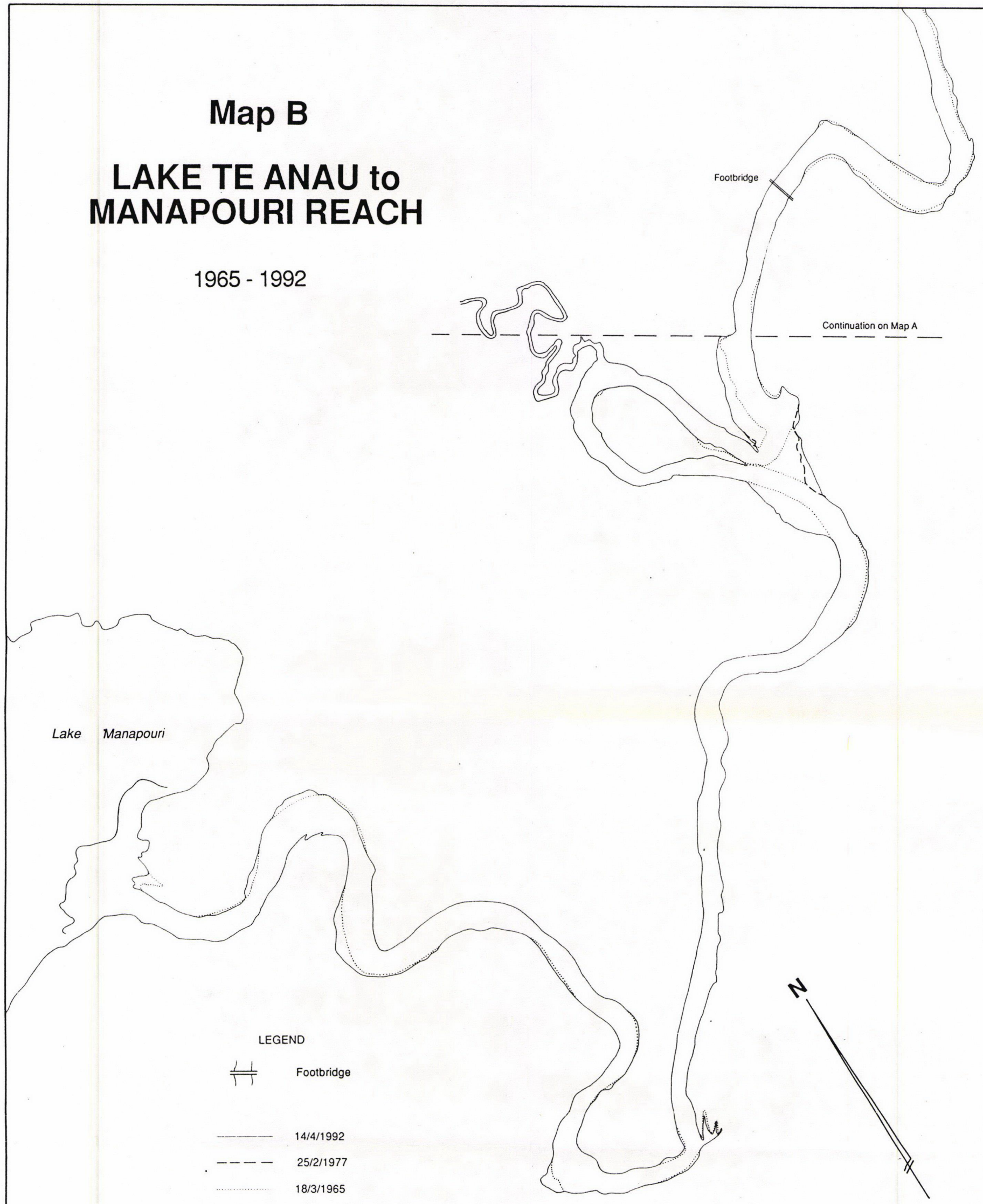


Figure 6.5

6.1.2 Channel adjustments along Yerex reach

Table 6.1.2 Yerex reach, Left and right bank

		Areal adjustments (in m^2 x 1000)		Areal adjustments (in m^2/day)	
	# Days	Erosion	Deposition	Erosion	Deposition
Left bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-25.02.77	4355	0.00	0.00	0.00	0.00
25.02.77-14.04.92	5470	0.50	5.19	0.09	0.95
Right bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-25.02.77	4355	0.00	0.00	0.00	0.00
25.02.77-14.04.92	5470	10.18	1.5	1.86	0.27

No channel adjustments were evident in Yerex reach between 1957-1977. However, between 1977-1992 up to 26 m of lateral erosion occurred along the right bank immediately downstream of the control structure (GR 941158), with consequent deposition of a shallow bench (4-5 m high) on the inside of the bend. Equivalent rates of bend expansion occurred in the next right concave bank downstream (GR 945149), but in this instance there was no concomitant deposition on the convex bank. Beyond this trimming of bends, negligible changes were evident in Yerex reach in the period of record. However, field observations indicate deposition of significant shallow platform deposits (2-3 m high, 30 m wide) on the left bank at GR 949144.

6.1.3 Channel adjustments along Queens reach

Table 6.1.3 Queens reach, Left and right bank

		Areal adjustments (in m^2 x 1000)		Areal adjustments (in m^2/day)	
	# Days	Erosion	Deposition	Erosion	Deposition
Left bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-25.02.77	4355	0.00	0.00	0.00	0.00
25.02.77-14.04.92	5470	0.00	2.00	0.00	0.37
Right bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-25.02.77	4355	0.00	0.00	0.00	0.00
25.02.77-14.04.92	5470	2.5	1.00	0.46	0.18

No changes were evident in Queens reach between 1957-1977. Between 1977-1992 about 2000 m^2 of land was added along the margins of the shallow bend at the head of Queens reach, while around 2,500 m^2 of land was removed along the opposite bank. Extensive 2-3 m high flats upstream of the boat launch have not been modified in the period of air photo record. Large boulders form the bed of the river at the head of the reach. Anecdotal evidence indicates that the manuka cover of the island adjacent to these boulders was stripped in a 1991 flood event.

6.1.4 Channel adjustments along Horseshoe Bend

Table 6.1.4 Horseshoe Bend, Left and right bank

		Areal adjustments (in m^2 x 1000)		Areal adjustments (in m^2/day)	
	# Days	Erosion	Deposition	Erosion	Deposition
Left bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-25.02.77	4355	0.00	0.00	0.00	0.00
25.02.77-14.04.92	5470	1.00	0.00	0.18	0.00
Right bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-25.02.77	4355	0.00	0.00	0.00	0.00
25.02.77-14.04.92	5470	2.00	0.50	0.37	0.09

No changes were evident in Horseshoe Bend between 1957-1977. However, between 1977-1992 trimming occurred along the downstream end of the left bank bend adjacent to the boat launch. Anecdotal evidence infers that materials removed during land clearance adjacent to Queens reach road were deposited as within-channel bars immediately downstream of the bend. However, materials were also supplied to the channel by erosion of the head of the right bank bend opposite the boat launch. This 3-4 m high bank forms the margin of a platform composed of well-banded clast-supported gravels.

6.1.5 Channel adjustments along Rainbow reach

Table 6.1.5 Rainbow reach, Left and right bank

		Areal adjustments (in m^2 x 1000)		Areal adjustments (in m^2/day)	
	# Days	Erosion	Deposition	Erosion	Deposition
Left bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-25.02.77	4355	0.00	0.00	0.00	0.00
25.02.77-14.04.92	5470	19.46	5.00	3.56	0.91
Right bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-25.02.77	4355	0.00	0.00	0.00	0.00
25.02.77-14.04.92	5470	1.50	1.00	0.27	0.18

No changes were evident between 1957-1977 in Rainbow reach. However, between 1977-1992 there was significant erosion along large sections of the bank. Around 1500 m^2 of land was removed from the 10 m high terrace in the bend at GR 946106, giving an estimated volume of removal of 1.5 x 10^4 m^3. An equivalent area of material (but much smaller volume) was removed from the head of the next bend downstream (GR 943113). A large volume of sand has accumulated in the pool opposite this bend, while around 1,000 m^2 of land was added at the downstream half of this bend. Severe trimming took place along the left bank downstream of this bend. Around 7,500 m^2 of land was lost. This bank is only around 4 m high, so the volume of removed material is only twice that observed at the bend upstream (about 3.0 x 10^4 m^3).

The most visually striking erosion in Rainbow reach is in the right concave bank at GR 936102. While this is a natural focal point of erosion, at the outside of a tight bend, rates of erosion have been severe in the 1980's with removal of around 5,000 m^2 of land. Given the terrace height of around 30 m at this location, this translates to volumetric removal of around 1.5 x 10^5 m^3 (ie. an order of magnitude greater than estimates at upstream locations in this reach). Erosion of the opposite right bank and deposition on the inside of the next left bank bend are trivial in relation to erosion of this bend. Apparently ECNZ have some erosion rate data from this site, determined from a series of erosion pegs. This information would be very useful to confirm/refute these air photo interpretations. The section of Rainbow reach adjacent to the footbridge is relatively stable, with erosion restricted to localised trimming of the left bank.

6.1.6 Channel adjustments at Balloon Loop

Table 6.1.6 Balloon Loop, Left and right bank

		Areal adjustments (in m^2 x 1000)		Areal adjustments (in m^2/day)	
	# Days	Erosion	Deposition	Erosion	Deposition
Left bank					
15.02.57-18.03.65	2951	5.44	0.00	1.84	0.00
18.03.65-25.02.77	4355	21.52	0.00	4.94	0.00
25.02.77-14.04.92	5470	11.56	3.26	2.11	0.60
Right bank					
15.02.57-18.03.65	2951	11.71	0.00	3.97	0.00
18.03.65-25.02.77	4355	25.00	0.00	5.74	0.00
25.02.77-14.04.92	5470	0.60	31.70	0.11	5.80

Significant controversy surrounds the history of Balloon Loop cut-off, with earlier reports indicating that the natural progression of the cut-off was "assisted" by dynamite in 1965. Active bank erosion certainly occurred in this reach prior to 1965, as indicated by a 1964 photograph of the right bank at GR 923102 (observed at the cafe in Pearl Harbour). Although occasional slumps along the sand-dominated bank face are evident, rates of bank retreat are negligible.

Between 1957-1965 erosion was pronounced along the left bank at the neck and along the left bank at the downstream outlet of Ballon Loop (beyond Forest Burn). This was the only section of Wairoa reach in which channel adjustments were discerned between 1957-1965. As Waiau River realigned between 1965-1977 the cut-off developed and around 25,000 m^2 of land was eroded from the right bank immediately upstream of the neck. There was concomitant erosion on the left bank where an estimated 21,000 m^2 of land was eroded. Erosion continued along the left bank between 1977-1992, while the right bank stabilised. Indeed, around 31,000 m^2 of land was accumulated along the right bank at the outlet of the cut-off channel. A large bank-attached bar complex developed in the 'gap' left by erosion of the left bank at the neck. This bar is the site for occasional gravel extraction.

6.1.7 Channel adjustments along Boulder reach

Table 6.1.7 Boulder reach, Left and right bank

		Areal adjustments (in m^2 x 1000)		Areal adjustments (in m^2/day)	
	# Days	Erosion	Deposition	Erosion	Deposition
Left bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-14.04.92	9825	4.49	0.00	0.46	0.00
Right bank					
15.02.57-18.03.65	2951	0.00	0.00	0.00	0.00
18.03.65-14.04.92	9825	0.00	0.00	0.00	0.00

As the cut-off developed at Balloon Loop, significant erosion ensued at the head of Boulder reach. While no erosion occurred along the left bank bend (GR 923090) between 1957-1965, around 4500 m^2 of land was lost between 1965-1992. Given an estimated bank height of 40 m, this constitutes around 1.8 x 10^5 m^3 of material. Anecdotal evidence suggests that bend erosion started prior to the emplacement of Lake Te Anau control structure, likely associated with its position opposite the outlet from Balloon Loop initially. Following the cut-off at Balloon Loop, erosion continued as downstream extension of a straightened channel. This process locally increased slope and hence erosive potential, inducing bank erosion downstream. The left bank is presently stabilising. No adjustments were evident in the period of record in the relatively straight reach beyond the initial bend.

6.1.8 Channel adjustments along Downstream of Boulder reach

Table 6.1.8 Downstream of Boulder reach, Left and right bank

		Areal adjustments (in m^2 x 1000)		Areal adjustments (in m^2/day)	
	# Days	Erosion	Deposition	Erosion	Deposition
Left bank					
15.02.57-18.03.65	2951	0	0	0.00	0.00
18.03.65-25.02.77	4355	0	0	0.00	0.00
25.02.77-14.04.92	5470	27.85	2.6	5.09	0.48
Right bank					
15.02.57-18.03.65	2951	0	0	0.00	0.00
18.03.65-25.02.77	4355	0	0	0.00	0.00
25.02.77-14.04.92	5470	15.55	10.36	2.84	1.89

Channel adjustments in Downstream of Boulder reach were restricted to the period 1977-1992, when trimming occurred at ten locations. Processes of channel trimming which induced the sinuous channel outline must have occurred at *rates significantly lower* than those evident in the period following construction of Lake Te Anau control structure. This greater rate of channel adjustments could, however, be associated with the higher flow levels recorded during the 1980's.

Minor trimming of both banks occurred in the bend at GR 687073 (Manapouri 1:63,360), while substantially more erosion occurred along the concave bank at GR 680076. This tight bend has finer grained bank materials than observed elsewhere in this reach. The basal 15 m of the bank are composed of finely laminated blue muddy sands, with

approximately 5 m of sand atop. Erosion of the finer materials induced much greater turbidity in the lower section of Wairoa River. An estimated 1.1 x 10^5 m^3 of material was removed from this site between 1977-1992.

Moving downstream, the 20-25 m high right bank bend at GR 686088 shows no evidence of erosion from the photo record, but field observation indicated several slumped trees with attached roots. The next major site of erosion is the 8 m high concave bank of the bend at GR 678090. An estimated 1.3 x 10^5 m^3 of material was removed from this site between 1977-1992. Erosion was spread over a greater bank length than at the upstream bend, and rates of bank retreat were less localised and hence less dramatic.

An estimated 6.3 x 10^4 m^3 of material was removed from the next concave bank downstream on the right (GR 681098) between 1977-1992. A thin strip of material was laid down at the upstream end of this 8-10 m high bank. An estimated 2.6 x 10^4 m^3 of material was removed from the 8 m high bank in the bend immediately upstream of Lake Manapouri. Erosion was restricted to the bar head, while deposition occurred at the bend apex. Along with the abundant channel trimming along Wairoa River, there has been significant expansion of the delta into Lake Manapouri.

6.1.9 Summary channel adjustments in Wairoa reach, 1957-1992

Summary areal measurements of erosion and deposition and the erosion:deposition ratio are presented in Appendix 1, while the character of channel adjustments is summarised in Appendix 2. Channel adjustments in Wairoa reach were negligible between 1957-1965 and 1965-1977. Discernible changes during both periods were restricted to erosion adjacent to Balloon Loop. Erosion and deposition were much more substantive between 1977-1992 when significant trimming took place. This was particularly evident in Yerex, Rainbow, Balloon Loop and Downstream of Boulder reaches. The overall ratio of areal erosion:deposition of 1.55:1 is very much an underestimate of volumetric change, as the significant bank heights of eroded terraces would constitute a much greater volume of removed material than would the narrow zones of deposition adjacent to the banks. Materials removed from banks in this reach either accumulate on the channel bed, or are flushed through the reach and add to the growing delta into Lake Manapouri.

6.2 Channel adjustments in Lower Redcliff Reach, 1954-1992

Channel adjustments in Lower Redcliff reach were analysed using air photographs dating to 1954/57, 1969, 1982, 1989 and 1992. Three subreaches were identified, namely Upstream of Redcliff, Redcliff confluence zone and Downstream of Redcliff. The boundaries of these various units are indicated on Figure 6.6. Channel adjustments for the various photographic intervals are presented in Figures 6.7 and 6.8.

6.2.1 Channel adjustments in Upstream of Redcliff subreach

Table 6.2.1.1 Upstream of Redcliff, Left bank

Upstream of Redcliff Left bank		Areal adjustments (in m^2 x 1000)		Areal adjustments in m^2/day	
	# days	Erosion	Deposition	Erosion	Deposition
28.01.54 / 15.02.57 to 12.02.69	5490	4.50	10.80	0.82	1.97
12.02.69 to 12.08.82	4926	0.00	24.70	0.00	5.01
12.08.82 to 04.04.89	2425	0.00	9.10	0.00	3.75
04.04.89 to 14.04.92	1052	2.00	81.20	1.90	77.19

The left bank upstream of Redcliff confluence was relatively stable between 1954-1969. Adjustments were restricted to a small erosional zone at GR 935917 and an accumulation zone on the inside of a shallow bend in a secondary channel (GR 919899). Between 1969-1982, 24,700 m^2 of land was added to the left bank as a small island became bank-attached adjacent to the site of erosion in the 1954-1969 interval. The point bar surface at GR 928914 stabilised, with increased vegetation cover and potentially greater deposition. Gradual accumulation continued between 1982-1989, with infilling of a left bank secondary channel at GR 919900. No other modifications were evident during this interval. Infilling and stabilisation of this secondary channel proceeded at a much greater rate between 1989-1992.

Table 6.2.1.2 Upstream of Redcliff, Right bank

Upstream of Redcliff Right bank		Areal adjustments (in m^2 x 1000)		Areal adjustments in m^2/day	
	# days	Erosion	Deposition	Erosion	Deposition
28.01.54 / 15.02.57 to 12.02.69	5490	26.50	0.00	4.83	0.00
12.02.69 to 12.08.82	4926	2.30	36.30	0.47	7.37
12.08.82 to 04.04.89	2425	2.00	7.70	0.82	3.18
04.04.89 to 14.04.92	1052	0.00	3.50	0.00	3.33

Erosion along the right bank between 1957-1969 was restricted to the island immediately upstream of Redcliff confluence (GR 917902 to 913892). Most removal was associated with reworking of alluvial flats and reoccupation of former channel positions. Since 1969 there has been a marked transition to a predominantly depositional regime. Rate of deposition was particularly high between 1969-1982. Most deposition occurred at locations of former bank erosion, with replacement of materials on alluvial flats and in formerly eroded channels.

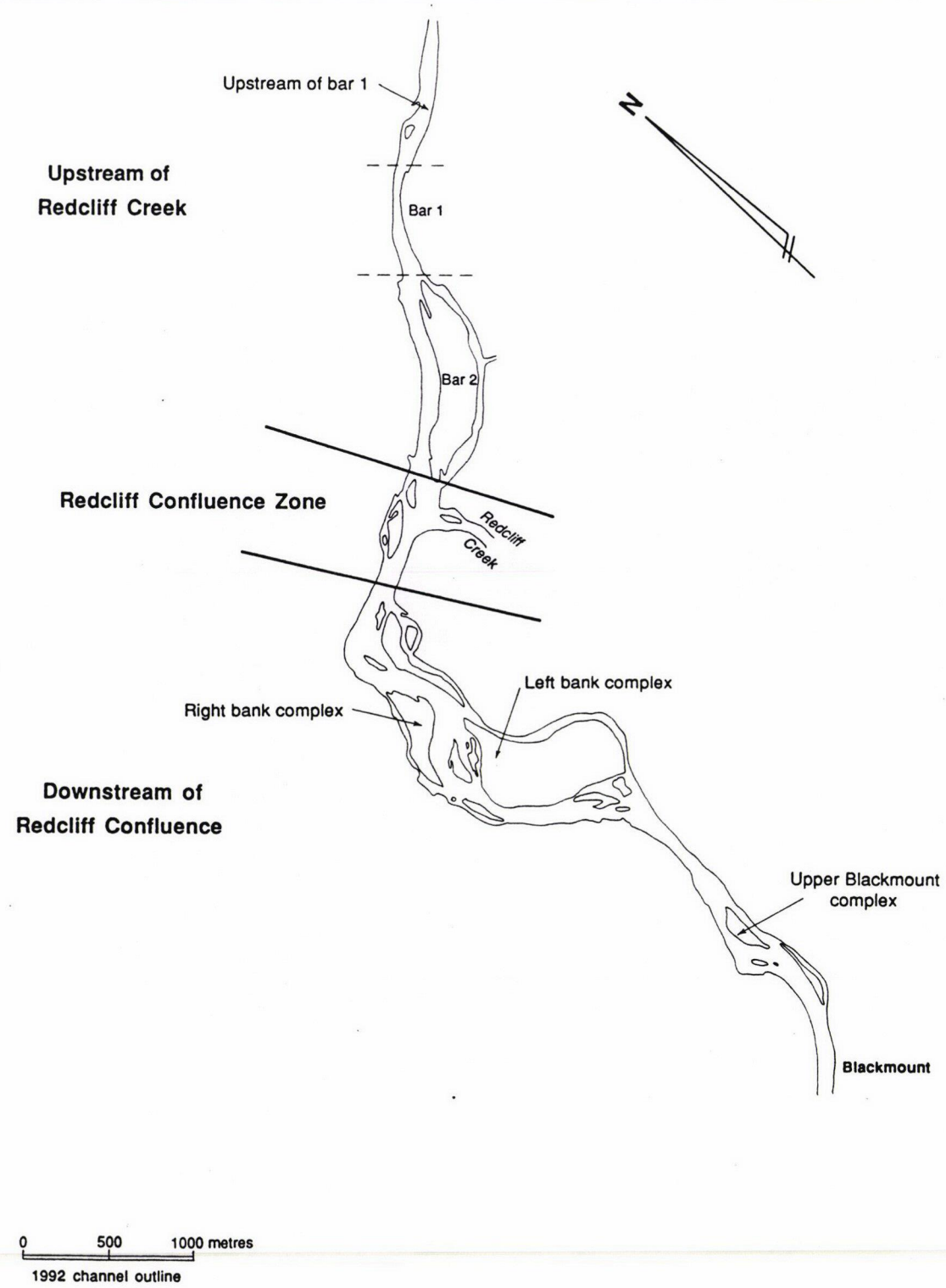


Figure 6.6 Reach designation in Lower Redcliff Reach.

LOWER REDCLIFF REACH

1954 - 1969

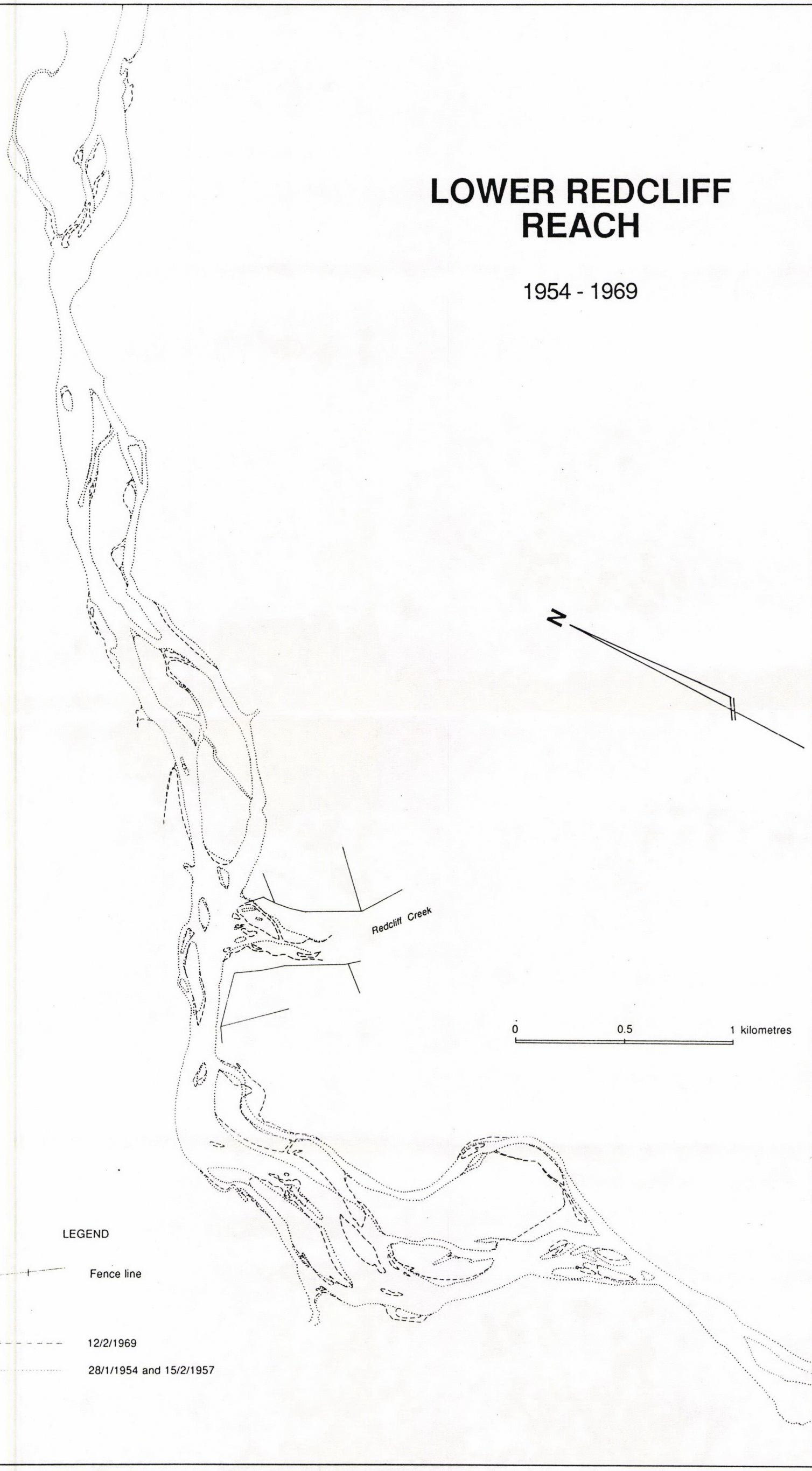


Figure 6.7

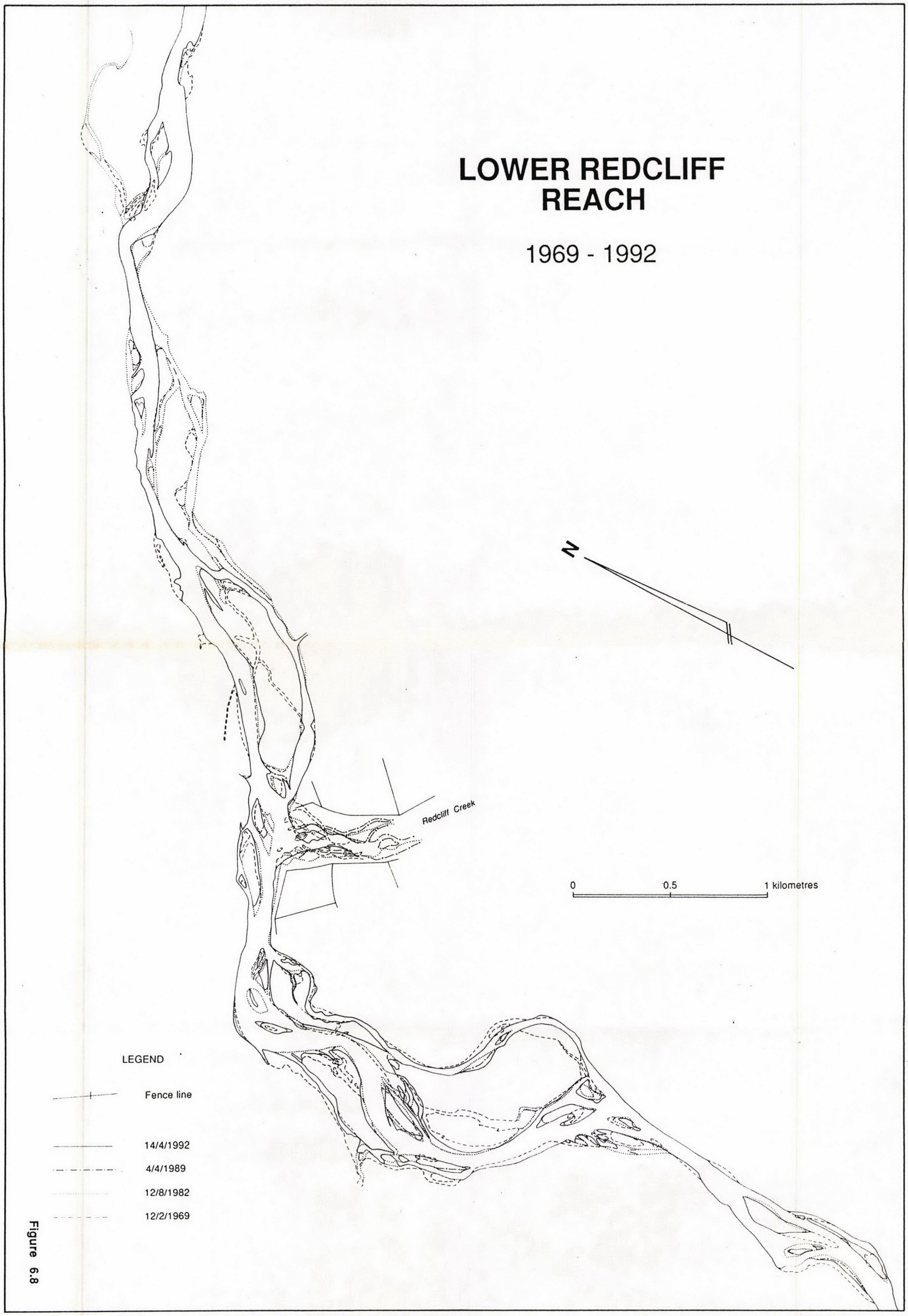

LOWER REDCLIFF REACH
1969 - 1992
N
0
0.5
1 kilometres
Redcliff Creek
LEGEND
Fence line
14/4/1992
4/4/1989
12/8/1982
12/2/1969

Figure 6.8

Table 6.2.1.3 Upstream of Redcliff, Within-channel

	# days	Areal adjustments (in m^2 x 1000) Erosion	Deposition	Areal adjustments in m^2/day Erosion	Deposition
Upstream of bar 1					
28.01.54 / 15.02.57 to 12.02.69	5490	4.00	4.50	0.73	0.82
12.02.69 to 12.08.82	4926	1.00	5.60	0.20	1.14
12.08.82 to 04.04.89	2425	1.50	1.00	0.62	0.41
04.04.89 to 14.04.92	1052	0.00	(Bank)	0.00	?
Bar 1					
28.01.54 / 15.02.57 to 12.02.69	5490	8.50	0.00	1.55	0.00
12.02.69 to 12.08.82	4926	17.80	9.00	3.61	1.83
12.08.82 to 04.04.89	2425	0.50	0.50	0.21	0.21
04.04.89 to 14.04.92	1052	0.00	16.80	0.00	15.97
Bar 2					
28.01.54 / 15.02.57 to 12.02.69	5490	6.50	3.00	1.18	0.55
12.02.69 to 12.08.82	4926	5.00	18.80	1.02	3.82
12.08.82 to 04.04.89	2425	3.50	4.00	1.44	1.65
04.04.89 to 14.04.92	1052	0.00	4.00	0.00	3.80

The river section upstream of bar 1 refers to a 1 km stretch of Waiau River upstream of GR 926909. Between 1954-1969 channel adjustments in this section of Waiau River were restricted by numerous small zones of erosion and deposition, as small channels reworked bar surfaces. Similar processes continued between 1969-1992, but the relative proportion of deposition increased markedly.

Bar 1 is a mid-channel compound bar that extends between GR 926909 to 919899. Between 1954-1969 nine sites of trimming were recorded adjacent to Bar 1. Between 1969-1982 the bar was dissected by a chute channel, but this channel was subsequently refilled between 1989-1992. Sites of erosion in 1954-1969 were sites of deposition in 1969-1982, the areas covered being almost equal. Between 1989-1992 this bar became attached to the left bank.

Bar 2 is a mid-channel compound bar located upstream of Redcliff confluence between GR 918900 and 814888. Between 1954-1969 this bar was eroded at its bar head, trimmed at its margins and a former dissection channel was reoccupied. Style of bar development was reversed between 1969-1982, when dissection channels infilled. However, some trimming occurred at the bar tail. Localised erosion occurred at the bar head between 1982-1889, but an equivalent area of material was added to the bar tail. Downstream progradation of the bar continued between 1989-1992, when a small bar became incorporated into this larger feature.

6.2.2 Channel adjustments in Redcliff confluence zone

Table 6.2.2.1 Redcliff confluence zone, Left bank, right bank and within-channel zone

Redcliff confluence zone		Areal adjustments (in m^2 x 1000)		Areal adjustments in m^2/day	
	# days	Erosion	Deposition	Erosion	Deposition
Left bank					
28.01.54 / 15.02.57 to 12.02.69	5490	15.70	8.40	2.86	1.53
12.02.69 to 12.08.82	4926	22.40	9.00	4.55	1.83
12.08.82 to 04.04.89	2425	8.00	14.00	3.30	5.77
04.04.89 to 14.04.92	1052	1.00	2.50	0.95	2.38
Right bank					
28.01.54 / 15.02.57 to 12.02.69	5490	0.00	0.50	0.00	0.09
12.02.69 to 12.08.82	4926	0.00	0.00	0.00	0.00
12.08.82 to 04.04.89	2425	0.00	0.00	0.00	0.00
04.04.89 to 14.04.92	1052	0.00	0.00	0.00	0.00
Within channel					
28.01.54 / 15.02.57 to 12.02.69	5490	1.20	18.50	0.22	3.37
12.02.69 to 12.08.82	4926	0.50	12.00	0.10	2.44
12.08.82 to 04.04.89	2425	0.00	5.00	0.00	2.06
04.04.89 to 14.04.92	1052	9.50	0.00	9.03	0.00

Between 1954-1969 pronounced erosion occurred along the left bank of Redcliff Creek, with concomitant deposition within-channel and adjacent to the right bank. Between 1969-1982 erosion continued at the confluence, whereas accretion occurred 200 m upstream. While some of the secondary channels at the confluence zone were abandoned, erosion of within-channel bar deposits continued.

Areas of bank erosion and deposition switched in the period 1982-1989, with deposition along the left bank of Redcliff Creek at the confluence, and erosion upstream. This switch reflected a shift in the position of Redcliff Creek itself, which reoccupied a secondary channel along the right hand side of its active channel zone. Substantial within-channel deposition occurred at this time. A complex sequence of channel changes occurred between 1989-1992, as Redcliff Creek switched position in the confluence zone. Shifts in the position of Redcliff Creek modified the nature of within-channel processes in Waiau River. Between 1954-1969 small deposition occurred adjacent to vegetated bars. This process accelerated between 1969-1982, and to a lesser extent between 1982-1989, but the period 1989-1992 was characterised by substantial erosion. Virtually no changes were evident along the right bank of Waiau River, indicating that tributary impacts of Redcliff Creek were restricted to the within-channel zone and areas downstream.

6.2.3 Channel adjustments in Downstream of Redcliff confluence subreach

Table 6.2.3.1 Downstream of Redcliff confluence, Left bank

Downstream of Redcliff Left bank		Areal adjustments (in m^2 x 1000)		Areal adjustments in m^2/day	
	# days	Erosion	Deposition	Erosion	Deposition
28.01.54 / 15.02.57 to 12.02.69	5490	20.30	0.00	3.70	0.00
12.02.69 to 12.08.82	4926	2.50	9.50	0.51	1.93
12.08.82 to 04.04.89	2425	0.00	2.00	0.00	0.82
04.04.89 to 14.04.92	1052	4.00	2.00	3.80	1.90

Between 1954-1969 a number of locations along the left bank of Waiau River eroded as the adjacent secondary channel expanded its margins. Erosion was especially evident at the head of the large compound point bar immediately downstream of Redcliff Creek (GR 906882), where around 17,000 m^2 of land was removed. This erosional trend was reversed between 1969-1982, when the left bank of the secondary channel experienced deposition at three points. In the period following 1982 there have been virtually no subsequent channel modifications, other than localised changes at the entrance of Blackmount-Mangapiri reach.

Table 6.2.3.2 Downstream of Redcliff confluence, Right bank

Downstream of Redcliff Right bank		Areal adjustments (in m^2 x 1000)		Areal adjustments in m^2/day	
	# days	Erosion	Deposition	Erosion	Deposition
28.01.54 / 15.02.57 to 12.02.69	5490	4.50	4.00	0.82	0.73
12.02.69 to 12.08.82	4926	10.60	123.40	2.15	25.05
12.08.82 to 04.04.89	2425	2.90	4.50	1.20	1.86
04.04.89 to 14.04.92	1052	3.50	1.50	3.33	1.43

Between 1954-1969 rates of erosion and deposition were roughly equivalent along the right bank downstream of Redcliff Creek. Areas of adjustment were negligible, and were restricted to the section downstream of the concave bank 1 km downstream of Redcliff confluence (GR 903880). Between 1969-1982, however, erosion upstream of this point removed 1,000 m^2 of land. A further 1,500 m^2 of land was removed between 1989-1992. Given a bank height of 2.5 m at this location, this equates to volumes of material of 2,500 m^3 between 1969-1982 and 3,750 m^3 between 1989-1992 and average rates of removal of material of 3.76 x 10^2 m^3/year and 1.3 x 10^3 m^3/year respectively. Of greater note, however, is the increase in rate of deposition between 1969-1982, when over 120,000 m^2 of land was added to the bank. Attachment of a large mid-channel bar complex to the right bank could reflect either channel contraction or additional deposition (aided by materials supplied by erosion of the upstream terrace and from Redcliff Creek). Since 1982 negligible changes occurred along the right bank in this reach.

Table 6.2.3.3.1 Downstream of Redcliff confluence, Within-channel

Downstream of Redcliff confluence Within-channel	# days	Areal adjustments (in m^2 x 1000) Erosion	Deposition	Areal adjustments in m^2/day Erosion	Deposition
Left bank complex					
28.01.54 / 15.02.57 to 12.02.69	5490	68.70	33.80	12.51	6.16
12.02.69 to 12.08.82	4926	17.20	88.50	3.49	17.97
12.08.82 to 04.04.89	2425	31.50	3.50	12.99	1.44
04.04.89 to 14.04.92	1052	10.00	5.80	9.51	5.51
Right bank complex					
28.01.54 / 15.02.57 to 12.02.69	5490	20.10	7.50	3.66	1.37
12.02.69 to 12.08.82	4926	0.00	(Bank)	0.00	?
12.08.82 to 04.04.89	2425	8.50	0.00	3.51	0.00
04.04.89 to 14.04.92	1052	3.50	1.20	3.33	1.14
Upper Blackmount complex					
28.01.54 / 15.02.57 to 12.02.69	5490	14.80	1.50	2.70	0.27
12.02.69 to 12.08.82	4926	4.00	16.50	0.81	3.35
12.08.82 to 04.04.89	2425	0.00	3.50	0.00	1.44
04.04.89 to 14.04.92	1052	8.00	2.70	7.60	2.57

Three within-channel complexes are differentiated downstream of Redcliff confluence, namely a major complex separated from the left bank by a secondary channel, a substantial complex separated from the right bank by a secondary channel and a smaller complex at the entrance to Blackmount-Mangapiri reach. These are referred to as the left bank complex, right bank complex and Upper Blackmount complex respectively.

Areas of channel adjustment adjacent to the left bank bar complex were considerably greater than observed elsewhere in this reach, indicating that the within-channel zone immediately downstream of Redcliff confluence is an area of intense activity. Between 1954-1969 trimming was dominant, with removal of around 29,000 m^2 of land at the bar head and around 24,000 m^2 of land at the bar tail. Deposition of longitudinal bars was also prominent. In the following period, between 1969-1982, one of the channels dividing this bar complex was abandoned. Indeed, rate of deposition exceeded erosion by five times whereas erosion exceeded deposition by two times in the preceding interval. Between 1982-1989, however, the roles of erosion and deposition reversed once more, with erosion of various units at the head of the bar complex. Several small bars stabilised in this and the following interval.

Between 1954-1969 significant erosion occurred at the head of the right bank bar complex, while the bar tail was trimmed. This trend was dramatically reversed between 1969-1982 when this bar complex became attached to the right bank. Over 100,000 m^2 of land was added at this time (included in the right bank analysis). Relatively little change occurred between 1982-1989, although some erosion was evident at the bar head, where a chute channel initiated. Trimming at the head and tail of this bar complex continued into the 1989-1992 interval.

The erosion/sedimentation balance was tilted markedly towards erosion adjacent to Upper Blackmount bar complex between 1954-1969, with wholesale destruction of a series of small longitudinal bars. As noted for other bars downstream of Redcliff, however, a reversal in roles took place between 1969-1982, when deposition became dominant. This primarily took the form of within-channel bars of similar character to those removed in the earlier

period. This depositional framework continued into the 1989-1992 period, but significant erosion of bars at the head of Blackmount reach (GR 914856) occurred in this period.

6.2.4 Summary channel adjustments data, Lower Redcliff reach

Summary areal measurements of erosion and deposition over the differing photographic intervals are presented in Appendix 1. Between 1954-1969 erosion was dominant along both banks and in the within-channel zone. Erosion was especially prominent on the left bank bar complex downstream of Redcliff confluence. A distinct shift in the erosion/deposition balance occurred between 1969-1982. Deposition became dominant and a large bar complex downstream of Redcliff confluence became attached to the right bank associated with channel contraction and a reduction in channel multiplicity. Between 1982-1989 channel adjustments were relatively trivial, although some erosion occurred along margins of the left bank complex downstream of Redcliff confluence. Erosion downstream of Redcliff confluence continued between 1989-1992. During this interval, erosion of within-channel bars was balanced by an equal area of within-channel deposition. However, deposition was predominant upstream of Redcliff between 1989-1992, when channel abandonment resulted in attachment of a substantial bar complex to the left bank.

6.3 Channel adjustments in Wairaki reach

Eleven sets of air photographs were used to evaluate channel adjustments in Wairaki reach, including three sets prior to 1969, two sets in the 1970's, five sets in the 1980's and the 1992 set. Four subreaches were differentiated for the channel adjustments analysis (Figure 6.9). *Upstream of Wairaki* subreach extends from the compound point bar at the exit of Mangapiri subreach to Wairaki confluence (Section 6.3.1). In this subreach the left bank is effectively sheltered by a large mid-channel bar complex, whereas the right bank is transitional from a compound point bar through an eroding concave bank to a second compound point bar. These three components of the right bank are analysed separately. The within-channel zone in Upstream of Wairaki subreach is differentiated into two zones, namely those mid-channel features associated with the large left-bank bar complex and those within-channel units adjacent to the compound point bar just upstream of Wairaki confluence. *Wairaki confluence zone* was differentiated into two components, namely the left bank and within-channel zones (Section 6.3.2). The left bank analysis includes channel adjustments along the lower 500 m of both banks of Wairaki River itself.

The active channel zone and alluvial flats are extensive in *Downstream of Wairaki* subreach. Significant channel adjustments took place in this subreach, which is also coincident with Dean Burn confluence. A few hundred metres downstream of Dean Burn confluence bedrock constrains both banks. The final subreach of Wairaki reach is the 1 km reach *Downstream of bedrock constriction*, where negligible changes have occurred throughout the period of record.

6.3.1 Channel adjustments in Upstream of Wairaki confluence subreach

Table 6.3.1.1 Upstream of Wairaki confluence, Left bank

Upstream of Wairaki confluence Left bank		Areal adjustments (in m^2 x 1000)		Areal adjustments in m^2/day	
	# days	Erosion	Deposition	Erosion	Deposition
28.03.47 / 03.12.47 to 10.03.63	5822	1.00	0.50	0.17	0.09
10.03.63 to 12.02.69	2164	0.00	18.90	0.00	8.73
12.02.69 to 31.05.74	1933	0.00	9.60	0.00	4.97
31.05.74 to 11.02.78	1352	3.00	0.00	2.22	0.00
11.02.78 to 14.04.80	791	0.00	60.10	0.00	75.98
14.04.80 to 12.08.82	850	0.00	13.30	0.00	15.65
12.08.82 to 07.02.84	544	157.20	0.00	288.97	0.00
07.02.84 to 21.06.84	134	3.50	121.27	26.12	905.00
21.06.84 to 04.04.89	1747	5.40	20.35	3.09	11.65
04.04.89 to 14.04.92	1052	10.10	4.00	9.60	3.80

Between 1947-1963 the 3 km left bank section of Waiau River above Wairaki confluence was essentially stable. In the following six years (1963-1969) deposition occurred adjacent to the concave bank at the head of the reach while the valley-marginal secondary channel at GR 987620 partially infilled. Infilling increased between 1969-1974. No erosion was evident at this time, but part of the accumulation on the concave bank at the head of the reach was removed between 1974-1978.

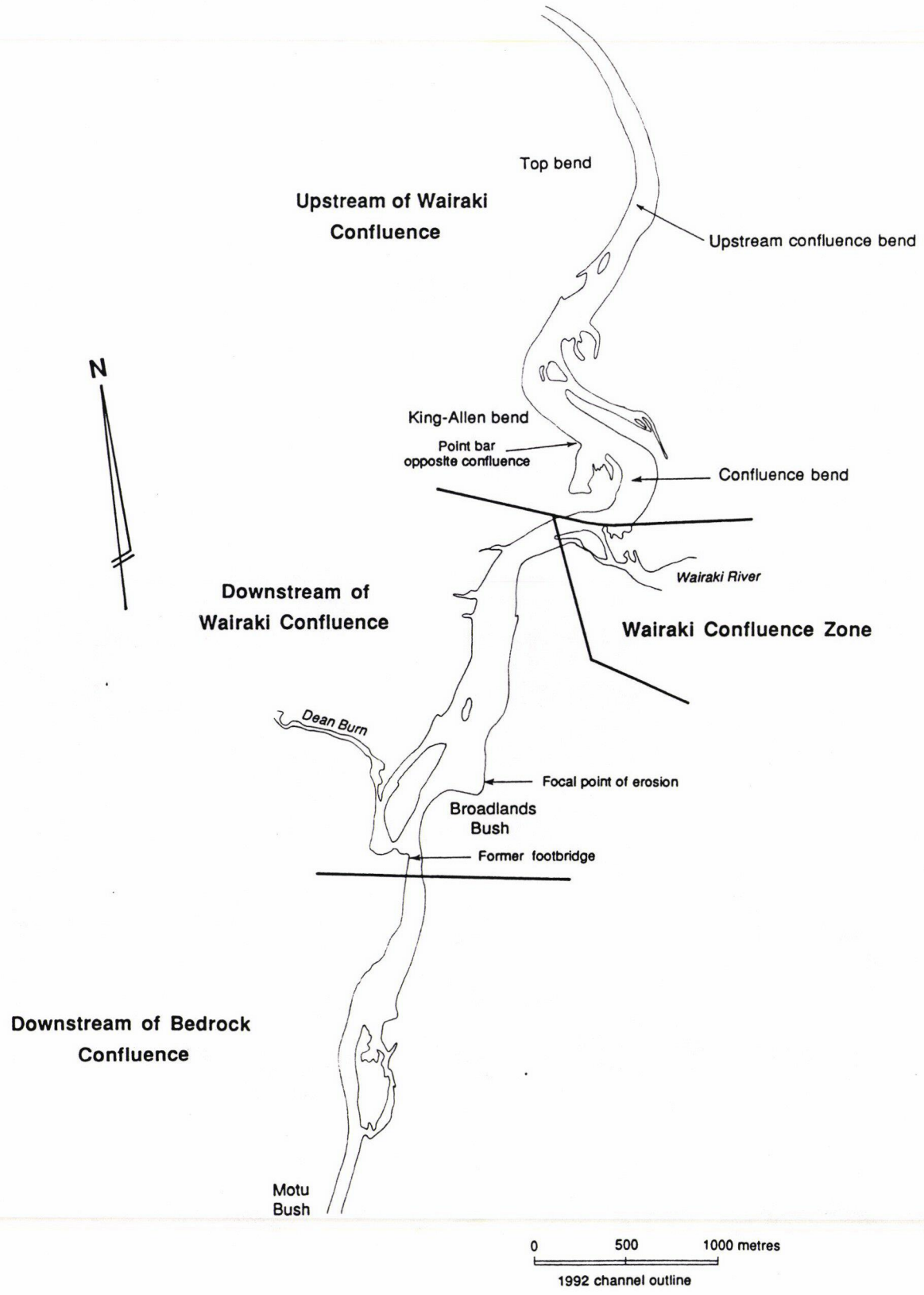


Figure 6.9 Reach designation in Wairaki Reach.

WAIRAKI REACH

1947 - 1969



Figure 6.10

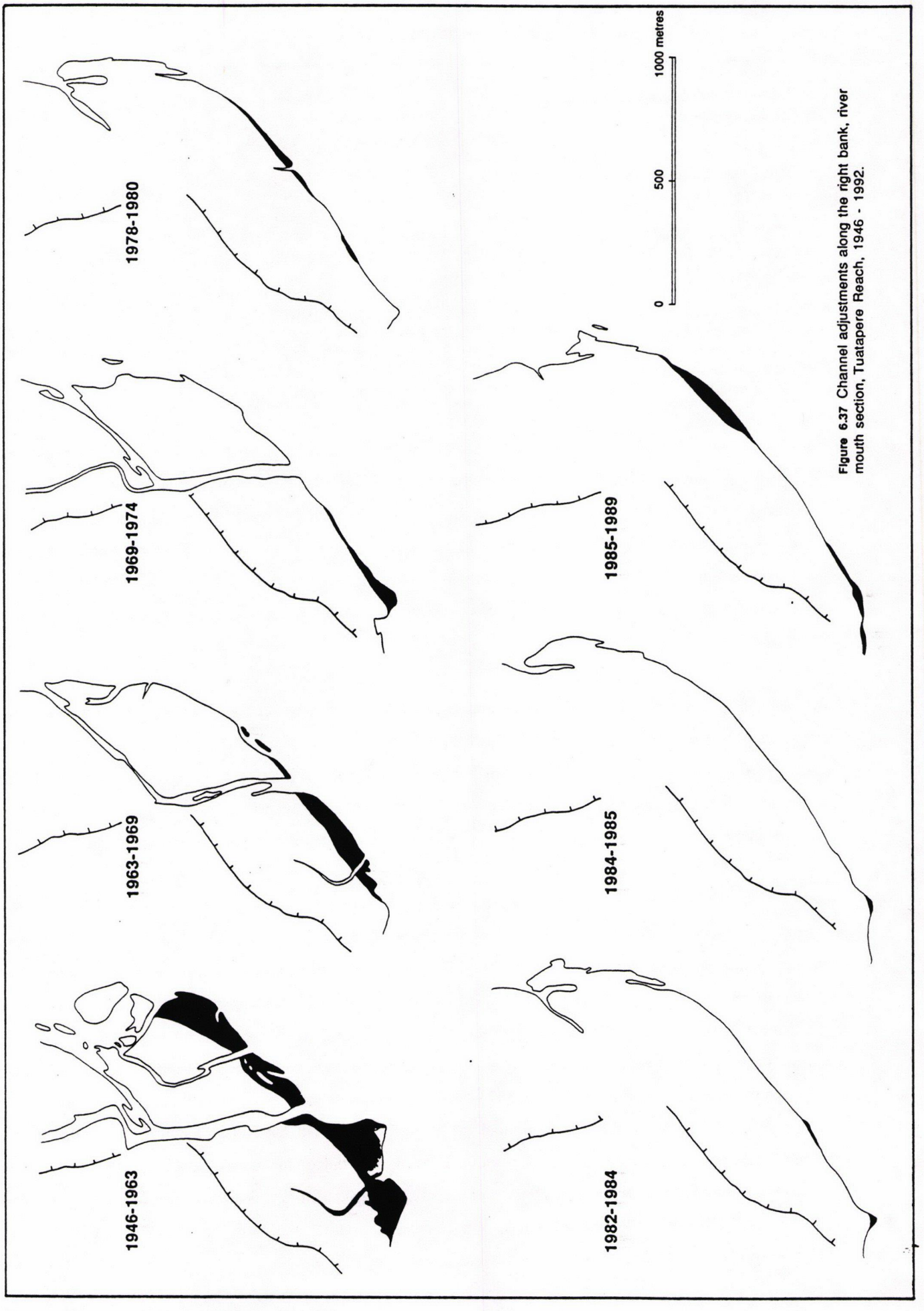


Figure 6.37 Channel adjustments along the right bank, river mouth section, Tuatapere Reach, 1946 - 1992.

Table 6.6.4.3 Downstream of bend break, Within-channel

Tuatapere reach Downstream of bend break, within-channel Mouth complex	# days	Areal adjustments (in m^2 x 1000)		Areal adjustments in m^2/day	
		Erosion	Deposition	Erosion	Deposition
22.03.46 / 28.03.47 to 10.03.63	6193	35.70	84.40	5.76	13.63
10.03.63 to 12.02.69	2164	1.80	46.80	0.83	21.63
12.02.69 to 07.07.74	1980	2.00	129.40	1.01	65.35
07.07.74 to 03.03.75	229	0.00	7.90	0.00	34.50
03.03.75 to 25.02.77	724	2.20	14.90	3.04	20.58
25.02.77 to 11.02.78	351	15.80	14.60	45.01	41.60
11.02.78 to 14.04.80	791	5.40	24.00	6.83	30.34
14.04.80 to 12.08.82	850	11.00	32.60	12.94	38.35
12.08.82 to 21.06.84	678	53.40	2.30	78.76	3.39
21.06.84 to 08.10.85	474	34.30	14.90	72.36	31.43
08.10.85 to 04.04.89	1275	27.60	31.40	21.65	24.63
04.04.89 to 14.04.92	1052	0.00	5.20	0.00	4.94

Within-channel erosion and deposition were pronounced in the 1.5 km section upstream of the river mouth between 1946-1963. Several mid-channel bars were completely eroded, but a series of similar-shaped bars were deposited approximately 150 m to the west as the channel position shifted, eroding the right bank. Significant deposition also occurred as mid-channel bars adjacent to the right bank at the head of the reach. These mid-channel features subsequently became part of a compound point bar. Substantial accretion occurred adjacent to the mid-channel bars between 1963-1969. In general this deposition took the form of secondary channel infilling and accretion to the western bar margins.

A dramatic adjustment in the erosion/sedimentation regime was evident between 1969-1974, as virtually no erosion of within-channel bars occurred, but extensive deposition took place. A mid-channel bar was deposited at the head of the reach, lateral expansion of the right bank occurred downstream of the concave bank at the head of the reach (ie. incipient compound point bar development), headward extension of a diagonal bar occurred in mid-reach, and secondary channel infilling and accretion were evident along the right margin of the mid-channel bar complex at the river mouth.

Between 1974-1975 the rate of deposition was reduced, but erosion was barely evident. Deposition was generally restricted to channel infilling adjacent to the left margin of the diagonal bar in mid reach. Localised deposition continued to dominate over erosion between 1975-1977. A series of small depositional units were added to most of the mid-channel bar complexes. A large part of the tail of the tongue-shaped mid-channel unit at the head of the reach (deposited between 1969-1974) was eroded between 1977-1978. During this interval there was significant infilling of secondary channels on these mid-channel bar complexes. The material removed from the tongue-shaped bar at the head of the reach was essentially replaced between 1978-1980. Infilling of secondary channels continued during this period, and the channel adjacent to the diagonal bar in mid-reach was abandoned, so that this bar feature became attached to the left bank. Narrow strips of land were eroded from the left margin of the tongue-shaped feature and the right margin of the former diagonal bar. The downstream margin of the tongue-shaped feature at the head of the reach was eroded once more between 1980-1982. During this interval the channel separating this feature from the left bank was largely infilled. A number of small mid-channel bars were deposited at the river mouth.

The period 1982-1984 was largely erosional, with continued trimming of the tail of the tongue-shaped feature and the former diagonal bar. The channel that separated this diagonal bar from the left bank was reactivated once more. However, most erosion occurred along the downstream margin of the large mid-channel bar complex at the river mouth, where over 32,000 m^2 of land was lost. Trimming of the tongue-shaped feature at the head of the reach continued between 1984-1985. Much of the land lost between the diagonal bar and the left bank was replaced, while deposition occurred against the right margin of the diagonal bar. A large strip of material was deposited adjacent to the left margin of the large mid-channel bar complex at the river mouth. However, numerous smaller mid-channel bars within the main channel were completely eroded.

By 1985 the alignment of Waiau River had stabilised in the lower reach. The channel adopted a more sinuous pattern in which the primary channel was more pronounced. Between 1985-1989 there was significant erosion of the left and right banks at the outside of concave banks, with deposition on the right bank compound point bar. Within-channel changes were relatively small, and were largely restricted to deposition at the margins of the large mid-channel bar complex. Over 15,000 m^2 of land were added to the downstream margin of this complex. Negligible channel modifications were evident between 1989-1992.

6.6.5 Summary channel adjustments in Tuatapere reach, 1946-1992

Summary channel adjustments data in Tuatapere reach are presented for each photographic interval in Appendix 1 and the character of adjustments is summarised in Appendix 2. While erosion was dominant over deposition along the banks between 1946-1963, deposition was dominant in the within-channel zone. Erosion was focussed along the left and right banks alternately, reflecting the broadly sinuous nature of the active channel zone. Erosion was particularly severe along the left bank in Carr's to mid-break reach and along the right bank immediately upstream of the river mouth. Deposition rate was highest in the within-channel zone in Mid-break to bend break subreach. The spatial pattern of channel changes between 1963-1969 was similar to that shown for 1946-1963. Erosion was dominant along the banks, while deposition dominated in the within-channel zone. Localised erosion continued along the left bank in Carr's to mid break reach and along the right bank immediately upstream of the river mouth.

A dramatic adjustment in the erosion/sedimentation regime occurred between 1969-1974. Deposition was dominant throughout the reach, especially in the within-channel zone. Erosion was localised, and was especially pronounced along the left bank in Carr's to mid-break reach. Negligible channel adjustments were evident between 1974-1975 and 1975-1977, although deposition dominated over erosion. Deposition continued to be dominant between 1977-1978, but erosion recurred along the left bank in Carr's to mid-break reach. Deposition was clearly dominant over erosion between 1978-1980. Erosion was negligible other than along the right bank upstream of the river mouth, while deposition was prominent in the within-channel zone in Mid-break to bend break reach and adjacent to the left bank upstream of the river mouth. Between 1980-1982 within-channel processes continued to dominate over bank-marginal processes. While erosion dominated along the banks, deposition was dominant in the within-channel zone. Significant erosion continued along the left bank throughout the reach, while erosion of the concave bank at Carr's property was reactivated.

Between 1982-1984 erosion dominated over deposition throughout Tuatapere reach, especially along the left bank and in the within-channel zone. A notable shift occurred in the location of erosion along banks. Upstream of Carr's subreach erosion was dominant along the left bank, whereas between 1946-1963 erosion had been dominant along the right bank. A similar shift in location of erosion occurred in Carr's to mid-break, where erosion shifted from the left bank to the right bank. This transition reflects the downstream shift in the pattern of bends

Between 1984-1985 erosion continued to dominate in the within-channel zone, especially Upstream of Carr's and immediately upstream of the river mouth. Rate of deposition was high along the left bank at the river mouth, while erosion continued along the right bank. This reflects the gradual westward shift in the position of the river mouth over the period of record. High rates of erosion and deposition were evident between 1985-1989 although erosion dominated over deposition. Erosion was especially severe along the left bank Upstream of Carr's (ie. the opposite bank to erosional activity between 1946-1963) and along the right bank between Mid break and bend break (again opposite to the trend shown between 1946-1963). Erosion was particularly active in the within-channel zone, especially Upstream of Carr's, as flood channels dissected the large bar complex. Between 1989-1992 a return to depositional dominance was recorded. This was especially pronounced in the within-channel zone.

7.0 Relationship between channel adjustments and the hydrologic record

In this section the detailed record of channel adjustments described for various reaches in Section 6 is related to the hydrologic record. Discharge data are used from Sunnyside and Tuatapere gauging stations. Unfortunately this data only date to 1964, whereas the air photograph record of channel adjustments dates back to 1946. The character of flood events and their variability over differing time intervals determined by the air photograph record is undertaken in Section 7.1. The daily discharge relationship of all flood events > 800 m^3s^{-1} at Tuatapere or > 600 m^3s^{-1} at Sunnyside is used to assess whether individual floods are upper and/or lower catchment events.

The relationship between the discharge record and the nature of channel adjustments was determined by two styles of analysis. In the first instance channel adjustments documented for each reach in Section 6 are related to the discharge record for each air photograph interval. Analysis is undertaken for total erosion and deposition, bank erosion and deposition, within-channel erosion and deposition and the ratio of erosion:deposition. Both total (absolute) measurements of areal adjustments and relative (averaged over time) assessments of channel change are considered in Section 7.2.

In Section 7.3 the method of analysis is inverted, and the consequences of individual flood events and sequences of floods are evaluated in terms of channel adjustments along Waiau River. Impacts of floods are determined, in part, by analysis of relative rates of bank retreat and volumetric removal of material at selective sites of continued erosion along Waiau River. Magnitude of floods required to mobilise gravels essentially reflects a threshold condition. From the analysis undertaken in this study inferences can be made about the character of channel adjustments in each reach and their relationship to floods of differing magnitude, peakedness, duration and sequence. In addition, reach to reach variability in river response to flood events is evaluated in terms of the landscape condition at the time of the event(s), determined in part by the period since the last flood, local channel configuration and alignment, and sediment calibre and availability (determined partially by proximity to tributary confluences).

7.1 Waiau River discharge record, 1964-1992

The character of flood events is determined for each of the primary intervals evaluated in the air photograph record, namely 1964-1969, 1969-1974, 1974-1978, 1978-1980, 1980-1982, 1982-1984, 1984-1989, 1989-1992. Analysis of the flood record is restricted to Tuatapere gauging station between 1964-1969 and 1969-1974, whereas in subsequent intervals daily discharge levels are compared for individual floods > 800 m^3s^{-1} at Tuatapere or 600 m^3s^{-1} at Sunnyside. Flood records of different photographic intervals are considered separately in the following sections.

7.1.1 Waiau River discharge record, 1964-1969

Flood events between 1964-1969 in which discharge at Tuatapere exceeded 800 m^3s^{-1} are summarised in Table 7.1 and are presented graphically in Figure 7.1 (Appendix 5).

Table 7.1 Flood events at Tuatapere 1964-1969

Date	# Days with Q > 800 m^3s^{-1}	# Days with Q > 1200 m^3s^{-1}	Q_{max} in m^3s^{-1}	Comments
1964				
26.11-23.12	27	1	1253	
1965				
15.03-17.03	1		805	
22.05-27.05	4		1067	
13.06-30.06	10		1127	
01.10-12.10	10		1072	
31.10-03.11	2		823	
16.11-01.12	12		1003	
1966				
01.01-04.01	2		826	
09.04-11.04	1		935	
1967				
18.02-20.02	1		811	
10.03-17.03	6		1035	
25.04-22.05	25+	4+	1469+	No discharge record at beginning of event. Discharge peaked above 1200 m^3s^{-1} on two occasions.
06.11-03.12	21		915	
10.12-29-12	18	4	1737	Rapid increase in discharge during event (ie. event is very peaked).
1968				
04.01-06.01	1		807	
05.03-23.03	17	4	1268	Discharge peaked above 1200 m^3s^{-1} on two occasions.
12.04-15.04	2		1029	
03.10-06.10	2		847	
12.10-11.12	58	7	1290	Discharge peaked above 1200 m^3s^{-1} on three occasions.
21.12-23.12	1		805	

There were 20 recorded events in which discharge exceeded 800 m^3s^{-1} between 1964-1969 and 5 events in which discharge exceeded 1200 m^3s^{-1}. The discharge regime between 1964-1969 was marked by numerous periods of sustained high flow levels, with intervals greater than 10 days in length in which discharge exceeded 800 m^3s^{-1} in each year other than 1966 (when discharge exceeded 800 m^3s^{-1} on only 3 days). The highest magnitude event in this interval occurred between 10.12.67-29.12.67, when a discharge of 1737 m^3s^{-1} was attained. However, note that there was no gauging record at the beginning of the April/May event in 1967, and it is quite possible that this may have been the flood of record in this interval. The longest period in which discharge levels above 800 m^3s^{-1} were maintained was between 12.10.68 to 11.12.68, when 57 days had flow levels above 800 m^3s^{-1}.

Flood were spread throughout the year other than between July-September, with no clearly defined seasonal peak.

7.1.2 Waiau River discharge record, 1969-1974

Flood events > 800 m^3s^{-1} at Tuatapere between 1969-1974 are summarised in Table 7.2 and are presented graphically in Figure 7.2 (Appendix 5).

Table 7.2 Flood events at Tuatapere 1969-1974

Date	# Days with Q > 800 m^3s^{-1}	# Days with Q > 1200 m^3s^{-1}	Q_{max} in m^3s^{-1}	Comments
1969				
07.09-02.10	24	2	1270	Sustained high discharge event
24.12-28.12	3		1060	
06.01-08.01	1		835	
31.08-03.09	2		860	
06.09-13.10	32	4	1389	Discharge peaked above 1200 m^3s^{-1} on two occasions. First event lasted 25 days and peaked much higher than the second event. This flood of record in this interval was distinctly peaked.
1971				
01.11-03.11	1		809	
1972				
23.03-25.03	0		746	Event > 600 m^3s^{-1} at Sunnyside, but did not peak above 800 m^3s^{-1} at Tuatapere.
18.09-03.10	7		1048	Discharge levels above 600 m^3s^{-1} at Sunnyside were maintained for a longer period than discharge levels above 800 m^3s^{-1} were maintained at Tuatapere, indicating that this was primarily an upper catchment event.

Between 1969-1974 there were 7 flood events in which discharges > 800 m^3s^{-1} were recorded. Only two of these events extended for > 10 days, and in both these instances discharges > 1200 m^3s^{-1} were attained. One of these events was the major flood of this interval, in September 1970, when a peaked event had a maximum discharge of almost 1400 m^3s^{-1}. Flood events in this interval occurred between August-March.

7.1.3 Waiau River discharge record, 1974-1978

Flood events between 1974-1978 in which discharge at Tuatapere exceeded 800 m^3s^{-1} are summarised in Table 7.3 and are presented graphically in Figure 7.3 (Appendix 5).

Table 7.3 Flood events at Tuatapere and Sunnyside, 1974-1978

Date	# Days with Q > 800 m^3s^{-1}	# Days with Q > 1200 m^3s^{-1}	Q_{max} in m^3s^{-1}	Relationship between discharge levels at Sunnyside and Tuatapere
1975				
06.04-20.04	8		1168	Flows at Tuatapere exceeded those at Sunnyside during the peak stage of the event, but following the event flow levels were actually higher at Sunnyside, indicating that this was an upper catchment event.
21.05-30.05	1		826	Discharge levels at Sunnyside and Tuatapere were virtually equivalent throughout the event, indicating that this was an upper catchment event.
1977				
01.02-05.02	0		605	No record at Tuatapere during early stage of event.
02.05-04.05	1		878	Much higher discharge at Tuatapere than at Sunnyside; ie. this was a lower catchment rainfall event

Between 1974-1978 no flood events exceeded 1200 m^3s^{-1}, and only 3 events exceeded 800 m^3s^{-1}. None of these events were sustained for more than 10 days. Other than the event in May 1977, these were all upper catchment floods.

7.1.4 Waiau River discharge record, 1978-1980

Flood events between 1978-1980 in which discharge at Tuatapere exceeded 800 m^3s^{-1} are summarised in Table 7.4 and are presented graphically in Figure 7.4 (Appendix 5).

Table 7.4 Flood events at Tuatapere and Sunnyside, 1978-1980

Date	# Days with Q > 800 m^3s^{-1}	# Days with Q > 1200 m^3s^{-1}	Q_{max} in m^3s^{-1}	Relationship between discharge levels at Tuatapere and Sunnyside
1978				
31.05-02.06	1		910	Discharge levels were notably higher at Tuatapere than at Sunnyside, indicating that this was primarily a lower catchment rainfall event.
1979				
14.05-17.05	2	1	1240	Extremely peaked, lower catchment event, in which discharge levels at Tuatapere on 16.05.79 were over 600 m^3s^{-1} higher than at Sunnyside.
1980				
16.01-18.01	1		967	Discharge levels at Tuatapere were over 600 m^3s^{-1} higher than at Sunnyside, indicating that this was a lower catchment rainfall event.
26.01-28.01	0		634	Event > 600 m^3s^{-1} at Sunnyside, but did not peak above 800 m^3s^{-1} at Tuatapere.

Only three flood events exceeded 800 m^3s^{-1} between 1978-1980, but one of these events, in May 1979, was extremely peaked and exceeded 1200 m^3s^{-1}. All three of these events were lower catchment events, while the > 600 m^3s^{-1} discharge levels in late January 1980 reflected upper catchment runoff contribution. Each of the flood events recorded in this interval was of very short duration.

7.1.5 Waiau River discharge record, 1980-1982

Flood events between 1980-1982 in which discharge at Tuatapere exceeded 800 m^3s^{-1} are summarised in Table 7.5 and are presented graphically in Figure 7.5 (Appendix 5).

Table 7.5 Flood events at Tuatapere and Sunnyside, 1980-1982

Date	# Days with Q > 800 m^3s^{-1}	# Days with Q > 1200 m^3s^{-1}	Q_{max} in m^3s^{-1}	Relationship between discharge levels at Tuatapere and Sunnyside
1980				
04.06-06.06	1		873	Discharge levels at Tuatapere were over 400 m^3s^{-1} higher than at Sunnyside, indicating that this was a lower catchment rainfall event.
25.08-03.09	1	1	1357	Extremely peaked event - the second most peaked in the entire discharge record. Discharge rose from less than 200 m^3s^{-1} to over 1350 m^3s^{-1} between 25.08 to 26.08. Event was peaked at both Tuatapere and Sunnyside, but was significantly greater at Tuatapere, indicating that this rainfall event occurred throughout the catchment.
25.09-02.10	0		656	Event > 600 m^3s^{-1} at Sunnyside, but did not peak above 800 m^3s^{-1} at Tuatapere.
1982				
01.02-03.02	0		617	Event > 600 m^3s^{-1} at Sunnyside, but did not peak above 800 m^3s^{-1} at Tuatapere.
21.05-23.05	1		991	Discharge at Tuatapere was almost 400 m^3s^{-1} greater than that at Sunnyside, indicating that this was predominantly a lower catchment rainfall event.

Although only three floods exceeded 800 m^3s^{-1} at Tuatapere between 1980-1982, one of these events, in August 1980, was one of the most peaked events on record, as discharge rose from less than 200 m^3s^{-1} to over 1350 m^3s^{-1} in less than 24 hours. The higher peak at Tuatapere indicates that this event reflected rainfall throughout the catchment. In contrast the June 1980 and May 1982 floods were lower catchment events, while the September 1980 and February 1982 events reflected upper catchment rainfall.

7.1.6 Waiau River discharge record, 1982-1984

Flood events between 1982-1984 in which discharge at Tuatapere exceeded 800 m^3s^{-1} are summarised in Table 7.6 and are presented graphically in Figure 7.6 (Appendix 5).

Table 7.6 Flood events at Tuatapere and Sunnyside, 1982-1984

Date	# Days with Q > 800 m^3s^{-1}	# Days with Q > 1200 m^3s^{-1}	Q_{max} in m^3s^{-1}	Relationship between discharge levels at Sunnyside and Tuatapere
1982				
10.11-12.11	1		823	Discharge at Tuatapere was almost 400 m^3s^{-1} greater than that at Sunnyside, indicating that this was predominantly a lower catchment rainfall event.
19.11-04.12	8		1035	Discharge at Tuatapere closely mirrored that at Sunnyside, in both trend and extent, indicating that this was an upper catchment event.
1983				
10.01-29.01	17	2	1571	Sustained high discharge event, in which discharge at Tuatapere mirrored that at Sunnyside in terms of both trend and extent on all days other than the peak discharge day, indicating that significant rainfall must have occurred in the lower catchment at this stage. This was the second highest event of magnitude in the entire discharge record, and was distinctly peaked, as discharge at Tuatapere rose from 850 m^3s^{-1} to 1571 m^3s^{-1} between 13.01 to 14.01.
11.03-15.03	0		679	Event > 600 m^3s^{-1} at Sunnyside, but did not peak above 800 m^3s^{-1} at Tuatapere. Indeed, discharge at Sunnyside exceeded that at Tuatapere.
26.06-28.06	1		879	Discharge at Tuatapere was over 400 m^3s^{-1} greater than that at Sunnyside, indicating that this was predominantly a lower catchment rainfall event.
1984				
26.01-04.02	4	2	2182	Flood of record and most peaked event. Discharge rose from 74 m^3s^{-1} on 26.01 to 2182 m^3s^{-1} on 27.01. High flood levels were not maintained for very long, indicating that this was a short-duration storm event. Discharge at Sunnyside and Tuatapere was roughly equivalent (although the Sunnyside gauge was not operational on several days), but the peak discharge was over 400 m^3s^{-1} higher at Tuatapere reflecting runoff contribution throughout the catchment.

The two highest discharge events of record occurred between 1982-1984. Both events occurred in January, in 1983 and 1984, when discharges exceeded 1550 and 2150 m^3s^{-1} respectively. These were extremely peaked events, and discharge > 1200 m^3s^{-1} was only maintained for 2 days during each event. Indeed, the January 1984 flood discharge was an extremely short event, and there were only 4 days in which discharge exceeded 800 m^3s^{-1}, whereas during the January 1983 event discharges above 800 m^3s^{-1} were sustained for 17 days. Both events reflected runoff contribution throughout the catchment. Of the other 4 events in this interval, two each reflected upper and lower catchment rainfall. The longer duration event in November/December 1982 reflected upper catchment supply.

7.1.7 Waiau River discharge record, 1984-1989

Flood events between 1984-1989 in which discharge at Tuatapere exceeded 800 m^3s^{-1} are summarised in Table 7.7 and are presented graphically in Figure 7.7 (Appendix 5).

Table 7.7 Flood events at Tuatapere 1984-1989

Date	# Days with Q > 800 m^3s^{-1}	# Days with Q > 1200 m^3s^{-1}	Q_{max} in m^3s^{-1}	Relationship between discharge levels at Sunnyside and Tuatapere
1985				
12.01-14.01	0		637	Event > 600 m^3s^{-1} at Sunnyside, but did not peak above 800 m^3s^{-1} at Tuatapere. Discharge at Sunnyside and Tuatapere were equal, indicating that this was an upper catchment event.
21.01-28.01	2		967	While discharge was maintained at around 600 m^3s^{-1} during this event, discharge was more peaked at Tuatapere, indicating lower catchment supply.
1987				
27.02-01.03	1		855	Highly peaked event that reflects lower catchment runoff. Discharge at Tuatapere was over 500 m^3s^{-1} greater than at Sunnyside.
09.03-12.03	2	2	1310	Discharge at Tuatapere was over 500 m^3s^{-1} greater than at Sunnyside, indicating that this was largely a lower catchment event. This was a highly peaked event, in which discharge rose from less than 400 m^3s^{-1} on 09.03 to over 1250 m^3s^{-1} on 10.03.
07.10-14.10	2		1057	Discharge at Tuatapere generally mirrored that at Sunnyside other than on 10.10 when discharge at Tuatapere was 300 m^3s^{-1} higher than at Sunnyside. In general this was an upper catchment event.
1988				
12.09-23.09	2		1044	Discharge at Tuatapere generally mirrored that at Sunnyside other than on 13.09 when discharge at Tuatapere was 200 m^3s^{-1} higher than at Sunnyside. In general this was an upper catchment event.
06.10-17.11	29	16	1484	Discharge at Tuatapere mirrored that at Sunnyside throughout this event, which was the most sustained period of high discharges (above 1200 m^3s^{-1}) in the period of record. This was a poorly peaked upper catchment event reflecting the regulated rate of supply from the lakes at the head of the catchment.

Between 1984-1989 there were 6 flood events which exceeded 800 m^3s^{-1}. One of these events, in October/November 1988 was the longest period of sustained high flows in the period of record, with 16 days > 1200 m^3s^{-1}. Maximum discharge attained during this interval was almost 1500 m^3s^{-1}. Discharge at Tuatapere closely mirrored that at Sunnyside throughout this event, indicating that runoff during this event was provided almost solely from the upper catchment. The second highest magnitude event in this period, in March 1987, was a completely different style of event, in which discharge levels rose very rapidly following a storm in the lower catchment. Two further events exceeded 1000 m^3s^{-1} between 1984-1989, in October 1987 and September 1988. These were both upper catchment events.

7.1.8 Waiau River discharge record, 1989-1992

Flood events between 1989-1992 in which discharge at Tuatapere exceeded 800 m^3s^{-1} are summarised in Table 7.8 and are presented graphically in Figure 7.8 (Appendix 5).

Table 7.8 Flood events at Tuatapere and Sunnyside, 1989-1992

Date	# Days with Q > 800 m^3s^{-1}	# Days with Q > 1200 m^3s^{-1}	Q_{max} in m^3s^{-1}	Relationship between discharge levels at Sunnyside and Tuatapere
1991				
17.02-20.02	2	1	1237	Highly peaked event in which discharge at Tuatapere was notably higher (more than 500 m^3s^{-1}) than at Sunnyside, indicating that this was primarily a lower catchment event. Discharge rose from less than 400 m^3s^{-1} on 17.02 to almost 1250 m^3s^{-1} on 18.02.
15.08-18.08	2		1180	Discharge at Tuatapere was consistently higher at Tuatapere than at Sunnyside throughout this event, indicating that this was primarily a lower catchment event.

Although there were only 2 events > 800 m^3s^{-1} between 1989-1992, both of these events were relatively high magnitude events which exceeded 1000 m^3s^{-1}. While the character of the two events differed, in that the February 1991 event was more peaked than the August 1991 event, discharge levels were notably higher at Tuatapere than at Sunnyside during both events indicating that these were primarily lower catchment events.

7.1.9 Summary flood record in the differing air photograph intervals

The flood history for the differing air photograph intervals is summarised in Table 7.9.

Table 7.9 Upper and lower catchment floods in the period of air photograph intervals

Date	Summary flood record	
	Upper catchment	*Lower catchment*
1964-1969	Upper and lower catchments cannot be differentiated as Sunnyside gauging station was not operational. There were 20 events > 800 m^3s^{-1}, and 5 events > 1200 m^3s^{-1}. On 9 occasions flow levels > 800 m^3s^{-1} were sustained for 10 days or longer. Greatest discharge recorded in this interval was 1737 m^3s^{-1}.	
1969-1974	Upper and lower catchments cannot be differentiated as Sunnyside gauging station was not operational until 1972. 7 events exceeded 800 m^3s^{-1}, 2 of which extended for > 10 days and attained discharges > 1200 m^3s^{-1}. Greatest discharge recorded in this interval was 1389 m^3s^{-1}.	
1974-1978	Two events exceeded 800 m^3s^{-1} neither of which extended for > 10 days. Maximum discharge was 1168 m^3s^{-1}.	One event exceeded 800 m^3s^{-1}. This lasted for one day only with a maximum discharge of 878 m^3s^{-1}.
1978-1980	One event exceeded 600 m^3s^{-1} at Sunnyside, but did not exceed 800 m^3s^{-1} at Tuatapere. This was the only upper catchment event in this interval.	Three, short duration flood events exceeded 800 m^3s^{-1}. Maximum recorded discharge was 1240 m^3s^{-1}.
1980-1982	Three of the five events which exceeded 600 m^3s^{-1} at Sunnyside were short-lived upper catchment events. One of these was an extremely peaked event which had a maximum discharge of 1357 m^3s^{-1}. This event reflected runoff contribution throughout the catchment. The two other events were relatively low discharge events.	Two one-day events with discharge levels < 1000 m^3s^{-1} occurred in association with lower catchment runoff contribution during this interval.
1982-1984	The two largest floods on record both reflected runoff contribution from throughout the catchment. Both events were extremely peaked and short-lived. Discharges > 1200 m^3s^{-1} were only maintained for 2 days (although the January 1983 event sustained discharge levels > 800 m^3s^{-1} for 17 days). Maximum recorded discharge in the January 1983 and January 1984 events were 1571 m^3s^{-1} and 2182 m^3s^{-1} respectively. There were two further upper-catchment events in this interval, one > 1000 m^3s^{-1} and sustained discharge > 800 m^3s^{-1} for 8 days.	Two one-day events > 800 m^3s^{-1} occurred during this interval.
1984-1989	4 upper catchment events were recorded in this interval, 3 > 1000 m^3s^{-1}. While the first two of these events were 2-day events, the third event, in October/November 1988 maintained discharge levels > 1200 m^3s^{-1} on 16 days, while levels > 800 m^3s^{-1} were maintained for 29 days. This was the longest such event in the period of record. Maximum recorded discharge was 1484 m^3s^{-1}.	3 events > 800 m^3s^{-1} were dominated by runoff contribution from the lower catchment. While 2 of these events had peak discharge < 1000 m^3s^{-1}, the third event in March 1987 was an extremely peaked event with a maximum discharge of 1310 m^3s^{-1}. All 3 events lasted 2 days or less.
1989-1992	No upper-catchment events were recorded in this interval.	Two lower catchment events were recorded in this interval. Both were short-lived (< 2 day) events which had a peak discharged >1000 m^3s^{-1}. Maximum recorded discharge was 1237 m^3s^{-1}.

7.2 Floods and channel adjustments in Wairoa (Upper Waiau) reach

Table 7.10 Summary channel adjustments in Wairoa reach over differing photographic intervals

Year	Channel adjustments
1957-1965	Adjustments restricted to Balloon Loop. No channel trimming evident elsewhere.
1965-1977	Adjustments restricted to Balloon Loop. No channel trimming evident elsewhere.
1977-1992	Erosion along left bank and deposition along right bank at Lake Te Anau Control Structure. Right bank trimming in Yerex reach. Negligible change in Queens and Horseshoe Bend reaches. Substantial left bank erosion in Rainbow reach. Continued readjustment in Balloon Loop, with significant deposition along the right bank. Relatively small trimming at the head of Boulder reach, but major trimming of both banks in Downstream of Boulder reach.

Negligible channel adjustments were evident in Wairoa reach before 1977. Since 1977 extensive trimming of bends has occurred, especially in Rainbow and Downstream of Boulder subreaches. Erosion almost certainly reflects the high discharge events through the 1980's, which are amalgamated between 1977-1992 in this analysis. Discharge data from lower Waiau River bear little relation to processes operative in Upper Waiau (Wairoa) reach and cannot be used to provide more detailed analysis. However, discharges in excess of 1000 m^3s^{-1} were maintained for several days during the October/November 1988 flood event and it is likely that a significant proportion of bank trimming occurred during this period of sustained high flows. It is not possible to determine the relative erosion attributable to individual floods or assess the role of flow regulation on channel adjustments in this reach.

7.2 Floods and channel adjustments in Lower Redcliff reach

The character of channel changes in Lower Redcliff reach is presented for differing photographic intervals in Appendix 2. Rates of channel adjustment are summarised in Table 7.11. In this section the character and rate of erosion and deposition are related to the history of flood events. Hydrologic data from Tuatapere gauging station must be viewed with caution in assessment of channel adjustments in Lower Redcliff reach, as peak flood heights at Tuatapere also reflect discharge inputs from lower Waiau catchments. Flow data are only available for the second half of the interval between 1957-1969 (ie. since June 1964) and channel adjustments in this interval may be attributable to flow conditions prior to the period of record. Daily discharge data are summarised in Appendices 3-5.

Table 7.11 Summary rates of channel adjustments over differing time intervals: Lower Redcliff Reach

	Combined banks		Within-channel		Total	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
Total areal adjustment (in m^2 x 1000)						
28.01.54/15.02.57 to 12.02.69	71.50	23.70	123.80	68.80	195.30	92.50
12.02.69 to 12.08.82	37.80	202.90	45.50	150.40	83.30	353.30
12.08.82 to 04.04.89	12.90	37.30	45.50	17.50	58.40	54.80
04.04.89 to 14.04.92	10.50	90.70	31.00	30.50	41.50	121.20
Average rate of areal adjustment (in m^2/day)						
28.01.54/15.02.57 to 12.02.69	13.02	4.32	22.55	12.53	35.57	16.85
12.02.69 to 12.08.82	7.67	41.19	9.24	30.53	16.91	71.72
12.08.82 to 04.04.89	5.31	15.38	18.76	7.22	24.08	22.59
04.04.89 to 14.04.92	9.98	86.22	29.46	28.99	39.45	115.21

7.2.1 Erosional regime

Extent of erosion in Lower Redcliff reach decreased over time in the period of record, from almost 200,000 m^2 of land loss between 1954-1969, to over 80,000 m^2 between 1969-1982, to almost 60,000 m^2 between 1982-1989 and finally over 40,000 m^2 between 1989-1992. While erosional extent totals tally in sequence with the discharge record for percentage of days with discharge > 500 m^3s^{-1}, they are also coincident with the length of time evaluated in each period. Rate of land loss was actually greatest between 1989-1992 (almost 40 m^2/day). Hence, in assessment of the erosional regime, length of record must be considered along with the flood history, as it is likely that channel adjustments in the longer intervals have been integrated over time.

Of the almost 200,000 m^2 of land that was lost between 1954-1969, over 60 % of land loss occurred in the within-channel zone. Erosion was extensive in all subreaches of Lower Redcliff reach. Bank erosion was especially severe along the right bank upstream of Redcliff Creek and along the southern bank of Redcliff Creek itself. The high rate and extent of bank erosion reflected the sustained high flow levels throughout this interval. Although discharge level was consistently above 500 m^3s^{-1}, few extreme floods occurred between 1964-1969. Erosion dominated over deposition in the within-channel zone between 1954-1969. However, a large number of changes in this period are undetectable in the available air photograph record.

Erosion between 1989-1992 was significantly less than deposition, and was generally concentrated in the Redcliff Creek/Waiau confluence zone. This probably reflects shifting in the position of Redcliff Creek as it adjusted to the sustained high discharges in October/November 1988. Although extent of within-channel erosion between 1989-1992 was less than one-sixth that recorded between 1954-1969, the relative rate of within-channel erosion was greatest in this short period. Rate of within-channel erosion was almost 30 m^2/day between 1989-1992, almost 25 % higher than that evidenced between 1954-1969 and 1982-1989. The discharge record between 1989-92 shows < 2.5% of days with discharge > 500 m^3s^{-1} and no flood events > 1250 m^3s^{-1}. The relatively high rates of erosion evident in this interval clearly reflect the shortness of the interval rather than river responses to high discharge events.

Rate of erosion between 1982-1989 was 40 % lower than that between 1989-1992. This lower rate of erosion is surprising, as the major flood event of record (January 1984) and the longest period of sustained high discharge levels (October/November 1988) were both between 1982-1989. Extent of land loss along banks was anomalously low. Erosion exceeded deposition in the within channel zone, reflecting significant reworking, especially downstream of Redcliff Creek. The main channel upstream of this point had effectively stabilised between 1969-1982. The move towards equilibrium post-regulation was essentially complete, as large deposition in this interval had induced a less multichannelled condition.

Between 1969-1982 the rate of erosion was 60 % lower than that recorded between 1984-1992. Deposition dominated over erosion, both along the banks and in the within-channel zone, as Waiau River adjusted to lower discharge conditions associated with flow regulation. Lower mean discharge and lack of extreme flood events in this interval resulted in negligible erosion and absolute depositional dominance. Extent of bank erosion between 1969-1982 was roughly half that experienced between 1954-1969, while rate of within-channel erosion was the lowest on record. Less than 10 m^2/day of land was lost in the within-channel zone.

In general, within-channel erosion dominated over bank erosion, but the extent of bank erosion was relatively high between 1969-1982.

7.2.2 Depositional regime

Extent of deposition was greatest between 1969-1982, when over 350,000 m^2 of land was added in Lower Redcliff reach. Almost 60 % of this land was added adjacent to banks. This period marked a profound transition in the depositional regime of Waiau River, associated with lower discharge conditions. Deposition was especially pronounced along the banks upstream of Redcliff confluence, and along the right bank downstream of Redcliff confluence where a former mid-channel bar became bank-attached. Channel contraction resulted from reduced mean flow conditions associated with flow regulation, as secondary channels were abandoned and within-channel deposition ensued. There were no substantial floods between 1969-1982, and the proportion of days with discharge levels > 500 m^3s^{-1} decreased from over 45 % between 1964-1969 to just 11 % between 1969-1982. Extent of land added in the within-channel zone

between 1969-1982 was more than 2 x the land added between 1954-1969 (almost 70,000 m^2), almost 5 x the land added between 1989-1992 (30,000 m^2) and over 8 x the land added between 1982-1989.

Extent of deposition between 1969-1982 was almost 3 x as extensive as that between 1989-1992 when over 120,000 m^2 of land was added. However, rate of deposition was greatest over the shortest interval on record, between 1989-1992, when a rate of over 115 m^2/day of land addition was recorded. This rate was over 5 x the rate of deposition recorded between 1982-1989 and 1954-1969, but only 40 % higher than the rate of deposition between 1969-1982 (over 70 m^2/day). The predominance of deposition between 1989-1992 reflected the low discharge levels and lack of substantive flood events in this interval. Rate of bank-marginal deposition was highest between 1989-1992, when over 90,000 m^2 of land was added to bank margins at a rate of deposition of over 85 m^2/day. This rate of bank-marginal deposition was more than twice that recorded in the next highest interval between 1969-1982 (41 m^2/day). The high extent and rate of deposition between 1989-1992 were largely accounted for by the attachment of a former mid-channel bar to the left bank upstream of Redcliff confluence.

Extent of deposition between 1954-1969 was over 90,000 m^2, roughly one-quarter that recorded between 1969-1974. Significant reworking of deposits in the sustained high discharge conditions between 1954-1969 resulted in the overall low rate of deposition. Less than 25,000 m^2 of land was added adjacent to banks, at a rate of deposition of 5 m^2/day. Banks were kept clear of deposits by the continuous 'high' discharge levels in the period pre-regulation. High discharge events in the 1980's were not able to effectively clear these deposits that have stabilised Lower Redcliff reach.

Between 1982-1989 extent of deposition was over 50,000 m^2, roughly one-sixth that experienced between 1969-1974. Erosion was dominant in the within-channel zone, associated with the high discharge events in 1984 and 1988. Less than 40,000 m^2 of land was added adjacent to banks between 1982-1989, at a rate of deposition of 15 m^2/day.

In general deposition was greatest adjacent to the banks rather than in the within-channel zone, but within-channel deposition exceeded bank-marginal deposition between 1954-1969. The modified depositional pattern since 1969 probably reflects the lower flow regime, which has effectively contracted the channel.

7.2.3 Ratio of erosion:deposition

In overall terms, the ratio of erosion:deposition was biased to erosion between 1954-1969 (over 2 x), was heavily biased to deposition between 1969-1982 (over 4 x) and 1989-1992 (almost 3 x) and was roughly equal between 1982-1989. The balance between erosion and deposition in the overall data between 1982-1989 masks the dominance of deposition along banks and erosion in the within-channel zone. The bias towards deposition in the 1989-1992 overall data was determined by the dominance of deposition adjacent to the banks, whereas erosion and deposition were roughly equivalent in the within channel zone. The erosion:deposition ratio corresponds well with the discharge record. Sustained high flow levels before 1969 resulted in a dominantly erosional regime. As flow levels were reduced in 1970, the channel adjusted its morphology by contracting in width and abandoning secondary channels. This resulted in

deposition both adjacent to channels and in the within-channel zone, and negligible rates of erosion. The greater frequency of higher magnitude events between 1982-1989 largely redressed this depositional imbalance, as within-channel erosion rate increased. During this interval there was a pronounced decrease in deposition. Finally, between 1989-1992 the deposition rate increased markedly, largely in association with the abandonment of a mid-channel bar upstream of Redcliff confluence and its attachment to the left bank.

7.2.4 Summary assessment of discharge relationship with channel adjustments, Lower Redcliff reach

The most dramatic feature of the erosion and sedimentation regime in Lower Redcliff is the shift from erosional dominance before 1969 to pronounced depositional dominance between 1969-1982. This clearly reflects impact of flow regulation in this reach immediately downstream of Lake Manapouri Control Structure. Erosion rates were rapid between 1954-1969, especially in the within-channel zone, reflecting the dynamic nature of this reach. As mean flow condition was drastically altered following flow regulation, deposition became pronounced along banks, as the channel contracted and former mid-channel bars became bank-attached. The erosion rate was exceptionally low between 1969-1981.

The high discharge events of the 1980's were surprisingly ineffective in geomorphic terms, possibly associated with the restricted upper catchment runoff contribution and relatively small tributary impacts. This indicates that associations between areal channel adjustments and the discharge regime are complex, although the relative rate of erosion between 1982-1989 did exceed that between 1969-1982. This suggests that erosion was primarily brought about by extreme rather than mean flow conditions, as there were 18 days with discharge >1250 m^3s^{-1} between 1982-1989 but just 6 days between 1969-1992. This argument is negated, however, by the higher erosion rates between 1989-1992, when discharge levels > 1250 m^3s^{-1} were never exceeded. This seemingly reflects the 'condition' of the system at the time of an event, as significant reworking of deposits has occurred at a lower discharge stages, probably reflecting sediment availability in the within-channel zone following flood events in the 1980's. Within-channel deposition was relatively low between 1982-1989 associated with the flushing effect of floods. Channels were realigned, and within-channel sedimentation subsequently occurred. The majority of channel adjustments between 1989-1992 were associated with tributary flows from Redcliff Creek itself. Rates of deposition was highest between 1989-1992, as materials were reworked following floods in the 1980's and a former mid-channel bar became attached to the left bank upstream of Redcliff confluence.

7.3 Floods and channel adjustments in Wairaki reach

The character of channel changes in Wairaki reach is presented for differing photographic intervals in Appendix 2, while the discharge regime is summarised in Appendices 3-5. Extent and rates or erosional and depositional activity are presented in Table 7.12.

Table 7.12 Summary rates of channel adjustments over differing time intervals: Wairaki Reach

	Combined banks		Within-channel		Total	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
Total areal adjustment (in m^2 x 1000)						
28.03.47/03.12.47 to 10.03.63	131.98	246.77	185.22	262.59	317.53	509.36
10.03.63 to 12.02.69	146.71	114.42	93.44	70.03	240.15	184.45
12.02.69 to 31.05.74	30.77	67.88	25.91	327.77	56.68	395.65
31.05.74 to 11.02.78	16.87	121.71	3.50	36.28	20.37	157.99
11.02.78 to 14.04.80	187.16	218.58	0.20	145.40	187.36	363.98
14.04.80 to 12.08.82	30.30	96.92	7.50	51.34	37.8	148.26
12.08.82 to 07.02.84	657.01	0.00	230.98	15.29	887.99	15.29
07.02.84 to 21.06.84	45.91	429.27	60.08	207.79	105.99	637.06
21.06.84 to 04.04.89	41.58	66.31	89.88	47.75	131.46	114.06
04.04.89 to 14.04.92	54.63	51.00	48.20	21.03	102.83	72.03
Average rate of areal adjustment (in m^2/day)						
28.03.47/03.12.47 to 10.03.63	22.67	42.39	31.81	45.15	54.54	87.49
10.03.63 to 12.02.69	67.80	52.87	43.17	32.36	110.98	85.24
12.02.69 to 31.05.74	15.92	35.11	13.40	169.57	29.32	204.68
31.05.74 to 11.02.78	12.48	90.02	2.59	26.83	15.07	116.86
11.02.78 to 14.04.80	236.61	276.33	0.25	183.82	236.86	460.15
14.04.80 to 12.08.82	35.65	114.02	8.82	60.40	44.47	174.42
12.08.82 to 07.02.84	1207.7	0.00	424.60	28.11	1632.3	28.11
07.02.84 to 21.06.84	342.61	3203.5	448.36	1550.67	790.97	4754.18
21.06.84 to 04.04.89	23.80	37.96	51.45	27.33	75.25	65.29
04.04.89 to 14.04.92	51.93	48.48	45.82	19.99	97.75	68.47

7.3.1 Erosional regime

Great variability is evident in the extent and rate of land eroded during differing intervals in Wairaki reach. Total erosion was greatest between 1982-1984, when almost 900,000 m^2 of land was lost. Rate of land loss was also highest during this interval, when over 1,600 m^2/day of land was eroded. Bank erosion was especially severe, as over 650,000 m^2 of land was lost at an average rate > 1200 m^2/day. Erosion was clearly associated with the peaked high magnitude floods in January 1983 and January 1984, the latter event being the flood of record. Erosion was prominent adjacent to the compound bar upstream of Wairaki confluence, at the northern margin of Wairaki River at the confluence, and was particularly extensive along the left bank downstream of the confluence. Bank erosion greatly outstripped within-channel erosion, but no erosion was evident at King-Allen bend.

Extent of land loss between 1982-1984 was almost 2.5 x that between 1947-1963, when almost 320,000 m^2 of land was removed. Between 1947-1963 erosion was prominent in the within-channel zone upstream of Wairaki confluence and along the left bank downstream of the confluence. Sustained high discharge conditions can be assumed during this

interval. The low rate of erosion in this interval (< 60 m^2/day) can be attributed to the length of the interval and the inability to measure adjustments for differing time slices within this sixteen year period. Erosion at King-Allen bend was initiated between 1947-1963, while extensive erosion occurred along the left bank downstream of Wairaki confluence as sinuosity increased. In contrast to most other intervals in Wairaki reach, erosion in the within-channel zone exceeded erosion along banks.

Between 1963-1969 almost 240,000 m^2 of land was eroded, ie. less than one-third the extent demonstrated between 1982-1984. However, extent of bank erosion between 1963-1969 actually exceeded that between 1947-1963, as over 140,000 m^2 of land was lost. Extensive erosion reflected sustained high discharge levels, as almost 47 % of days had discharge levels > 500 m^3s^{-1} and there were 5 events > 1250 m^3s^{-1} (4 of which were sustained for > 4 days). Sinuosity continued to increase during this interval, with extensive erosion of King-Allen bend. Rate of erosion between 1963-1969 exceeded 100 m^2/day. Of this, about 70 m^2/day of land was removed from along banks.

Almost 200,000 m^2 of land was lost between 1978-1980, at a rate of almost 240 m^2/day. Erosion was almost entirely restricted to bank-margins, where almost 190,000 m^2 of land was eroded at a rate > 230 m^2/day. Bank erosion during this interval was largely restricted to the northern margin of Wairaki confluence and along the left bank downstream, as Waiau River shifted over 130 m to the west. A small number of high discharge events occurred in this interval, with only three short-lived events > 800 m^3s^{-1} and no events > 1250 m^3s^{-1}. Indeed, only one day in this interval that had a discharge > 1000 m^3s^{-1}. Bank erosion between 1978-1980 likely reflects the peaked, lower-catchment flood event in May 1979, when a discharge of 1240 m^3s^{-1} was attained. The high erosion rate relative to preceding intervals may relate to the earlier periods of quiescence and depositional dominance between 1969-1978, such that the major lower catchment flood in May 1979 was a more *effective* event than preceding floods, especially at Wairaki confluence.

Between 1984-1989 over 130,000 m^2 of land was eroded, at an erosion rate < 80 m^2/day. Although erosion was extensive, it was less than one-sixth that experienced between 1982-1984, yet the proportion of days with discharge levels above 1250 m^3s^{-1} was actually greater between 1984-1989. Indeed, 15 days had discharge levels beyond 1250 m^3s^{-1}, compared to just 3 days between 1982-1984. Erosion at King-Allen bend was prominent between 1984-1989, while it was non-existent at this site between 1982-1984. The focal point of erosion between 1982-1984 was along the left bank downstream of Wairaki confluence. These differences probably reflect modifications to flow alignment, associated with the character of within-channel sedimentation, and the fact that the flood of record in January 1984 was able to inundate and remobilise materials over a more extensive area of alluvial flats.

Over 100,000 m^2 of land was eroded between February-June 1984, at an erosion rate of almost 800 m^2/day. This was the second highest erosion rate recorded, but it is somewhat anomalous as no discharge events above 500 m^3s^{-1} were recorded in this interval. The high erosion rate reflects channel shifting at Wairaki and Dean Burn confluences, as the river adjusted to impacts of the January 1984 flood event.

Anomalously high extent and rate of erosion were recorded between 1989-1992, when over 100,000 m^2 of land was eroded at an average rate of removal of almost 100 m^2/day. This is difficult to relate to either sustained or peak

discharge events, as there were only 2 events > 800 m^3s^{-1} in this interval, both of which lasted for just 2 days. As indicated for the period between February-June 1984, it is likely that the high rate of erosion between 1984-1989 was associated with channel adjustments following the sustained high discharge levels in October/November 1988, especially at Wairaki confluence zone and immediately downstream. A shift in the alignment of Wairaki River resulted in extensive erosion along the right bank opposite the confluence.

Less than 60,000 m^2 of land was lost between 1969-1974, 1974-1978 and 1980-1982. Although there was a lack of lower catchment events between 1974-1978 and flood events between 1980-1982 were only of very short duration, the discharge record in these intervals is not strikingly dissimilar to other periods in which pronounced erosion occurred (eg. 1978-1980, 1989-1992). The lack of erosion between 1969-1974 is even more dramatic, as discharge levels > 500 m^3s^{-1} were recorded on almost 20 % of days, which was clearly the second highest proportion of days for all intervals. Two events > 1200 m^3s^{-1} were recorded in this interval. The lack of erosion in this interval may be attributed to the dramatic shift in erosion/deposition regime in the period following regulation. This effect was pronounced and short-lived.

Just as great variability in extent and rate of erosional activity was evident in Wairaki reach, so the spatial pattern of erosion varied over time. Erosion was concentrated along banks relative to the within-channel zone between 1978-1980 and 1982-1984. Indeed, virtually no within-channel erosion was recorded between 1978-1980. Banks were also the preferred location for erosion between 1963-1969 and 1980-1982. Within-channel erosion was much more prominent than bank erosion between February-June 1984 and 1984-1989, whereas between 1969-1974, 1974-1978 and 1989-1992 the extent of erosion along banks and in the within-channel zone was roughly equal.

7.3.2 Depositional regime

Areal extents of deposition were quite variable over the differing intervals of record in Wairaki reach. Greatest extent of deposition was between February-June 1984 when over 600,000 m^2 of land was added at a rate > 4,500 m^2/day. Deposition was especially prevalent along banks, where over 420,000 m^2 of land was added. Extensive deposition occurred adjacent to the left bank compound bar upstream of Wairaki confluence, along the left bank downstream of Wairaki confluence and adjacent to mid-channel bars downstream of the bedrock constriction. High rates of deposition were attained as extensive volumes of material mobilised during the January 1984 flood were readily available to be reworked by subsequent lower-stage events. Discharge levels never exceeded 500 m^3s^{-1} between February-June 1984.

Between 1947-1963 Waiau River was a dynamic gravel bed system in which over 500,000 m^2 of land was added. Land addition was split roughly equally into bank-marginal and within-channel deposition. Deposition was pronounced along the right bank of Wairaki River at Waiau confluence, and along the right bank and in the within-channel zone downstream of Wairaki confluence. Deposition filled gaps left behind as the channel shifted position.

Almost 400,000 m^2 of land was added in Wairaki reach between 1969-1974. Over 325,000 m^2 of land was added in the within-channel zone and just 30,000 m^2 of land was added adjacent to banks (a ratio of almost 5:1). Indeed, deposition was more extensive in the within-channel zone during this interval than any other, when an average rate of around 175 m^2/day of land addition was maintained. Extensive deposition occurred adjacent to the left bank bar complex and right bank compound point bar upstream of Wairaki confluence, while the secondary channel adjacent to the right bank downstream of Wairaki confluence was largely infilled. This extensive deposition marks the most profound shift in discharge regime associated with flow regulation, as the proportion of days with discharge levels > 500 m^3s^{-1} was reduced from 46.9 % of days between 1964-1969 to just 19.4 % of days between 1969-1974. The effective channel-maintenance flows were adjusted, as the river sought to adopt a new equilibrium morphology. The channel no longer had the capacity to move the extensive volumes of material that it was previously able to, and extensive within-channel deposition occurred. This was a dramatic and rapid adjustment to flow regulation. This effect was exaggerated by the lack of major flood events between 1969-1974, although 7 events > 800 m^3s^{-1} were recorded and there were 2 events > 1200 m^3s^{-1}. Both of the latter events were part of sustained periods of flow > 800 m^3s^{-1}, in which such levels were maintained for 24 and 32 days.

Although extensive erosion occurred between 1978-1980, the erosion/deposition balance was tilted clearly towards deposition. This maintained the depositional dominance evident since flow regulation. Over 360,000 m^2 of land was added between 1978-1980, at an average rate of 460 m^2/day. Deposition along banks exceeded within-channel deposition by a ratio of roughly 3:2. Substantial deposition occurred along the right bank compound bar and left bank compound point bar immediately upstream of Wairaki confluence, partially infilled the secondary channel along the left bank downstream of Wairaki confluence, and amalgamated bar units upstream and downstream of the bedrock constriction. Extensive erosion occurred during the peaked lower catchment event in May 1979. Other than this event, 1978-1980 was characterised by relatively low discharge conditions in which only 4 days experienced discharge levels > 750 m^3s^{-1}.

Between 1963-1969 over 180,000 m^2 of land was added at an average rate of deposition > 200 m^2/day. Over 60 % of deposition occurred adjacent to banks. Significant deposition occurred in the within-channel zone and on the right bank opposite Wairaki confluence. This was a period of sustained high discharge levels in which erosion and deposition were crudely balanced, as Waiau River adopted a more sinuous outline in Wairaki reach.

Deposition greatly exceeded erosion between 1974-1978, when almost 160,000 m^2 of land was added at a rate > 110 m^2/day. Around 120,000 m^2 of land was added to the banks. Deposition was localised adjacent to the right bank compound point bar at the head of the reach, at the northern side of Wairaki confluence, and infilling a channel adjacent to Dean Burn confluence. Other than one flood event which exceeded 1000 m^3s^{-1} in April 1975, this was a period of relatively low discharge levels in which over 96 % of days had discharge levels < 500 m^3s^{-1}.

Around 150,000 m^2 of land was added between 1980-1982 at a rate of almost 175 m^2/day. Two-thirds of deposition occurred marginal to banks. Significant deposition occurred around the compound point bar at the reach head and at the

northern side of Wairaki confluence zone. The lack of high discharge events in this interval, in which just 1 day had a discharge level > 1000 m^3s^{-1}, ensured that deposition dominated over erosion during this period.

The only other interval in which over 100,000 m^2 of land was added was between 1984-1989. Over 65,000 m^2 of land was added to banks in this interval, primarily along the southern bank of Wairaki River at Waiau confluence as Wairaki River shifted to the north. Extent of erosion was greater than that of deposition in this period in which channel adjustments were dominated by the period of sustained high flow levels in October/November 1988. Mobilisation of gravels in this event ensured that bar surfaces were prone to reworking in the subsequent interval, and over 70,000 m^2 of land was added was between 1989-1992. The majority of this deposition occurred along banks, where 51,000 m^2 of land was added. Bank-marginal deposition was restricted to the left bank downstream of Wairaki confluence and along the right bank upstream of Dean Burn confluence. Both of these areas of adjustment may indicate channel realignments within tributaries, as it is difficult to explain the dominance of erosion over deposition in this period of essentially low discharge in which there were only 4 days on which discharge levels were > 800 m^3s^{-1}.

Extent and rate of deposition were significantly lower between 1982-1984 than in any other interval, reflecting the cleaning out of the channel during the January 1984 flood. During this period no deposits were preserved adjacent to the banks.

Deposition was higher adjacent to the banks relative to the within-channel zone between 1974-1978, 1978-1980, 1980-1982, between February-June 1984, and 1989-1992. Extents of within-channel and bank deposition were roughly equivalent between 1969-1974, but within-channel deposition was dominant over bank deposition between 1947-1963, 1963-1969, 1982-1984 and 1984-1989. It is interesting to note that highest deposition rates adjacent to banks were recorded in periods without major floods, whereas those intervals which experienced major floods tended to have lower proportions of bank-marginal deposition.

7.3.3 Ratio of erosion:deposition

Between 1982-1984 erosion greatly exceeded deposition, both along the banks and in the within-channel zone. This was clearly associated with the two floods of record, in January 1983 and January 1984. Erosion also exceeded deposition between 1963-1969 and 1989-1992, although deposition and erosion were roughly balanced along banks in the latter interval. While erosional dominance is readily explained between 1963-1969 by reference to the prevailing high discharge conditions, this relationship does not apply between 1989-1992 when discharge levels were consistently low and few extreme events were recorded. This anomaly is explained, however, by the location of channel adjustments, as channel changes were primarily restricted to Wairaki confluence zone, where Wairaki River shifted its position.

Deposition greatly exceeded erosion between 1969-1974, 1974-1978, 1980-1982 and between February-June 1984, and also exceeded erosion between 1947-1963 and 1978-1980. In other words, deposition was most prominent in the decade following flow regulation and in the short interval following the January 1984 flood.

Between 1984-1989 erosion and deposition were balanced in summary terms, although erosion exceeded deposition in the within-channel zone. Flood impacts between 1984-1989 were less prominent in Wairaki reach than they were elsewhere along Waiau River.

7.3.4 Summary assessment of discharge relationship with channel adjustments, Wairaki reach

The primary indicator of channel adjustments over the period of record is the ratio of erosion:deposition. In Wairaki reach a major switch in the erosion/deposition balance of Waiau River occurred between 1969-1974, when erosion exceeded deposition by a ratio of over 5:1. Deposition continued to dominate over erosion throughout the 1970's. Initially within-channel deposition was prominent, but subsequently bank-attachment became dominant. The shift to depositional dominance between 1969-1974 reflected changes to the discharge regime associated with flow regulation. The proportion of days with discharge levels > 500 m^3s^{-1} was reduced from 46.9 % of days between 1964-1969 to just 19.4 % of days between 1969-1974. The channel no longer had the capacity to move the extensive volumes of material that it was previously able to, and extensive within-channel deposition occurred. This effect was exaggerated by the lack of major flood events between 1969-1974. Relative change in mean flow conditions was more dramatic in this period than at any other stage.

Relative rate of erosion was higher between 1978-1980 than at any other stage during the 1970's. The lack of substantive flood events in this period indicate the difficulty in identifying limiting discharges which induce which certain types of channel adjustments, as each event modifies the channel condition at the time of that particular event. This is especially important in terms of tributary contribution of material. It appears that the May 1979 event induced much greater adjustments than would be expected for an event of its magnitude and recurrence. This is partially explained by the fact that this was a lower catchment event in which the alignment of flow from Wairaki may be different to that experienced during upper catchment events.

Flood events between 1982-1984, ie. the two floods of record in January 1983 and January 1984, almost completely redressed the depositional dominance evident throughout the 1970's. Indeed, these events exerted more extensive channel adjustments in Wairaki reach than anywhere else along Waiau River. These events flushed out the channel and inundated large areas of alluvial flats downstream of Wairaki confluence. While erosion was extensive along banks, King-Allen bend did not erode during this interval. Virtually no deposits were preserved between 1982-1984. February-June 1984 was a period of rapid channel recovery, as much of the land eroded between 1982-1984 was replaced.

In contrast to the dominant impact of the peaked floods of record between 1982-1984 on the morphologic outline in Wairaki reach, the sustained high discharge conditions in October/November 1988 were less effective in bringing about

channel adjustments that was evident elsewhere along the river. Indeed, extent of erosion between 1984-1989 was one-sixth of that recorded between 1982-1984 and erosion only marginally exceeded deposition. However, erosion King-Allen bend did recommence in this interval.

Two other characteristics were evident in the relationship between channel adjustments and the flood regime in Wairaki reach. The majority of channel adjustments occurred at, or immediately downstream of, the confluence zone. This reflects the greater width of the active channel zone downstream of the convergence zone. Inputs of flow and sediment into this zone induce extensive channel modifications, especially as the tributary shifts position within the confluence zone. One common response is realignment of Waiau River, and concomitant shift in erosion and deposition zones downstream. Tributary inputs also induce differing responses to individual flood events, contingent on sediment supply during individual events and the storage of those sediments in the confluence zone. This exerts considerable control on the 'condition of the system', which in turn may greatly modify the geomorphic effectiveness of events of differing magnitudes. The consequences of lower and upper catchment events appear to differ notably, with much greater geomorphic change associated with lower catchment runoff contribution. Such factors may explain the relative ineffectiveness of flood events between 1974-1978 and 1980-1982.

The second point of note is the differing channel response to the peaked and sustained high discharge events in the 1980's and the pronounced adjustments that occurred in the following intervals. Depositional adjustments following the floods between 1982-1984 were rapid. Sediment redistribution was also significant following the sustained high flow levels in October/November 1988. Indeed, between 1989-1992 considerable erosion resulted from events of relatively low discharge, as there were only 3 days > 1000 m^3s^{-1}. This indicates that lower discharge events may be geomorphologically effective if sediment is available and the channel can realign. This seemingly occurred in Wairaki reach, associated with shift in the position of Wairaki River and contribution of relatively fine clasts to Waiau River (Brierley, 1992). These materials may choke the channel, locally inducing lateral expansion.

7.4 Floods and channel adjustments in Lill Burn reach

The character of channel adjustments in Lill Burn reach is summarised in Appendix 2, while discharge data for the various photographic intervals analysed for this reach are presented in Appendices 3-5. Summary rates of erosion and deposition are presented in Table 7.13.

Table 7.13 Summary rates of channel adjustments over differing time intervals: Lill Burn reach

		Combined banks		Within-channel		Total	
		Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
Total areal adjustment (in m^2 x 1000)							
28.03.47 to 10.03.63	5822	132.60	132.09	144.30	266.70	276.90	398.79
10.03.63 to 12.02.69	2164	89.20	103.69	141.60	119.15	230.80	222.84
12.02.69 to 31.05.74	1933	61.65	165.40	2.60	247.10	64.25	412.50
31.05.74 to 25.02.77	1000	17.10	47.20	11.90	81.30	29.00	128.50
25.02.77 to 14.04.80	1131	51.30	15.10	69.80	36.40	121.10	51.50
14.04.80 to 12.08.82	850	26.90	117.00	12.20	131.80	39.10	248.80
12.08.82 to 07.02.84	544	358.10	6.60	103.10	3.50	461.20	10.10
07.02.84 to 21.06.84	134	36.90	159.70	26.20	128.50	63.10	288.20
21.06.84 to 04.04.89	1747	260.40	43.00	88.30	72.30	348.70	115.30
04.04.89 to 14.04.92	1052	45.40	98.90	33.20	111.00	78.60	209.90
Average rate of areal adjustment (in m^2/day)							
28.03.47 to 10.03.63	5822	22.78	22.69	24.79	45.81	47.56	68.50
10.03.63 to 12.02.69	2164	41.22	47.92	65.43	55.06	106.65	102.98
12.02.69 to 31.05.74	1933	31.89	85.57	1.35	127.83	33.24	213.40
31.05.74 to 25.02.77	1000	17.10	47.20	11.90	81.30	29.00	128.50
25.02.77 to 14.04.80	1131	45.36	13.35	61.72	32.18	107.07	45.53
14.04.80 to 12.08.82	850	31.65	137.65	14.35	155.06	46.00	292.71
12.08.82 to 07.02.84	544	658.27	12.13	189.52	6.43	847.79	18.57
07.02.84 to 21.06.84	134	275.37	1191.8	195.52	958.96	470.90	2150.75
21.06.84 to 04.04.89	1747	149.06	24.61	50.54	41.39	199.60	66.00
04.04.89 to 14.04.92	1052	43.16	94.01	31.56	105.51	74.71	199.52

7.4.1 Erosional regime

The timing and character of erosion in Lill Burn reach show a clear relationship to the pattern of extreme flood events. Extent of erosion was greatest between 1982-1984 and 1984-1989, coincident with the flood of record and the longest period of sustained high discharge post-regulation. Total erosion was most extensive between 1982-1984 when over 460,000 m^2 of land was eroded at an average rate of erosion of almost 850 m^2/day. Erosion was especially prevalent adjacent to banks, where over 350,000 m^2 of land was removed. The ratio of erosion along banks compared to the within-channel zone was 3.5:1. Between 1982-1984 the chute channel on the left bank compound bar upstream of Lill Burn was reactivated, as was the secondary channel adjacent to the left bank opposite Lill Burn. The bar margin adjacent to the main channel experienced significant erosion, as the channel shifted to the west. The compound point bar downstream of the bedrock constriction was also extensively eroded. Between 1982-1984 there were 5 events > 800 m^3s^{-1}, two of which exceeded 1500 m^3s^{-1}. These events occurred in January 1983 and January 1984. Both events were highly peaked and reflected runoff contribution from throughout the catchment.

Extent of erosion was somewhat lower between 1984-1989 than that between 1982-1984, indicating that in Lill Burn reach the extreme 1984 flood event was more effective in bringing about channel adjustments than was the period of sustained high level discharge in October/November 1988. About 350,000 m^2 of land was eroded between 1984-1989 at an average rate of erosion of almost 200 m^2/day. Channel alignment was modified significantly as Lill Burn cut a new course to the south. This resulted in major erosion of the right bank point bar immediately downstream of Lill Burn confluence and along the tail of the left bank compound bar opposite the confluence. The left bank of Waiau River upstream of the bedrock constriction as the channel straightened. The compound point bar downstream of the bedrock constriction was largely dissected. In total, about 260,000 m^2 of land was removed from along the banks. While most of the erosion between 1984-1989 was doubtless associated with the period of sustained high discharges in October/November 1988, when discharge levels above 1200 m^3s^{-1} were maintained for 16 days, there were 3 further events, lasting 4 days in total, with discharges > 1000 m^3s^{-1}.

While bank erosion was prominent during extreme floods, the extent of within-channel erosion was greatest in the periods pre-regulation (ie. 1947-1963 and 1963-1969, when approximately 140,000 m^2 of land was removed in each interval). Although deposition dominated over erosion between 1947-1963, over 270,000 m^2 of land was eroded. In this period of sustained high discharge levels, relative to the present discharge regime of Waiau River, erosion was dominant upstream of Lill Burn, especially adjacent to the left bank opposite Lill Burn confluence and in the within-channel zone, and along the right bank at Lill Burn confluence. Between 1963-1969 230,000 m^2 of land was eroded, 90,000 m^2 of which was adjacent to banks. Average rate of erosion was about 110 m^2/day. Extensive erosion occurred along the left bank opposite Lill Burn confluence and at the head of diagonally-aligned bar complexes downstream of Lill Burn. High rates of erosion and deposition in this interval reflect the variable discharge regime, with 20 events > 800 m^3s^{-1} between 1964-1969. Five of these events exceeded 1500 m^3s^{-1}.

Extent of total erosion was notably less in other intervals. Between 1977-1980 erosion exceeded deposition and about 120,000 m^2 of land was removed at an average rate of erosion of about 110 m^2/day. Erosion continued along the left bank opposite Lill Burn confluence and along the right bank of Lill Burn itself 500 m upstream of Waiau confluence. The relatively high erosion rate in this interval reflects short-lived moderate-magnitude floods, as there were 4 events > 800 m^3s^{-1} in this interval, only one of which peaked above 1200 m^3s^{-1}. The relative effectiveness of these events may be explained by the fact that they were lower catchment events, in which the tributary streams themselves would be quite active.

About 80,000 m^2 of land was eroded between 1989-1992, at an average rate of erosion of about 75 m^2/day. Deposition exceeded erosion, which was restricted primarily to the right bank downstream of Lill Burn confluence. The dominance of deposition in this interval is explained by the lack of either high magnitude or sustained floods, as there were just two events > 800 m^3s^{-1} in this interval. Both of these were 2-day events in which a significant proportion of runoff contribution was from the lower catchment.

Between 1969-1974 about 60,000 m^2 of land was eroded, while deposition was extensive. Localised erosion occurred along the bank opposite Lill Burn confluence. Discharge variability was pronounced in this interval, as there were

seven events > 800 m^3s^{-1}, two of which extended for > 20 days and exceeded 1250 m^3s^{-1}. The dominance of deposition and the relative lack of erosion in this interval seemingly reflects the transitional nature of the discharge regime associated with flow regulation. The channel had previously adjusted to continuously high discharge conditions in which flow levels > 500 m^3s^{-1} were maintained for roughly 50 % of the time, but this proportion diminished to less than 20 % of days between 1969-1974. This change to mean flow condition resulted in channel contraction as Waiau River adapted rapidly to its altered hydrologic regime.

Between February-June 1984 about 60,000 m^2 of land was eroded. The high rate of erosion in this short interval reflects reworking of materials activated during the January 1983 and January 1984 floods. Erosion rate along banks alone was 275 m^2/day. This activity was generally restricted to the confluence zone and the subreach immediately downstream. Since no events > 500 m^3s^{-1} were recorded between February-June 1984, it is inferred that channel modifications were primarily a product of readjustments associated with tributary flows.

The two intervals which experienced least extensive erosion were 1974-1977 and 1980-1982, when less than 40,000 m^2 of land was eroded. Between 1974-1977 erosion was largely restricted to the left bank opposite Lill Burn confluence. Two events > 800 m^3s^{-1} occurred in this interval, both of which were upper catchment events. Virtually no erosion was evident between 1980-1982, but extensive deposition occurred. Three short-lived (one-day) events exceeded 800 m^3s^{-1} in this interval, one of which was > 1200 m^3s^{-1}. These were primarily lower catchment events. Between both 1974-1977 and 1980-1982 there were more than 40 days in which discharge levels > 500 m^3s^{-1} were attained, this proportion being much greater than, say, the period between 1989-1992 when much more erosion occurred. This is perhaps attributable to the timing and sequence of events and the condition of the system when individual events occurred. There were significantly fewer substantive flows along Waiau River in the 1970's than in the 1980's, and the lack of response to flood events between 1974-1977 and 1980-1982 could reflect the relative stability of the system, whereas the interval between 1989-1992 followed a period of substantive flows and channel modifications in the 1980's, and the river morphology was more sensitive to change.

Erosion was markedly higher along the banks than in the within-channel zone between 1969-1974, 1982-1984 and 1984-1989. Since the latter two intervals were associated with the flood of record and the longest period of sustained high discharge, it can be inferred that these were periods in which the channel zone was effectively flushed as erosion was concentrated along banks. Between 1989-1992 bank erosion also exceeded erosion in the within-channel zone, but to a lesser degree than for the intervals previously listed. Extent of bank and within-channel erosion were roughly equivalent between 1947-1963, but within-channel erosion exceeded bank erosion between 1963-1969, 1977-1980 and February-June 1984. Extent of erosion was negligible between 1974-1977 and 1980-1982.

7.4.2 Depositional regime

Extent of deposition in Lill Burn reach was notably higher between 1947-1963 and 1969-1974 than during any other intervals. About 400,000 m^2 of land was added during each interval. Deposition dominated over erosion between

1947-1963. Within-channel deposition was more extensive than in any other interval, as almost 270,000 m^2 of land was added. Deposition was prominent in the within-channel zone at Lill Burn confluence, but was dominant downstream of Lill Burn confluence, with substantial addition of land adjacent to the right bank both at the compound bar at the head of this subreach and on the right bank compound bar immediately upstream of the bedrock constriction. Deposition was also prominent on the mid-channel complex bar downstream of the bedrock constriction. Extensive erosion and deposition recorded between 1947-1963 reflect the dynamic nature of Waiau River associated with its fluctuating discharge and virtually unlimited sediment availability.

Over 165,000 m^2 of land was added adjacent to banks between 1969-1974, whereas almost 250,000 m^2 of land was added in the within-channel zone. Total rate of deposition was about 200 m^2/day. The extensive deposition in this interval marks one of the most profound transitions in the erosion/deposition balance in the period of record. This reflects a change in channel character and alignment, associated with the modified discharge regime. While there were relatively few high discharge events between 1969-1974, with just 2 events > 1200 m^3s^{-1}, perhaps more significant was the change in mean flow condition associated with flow regulation. While almost 50 % of days had discharge levels > 500 m^3s^{-1} between 1964-1969, just 20 % of days attained such levels between 1969-1974. This resulted in channel contraction and the shift to a dominantly depositional regime. A major mid-channel bar became attached to the left bank upstream of Lill Burn and significant deposition occurred at Lill Burn confluence. The left bank compound bar opposite Lill Burn confluence expanded considerably and became bank-attached, and the right bank compound bar upstream of the bedrock constriction expanded laterally, constricting the main channel of Waiau River. The mid-channel bar assemblage downstream of the bedrock constriction formed a compound point bar.

The highest rate of deposition in Lill Burn reach was experienced between February-June 1984, when over 2,100 m^2 of land were added each day during this five month interval. Channel recovery following the January 1984 flood was rapid, as significant deposition occurred throughout Lill Burn reach. Approximately 160,000 m^2 of land was added adjacent to banks, whereas about 130,000 m^2 of land was added in the within-channel zone. The left bank compound bar became bank-attached once more, and the dissection channels on the left bank bar complex opposite Lill Burn were largely abandoned. Land lost on the compound point bar downstream of the bedrock constriction was replaced. The significant addition of land in this interval reflected the lack of any discharge event > 500 m^3s^{-1} between February-June 1984.

Virtually no erosion occurred between 1980-1982, but 250,000 m^2 of land was added at an average rate of deposition of almost 300 m^2/day, the second highest rate in the period of record. Deposition along banks and in the within-channel zone were roughly equal. Deposition was prominent along the northern side of Lill Burn confluence, at the downstream end of the right bank bar complex opposite Lill Burn, and infilling the right bank secondary channel upstream of the bedrock constriction. Extensive deposition during this interval reflects the lack of substantive or sustained high magnitude floods during this interval, with just 6 days experiencing discharge levels > 750 m^3s^{-1}.

Over 220,000 m^2 of land was added between 1963-1969 at an average rate of about 100 m^2/day. Erosion continued to dominate over deposition upstream of Lill Burn confluence, but significant within-channel deposition occurred as the

mid-channel complex upstream of Lill Burn expanded upstream. Deposition was dominant at Lill Burn confluence, as the southern half of the active channel zone was abandoned. Downstream of Lill Burn confluence erosion was dominant, but substantial deposition occurred at the margins of the left bank compound bar opposite Lill Burn confluence and adjacent to the right bank mid-way between Lill Burn confluence and the bedrock constriction. In summary terms, extent of deposition was roughly equal along banks and in the within-channel zone. Over 20 events exceeded 800 m^3s^{-1} between 1963-1969, indicating the dynamic nature of gravel reworking in this period.

Between 1989-1992 deposition exceeded erosion and about 210,000 m^2 of land was added in Lill Burn reach. The northern channel at Lill Burn confluence was largely infilled, and substantial within-channel deposition occurred downstream of Lill Burn confluence. Extents of deposition in the within-channel zone and along banks were roughly equal. The high rate of deposition, about 200 m^2/day, probably reflects reworking and redeposition and materials activated during the high discharge levels in late 1988. There were only 2 events that had discharge levels > 800 m^3s^{-1} in this period, both of which lasted for just 2 days.

About 120,000 m^2 of land was added between 1974-1977, at a rate of about 130 m^2/day. About two-thirds of this land-addition occurred in the within-channel zone. Negligible erosion was evident, and rate of deposition was notably lower than in previous periods. Deposition was restricted to lateral expansion of a mid-channel bar at the reach head, within-channel deposition at Lill Burn confluence, and infilling of secondary channels on the bar complex opposite Lill Burn confluence. There were only 2 events > 800 m^3s^{-1} in this interval. The lack of extreme events resulted in continuance of the predominantly depositional regime that resulted from flow regulation, but rate of deposition was notably lower than between 1969-1974.

About 120,000 m^2 of land was added between 1984-1989 at an average rate of 65 m^2/day. Most deposition occurred in the within-channel zone. Lill Burn cut a new course to the south in this period, with erosion dominant. However, significant deposition occurred along the northern margin of the confluence. The dominance of erosion in this period reflected the sustained high discharge levels in October/November 1988, which flushed the channel.

Remaining intervals, 1977-1980 and 1982-1984, experienced additions of about 50,000 and 10,000 m^2 of land respectively, with rates of deposition < 50 m^2/day. Erosion exceeded deposition in both intervals, especially between 1982-1984 when the channel zone was flushed by high discharge events

Within-channel deposition generally exceeded bank-marginal deposition, although bank-marginal and within-channel deposition were roughly equal between 1963-1969, 1980-1982, February-June 1984 and 1989-1992. Within-channel deposition greatly exceeded bank-marginal deposition between 1947-1963.

7.4.3 Ratio of erosion:deposition

In summary terms erosion greatly exceeded deposition between 1982-1984 and 1984-1989, although extent of erosion and deposition were roughly equal in the within-channel zone between 1984-1989. This clearly demonstrates the dominance of high discharge events in inducing erosion in Lill Burn reach. Erosion also exceeded deposition between 1977-1980, especially adjacent to banks. This is seemingly accounted for by the peculiar geomorphic effectiveness of the highly peaked, lower catchment flood in May 1979.

Erosion and deposition were roughly balanced between 1963-1969, while deposition exceeded erosion between 1947-1963. In the latter instance, however, extent of erosion and deposition were balanced along the banks, indicating that the period prior to flow regulation demonstrated an equilibrium condition in terms of its erosional and sedimentation regime. In the remaining five intervals, namely 1969-1974, 1974-1977, 1980-1982, February-June 1984 and 1989-1992, deposition greatly exceeded erosion both along banks and in the within-channel zone. This reflects either the change in flow conditions associated with flow regulation in the 1970's or the dramatic channel responses to higher discharge events in January 1984 and October/November 1988.

7.4.4 Summary assessment of discharge relationship with channel adjustments, Lill Burn reach

The primary shifts in erosion:deposition balance in Lill Burn reach were induced by flow regulation which induced substantive deposition during the 1970's and major floods in the 1980's which induced significant erosion initially but subsequent channel recovery. While erosion and deposition were crudely balanced between 1947-1969, especially along the banks, extent of deposition exceeded extent of erosion by over 6 x between 1969-1974. Channel morphologic response to the change in mean flow condition associated with flow regulation was dramatic and rapid. High rates of deposition were maintained throughout the 1970's, other than between 1977-1980 when the May 1979 flood induced anomalously high erosion at, and downstream of, Lill Burn confluence.

The most prominent characteristic of channel adjustments and the flood regime in Lill Burn reach over the period of record was the prominence of erosion by the major flood events between 1982-1984 and 1984-1989. The erosional history was largely a reflection of these major events. In both instances erosion was dominant adjacent to the banks while deposition was relatively trivial, indicating the flushing nature of the January 1984 flood of record and the period of sustained high discharge in October/November 1988. Extents of erosion were roughly equal between 1982-1984 and 1984-1989. In relative terms, however, the sustained high flow levels in October/November 1988 was a significantly more effective erosive event in Lill Burn reach than it was in Wairaki reach, and the extent of deposition was notably lower. This implies that the channel was more effectively flushed in Lill Burn reach, possibly associated with the pattern of flow realignment and within-channel sedimentation followng flow regulation.

As indicated in Wairaki reach, channel adjustments were especially prominent downstream of Lill Burn confluence, while anomalously high erosion rates during periods of relatively low discharge have resulted from shifts in the position

of Lill Burn itself (eg. 1977-1980). February-June 1984 and 1989-1992 were periods of unusually high rates of activity, probably associated with reworking of deposits following the floods in the preceding intervals, such that lower discharge events are able to adjust channel and bar margins. Erosion was especially prominent at, and downstream of, Lill Burn confluence. Extensive deposition between 1989-1992 reflected abandonment of a secondary channel as flow realigned midway between Lill Burn confluence and the bedrock constriction.

7.5 Floods and channel adjustments in Downstream o'Clifden reach

The character of channel adjustments in Downstream o'Clifden reach is summarised in Appendix 2, while discharge data at Tuatapere are analysed for the various photographic intervals considered in this reach in Appendices 3-5. Summary rates of erosion and deposition are presented in Table 7.14.

Table 7.14 Summary rates of channel adjustments over differing time intervals: Downstream o'Clifden Reach

	Combined banks		Within-channel		Total	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
Total areal adjustment (in m^2 x 1000)						
28.03.47 to 10.03.63	80.89	76.90	62.70	137.90	143.59	214.80
10.03.63 to 12.02.69	42.30	23.10	14.30	36.30	56.60	59.40
12.02.69 to 31.05.74	10.70	22.80	18.30	59.30	29.00	82.10
31.05.74 to 25.02.77	1.60	44.20	2.30	28.40	3.90	72.60
25.02.77 to 11.02.78	1.50	5.50	10.30	0.80	11.80	6.30
11.02.78 to 14.04.80	6.80	24.90	5.00	30.00	11.80	54.90
14.04.80 to 12.08.82	14.40	9.20	8.10	39.00	22.50	48.20
12.08.82 to 07.02.84	18.50	1.80	41.00	0.00	59.50	1.80
07.02.84 to 21.06.84	1.20	26.50	0.00	11.00	1.20	37.50
21.06.84 to 04.04.89	32.40	2.00	44.00	9.20	76.40	11.20
04.04.89 to 14.04.92	12.00	11.70	13.70	26.80	25.70	38.50
Average rate of areal adjustment (in m^2/day)						
28.03.47 to 10.03.63	13.89	13.21	10.77	23.69	24.66	36.89
10.03.63 to 12.02.69	19.55	10.67	6.61	16.77	26.16	27.45
12.02.69 to 31.05.74	5.54	11.80	9.47	30.68	15.00	42.47
31.05.74 to 25.02.77	1.68	46.38	2.41	29.80	4.09	76.18
25.02.77 to 11.02.78	4.27	15.67	29.34	2.28	33.62	17.95
11.02.78 to 14.04.80	8.60	31.48	6.32	37.93	14.92	69.41
14.04.80 to 12.08.82	16.94	10.82	9.53	45.88	26.47	56.71
12.08.82 to 07.02.84	34.01	3.31	75.37	0.00	109.38	3.31
07.02.84 to 21.06.84	8.96	197.76	0.00	82.09	8.96	279.85
21.06.84 to 04.04.89	18.55	1.14	25.19	5.27	43.73	6.41
04.04.89 to 14.04.92	11.41	11.12	13.02	25.48	24.43	36.60

7.5.1 Erosional regime

Great variability was evident in the extent and rate of erosion in Downstream o'Clifden reach over the period of record. Extent of erosion was greatest between 1947-1963 when over 140,000 m^2 of land was eroded. Over 80,000 m^2 of land was removed from along banks, while over 60,000 m^2 of land was eroded from the within-channel zone. Sinuosity increased markedly, and extensive bank erosion occurred along the right concave bank as the major bend enlarged. The extent of erosion in this interval reflects the sustained high discharge record prior to flow regulation. Waiau River was a highly dynamic system, and in laterally unconfined settings such as those in Downstream o'Clifden reach the river was able to shift its course within a relatively extensive active channel zone, eroding the adjacent alluvial flats.

After the 1947-1963 period, the interval in which erosion was most extensive was between 1984-1989, when over 75,000 m^2 of land was eroded at a rate of almost 45 m^2/day. Erosion was absolutely dominant during this period, with

negligible deposition. Erosion of the right concave bank was greater than during any other interval, while substantial trimming occurred along margins of the major bar complex. Within-channel erosion was marginally more extensive than bank erosion. Between 1984-1989 there were six events > 800 m^3s^{-1}. These were relatively short-lived events, which lasted just 1-2 days, other than the event in October/November 1988 which had 29 days > 800 m^3s^{-1}, with 16 days > 1200 m^3s^{-1}. Peak discharge in this event, however, was < 1500 m^3s^{-1}.

Relative rate of land removal was highest between 1982-1984, when over 100 m^2/day of land was removed. Around 60,000 m^2 of land was eroded, almost one-third of which was along the banks. Significant erosion occurred along the right concave bank and along the margins of the bar complex. Numerous dissection channels were reactivated. Erosion was primarily associated with the flood of record in January 1984, which had a maximum discharge of 2182 m^3s^{-1}. There was a second event > 1500 m^3s^{-1} in this interval, in January 1983. Both of these events were highly peaked, short-lived events with runoff contribution from throughout the catchment.

Around 60,000 m^2 of land was eroded between 1963-1969, over 2/3 of which was eroded along banks as the bend enlarged. Erosion and deposition were balanced in this interval of significant channel realignment, in which almost 50 % of days experienced discharge levels > 500 m^3s^{-1}. In nine instances discharge levels exceeded 800 m^3s^{-1} for 10 or more days. There were also 2 events > 1500 m^3s^{-1}.

Remaining intervals all experienced extents of erosion less than 30,000 m^2 of land, although rates of land loss of between 20-35 m^2/day were maintained between 1977-1978, 1980-1982 and 1989-1992.

Between 1969-1974 almost 30,000 m^2 of land was eroded, but deposition was dominant in this interval. Bank erosion, which accounted for roughly one-third of the total erosion, was largely restricted to the right concave bank, as a slice was eroded from the downstream half of the bend. The shift from a balanced erosion/deposition regime to one in which deposition dominated can be explained by the abrupt transition in mean flow condition between 1963-1969 and 1969-1974, as the proportion of days with discharge levels > 500 m^3s^{-1} dropped from almost 50 % to < 20 %. Although there were four events > 1000 m^3s^{-1} between 1969-1974, including two events which sustained discharge levels > 800 m^3s^{-1} for more than 20 days, the modification in mean flow resulted in substantial channel contraction.

Between 1989-1992 over 25,000 m^2 of land was removed, almost half of which was accounted for by erosional trimming of the right concave bank. Rate of erosion was almost 25 m^2/day. Two short-lived events > 1000 m^3s^{-1} occurred in this interval; these were the only events which occurred > 800 m^3s^{-1}. The high effectiveness of these events is possibly accounted for by flow concentration against the right bank following the sustained high discharge conditions in late 1988.

Extent of removal of materials from banks was around 15,000 m^2 between 1980-1982, at an average of < 15 m^2/day. Erosion along the right concave bank was restricted to the upstream part of the bend, as sinuosity increased. While three events exceeded 800 m^3s^{-1} in this interval, most erosion probably resulted from a peaked event in August 1980,

in which runoff contribution throughout the catchment resulted in discharge increase from 200 m^3s^{-1} on August 25 to > 1350 m^3s^{-1} on August 26.

In the short interval between 1977-1978, just over 10,000 m^2 of land was eroded, at a rate > 30 m^2/day. Erosion dominated over deposition as bar margins were trimmed. Erosion was almost entirely restricted to the within-channel zone, and the right concave bank did not erode at all. No event exceeded 1000 m^3s^{-1} in this interval, and within-channel erosion must have resulted from the 1-day May 1977 lower catchment event which had a peak discharge of 878 m^3s^{-1}.

Extents and rates of erosion were negligible between 1974-1977, 1977-1978, 1978-1980 and February-June 1984. Between 1974-1977 there was just one event > 1000 m^3s^{-1}, most of the runoff for which was derived from the upper catchment. The erosion/deposition regime in this interval essentially continued in the manner demonstrated between 1969-1974. Although rates of activity were negligible between 1978-1980, erosion recommenced along the right concave bank, where three narrow strips of land were removed. Three events exceeded 800 m^3s^{-1} in this interval in which deposition greatly exceeded erosion . One of these events, in May 1979, was a highly peaked lower catchment event, in which a discharge level of almost 1250 m^3s^{-1} was attained. The lack of erosion between February-June 1984 reflects the lack of any discharge events > 500 m^3s^{-1} in this interval.

Bank erosion greatly exceeded within-channel erosion between 1963-1969 and 1982-1984, and exceeded within-channel erosion to a lesser extent between 1947-1963. Bank and within-channel erosion were roughly equal between 1969-1974, while within-channel erosion exceeded bank erosion between 1984-1989.

7.5.2 Depositional regime

Extent of deposition between 1947-1963 was > 210,000 m^2, more than twice that experienced in any other interval. As sinuosity increased, there was associated deposition in the within-channel zone and on the compound point bar downstream of the concave bank. Almost 80,000 m^2 of land was added adjacent to banks, while 140,000 m^2 of land was added in the within-channel zone. While erosion and deposition were roughly balanced along the banks, deposition greatly exceeded erosion in the within-channel zone. Extensive channel adjustments reflected the dynamic nature of Waiau River pre-regulation.

Over 80,000 m^2 of land was added between 1969-1974, over 70 % of which was added in the within-channel zone. Numerous units were added to the bar complex as it expanded laterally, and significant deposition occurred at the head of the compound point bar downstream of the eroding bank. The pronounced shift to a dominantly depositional regime between 1969-1974 reflected reduction in erosion rate as the number of high magnitude floods and the periods of sustained discharge levels > 500 m^3s^{-1} were greatly reduced between 1969-1974 compared to 1963-1969. This reflected the combined effects of flow regulation and the lack of high magnitude runoff events in this interval.

The shift towards a predominantly depositional regime continued between 1974-1977, when the imbalance of erosion and deposition was even more pronounced. Over 70,000 m^2 of land was added between 1974-1977, while < 5,000 m^2 of land was eroded. Around 30,000 m^2 of land was added to the within-channel zone as secondary channels on the bar complex infilled, and 44,000 m^2 of land was added adjacent to the left bank. Rates of deposition were second only to those evident following the January 1984 flood. This largely reflected the discharge regime, as there were just two events > 800 m^3s^{-1} in this interval. One of these was an upper catchment event which exceeded 1000 m^3s^{-1}.

In the period prior to flow regulation, between 1963-1969, areal extents of erosion and deposition were balanced at almost 60,000 m^2 reflecting the 'equilibrium' condition of the channel at this time. Deposition was much less significant than between 1947-1963. Almost 40,000 m^2 of land was added as a series of small depositional units adjacent to the bar complex in the within-channel zone, while almost 25,000 m^2 of land was added marginal to banks. The large number of high discharge events, and periods of sustained flow levels > 500 m^3s^{-1}, resulted in channel adjustments which retained a balance between areal extents of erosion and deposition. While major flood events brought about substantial erosion, this was balanced by deposition during lower flow conditions.

Between 1977-1978 the relative dominance of deposition in Downstream o'Clifden reach was reversed, but this was replaced between 1978-1980 when almost 55,000 m^2 of land was deposited. Between 1977-1978 erosion was restricted to the within-channel zone, but erosion of the right concave bank recommenced between 1978-1980. In the latter interval, however, deposition greatly exceeded erosion as a secondary channel adjacent to the left bank infilled. In addition, secondary channels on the major bar complex infilled and the compound point bar expanded laterally. Almost 25,000 m^2 of land was added marginal to banks between 1978-1980, at a rate > 30 m^2/day. Extent of deposition in the within-channel zone between 1978-1980 was 30,000 m^2, at a rate of deposition of almost 40 m^2/day. This extensive deposition reflected the lack of sustained high discharge flood events in this period, as there was just one, 1-day event > 800 m^3s^{-1}.

Just less than 50,000 m^2 of land was deposited between 1980-1982. As sinuosity increased in this interval, most deposition occurred in the left bank secondary channel. While < 10,000 m^2 of land was added adjacent to banks, almost 40,000 m^2 of land was added in the within-channel zone. Indeed, this was the second highest rate of within-channel deposition experienced in the period of record (45 m^2/day). Deposition continued to dominate over erosion, but the extent was not as pronounced as during most intervals in the 1970's. This probably reflected reworking of deposits during the August 1980 flood event, which peaked at > 1350 m^3s^{-1}. This 1-day event reflected runoff throughout the catchment. Only two other 1-day events > 800 m^3s^{-1} were recorded in this interval.

Around 40,000 m^2 of land was deposited between February-June 1984. Rate of deposition was the highest on record, at almost 280 m^2/day. No erosion was evident during this period, but extensive within-channel deposition did not occur (only 11,000 m^2 of land was added in the within-channel zone). Rather, deposition was largely restricted to a long strip around the bend of the compound point bar. This resulted in a rate of bank-marginal deposition almost 4 x greater than any other interval (almost 200 m^2/day). The high deposition rate in this interval reflects the lack of any discharge event

> 500 m^3s^{-1}, the abundant materials available for redistribution following the January 1984 event, and rapid vegetative recovery on bar surfaces.

Around 40,000 m^2 of land was deposited between 1989-1992, at an average rate of deposition of almost 40 m^2/day. While trimming of the right concave bank continued, this period was characterised primarily by deposition of numerous small units in the within-channel zone, where almost 70 % of deposition occurred. The dominance of deposition in this interval reflected the infrequency of flood events (only two, 2-day events > 800 m^3s^{-1} were recorded) and the high sediment availability in the within-channel zone following the period of sustained high discharge levels in October/November 1988.

Less than 15,000 m^2 of land was deposited during remaining intervals (ie. 1977-1978, 1982-1984 and 1984-1989) at rates of addition < 20 m^2/day. Between 1977-1978 rates of adjustment were slow, but erosion dominated over deposition as bar margins were trimmed. This somewhat anomalous short interval seemingly records the impacts of just one event > 800 m^3s^{-1} that occurred in May 1977. This lower catchment event had a discharge of just 878 m^3s^{-1}, but was seemingly a highly effective erosive event in the within-channel zone. A trivial amount of deposits was preserved between 1982-1984, as the major floods in this interval effectively cleared out the channel. The five events > 800 m^3s^{-1} in this interval include the two highest magnitude floods of record, in January 1983 and January 1984. A similar situation was evidenced between 1984-1989, when erosion was absolutely dominant over deposition, as the sustained high discharge events in late 1988 effectively cleared out the channel zone, such that any bank-marginal or within-channel deposits that had occurred prior to that event were flushed through.

Deposition was significantly greater along banks than in the within-channel zone between February-June 1984, and bank-marginal deposition exceeded within-channel deposition between 1974-1977. Rates of bank and within-channel deposition were roughly equal between 1978-1980, but within-channel deposition greatly exceeded bank-marginal deposition between 1969-1974, 1980-1982 and 1989-1992. Within-channel deposition exceeded bank-marginal deposition to a lesser extent between 1947-1963 and 1963-1969. Negligible deposition occurred between 1977-1978, 1982-1984 and 1984-1989.

7.5.3 Ratio of erosion:deposition

Significant variability was evident in the ratio of erosion:deposition along banks and in the within-channel zone for many of the intervals in Downstream o'Clifden reach. Erosion was greatest during the most extreme discharge conditions, as erosion greatly exceeded deposition along banks and in the within-channel zone between 1982-1984 and 1984-1989.

Erosion and deposition were crudely balanced between 1963-1969, although erosion exceeded deposition along banks and deposition exceeded erosion in the within-channel zone. Extent of erosion and deposition were also crudely in balance along the banks between 1947-1963. In this pre-regulation era, Waiau River maintained an equilibrium condition, in

which dynamic adjustments to events of differing magnitudes induced an overall balance in erosion and depositional terms.

Deposition exceeded erosion in all remaining intervals, although erosion and deposition were crudely in balance along banks between 1980-1982 and 1989-1992. Summary deposition greatly exceeded erosion between 1969-1974, 1974-1977, 1978-1980, 1980-1982 and February-June 1984. In general, rate of deposition was high during the lower discharge phase in the 1970's, in which the low frequency of floods was combined with reduced mean flow levels associated with flow regulation, and following the flood of record in January 1984.

7.5.4 Summary relationship between discharge and channel adjustments in Downstream o'Clifden reach

Extents of erosion and deposition in Downstream o'Clifden reach were greatest in the period prior to flow regulation. Erosion and deposition were crudely balanced between 1947-1963 and 1963-1969, although deposition dominated in the within-channel zone. Waiau River effectively maintained an equilibrium condition at this stage, in which erosion of the concave bank was balanced by within-channel deposition. In the period following flow regulation the rate of erosion decreased, while deposition increased. However the shift to a predominantly depositional regime after 1969 was not as dramatic as observed in Wairaki and Lill Burn reaches. Rate of deposition between 1969-1974 was only marginally greater than that between 1947-1963 and 1963-1969. Flow alignment allowed erosion to continue in the concave bank despite the greatly reduced mean flow between 1969-1974. Rate of deposition was actually higher in the following interval, between 1974-1977. Erosion was absolutely trivial in this period of low discharge. Erosion and deposition were both negligible between 1977-1978, but deposition continued to dominate between 1978-1980 and 1980-1982. In both these intervals there was just one, 1-day event >1200 m^3s^{-1}. The lack of tributary impacts in Downstream o'Clifden reach, combined with the lack of extreme events in the decade following flow regulation and the reduction in mean flow associated with regulation, induced a shift to a depositional regime and a reduction in the rate of bank erosion throughout the 1970's.

The pattern of depositional dominance was modified during the high discharge intervals in the 1980's, although rapid channel recovery followed the erosional phases induced by the major floods in January 1983 and January 1984 and the period of sustained high discharge in October/November 1988. In contrast to the laterally unconfined reaches upstream, extent of erosion between 1984-1989 was actually greater than between 1982-1984, especially along banks. However, rate of erosion was greater between 1982-1984 than any other interval in the period of record. Extent of deposition was exceedingly low between 1982-1984 and 1984-1989, reflecting efficient flushing of the channel zone. The negligible area of deposition between 1984-1989 contrasted starkly with Wairaki and Lill Burn reaches. Deposition was dominant between February-June 1984 and 1989-1992 as materials were reworked and the channel contracted during relatively low discharge conditions.

7.6 Floods and channel adjustments in Tuatapere reach

The character of channel adjustment in Tuatapere reach is summarized in Appendix 2. Discharge data at Tuatapere gauging station are analysed for the various photographic interval used in Appendices 3-5. Summary extents and rates of erosion and deposition are presented in Table 7.15.

Table 7.15 Summary rates of channel adjustments over differing time intervals: Tuatapere reach

	Combined banks		Within-channel		Total	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
Total areal adjustment (in m^2 x 1000)						
22.03.46/28.03.47 to 10.03.63	355.10	169.70	340.70	561.00	695.80	730.70
10.03.63 to 12.02.69	123.10	78.90	104.20	148.40	227.30	227.30
12.02.69 to 07.07.74	65.20	42.90	45.10	536.20	110.30	579.10
07.07.74 to 03.03.75	0.00	24.90	2.00	12.20	2.00	37.10
03.03.75 to 25.02.77	16.80	28.80	10.30	58.30	27.10	87.10
25.02.77 to 11.02.78	13.70	17.30	38.00	76.50	51.70	93.80
11.02.78 to 14.04.80	25.50	66.50	15.70	143.30	41.20	209.80
14.04.80 to 12.08.82	30.20	13.70	36.60	80.90	66.80	94.60
12.08.82 to 21.06.84	79.00	2.20	166.90	42.00	245.90	44.20
21.06.84 to 08.10.85	25.80	21.40	123.00	42.10	148.80	63.50
08.10.85 to 04.04.89	215.40	120.80	247.00	121.50	462.40	242.30
04.04.89 to 14.04.92	21.70	24.60	34.60	146.00	56.30	170.60
Average rate of areal adjustment (in m^2/day)						
22.03.46/28.03.47 to 10.03.63	57.34	27.40	55.01	90.59	112.35	117.99
10.03.63 to 12.02.69	56.89	36.46	48.15	68.58	105.04	105.04
12.02.69 to 07.07.74	32.93	21.67	22.78	270.81	55.71	292.47
07.07.74 to 03.03.75	0.00	108.73	8.73	53.28	8.73	162.01
03.03.75 to 25.02.77	23.20	39.78	14.23	80.52	37.43	120.30
25.02.77 to 11.02.78	39.03	49.29	108.26	217.95	147.29	267.24
11.02.78 to 14.04.80	32.24	84.07	19.85	181.16	52.09	265.23
14.04.80 to 12.08.82	35.53	16.12	43.06	95.18	78.59	111.29
12.08.82 to 21.06.84	116.52	3.24	246.17	61.95	362.68	65.19
21.06.84 to 08.10.85	54.43	45.15	259.49	88.82	313.92	133.97
08.10.85 to 04.04.89	168.94	94.75	193.73	95.29	362.67	190.04
04.04.89 to 14.04.92	20.63	23.38	32.89	138.78	53.52	162.17

7.6.1 Erosional regime

Extensive erosion occurred in Tuatapere reach in most of the intervals in the photographic record. Extent of erosion was greatest between 1946-1963, when almost 700,000 m^2 of land was eroded. In this pre-regulation interval, Waiau River freely shifted its course in Tuatapere reach, which is the most alluvial reach along the entire river course. Extensive adjustments occurred, at rates which simply cannot be unravelled from photographs taken at the beginning and end of this 17 year interval. Measured extents of erosion were roughly equal along banks and in the within-channel zone. While deposition exceeded erosion in the within-channel zone, erosion exceeded deposition along both banks, reflecting the shifting nature of the main channel. Waiau River shifted over 100 m to the west in Upstream of Carr's reach and over 150 m to the east in Mid-break to bend break subreach. Erosion was especially severe along the right bank at Carr's property, along the left bank in Carr's to mid-break subreach, and along the right bank at the river mouth. Erosion in the within-channel zone was prominent in Upstream of Carr's and Mid-break to bend break subreaches.

In contrast to other reaches, the most extensive erosion in Tuatapere reach post-regulation was not associated with the interval including the flood of record (1982-1984), but occurred in the interval that included the longest period of sustained high discharge levels, between 1985-1989. Extensive erosion throughout Tuatapere reach resulted in removal of over 460,000 m^2 of land between 1985-1989. Between 1985-1989 a greater proportion of flow was oriented down the left bank channel adjacent to the large bar complex in Upstream of Carr's subreach, increasing channel width. Significant erosion occurred at the head of this bar complex, while a diagonally-oriented flood channel reworked the bar immediately upstream. Significant erosion occurred along the left bank and in the within-channel zone in the remainder of Carr's to mid-break subreach, as the channel straightened. In contrast, channel sinuosity increased in Mid-break to bend break subreach, with up to 80 m of erosion along the right concave bank at the head of the subreach, and over 50 m of erosion along the left bank downstream of this point. The head of the compound point bar at the downstream end of this subreach eroded by almost 80 m. Downstream translation of bends effectively destroyed the next compound point bar in sequence. Increase in the definition of the main channel, along with its altered alignment as sinuosity increased, resulted in erosion of the right concave bank at the head of Downstream of bend break subreach. The next bend downstream experienced almost 100m of bank retreat. Associated with the development of this sequence of bends, erosion was renewed along the right bank at the river mouth.

In summary terms, erosion in the within-channel zone exceeded bank erosion between 1985-1989. Almost 250,000 m^2 of land was eroded from the within-channel zone, while 210,000 m^2 of land was eroded from along banks. Extensive bank erosion reflects the ability of Waiau River to shift its position in the active channel zone, reworking adjacent alluvial flats. Bank erosion was primarily associated with downstream translation rather than lateral migration of bends, as the active channel zone retained a roughly straight alignment from Tuatapere to Te Waewae Bay (see Figures 6.34-6.37). High erosion rates between 1985-1989 were induced by four events > 1000 m^3s^{-1}. While three of these events were short-lived 1 or 2-day floods, there were 29 days in October and November 1988 in which discharge levels > 800 m^3s^{-1} were experienced, and on 16 of these days discharge exceeded 1200 m^3s^{-1}. This sustained high discharge event reflected upper catchment runoff contribution. While the high discharge levels in October/November 1988 induced significant erosion along the entire reach, localised erosion occurred at greater rates during differing intervals.

While rate of land loss between 1982-1984 was equivalent to that demonstrated between 1985-1989, at 360 m^2/day, the extent of erosion was notably smaller, at < 250,000 m^2. The apparent effectiveness of the 1985-1989 period of sustained high flows relative to the 1982-1984 period of high magnitude events may partially be explained by the air photograph sequences used in analysis. In contrast to other reaches studied, the 1982-1984 period analysed in Tuatapere reach extends to June 1984 rather than February 1984. As such it includes the five month interval between February-June 1984 which has been identified as a period of significant channel recovery and extensive deposition in other reaches. While erosion and deposition could be seen to 'balance-out' in association with this channel recovery, thereby reducing the extent of erosion measured, this effect is considered to be relatively unlikely given the low extent of deposition evident between 1982-June 1984.

The distribution of erosion between 1982-1984 is noteworthy, as almost 70 % of erosion occurred in the within-channel zone, where numerous secondary channels were reactivated. Erosion was especially prevalent downstream of

Upstream of Carr's subreach. Extensive trimming occurred in Carr's to mid-break subreach. In Mid-break to bend break subreach the main channel shifted over 80 m with extensive erosion along the right bank. The head of the compound point bar at the head of Downstream of bend break subreach was eroded, as was the opposite concave bank. Somewhat surprisingly, this newly formed concave bank was the only site in Tuatapere reach in which bank erosion between 1982-1984 was more extensive than in any other interval. The left bank secondary channel at the head of Downstream of bend break subreach was reactivated, while the margin at the bar head eroded. The tail end of the bar complex at the river mouth also eroded severely.

While the geomorphic effectiveness of the two largest floods of record, the highly peaked 2-day events in January 1983 and January 1984 which both exceeded 1500 m^3s^{-1}, was pronounced, it was perhaps less dramatic than elsewhere because Tuatapere reach is the most alluvial reach along Waiau River. Accordingly, this reach is prone to reworking and redistribution of materials over a wide range of discharge stages, such that the relative effectiveness of extreme events is less pronounced. This effect could be exaggerated as the river reworks smaller-sized gravels selectively supplied from tributary catchments along its lower course.

Between 1963-1969 areal extents of erosion and deposition were almost exactly equal. Erosion along banks marginally exceeded erosion in the within-channel zone, as a total of > 225,000 m^2 of land was removed. Erosion dominated over deposition along the banks, but deposition dominated in the within-channel zone. Erosion was especially prominent at the head and tail of the mid-channel complex in Upstream of Carr's subreach, along the left bank in Carr's to mid-break subreach and along the right bank at the river mouth. Indeed, rate of bank retreat at Carr's place, along the left bank in Carr's to Mid-break subreach, and at the river mouth was more rapid between 1963-1969 than during any other interval. This reflects changes in channel alignment associated with sustained high discharge levels in the period prior to flow regulation. Between 1964-1969 there were twenty events > 800 m^3s^{-1}, five of which exceeded 1200 m^3s^{-1}. Almost 50 % of days experienced discharge levels > 500 m^3s^{-1}, indicating that this was a period of continual channel adjustments in the alluvial Tuatapere reach.

Extent of erosion between 1946-1963, 1985-1989, 1982-1984 and 1963-1969 was notably greater that recorded during other intervals. However, relative rate of erosion was exceptionally high between 1984-1985, when 310 m^2/day of land was eroded. Erosion continued to dominate over deposition in this interval, and a total of almost 150,000 m^2 of land was eroded. The spatial distribution of land loss differed notably from that evident between 1982-1984, as bank erosion was trivial relative to within-channel erosion. The latter accounted for > 80 % of erosion between 1984-1985. Indeed, rate of within-channel erosion between 1984-1985 was greater than during any other interval in the period of record (> 250 m^2/day). Despite the relative lack of bank erosion in this interval, localised bank erosion between 1984-1985 actually exceeded that recorded between 1982-1984 at selected sites (eg. along the right bank at Carr's place and along the left bank in Carr's to Mid-break reach; Figures 6.34 and 6.35).

Between 1984-1985 flood channels were reactivated in the large bar complex upstream of Carr's, and significant erosional reworking of within-channel bars occurred in Carr's to mid-break subreach. Negligible changes were evident in Mid-break to bend break subreach, but erosion continued at the head of Downstream of bend break subreach where a

series of small bars eroded. There was only one event > 800 m^3s^{-1} between 1984-1985, a 2-day lower catchment event in January 1985. However, almost 7 % of days maintained discharge levels > 500 m^3s^{-1}. It is clear that in this alluvial reach these relatively low magnitude flows, which were equivalent to the normal discharge levels pre-regulation, were able to induce notable channel changes, including bank erosion. Localised erosion probably reflected shifts in channel alignment during major events. For example, secondary channels may be abandoned and concave banks may become more defined as bends develop, such that lower discharge flows become concentrated against banks in certain locations. This effect may be aided by aggradation of finer gravels selectively supplied from tributary catchments following regulation, as the channel is able to mobilise these clasts at lower discharge stages (Brierley, 1992).

As evidenced in all other reaches of pronounced channel adjustments along Waiau River, there was a pronounced shift in the erosion/deposition balance between 1969-1974. While summary extents of erosion and deposition were equal between 1946-1963 and 1963-1969, areal extent of deposition was over 5 x greater than that of erosion between 1969-1974. However, 110,000 m^2 of land was eroded between 1969-1974, almost 60 % of which occurred adjacent to banks. Erosion was focussed at the downstream end of Carr's to mid-break subreach and along the right bank at the head of Mid-break to bend break subreach, where concave banks had developed as the main channel adopted a more sinuous outline. Erosion also continued along the right bank at the river mouth. The maintenance of high bank erosion rates at certain sites in Tuatapere reach between 1969-1974 reflects the dynamic alluvial nature of this reach which has enabled reworking of deposits and realignment of channels associated with bend development. This was supported by relatively high discharge levels, in which almost 20 % of days had flow levels > 500 m^3s^{-1}. There were seven floods > 800 m^3s^{-1}, two of which extended for > 10 days. Both of these events exceeded 1200 m^3s^{-1}.

All remaining intervals experienced less than 100,000 m^2 of land loss. Between 1980-1982 deposition dominated over erosion, especially in the within-channel zone. In total, over 65,000 m^2 of land was lost at a rate of land loss < 80 m^2/day. Bank erosion was primarily restricted to the left concave bank at the downstream end of Carr's to mid-break subreach and along the right concave bank downstream of Bend break. Notable trimming occurred along mid-channel bars. There were only three 1-day events > 800 m^3s^{-1} during this interval. Most erosion probably occurred during the highly peaked event on August 26 1980 which attained a peak discharge of > 1350 m^3s^{-1}.

Between 1989-1992 deposition dominated over erosion. Over 55,000 m^2 of land was lost in this interval, at a rate > 50 m^2/day. Over 60 % of erosion occurred in the within-channel zone. Localised erosion continued in Upstream of Carr's subreach, especially along the left bank channel. Trimming continued along the right bank in Carr's to mid-break subreach. Of the 24 days in which discharge levels exceeded 500 m^3s^{-1} in this interval, only 3 days had discharge levels > 1000 m^3s^{-1}. The two events in which discharge levels > 1200 m^3s^{-1} were attained were both lower catchment events, one of which rose from < 400 m^3s^{-1} to 1237 m^3s^{-1} between 17-18 February 1991.

Between 1977-1978 deposition was dominant over erosion, but just over 50,000 m^2 of land was lost. Given the short time interval considered, however, the rate of erosion was surprisingly high, as almost 150 m^2/day of land loss was recorded. Erosion was concentrated in the within-channel zone where the rate of land loss was almost 110 m^2/day. Bank erosion was restricted to the left concave bank at the downstream end of Carr's to mid-break subreach and the right

concave bank at the head of Downstream of bend break subreach. Reworking of mid-channel bars took place at the downstream end of Mid-break to bend break subreach and the upstream end of Downstream of bend break subreach. The high rate of erosion in Tuatapere reach between 1977-1978 is quite anomalous, as discharge exceeded 500 m^3s^{-1} on just 4 days in this interval. Indeed, the only event which exceeded 800 m^3s^{-1} occurred on 23 May 1977, and had a peak discharge of just 878 m^3s^{-1}. It appears that this lower catchment event was particularly effective in bringing about localised erosion.

Deposition was absolutely dominant over erosion between 1978-1980. However, just over 40,000 m^2 of land was lost at a rate of land loss > 50 m^2/day. Over 60 % of erosion occurred along banks. Erosion was restricted to trimming of the left bank at the downstream end of Carr's to mid-break subreach and along the right bank at the river mouth. Just 3 events exceeded 800 m^3s^{-1} in this interval. However, one of these events was an extremely peaked event in May 1979, which exceeded 1200 m^3s^{-1}. It is certainly strange that the extent and rate of total erosion between 1977-1978 should exceed that between 1978-1980, as flow levels > 500 m^3s^{-1} were recorded on almost 7 % of days in the latter interval but just over 1 % of days in the former interval. However, it is interesting to note that bank erosion, which is a more significant indicator of permanent channel adjustment, was greater in terms of both extent and rate between 1978-1980 compared to 1977-1978.

Less than 30,000 m^2 of land was lost between 1975-1977. Erosion was essentially restricted to the incipient right bank concave bank at the head of Mid-break to bend break subreach, as flow realigned following deposition of the left bank compound point bar between 1969-1974. Erosion in this interval can be attributed to 2 upper catchment events, one of which, in April 1975, sustained flow levels > 800 m^3s^{-1} for 8 days and had a peak discharge > 1150 m^3s^{-1}. No bank erosion whatsoever was recorded between 1974-1975. Discharge levels > 500 m^3s^{-1} were never attained during this interval.

Rate of land loss was higher along the banks relative to the within-channel zone between 1963-1969, 1969-1974 and 1978-1980. Roughly equivalent areas of land were eroded along banks and in the within-channel zone between 1946-1963, 1980-1982 and 1985-1989. Within-channel erosion greatly exceeded bank erosion between 1977-1978 and 1984-1985, and exceeded bank erosion to a lesser extent between 1982-1984 and 1989-1992.

7.6.2 Depositional regime

Pronounced temporal variability is evident in the extent and rate of deposition in Tuatapere reach. Extent of deposition was greatest between 1946-1963, but rate of deposition was highest between 1969-1974. The period following flow regulation was associated with a distinct shift in the erosion/deposition balance, as high deposition rates (> 100 m^2/day) were maintained throughout the 1970's, and deposition rates were > 250 m^2/day between 1969-1974, 1977-1978 and 1978-1980.

Over 730,000 m^2 of land was added within Tuatapere reach between 1946-1963. Extensive channel adjustments occurred, especially in the within-channel zone where deposition exceeded erosion. Over 75 % of deposition occurred in the within-channel zone. Deposition was prominent as bars left behind as the main channel shifted over 100 m to the west in Upstream of Carr's reach and over 150 m to the east in Mid-break to bend break subreach. Deposits infilled the areas left behind as the channel shifted. The approximate balance between areas of erosion and deposition reflected the equilibrium nature of the channel at this time.

Almost 580,000 m^2 of land was added between 1969-1974, over 90 % of which occurred in the within-channel zone. Rate of land-addition in the within-channel zone was > 270 m^2/day. In Upstream of Carr's, Carr's to mid-break and Mid-break to bend break subreaches deposition generally took the form of lateral expansion units adjacent to compound point bars, as the main channel of Waiau River became better defined and adopted a more sinuous outline. Deposition was especially prominent in Mid-break to bend break subreach. Within-channel deposition at the river mouth amalgamated a series of small bars.

Extent of erosion and deposition were roughly in-balance prior to flow regulation. The shift to a predominantly depositional regime between 1969-1974 was characterised by both an increase in deposition rate and a reduction in the rate of erosion compared to 1963-1969. Extent of deposition was 5 x greater than that of erosion. This transition in the erosion/sedimentation regime reflected the reduction in mean flow associated with flow regulation. Whereas almost 50 % of days experienced discharge levels > 500 m^3s^{-1} between 1964-1969, the proportion dropped to < 19 % between 1969-1974. The reduction in mean flow was compounded by a reduction in peak flows, with over 4 % of days experiencing discharges > 1000 m^3s^{-1} between 1969-1974, but < 2 % of days between 1969-1974. Indeed, there were twenty events > 800 m^3s^{-1} between 1964-1969, but just seven between 1969-1974. Two events between 1969-1974 had more than 20 consecutive days with flow levels > 800 m^3s^{-1} and peak discharges > 1250 m^3s^{-1}.

Extents of deposition between 1946-1963 and 1969-1974 were much more extensive than in all other intervals. Indeed, the next highest extent, between 1985-1989, was less than one-half that experienced between 1969-1974. Almost 250,000 m^2 of land was added between 1985-1989. However this was a period of extensive erosion throughout Tuatapere reach, in which erosion outstripped deposition by a ratio of almost 2:1. Between 1985-1989 extents of deposition adjacent to banks and in the within-channel zone were equal, with rates of addition of land of almost 100 m^2/day. While this was the second highest deposition rate adjacent to banks, it was only the fifth highest within-channel deposition rate. Realignment of flow in Upstream of Carr's subreach resulted in deposition adjacent to the right bank at the head of Carr's to mid-break subreach. In Mid-break to bend break subreach the sequence of bends expanded, as channel sinuosity increased. Downstream translation of bends and erosion of concave banks was compensated by compound point bar development. The bar complex adjacent to the left bank at the river mouth amalgamated into a much larger form. Extensive deposition in this interval reflected substantial reworking of materials by sustained high discharges, but greater width of the active channel zone in Tuatapere reach resulted in less effective flushing of deposits and higher extent and rate of relative preservation of materials relative to upstream reaches. Five events between 1985-1989 exceeded 800 m^3s^{-1}, four of which exceeded 1000 m^3s^{-1}. After 1964-1969 (ie. pre-regulation), there was a greater proportion of days with discharge levels > 1000 m^3s^{-1} between 1985-1989 than in any other interval (26 days,

ie. > 2 % of total) while 1.2 % of days had discharge levels > 1250 m^3s^{-1}, a proportion even greater than pre-regulation levels. This was almost entirely associated with the October/November 1988 period of sustained high discharge levels, in which there were 16 days on which discharge at Tuatapere was > 1200 m^3s^{-1}.

Between 1963-1969 over 225,000 m^2 of land was added, over 65 % of which was added in the within-channel zone. While erosion continued to dominate over deposition along the banks, overall areas of adjustment of erosion and deposition were similar. Although deposition was dominant in the within-channel zone, individual depositional units were small. Three bars formed in the new channel in Carr's to mid-break subreach, left bank compound bars in Mid-break to bend break subreach expanded laterally, and various mid-channel bars at the river mouth amalgamated. The balance between erosion and deposition between 1963-1969 reflected the equilibrium nature of the channel pre-regulation. A range of flood events were evident between 1964-1969, twenty of which exceeded 800 m^3s^{-1}. Nine events lasted for 10 or more days. Five events exceeded 1200 m^3s^{-1}, with a peak discharge events > 1469 m^3s^{-1} in April/May 1967.

Between 1978-1980 almost 210,000 m^2 of land was added at a rate of > 265 m^2/day. Deposition was absolutely dominant over erosion in this interval. Almost 70 % of land was added in the within-channel zone. Numerous small depositional units were laid down at the margins of bar complexes in Upstream of Carr's and Carr's to mid break subreaches. Deposition was much more substantial in Mid-break to bend break and Downstream of bend break subreaches. Three mid-channel bars were accreted to the right bank in Mid-break to bend break subreach, while a large mid-channel bar became attached to the left bank at the head of Downstream of bend break subreach. While almost 7 % of days experienced discharge levels > 500 m^3s^{-1} between 1978-1980, there were just 3 events > 800 m^3s^{-1}, but these were all fairly peaked lower catchment events. It can be inferred that events > 800 m^3s^{-1} induce erosion in Tuatapere reach, whereas events between 500-800 m^3s^{-1} are primarily depositional in nature.

The only other interval in which an extent of deposition > 100,000 m^2 was recorded was between 1989-1992, when over 170,000 m^2 of land was added. Over 85 % of this deposition occurred in the within-channel zone, at a rate of almost 140 m^2/day. Deposition dominated over erosion in this interval, especially in the within-channel zone in Carr's to mid-break and Mid-break to bend break subreaches. Substantial deposition occurred as within-channel bars adjacent to the left bank in Carr's to mid-break subreach (ie. the area of channel eroded earlier in the period of record). Deposition in Mid-break to bend break subreach occurred as a mid-channel bar complex at the entrance to this subreach and as extension of the left bank compound point bar at the downstream end of this subreach. While 24 days between 1989-1992 had discharge levels > 500 m^3s^{-1}, there were just 3 days in which discharge exceeded 1000 m^3s^{-1}. This reflected two short lived, lower catchment events. As indicated between 1978-1980, it appears that events between 500-750 m^3s^{-1} were primarily depositional in nature.

Between 1980-1982 deposition continued to dominate over erosion, especially in the within-channel zone. Almost 95,000 m^2 of land was added in Tuatapere reach, at a deposition rate > 110 m^2/day. Over 85 % of deposition occurred in the within-channel zone. Deposition generally took the form of small accretional units, although a series of units amalgamated opposite the concave bank at the downstream end of Carr's to mid-break subreach and numerous bars were

deposited at the river mouth. The greater extent of erosion relative to deposition along banks probably reflects the impact of the extremely peaked flood event in August 1980, which had a maximum discharge of 1357 m^3s^{-1}, as there were just two other 1 day events which had discharges > 800 m^3s^{-1}. However, almost 8 % of days between 1980-1982 had discharge levels > 500 m^3s^{-1}, suggesting that discharges between 500-800 m^3s^{-1} in Tuatapere reach were primarily depositional, especially in the within-channel zone.

Almost 95,000 m^2 of land was deposited between 1977-1978, over 80 % of which occurred in the within-channel zone. Summary rate of deposition in this interval was the second highest in the period of record, as > 265 m^2/day of land was added. Between 1977-1978 erosion and deposition were localised, but deposition was generally dominant in the within-channel zone. Numerous small units were deposited at the head of the mid-channel complex in Upstream of Carr's subreach. Downstream of this point, most within-channel deposition occurred as infilling and/or abandonment of secondary channels. The dominance of deposition between 1977-1978 is readily accounted for by the discharge record, as there was just one, 1-day event > 800 m^3s^{-1} in this interval. However, there were only 4 days in which discharge exceeded 500 m^3s^{-1}, from which it can be inferred that deposition is taking place at discharge levels < 500 m^3s^{-1}. This threshold phenomenon is difficult to define, especially as the calibre of materials moved by the river has changed over time.

Numerous small depositional units were spread throughout Tuatapere reach between 1975-1977, but overall rate of deposition was relatively low. Almost 90,000 m^2 of land was added in this interval, at an average rate of about 120 m^2/day. Over 65% of deposition occurred in the within-channel zone. Two events exceeded 800 m^3s^{-1} in this interval, one of which lasted for 8 days. However, neither event exceeded 1200 m^3s^{-1}. This seemingly explains the dominance of a depositional regime, as 46 days experienced discharge levels > 500 m^3s^{-1} (over 6 % of total days) but just 3 days had discharge levels > 1000 m^3s^{-1} (less than 0.5% of total days).

Over 60,000 m^2 of land was added between 1984-1985. Erosion was dominant during this interval, but the lower half of Downstream of bend break subreach was primarily depositional adjacent to the left bank bar complex. Despite the relatively limited extent of deposition in this interval, rates of deposition was fairly high at almost 135 m^2/day. As evidenced in most other intervals in Tuatapere reach, over 66% of deposition occurred in the within-channel zone. There was just one event > 800 m^3s^{-1} in this interval, in January 1985. This lower catchment event had a peak discharge of 967 m^3s^{-1}. While 32 days had discharge levels > 500 m^3s^{-1}, only 3 days had discharge levels >750 m^3s^{-1}. However, the pattern of dominant deposition associated with such a flow regime, as indicated for numerous intervals above, was not apparent between 1984-1985. This reflects the manner of channel adjustment following the January 1984 flood, as the river was destabilised in the subsequent period. In the process of adjusting to the flood of record, erosion continued at a much greater rate than would have been predicted for the given discharge regime between 1984-1985. The effectiveness of any discharge regime is clearly contingent on the condition of the system at the time of subsequent floods.

The two remaining intervals (1974-1975 and 1982-1984) experienced extents of deposition < 50,000 m^2. Between 1974-1975 deposition was restricted to the left bank bar complex upstream of the river mouth. However, rate of bank

adjacent to banks between 1974-1975 was 100 m^2/day, the highest rate on record in this reach. Discharge levels > 500 m^3s^{-1} were never exceeded in this interval, indicating that deposition, especially in the form of channel contraction, can occur at lower discharge stages. The exceedingly low extent and rate of bank-marginal deposition between 1982-1984 reflected the flushing effectiveness of major floods. Indeed, this was the only interval in which < 100 m^2/day of land was added in Tuatapere reach. This interval also included the period between February-June 1984, which was a period of channel recovery and depositional dominance in other reaches studied. The lower rates of deposition in Tuatapere reach probably reflect the alluvial nature of this reach, and the greater ease with which materials can be mobilised. Selective supply of finer-grained materials from by tributary catchments may partially explain this phenomenon.

Deposition in the within-channel exceeded bank-marginal deposition in all intervals other than between 1985-1989, and was associated with the development of compound point bars and secondary channel abandonment during this period. Within-channel deposition greatly exceeded bank-marginal deposition between 1946-1963, 1969-1974, 1978-1980, 1980-1982, 1982-1984 and 1989-1992.

7.6.3 Ratio of erosion:deposition

Pronounced variability was evident in the pattern of erosion and deposition along banks and in the within-channel zone for the differing intervals of record. Erosion greatly exceeded deposition in summary terms between 1982-1984 and 1984-1985. Between 1982-1984 erosion was pronounced along both banks and in the within-channel zone. However, erosion between 1984-1985 was dominant in the within-channel zone, as erosion and deposition were crudely balanced along the banks in this interval. Erosion also exceeded deposition between 1985-1989. As indicated for the period 1984-1985, this primarily reflects the high rate of erosion in the within-channel zone. The dominance of erosion in these intervals between 1982-1989 reflected channel responses to the major floods of record and the longest period of sustained high discharge.

Erosion and deposition were crudely balanced in summary terms between 1946-1963 and 1963-1969. In both instances, however, erosion exceeded deposition along banks, while deposition exceeded erosion in the within-channel zone. In these intervals prior to flow regulation the erosion/sedimentation regime reflected an equilibrium condition.

Summary deposition exceeded erosion between 1977-1978 and 1980-1982, although between 1980-1982 erosion exceeded deposition along banks. The degree to which deposition exceeded erosion was much greater between 1969-1974, 1974-1975, 1975-1977, 1978-1980 and 1989-1992. As indicated for several other intervals, however, deposition greatly outstripped erosion in the within-channel zone during each of these intervals, while erosion outstripped deposition along the banks between 1969-1974 and erosion and deposition rates were crudely equal along banks between 1989-1992. The predominance of deposition in each of these intervals reflected the combined influences of reduced mean flow condition associated with flow regulation and the lack of high magnitude floods.

7.6.4 Summary relationship between discharge and channel adjustments in Tuatapere reach

The dynamic nature of channel adjustments in Tuatapere reach throughout the period of photographic record is reflected in the rates of erosional and depositional activity summarised in Table 7.15. Of the 24 rates measured for differing photographic intervals, there are only two recordings < 50 m^2/day, and only one interval, between 1982-1984 had a rate of deposition < 100 m^2/day. While Tuatapere reach is the longest unconfined reach analysed in this study, it is also the most alluvial reach along the entire course of Waiau River. Extensive reworking of deposits in this reach is reflected in the greater proportion of within-channel deposition relative to bank-deposition for each other interval, other than the trivial activity between 1974-1975.

Many of the erosional and depositional trends described previously also apply to Tuatapere reach. Erosion and deposition were balanced in summary terms prior to flow regulation, although erosion was dominant along banks and deposition was dominant in the within-channel zone between 1946-1963 and 1963-1969. A dramatic shift in the erosion and sedimentation regime occurred between 1969-1974, when extent of deposition was 5 x that of erosion. While rate of erosion between 1969-1974 was roughly half that recorded between 1963-1969, rate of deposition increased by almost 3 x. Although this transition clearly reflected the impact of flow regulation, which reduced mean flow at Tuatapere from around 500 m^3s^{-1} to about 100 m^3s^{-1}, the timing of flow regulation was also coincident with a period of infrequent moderate-high magnitude floods. For example, 0.7 % of days between 1964-1969 had discharge levels > 1250 m^3s^{-1} compared to just 0.25 % of days between 1969-1974, whereas one flood event peaked above 1500 m^3s^{-1} between 1964-1969, while no events attained a discharge of 1500 m^3s^{-1} between 1969-1974 (see Appendix 4.5).

Deposition continued to dominate over erosion throughout the 1970's and between 1980-1982. High discharge events were infrequent throughout this period, but rates of erosion > 50 m^2/day were recorded between 1977-1978, 1978-1980 and 1980-1982. In each instance rate of removal of land from banks was > 30 m^2/day. This extent of bank erosion is not insubstantial, and reflects the ability of Waiau River to rework its boundaries under relatively low magnitude, high frequency events in Tuatapere reach. Floods of record between 1977-1978, 1978-1980 and 1980-1982 were 878 m^3s^{-1}, 1240 m^3s^{-1} and 1357 m^3s^{-1}. These were peaked events, the first two of which reflected lower catchment runoff contribution while the August 1980 flood reflected runoff contribution from throughout the catchment. The one-day floods of record between 1978-1980 and 1980-1982 were the only events to exceed 1000 m^3s^{-1}. Less than 0.5 % of days had discharge levels > 750 m^3s^{-1} in each interval. However, between 1978-1980 and 1980-1982 there were 6.7 % and 7.8 % of days with discharge levels > 500 m^3s^{-1}, and it is likely that most erosional reworking in Tuatapere reach between 1977-1982 occurred at discharge levels between 500-750 m^3s^{-1} (ie. flow levels marginally above the mean flow prior to regulation). It must be remembered, however, that deposition was clearly dominant in each of these intervals. The slightly different effectiveness of these events in Wairaki and Lill Burn reaches can be explained by reference to tributary system contributions of flow and sediment and implications for channel adjustment immediately downstream of the confluence zone.

The erosion/deposition balance shifted markedly towards erosion between 1982-1984, when erosion exceeded deposition by a ratio of over 5.5:1. This interval included the period between February-June 1984 which was characterised by pronounced channel recovery and extensive deposition in other laterally unconfined reaches. The two floods of record in January 1983 and January 1984 clearly induced instability in the pattern of erosion and deposition in Tuatapere reach. Indeed, erosion continued to dominate over deposition between 1984-1985, although this was a period of low magnitude floods with just one event > 800 m^3s^{-1}. However, 7 % of days maintained discharge levels > 500 m^3s^{-1} between 1984-1985, confirming the capability of flow levels between 500-800 m^3s^{-1} to induce erosion in Tuatapere reach. Between 1984-1985 over 80 % of this erosion occurred in the within-channel zone.

In contrast to other laterally confined reaches along Waiau River in which the greatest rate of bank erosion occurred between 1982-1984, associated with the flood of record, bank erosion in Tuatapere reach was most rapid between 1985-1989. This largely reflected the shift in channel alignment in this reach, as a more sinuous outline was adopted in the 4 km reach upstream of the river mouth. Deposition was also extensive between 1985-1989, as compound bars developed on the inside of bends and secondary channels were abandoned. The relatively high proportion of days with discharge levels > 800 m^3s^{-1} between 1985-1989 induced major erosional and depositional activity throughout this lowland alluvial reach.

While rate of erosion was maintained at > 50 m^2/day between 1989-1992, deposition was 3 x more extensive than erosion in this interval. This reflected the low proportion of days with discharge levels > 800 m^3s^{-1} between 1989-1992, as only 4 days had flow levels > 800 m^3s^{-1}, and discharge exceeded 1200 m^3s^{-1} on just one of these days. However, discharge was > 500 m^3s^{-1} on 24 days (2.3 % of total days) suggesting once more that erosion and deposition can occur at discharge levels between 500-800 m^3s^{-1}.

The major high discharge events in 1984 and 1988 exerted less areally significant adjustments in Tuatapere reach relative to other laterally unconfined reaches. Major floods exert relatively less impacts in more alluvial reaches, as adjustments can occur more readily at lower discharge stages.

Finally, changes in the position of the most dramatic bank erosion reflect changes in channel alignment and within-channel deposition over time. Rate of retreat of concave banks was greatest just after bends initiated, and cannot be tied directly to the flood regime. For example, the right concave bank at Carr's propoerty experienced the highest rate of bank retreat between 1946-1963, whereas the left bank in Carr's to Mid-break subreach and the right bank downstream of Bend break experienced maximum rates of bank retreat between 1963-1969 and 1982-1984 respectively.

7.7 Floods and channel adjustments: A comparative assessment of flood effectiveness along Waiau River

In this section summary areal estimates of total erosion and deposition are compared for each reach over each photographic time interval. This information is then interpreted in relation to the flood history. Analysis is restricted to the four reaches, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere, in which 10 or more air photograph runs were analysed. In Section 7.7.1 spatial and temporal variability in total erosion are discussed. This is followed, in Section 7.7.2, by consideration of bank erosion. This section is divided into two parts, the first of which assesses bank erosion throughout the four reaches, while the second part examines the temporal variability in volumetric removal of material at nine selected sites along the course of lower Waiau River. Temporal and spatial variability in depositional regime, and its relation to the discharge record, is evaluated in Section 7.7.3. Finally, the changing nature of the erosion/deposition balance, and the impacts of individual flood events before and after flow regulation are described in Section 7.7.4.

7.7.1 Spatial and temporal variability in total erosion

In Table 7.16 areal estimates of total erosion (ie. bank and within-channel erosion combined) are presented for one interval pre 1969 and eight intervals post 1969. Of the four reaches considered, identical intervals can be designated for Wairaki, Lill Burn and D/s o'Clifden reaches, whereas the differing photographic runs used in analysis of channel adjustments in Tuatapere reach resulted in two alternative intervals (1984-1985 and 1985-1989) being compiled. Data on total erosion are presented in three ways:

(i) Absolute areal estimate of erosion in m^2 x 1000, determined to the nearest 10,000 m^2.

(ii) Relative erosion rate assessed to the nearest 10 m^2/day, and

(iii) Percentage of total erosion occurring in each interval, calculated as the proportion of total erosion in each interval divided by the summary extent of erosion between 1963-1992.

In all four reaches the relative rate of erosion was greatest between 1982-1984, coincident with the two highest floods of record in January 1983 and January 1984. However, the relative significance, or geomorphic effectiveness, of these events differed spatially, as erosion in Wairaki reach between 1982-1984 accounted for > 50 % of total erosion experienced in areal terms, whereas this proportion diminished downstream such that in Tuatapere reach the period 1982-1984 accounted for < 20 % of total erosion in the period of record. An opposite downstream trend was evident for geomorphic effectiveness of the sustained high discharge levels between 1984-1989. This interval accounted for > 30 % of total erosion in Tuatapere reach, at rates equivalent to the shorter 1982-1984 period, but erosion in this interval diminished upstream, and accounted for < 10 % of erosion in Wairaki reach. The high proportion of total erosion in Lill Burn reach between 1984-1989 reflected the shift in course of the tributary at the confluence zone during this interval.

Table 7.16 Total erosion in differing reaches over differing photographic intervals in the period of discharge record

	Wairaki	*Lill Burn*	*Downstream o'Clifden*	*Tuatapere*
Absolute erosion to nearest 10,000 m^2 (in m^2 x 1000)				
1963-1969	240	230	60	230
1969-1974	60	60	30	110
1974-1978	20	30	20	80
1978-1980	190	120	10	40
1980-1982	40	40	20	70
1982-1984	890	460	60	250
1984-1984	110	60	< 10	
1984-1985				150
1984-1989	130	350	80	
1985-1989				460
1989-1992	100	80	30	60
Relative erosion rate to nearest 10 m^2/day				
1963-1969	110	110	30	110
1969-1974	30	30	20	60
1974-1978	20	30	10	60
1978-1980	240	110	10	50
1980-1982	40	50	30	80
1982-1984	1630	850	110	360
1984-1984	790	470	10	
1984-1985				310
1984-1989	80	200	40	
1985-1989				360
1989-1992	100	70	20	50
Percentage of total erosion in differing intervals				
1963-1969	13.6	16.1	19.0	15.8
1969-1974	3.2	4.5	9.7	7.7
1974-1978	1.2	2.0	5.3	5.6
1978-1980	10.6	8.4	4.0	2.9
1980-1982	2.1	2.7	7.6	4.6
1982-1984	50.2	32.1	20.0	17.1
1984-1984	6.0	4.4	0.4	
1984-1985				10.3
1984-1989	7.4	24.3	25.6	
1985-1989				32.1
1989-1992	5.8	5.5	8.6	3.9

The short interval that followed the January 1984 flood, between February-June 1984, was characterised by significant erosion in Wairaki and Lill Burn reaches. Adjustments along the lower courses of these tributary systems resulted in significant reworking of deposits within Waiau River. Reworking was much less evident in Downstream o'Clifden reach. No discharge levels > 500 m^3s^{-1} were experienced during this interval. Between 1984-1985 significant erosion occurred in Tuatapere reach, as a series of relatively low magnitude events reworked large volumes of material in this alluvial reach.

Three factors account for the spatial variability in the geomorphic effectiveness of these differing events, namely:

(i) The degree to which the river is able to shift laterally, condition by the extent of the active channel zone. This broadens considerably downstream, and is significantly greater in Tuatapere reach than elsewhere. This is effectively a measure of the alluvial extent of a reach.

(ii) Tributary confluence configuration, and the interaction of flows, can induce marked variable flood responses.

(iii) The "condition" of the river system at the time of any individual event, recorded by the availability of materials of differing sizes and their distribution, greatly affect flood effectiveness. In transport-limited river systems such as Waiau River, where sediment availability is virtually unlimited, the sequence and magnitude of floods in any given interval will determine how much material is freely able has be moved, or how "flushed-out" the channel may be. the history of channel adjustments in such rivers is largely determined by the history of flood events, as floods beyond a certain magnitude are required to initiate gravel movement.

Other than the period of extreme floods and sustained high discharge between 1982-1989, the next most significant period of erosion occurred in the period pre-regulation, between 1963-1969. The proportion of total erosion that occurred in this interval was remarkably uniform (between 13-19 %) for all four reaches. Clearly this interval in which discharge levels > 500 m^3s^{-1} were maintained in almost 47 % of days was one of active erosion, but it can only be conjectured what proportion of total erosion occurred for events > 1000 m^3s^{-1}. However, flood events > 1000 m^3s^{-1} occurred each year other that 1966, and there were two sustained events which peaked > 1500 m^3s^{-1} in 1967.

Remaining intervals (between 1969-1982 and 1989-1992) experienced notably less erosion, although there were some periods of localised relatively high erosion rates. For example, erosion rates > 100 m^2/day were experienced in Wairaki and Lill Burn reaches between 1978-1980. Indeed, in Wairaki reach the proportion of erosion that occurred in this interval was the third highest on record, as 240 m^2/day of land was eroded. The extensive erosion that occurred in this interval can almost certainly be attributed to the lower catchment flood event in May 1979 which had a peak discharge of 1240 m^3s^{-1}. This was an extremely peaked event, in which discharge at Tuatapere was > 600 m^3s^{-1} greater than at Sunnyside. This suggests that tributary catchments were highly active, such that high erosion rates were experienced at Wairaki and Lill Burn catchments and in the sub reaches immediately downstream of the confluences. In contrast to these high rates of erosional activity in Wairaki and Lill Burn reaches, negligible change was evident in Downstream o'Clifden and Tuatapere reaches. Erosion rates were selectively higher in the latter reaches between 1969-1974, reflecting the larger proportion of days which experienced discharge levels > 500 m^3s^{-1}.

All remaining intervals combined (ie. 1974-1978, 1980-1982 and 1989-1992) accounted for < 10 % of total erosion in Wairaki reach, just over 10 % of erosion in Lill Burn reach, < 15 % of erosion in Tuatapere reach and just over 20 % of erosion in Downstream o'Clifden reach. In the latter instance erosion rates were distributed more evenly throughout the various time intervals. The peaked flood events in August 1980 and February 1991 appear to have been selectively more effective erosional events in Downstream o'Clifden reach compared to elsewhere. The lack of either peaked or sustained flood events in these events resulted in relatively minor erosion in Wairaki, Lill Burn and Tuatapere reaches.

7.7.2 Spatial and temporal variability in bank erosion

This section is divided into two parts. In the first part the bank erosion component of total erosion is considered separately. Secondly, volumetric removal rates at selected sites of bank erosion are related to the flood record.

7.7.2.1 Summary bank erosion and the flood record

Summary bank erosion is recorded for each reach in absolute, relative and percentage terms in Table 7.17. The intervals including the two floods of record (1982-1984) and the longest period of sustained flow levels > 1200 m^3s^{-1} (1984-1989) were dominant periods of bank erosion. These two intervals collectively accounted for almost 60 % of bank erosion in Wairaki reach, over 60 % of bank erosion in Lill Burn reach, over 35 % of erosion in Downstream o'Clifden reach and almost 50 % of erosion in Tuatapere reach. As indicated in the total erosion data, however, the effectiveness of these two styles of flood event differed spatially. The highly peaked floods of record were dominant in Wairaki and Lill Burn reach, whereas the period of sustained high discharge in late 1988 was the dominant interval of bank erosion in Downstream o'Clifden and Tuatapere reach.

Spatial discontinuity of bank erosion was also evident prior to the January 1983 and January 1984 floods. In all reaches other than Wairaki reach the relative proportion of bank erosion was next highest between 1963-1969, associated with sustained flow levels > 500 m^3s^{-1} and numerous peaked flood events > 1200 m^3s^{-1}. However, in Wairaki reach the period between 1978-1980 accounted for > 15 % of total bank erosion. This suggests that the May 1979 flood, which peaked at 1240 m^3s^{-1} in Tuatapere, was especially prominent in Wairaki catchment, where it induced substantial erosion as Wairaki River realigned to the north in the confluence zone and the opposite right bank of Waiau River eroded severely.

The only other intervals which accounted for > 10 % of bank erosion were between 1980-1982 in Downstream o'Clifden reach and between 1969-1974 in Tuatapere reach. These selectively higher rates may be explained by the highly peaked flood event in August 1980 and the sustained periods of discharge > 500 m^3s^{-1} in alluvial Tuatapere reach between 1969-1974. In the former instance the higher rate of bank erosion may reflect the pattern of within channel sedimentation.

Table 7.17 Bank erosion in differing reaches over differing photographic intervals in the period of discharge record

	Wairaki	*Lill Burn*	*Downstream o'Clifden*	*Tuatapere*
Absolute erosion to nearest 10,000 m^2 (in m^2 x 1000)				
1963-1969	150	90	40	120
1969-1974	30	60	10	70
1974-1978	20	20	< 10	30
1978-1980	190	50	10	30
1980-1982	30	30	10	30
1982-1984	660	360	20	80
1984-1984	50	40	-	
1984-1985				30
1984-1989	40	260	30	
1985-1989				220
1989-1992	50	50	10	20
Relative bank erosion to nearest 10 m^2/day				
1963-1969	70	40	20	60
1969-1974	20	30	10	30
1974-1978	10	20	< 10	20
1978-1980	240	50	10	30
1980-1982	40	30	20	40
1982-1984	1210	660	30	120
1984-1984	340	280	10	
1984-1985				50
1984-1989	20	150	20	
1985-1989				170
1989-1992	50	40	10	20
Percentage of bank erosion in differing intervals				
1963-1969	12.1	9.4	30	20.0
1969-1974	2.5	6.5	7.6	10.6
1974-1978	1.4	1.8	2.2	4.9
1978-1980	15.5	5.4	4.8	4.1
1980-1982	2.5	2.8	10.2	4.9
1982-1984	54.3	37.8	13.1	12.8
1984-1984	3.8	3.9	0.8	
1984-1985				4.2
1984-1989	3.4	27.5	22.9	
1985-1989				35.0
1989-1992	4.5	4.8	8.5	3.5

Relative rates of bank erosion were notably lower in remaining intervals, associated with the lower discharge regime and lack of major floods. Greater variability in erosion rate over time along banks relative to total erosion reflects the greater ease with which the river is able to erode bars in the within channel zone at lower discharge stages. This temporal discontinuity in the timing and pattern of bank erosion is especially pronounced at the selected sites at which bank erosion was assessed in volumetric terms.

7.7.2.2 Bank erosion rates at selected sites and their relationship to the discharge record.

Nine sites were selected for detailed analysis of bank erosion over the period of photographic record. Field measurements of bank heights at these sites enabled estimates of volumes of removed material to be determined. These absolute, relative and proportional estimates of volumes of material eroded are presented in Table 7.18. The most striking feature of Table 7.18 is the spatial and temporal discontinuity in bank erosion. This largely reflects initiation, development and migration phases as bends evolve.

Table 7.18 Bank erosion at selected sites over differing photographic intervals in the period of discharge record (Sites 1-9 are listed on the next page)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Absolute volume of eroded material to nearest 10,000 m^3									
1963-1969	8.5	0.5	1.7	0.2	0.5	0.4	1.3	-	1.1
1969-1974	1.9	-	0.8	1.0	0.1	-	1.0	-	0.1
1974-1978	-	-	0.3	0.05	-	-	0.3	0.1	-
1978-1980	-	-	0.4	-	0.1	-	0.1	0.1	0.2
1980-1982	-	0.3	0.1	0.1	0.2	-	0.3	0.1	-
1982-1984	-	11.2	-	0.7	0.1	0.2	0.1	0.4	0.1
1984-1984	-	-	-	-	-				
1984-1985						0.3	0.2	0.3	0.05
1984-1989	1.3	0.1	-	2.8	0.4				
1985-1989						0.1	0.7	0.2	0.7
1989-1992	0.4	-	-	-	0.1	0.4	-	0.1	-
Rate of volume removal to nearest 100 m^3/year									
1963-1969	142.5	8.8	283.0	2.5	8.7	6.8	21.5	-	18.2
1969-1974	35.5	-	143.0	18.0	1.8	-	18.2	-	2.6
1974-1978	-	-	28.7	1.3	-	-	< 10	< 5	-
1978-1980	-	-	12.7	-	3.9	-	3.1	2.4	8.7
1980-1982	-	14.7	4.5	5.2	7.0	-	10.5	2.2	-
1982-1984	-	75.9	-	45.0	9.7	9.2	5.4	18.6	2.9
1984-1984	-	-	-	-	-				
1984-1985						20.8	18.3	21.0	2.0
1984-1989	27.0	2.9		59.0	8.8				
1985-1989						3.1	21.0	5.2	20.4
1989-1992	1.4	-	-	-	4.3	14.6	-	3.0	-
Percentage of material removed during differing intervals									
1963-1969	70.2	4.3	51.9	3.2	33.8	29.2	33.0	-	49.8
1969-1974	15.7	-	23.6	20.3	5.8	-	25.1	-	6.3
1974-1978	-	-	9.0	0.8	-	-	6.3	9.2	-
1978-1980	-	-	12.1	-	5.8	-	1.8	4.6	8.6
1980-1982	-	2.8	3.4	2.5	10.4	-	6.3	4.6	-
1982-1984	-	91.8	-	14.1	9.1	12.4	2.5	32.1	2.3
1984-1984	-	-	-						
1984-1985						19.7	6.1	24.8	1.4
1984-1989	10.7	1.1		57.0	27.3				
1985-1989						8.0	18.8	16.5	31.7
1989-1992	3.3	-	-	-	7.8	30.7	-	8.3	-

Sites at which volumetric bank erosion was assessed in Table 7.18	
Site 1	King-Allen bend in Wairaki reach
Site 2	Left bank downstream of Wairaki confluence
Site 3	Left bank opposite Lill Burn confluence
Site 4	Left bank downstream of Lill Burn confluence
Site 5	Right concave bank in Downstream o'Clifden reach
Site 6	Right concave bank at Carr's property, Tuatapere reach
Site 7	Left bank in Carr's to Mid-break subreach, Tuatapere reach
Site 8	Right bank in Downstream of Bend break subreach, Tuatapere reach
Site 9	Right bank at the river mouth, Tuatapere reach

In five of the nine instances studied, erosion rates were highest between 1963-1969. In the remaining sites, one example did not commence eroding until 1974-1978 (site 8), one site experienced negligible erosion until the floods of record between 1982-1984 (site 2), whereas sites 4 and 6 experienced anomalous erosion histories. At site 4, along the left bank downstream of Lill Burn confluence, erosion was prominent between 1969-1974 as a bend developed, but by far the greatest proportion of erosion took place between 1984-1989 as Waiau River shifted towards the left bank and effectively straightened (destroying this bend sequence.). At site 6, along the right concave bank on Carr's property in Tuatapere reach, erosion was prominent between 1963-1969 and 1989-1992. While the former interval is readily explained in terms of bend expansion during a period of relatively high discharge levels, the high erosion rate between 1989-1992 is somewhat anomalous, and is perhaps best explained in terms of local flow concentration associated with within-channel sedimentation.

It is interesting to note the relatively subdued role of the major floods of record and the period of sustained high discharge between 1982-1989 in bringing about bank erosion at these sites. Erosional effectiveness of floods at these sites is seemingly much less than is the case for general bank erosion or total erosion described in previous sections. It is clear that sustained high discharge levels, such as those evident pre-regulation and in the immediately following regulation (1969-1974) were relatively more effective in bringing about bank erosion at these more sensitive sites. Significant bank erosion was maintained between 1969-1974 at 4 of the 9 sites (sites 1, 3, 4 and 7).

The only other intervals which accounted for > 10 % of total bank erosion at these sites were 1978-1980 at site 3 and 1980-1982 at site 5. Erosion at these sites reflected bend erosion, probably associated with the peaked flood events in May 1979 and August 1980 which had maximum discharges of 1240 m^3s^{-1} and 1357 m^3s^{-1} respectively.

7.7.3 Spatial and temporal variability in total deposition.

While deposition rates were generally at a maximum in the five-month period following the January 1984 flood, extent and relative proportion of deposition were generally highest in the period pre-regulation and throughout the 1970's (Table 19). Perhaps the most telling statistic in Table 19 is the relative proportion of deposition between 1969-1974, when deposition was roughly twice as extensive as in the preceding, pre-regulation, interval. Although high deposition rates continued throughout the 1970's, the peak depositional interval differed among the four reaches. In Wairaki reach deposition was relatively higher in 1978-1980, in Lill Burn reach deposition was relatively high between 1980-1982, in

Downstream o'Clifden reach deposition rate diminished consistently in the three intervals following 1969-1974 whereas in Tuatapere reach the relative proportion of deposition was notably greater between 1969-1974 but remained high between 1974-1978 and 1978-1980. These differences largely reflect sediment movement through the system, induced in large part by tributary sediment supply. Over time these gravel slugs move downstream as pulses.

Table 7.19 Total deposition in differing reaches over differing photographic intervals in the period of discharge record

	Wairaki	*Lill Burn*	*Downstream o'Clifden*	*Tuatapere*
Absolute deposition to nearest 10,000 m^2 (in m^2 x 1000)				
1963-1969	180	220	60	230
1969-1974	400	410	80	580
1974-1978	160	130	80	220
1978-1980	360	50	50	210
1980-1982	150	250	50	90
1982-1984	20	10	< 10	40
1984-1984	640	290	40	
1984-1985				60
1984-1989	110	120	10	
1985-1989				240
1989-1992	70	210	40	170
Relative deposition rate to nearest 10 m^2/day				
1963-1969	90	100	30	110
1969-1974	200	210	40	290
1974-1978	120	130	60	170
1978-1980	460	50	70	270
1980-1982	170	290	60	110
1982-1984	30	20	< 10	70
1984-1984	4750	2150	280	
1984-1985				130
1984-1989	70	70	10	
1985-1989				190
1989-1992	70	200	40	160
Percentage of total deposition in differing intervals				
1963-1969	8.8	13.2	14.4	12.3
1969-1974	18.9	24.4	19.9	31.3
1974-1978	7.6	7.6	19.1	11.8
1978-1980	17.4	3.1	13.3	11.3
1980-1982	7.1	14.7	11.7	5.1
1982-1984	0.7	0.6	0.4	2.4
1984-1984	30.5	17.1	9.1	
1984-1985				3.4
1984-1989	5.5	6.8	2.7	
1985-1989				13.1
1989-1992	3.4	12.4	9.3	9.2

Between 1982-1984 the two floods of record effectively flushed the channel, and low deposition rates resulted. Channel recovery between February-June 1984 was rapid, with extremely high deposition rates in Wairaki and Lill Burn reaches. The period between 1984-1989 was primarily erosional, associated with the sustained high discharge in October/November 1988. However, extensive deposition continued in the alluvial Tuatapere reach during this interval.

Finally, it is interesting to note the relatively high deposition rates and proportion of total deposition that occurred between 1989-1992. The lack of sustained or high magnitude events in this period resulted in the river reverting to a predominantly depositional regime. This may be associated with the large volumes of material made available for reworking by the major flood events of the 1980's.

7.7.4 Spatial and temporal variability in the ratio of erosion:deposition

Perhaps the most telling statistic that reflects changes in the erosion and sedimentation regime of Waiau River over the period of record is recorded in the erosion:deposition ratio (Table 7.20). While erosion and deposition were roughly balanced between 1963-1969, with areal extents of erosion and deposition that were remarkably similar in Lill Burn, Downstream o'Clifden and Tuatapere reaches, a profound change was marked in the following interval, between 1969-1974, associated with the impacts of flow regulation. Between 1969-1974 and 1974-1978 deposition outstripped erosion by a ratio of at least 3:1 in all reaches. Indeed, this ratio was roughly maintained until 1982-1984, other than in Lill Burn reach between 1978-1980. Although there were 7 floods with peak discharge > 1000 m^3s^{-1} between 1969-1980, deposition was dominant. This reflects the pronounced shift in mean flow condition associated with flow regulation, as 47 % of days between 1964-1969 had discharge levels > 500 m^3s^{-1}, but this proportion dropped to < 20 % between 1969-1979 and < 8 % thereafter.

Table 7.20 Ratio of erosion:deposition in differing reaches over differing photographic intervals in the period of discharge record

	Wairaki	*Lill Burn*	*Downstream o'Clifden*	*Tuatapere*
1963-1969	1.30	1.04	0.95	1.00
1969-1974	0.14	0.16	0.35	0.19
1974-1978	0.13	0.22	0.20	0.37
1978-1980	0.51	2.35	0.21	0.20
1980-1982	0.25	0.16	0.47	0.71
1982-1984	58.08	45.66	33.06	5.56
1984-1984	0.17	0.22	0.03	
1984-1985				2.34
1984-1989	1.15	3.02	6.82	
1985-1989				1.91
1989-1992	1.43	0.37	0.67	0.33

The anomalous erosion:deposition ratio in Lill Burn reach between 1978-1980 seemingly reflects the peaked lower catchment flood in May 1979. This short lived event had a maximum discharge of 1240 m^3s^{-1}, but discharge at Tuatapere was > 600 m^3s^{-1} higher than at Sunnyside. Absolute extent of erosion was not especially high in this interval, but deposition was significantly less. Erosion was localised at Lill Burn confluence and immediately downstream, as Lill Burn shifted to the south in the confluence zone.

Just as dramatic as the shift to a predominantly depositional regime after 1969 was the reversal to erosional dominance associated with the floods of record between 1982-1984. Ratios of erosion:deposition are significantly greater in Wairaki, Lill Burn and Downstream of o'Clifden reaches relative to Tuatapere reach, as in the latter instance the 1984 photograph was taken in June (ie. the 1982-1984 interval includes the phase of rapid channel recovery that is so dramatically recorded for the 3 other reaches between February-June 1984). Erosion continued to dominate over deposition in all reaches in the period between 1984/1985-1989. This reflects the sustained high discharge levels of October/November 1988 which induced significant channel adjustments. Between 1989-1992, however, deposition dominated over erosion in all reaches other than Wairaki. This reflects the lack of sustained high discharge levels in this interval, as there were just 4 days in which discharge exceeded 800 m^3s^{-1}. Wairaki River effectively shifted to the north in the confluence zone during this interval, inducing substantive erosion downstream. This was probably associated with two peaked lower catchment events in February and August 1991.

8.0 Regulation impacts on channel adjustments along Waiau River

Section 8 summarises impacts of flow regulation on channel adjustments along Waiau River. The section is divided into eight parts. In the first instance impacts of flow regulation are assessed for those reaches in which detailed analysis of channel adjustments has been carried out (Sections 8.1 to 8.6). Tracings of channel outlines from the earliest available photographs (1946/1947 or 1954/1957), from 1969 and from 1992 are used to determine a range of channel planform characteristics, namely channel multiplicity, the width of the active channel zone, the braided index, and channel sinuosity. Procedures used to derive these parameters are presented in Appendix 6. These data are then used to compare channel adjustments pre-regulation (ie. 1946 or 1954-1969) with adjustments post-regulation (1969-1992). Secondly, summary rates of erosion and deposition, determined from data presented in Sections 6 and 7, are evaluated for each reach. This is followed by assessment of flow regulation impacts on rates of bank erosion at the nine selected sites in which volumetric estimates of material removed along banks were derived (Section 8.7). Impacts of flow regulation on the erosion/sedimentation regime along Waiau River from Lake Te Anau to Te Waewae Bay are summarised in Section 8.8.

8.1 Wairoa

Relatively little attention has been placed on the impacts of flow regulation in Wairoa/Upper Waiau reach as channel adjustments (the focal point of this report) have been negligible over the period of photographic record. This does not mean, however, that impacts of regulation have been trivial. While adjustments to channel alignment have been incidental, with no modification to planform style, significant trimming of banks has occurred at selected locations. Erosion has largely been restricted to the concave banks of numerous bends, especially in Rainbow, Boulder and Downstream of Boulder subreaches. Given the bank/terrace height throughout this reach, this erosion has removed a significant volume of material. It can be inferred from the photographic record that rates of bank erosion have increased since the construction of Lake Te Anau control structure. While virtually no erosion was evident on the air photographs between 1957-1965, significant trimming has taken place between 1965-1992. Given the scale of the air photographs, and the rates of channel adjustment measured in metres rather than tens of metres, it is difficult to differentiate this erosion rate specifically. Field based measurement of bank erosion at select sites would provide the necessary information to test this assertion. Survey data of erosion rates at Rainbow bend and other sites along Upper Waiau would be especially helpful in determining the impacts of fluctuating flow levels on bank erosion rates relative to the impacts of sustained high flow levels.

8.2 Lower Redcliff reach

Summary channel adjustments in Lower Redcliff reach in the photographic intervals pre- and post-1969 are shown in Figure 8.1. Analysis of regulation impacts on the erosion and sedimentation regime is divided into two parts. Summary channel adjustments indicated in Figure 8.1 are differentiated into standard channel planform characteristics in Table 8.1. The character of channel changes between 1954-1969 and 1969-1992 are discussed in Section 8.2.1.

Summary rates of erosion and deposition are summarised for each subreach in Table 8.2 and are discussed in Section 8.2.2.

8.2.1 Channel planform adjustments pre- and post-regulation

Various characteristics used to define channel planform are summarised from the air photograph record in Lower Redcliff reach in 1954/1957, 1969 and 1992 in Table 8.1.

Table 8.1 Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	1954/1957	1969	1992
Channel multiplicity			
Upstream of Redcliff	4	4	3
Downstream of Redcliff	4	5	4
Width of active channel zone (in m)			
Upstream of Redcliff	254	255	174
Downstream of Redcliff	367	376	360
Overall	308.0	312.4	262.2
Braided index			
Upstream of Redcliff	8.88	11.39	3.69
Downstream of Redcliff	14.76	16.83	14.81
Overall	11.63	13.93	8.89
Sinuosity			
Upstream of Redcliff	1.07	1.07	1.09
Downstream of Redcliff	1.33	1.34	1.41
Overall	1.18	1.19	1.23

While channel multiplicity remained constant upstream of Redcliff between 1954-1969, the number of channels decreased from 4 to 3 between 1969-1992 as former mid-channel bars became bank-attached. A similar reduction in number of channels was evidenced downstream of Redcliff, although in this instance one of the bar complexes dissected between 1954-1969 and reamalgamated between 1969-1992. Bar division between 1954-1969 is reflected in the increase in braided index both upstream and downstream of Redcliff, while the width of the active channel zone and channel sinuosity remained roughly constant. Dramatic changes were evident, however, in the period following flow regulation. Channel contraction was the primary morphologic response to altered mean flow, with reduction in width of the active channel zone upstream of Redcliff by > 30 % between 1969-1992. Even more pronounced, however, was the decrease in braided index upstream of Redcliff, which declined by over 67 %. Associated with these changes was an increase in sinuosity, as Waiau River adopted a better-defined sequence of bends around larger bar complexes. Increase in sinuosity was especially evident downstream of redcliff, where sinuosity increased from 1.34 to 1.41.

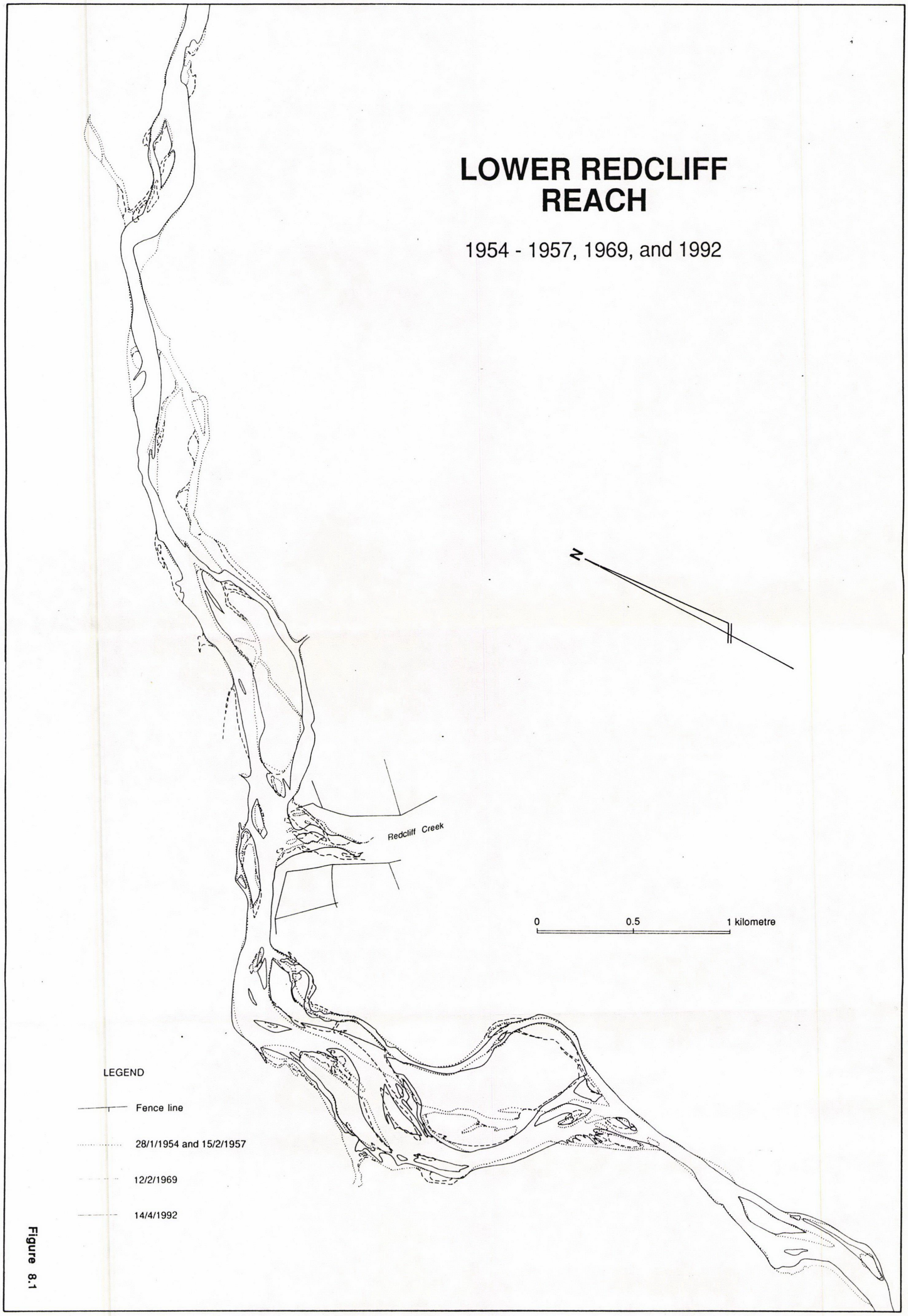

LOWER REDCLIFF REACH
1954 - 1957, 1969, and 1992
N
0
0.5
1 kilometre
Redcliff Creek
LEGEND
Fence line
28/1/1954 and 15/2/1957
12/2/1969
14/4/1992

Figure 8.1

8.2.2 Adjustments in the erosion/deposition regime pre- and post-regulation

The most dramatic change in erosion/sedimentation regime in Lower Redcliff reach since 1969 has been the increase in deposition adjacent to the banks, where there has been an 8-fold increase in the relative rate of deposition compared to the period pre-1969 (Table 8.2). This reflects the attachment of mid-channel bars to the left bank upstream of Redcliff confluence and to the right bank downstream of Redcliff confluence.

Table 8.2 Summary channel adjustments in Lower Redcliff reach before and after 1969

	Erosion			Deposition		
	Pre 1969	*Post 1969*	*% Change*	*Pre 1969*	*Post 1969*	*% Change*
	Areal adjustments in m^2/day			Areal adjustments in m^2/day		
Upstream of Redcliff confluence						
Left bank	0.82	0.24	*-70.7*	1.97	10.75	*+445.7*
Right bank	4.83	0.24	*-95.0*	0.00	1.33	*?*
Within-channel (i)	0.73	0.30	*-58.9*	0.82	0.79	*-3.6*
Within-channel (ii)	1.55	2.18	*+40.6*	0.00	3.13	*?*
Within-channel (iii)	1.18	1.01	*-14.4*	0.55	3.19	*+480.0*
Subreach total	**9.11**	**3.97**	***-56.4***	**3.34**	**19.19**	***+474.5***
Redcliff confluence zone						
Left bank	2.86	3.74	*+30.8*	1.53	3.03	*+98.0*
Right bank	0.00	0.00	-	0.09	0.00	*?*
Within channel	0.22	1.19	*+440.9*	3.37	2.02	*-40.1*
Subreach total	**3.08**	**4.93**	***+60.1***	**4.99**	**5.05**	***+1.2***
Downstream of Redcliff confluence						
Left bank	3.70	0.77	*-79.2*	0.00	1.61	*?*
Right bank	0.82	2.02	*+146.3*	0.73	15.40	*+2009.6*
Within-channel (i)	12.51	6.99	*-44.1*	6.16	11.64	*+89.0*
Within-channel (ii)	3.66	1.43	*-60.9*	1.37	0.14	*-89.8*
Within-channel (iii)	2.70	1.43	*-47.0*	0.27	2.70	*+900.0*
Subreach total	**23.39**	**12.64**	***-46.0***	**8.53**	**31.39**	***+268.0***
Banks vs Within-channel						
Combined banks	13.02	7.28	*-44.1*	4.32	39.38	*+811.6*
Within-channel	22.55	14.52	*-35.6*	12.53	23.61	*+88.4*
TOTAL	**35.57**	**21.80**	***-38.7***	**16.85**	**62.99**	***+273.8***

Rates of erosion and deposition were notably slower upstream of Redcliff confluence relative to the reach downstream of Redcliff confluence, associated with the wider active channel zone beyond the point of flow convergence. However, the pattern of channel adjustments associated with flow regulation has been consistent both upstream and downstream of the confluence. In both instances summary erosion rate decreased by around 50 % after 1969, whereas deposition rate increased by over 5 x upstream of Redcliff and over 3 x downstream of Redcliff. This is the most dramatic change in the erosion and sedimentation regime associated with flow regulation experienced throughout the entire catchment.

Reduced rates of erosion after 1969 were evident at virtually all locations *Upstream of Redcliff confluence*. Since 1969 erosion rates along the banks decreased by over 70 %. In contrast, deposition rate increased notably, especially along the left bank as a former mid-channel bar became bank-attached. While rate of erosion exceeded that of deposition along the right bank prior to 1969, this situation reversed since 1969. Channel changes in the within-channel zone upstream of Redcliff have been relatively trivial throughout the period of record, although Waiau River has become less multichannelled as the deposition rate has increased relative to the erosion rate since 1969. This change can be attributed to relative increase in deposition rate rather than substantive decrease in the rate of erosional activity. The marked increase in deposition was largely accounted for by infilling of the left bank secondary channel at the head of this subreach between 1989-1992.

Rates of erosion and deposition were crudely equivalent in *Redcliff confluence zone* both before and after 1969. Although the position of Redcliff Creek shifted within the confluence zone, summary rates of erosion and deposition were relatively low. However, notable increase in erosion of within-channel bars has occurred since 1969. Deposition rate effectively doubled along the left bank, but actually diminished in the within-channel zone.

Process rates were significantly higher in *Downstream of Redcliff confluence* subreach, than elsewhere in this reach. Summary rates of erosion and deposition were roughly double those observed in a similar length of river upstream of Redcliff confluence. This indicates the critical role played by tributary inputs of flow and sediment, and the increase in width of the active channel zone. Rates of erosion and deposition were much greater in the within-channel zone than adjacent to banks. While the rate of erosion decreased along the left bank since 1969, it actually increased along the right bank. Rates of activity were trivial, however, and were swamped by the substantial increase in deposition rate since 1969, especially along the right bank where a former mid-channel bar became bank-attached. Indeed, while the ratio of deposition:erosion along the right bank was roughly one before 1969, it increased to 7.5 x after 1969. Since 1982 negligible changes have occurred along this right bank, indicating that if adjustments were a response to flow regulation, they certainly responded quickly. The switch to a depositional regime between 1969-1982 but subsequent negligible deposition reflects reworking of deposits by floods in the 1980's. These events induced negligible erosion along the right bank in this reach. Of further note is the role played by switching channel positions at Redcliff confluence, as channel alignment is undoubtedly a prime factor affecting right bank erosion downstream. Erosion rate diminished over the period of record downstream of Redcliff, especially adjacent to the left bank bar complex immediately downstream of Redcliff confluence (Within-channel (i)). Since 1969 the rate of deposition adjacent to this bar complex has effectively doubled, while a former bar complex became attached to the right bank following abandonment of a secondary channel. Downstream of Redcliff the rate of erosion decreased by 46 % after 1969, while the rate of deposition increased by 268 %. Deposition also exceeded erosion along the right bank bar complex since 1969 (within-channel (ii) in Table 8.1), but this effect is negated by the inclusion of within-channel deposition in the right bank data. A shift from a predominantly erosional to a depositional regime before and after 1969 was evident for the bar complex at the head of Upper Blackmount reach (within-channel (iii) in Table 8.1). While erosion rate almost halved after 1969, deposition rate adjacent to this bar increased by an order of magnitude.

In summary, since 1969 rate of erosion has decreased both adjacent to the banks and in the within-channel zone, whereas rate of deposition has dramatically increased, especially adjacent to the banks. Channel multiplicity has reduced, as major bar complexes have become bank-attached. Rates of adjustment have been greatest in the subreach downstream of Redcliff confluence. Significant modification in the pattern of process from an erosional to a depositional regime is more pronounced in Lower Redcliff reach than elsewhere along Waiau River. This accords with theoretical expectations, which indicate that channel adjustments should be most-pronounced immediately downstream of the regulation structure and extend downstream over time. Lower Redcliff reach is the first reach downstream of Lake Manapouri Control Structure in which there is space for channel adjustments to be pronounced. Perhaps more notable in this reach, however, has been the incisional history of tributaries at the head of this reach, as Excelsior, Whare and Redcliff Creeks have incised into their beds into the period following modification of mean flow of Waiau River. While this topic is not the focus of this report, sediment made available for transport following tributary incision clearly modifies the availability and calibre of materials that are contributed to the trunk stream. Modification of the sediment balance will affect the aggradational regime downstream, and hence the pattern of subsequent channel adjustments.

8.3 Wairaki reach

Changes in channel morphology and alignment in Wairaki reach are presented in Figure 8.2 and are summarised in Section 8.3.1. This is followed by assessment of rates of erosion and deposition in Wairaki reach (Section 8.3.2).

8.3.1 Channel planform adjustments pre- and post-regulation

Planform adjustments in Wairaki reach between 1947-1969 and 1969-1992 are summarised in Table 8.3.

Table 8.3 Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	1947	1969	1992
Channel multiplicity			
Adjacent to left bank bar complex	3	1	2
King-Allen bend and confluence bend	6	?	3
Downstream of Wairaki confluence	6	5	2
Downstream of bedrock constriction	4	3	3
Width of active channel zone (in m)			
Adjacent to left bank bar complex	273	192	133
King-Allen bend and confluence bend	404	462	417
Downstream of Wairaki confluence	600	515	331
Downstream of bedrock constriction	281	288	196
Overall	398	366	265
Braided index			
Adjacent to left bank bar complex	10.4	n/a	1.5
King-Allen bend and confluence bend	21.4	n/a	10.5
Downstream of Wairaki confluence	20.1	8.0	6.9
Downstream of bedrock constriction	11.7	6.8	4.3
Overall	14.0	n/a	4.9
Sinuosity	1.12	1.12	1.14

Between 1947-1969 channel multiplicity decreased in each subreach of Wairaki reach. As the main channel became more prominent, numerous smaller bars amalgamated and the braided index decreased markedly. However, the active channel zone only decreased in width by about 8 %, and overall sinuosity of the reach remained constant. Change in width of the active channel zone was markedly variable within-reach. Width decreased notably at the reach head as numerous bars became attached to the right bank, forming a compound point bar. Greater channel definition in this reach, however, resulted in accelerated erosion downstream. Over 150 m of erosion occurred in King-Allen concave bank, increasing the width of the active channel zone in this subreach. Downstream of Wairaki confluence many bars amalgamated between 1947-1969, but the width of the active channel zone remained roughly constant. The only exception to this was adjacent to Dean Burn confluence, where several bars stabilised and the width of the active channel zone decreased from over 900 m to < 300 m. The braided index decreased from over 20 to < 8. The braided

index also increased downstream of the bedrock constriction, but this did not impact on the width of the active channel zone. Indeed, width actually increased as the left bank eroded by > 120 m at the head of Motu reach.

Between 1969-1992 the adjustments to channel planform were much more significant than those evidenced between 1947-1969, but the general 'direction' of change was consistent with that demonstrated in the previous interval. Channel multiplicity diminished greatly, as numerous bars amalgamated. This resulted in more extensive alluvial flats, with channel outlines on their surfaces, but a markedly narrower active channel zone. Associated with these changes, channel sinuosity increased from 1.12 to 1.14. While this was a relatively small change in quantitative terms, change 'on-the-ground' was quite dramatic, as the river meandered around more substantive bank-attached bars. This reflected a change in the within-channel sediment regime.

In the period following flow regulation, number of active channels decreased from 5 or more in 1969 to 3 or less in 1992. The definition of the primary channel increased while secondary channels were abandoned. Within-channel bars amalgamated, and the braided index decreased significantly in all subreaches. Width of the active channel zone was also lower in all subreaches in 1992 compared to 1969. This effect was especially pronounced adjacent to the compound point bar at the reach head and downstream of Wairaki confluence. In King-Allen bend, however, the active channel zone in 1992 was wider than evidenced in 1947, reflecting the shift in channel position by > 200 m. The left bank opposite King-Allen bend stabilised markedly post 1969, as a large compound point bar developed. Sedimentation adjacent to the bank contrasted notably with the pattern of within-channel bars evident in 1947. In summary terms, the width of the active channel zone decreased from over 360 m in 1969 to 265 m in 1992, a reduction of 25 %.

Channel adjustments in Wairaki reach were especially prominent downstream of Wairaki confluence, where the active channel zone widened appreciably. Between 1947-1969 Wairaki River shifted to the south, but since 1969 the confluence reverted to its northern position. The main channel of Waiau River became better defined between 1947-1969, shifting towards the eastern bank. Bars along the right bank amalgamated. Channel changes were especially prominent adjacent to Dean Burn confluence, which moved 600 m to the east as the bars immediately upstream of the confluence stabilised and became bank attached. Extensive erosion occurred along the left bank. As Wairaki River shifted to the north in the confluence zone after 1969, much of the amalgamated bar complex immediately opposite Wairaki confluence was removed, as Waiau River shifted over 200 m to the west. A large linear bar complex was deposited adjacent to the left bank, as Waiau River cut a straighter, more open course in this subreach. Downstream of the bedrock constriction the process of bar amalgamation and stabilisation commenced before 1969 but proceeded at a much greater rate between 1969-1992.

WAIRAKI REACH

1947, 1969, and 1992

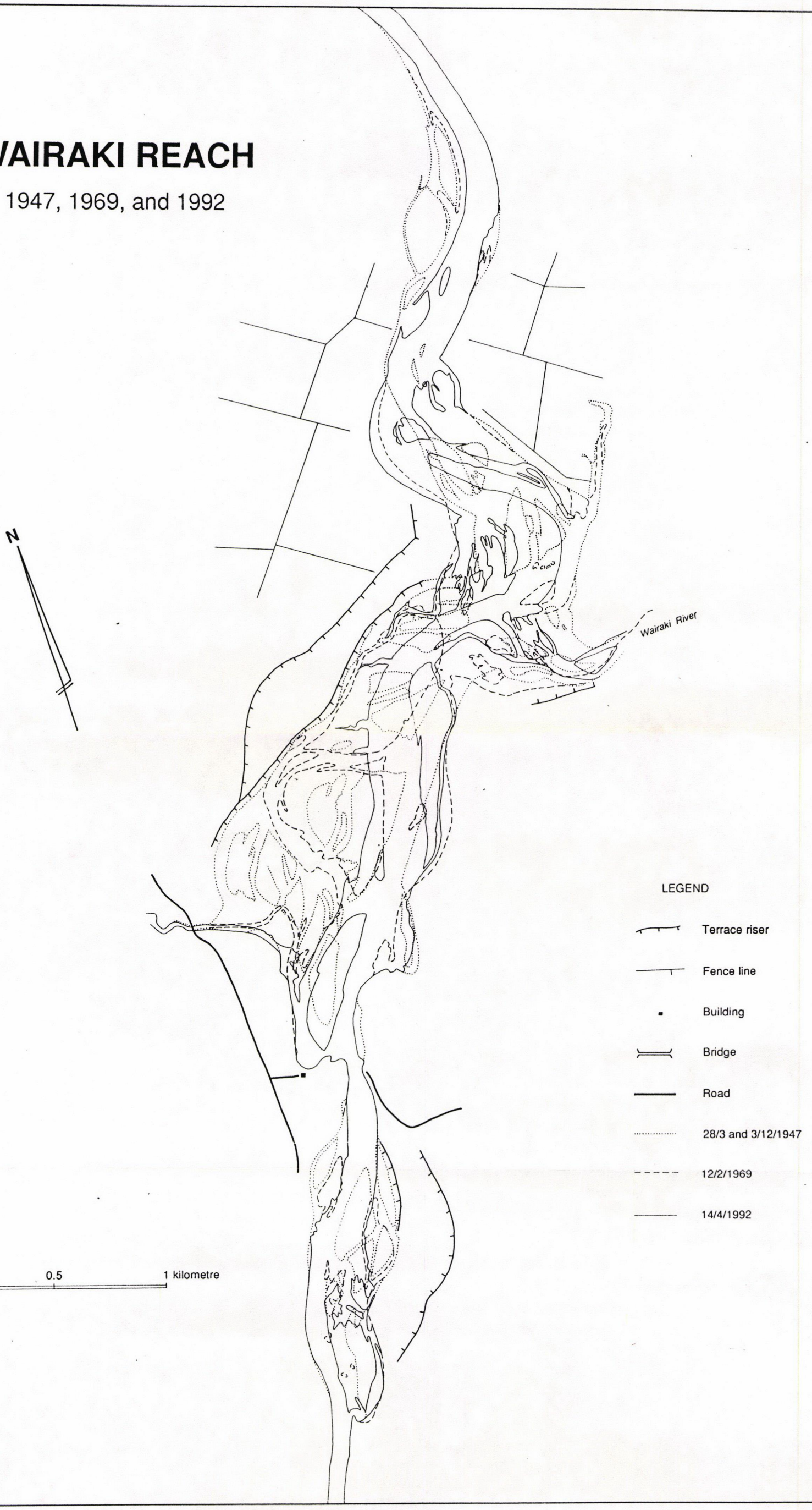


Figure 8.2

8.3.2 Adjustments in the erosion/deposition regime pre- and post-regulation

Summary rates of erosion and deposition in Wairaki reach pre- and post-regulation are presented in Table 8.4.

Table 8.4 Summary channel adjustments in Wairaki reach before and after 1969

	Erosion			Deposition		
	Pre 1969	*Post 1969*	*% Change*	*Pre 1969*	*Post 1969*	*% Change*
	Areal adjustments in m^2/day			Areal adjustments in m^2/day		
Upstream of Wairaki						
Left bank	0.13	21.33	*+16307.7*	2.43	27.21	*+1019.8*
Right bank (i)	0.15	2.36	*+1473.3*	3.81	11.76	*+208.7*
Right bank (ii)	12.07	4.26	*-69.9*	0.20	0.00	*-100.0*
Right bank (iii)	2.57	11.54	*+349.0*	0.83	10.88	*+1210.8*
Within-channel (i)	5.32	10.64	*+100.0*	0.00	24.79	*?*
Within-channel (ii)	7.50	0.90	*-88.0*	1.63	8.66	*+431.3*
Subreach total	**27.74**	**51.03**	***+84.0***	**8.90**	**83.30**	***+836.0***
Wairaki confluence zone						
Left bank	4.51	12.70	*+181.6*	10.21	9.81	*-3.9*
Within-channel	4.47	1.07	*-76.1*	4.23	9.25	*+118.7*
Subreach total	**8.98**	**13.77**	***+53.3***	**14.44**	**19.06**	***+32.3***
Downstream of Wairaki						
Left bank	8.55	38.24	*+347.3*	3.74	36.87	*+885.8*
Right bank	0.13	32.45	*+24861.5*	23.54	22.69	*-3.6*
Within-channel	10.29	30.04	*+191.9*	30.85	40.20	*+30.3*
Subreach total	18.97	100.73	***+431.0***	58.13	99.76	***+71.6***
Downstream of bedrock constriction						
Left bank	6.79	0.74	*-89.4*	0.39	2.74	*+602.6*
Right bank	0.00	3.06	*?*	0.10	3.25	*+3150.0*
Within-channel	7.31	12.84	*+75.6*	4.95	18.60	*+275.8*
Subreach total	**14.10**	**16.64**	***+18.0***	**5.44**	**24.59**	***+352.0***
Banks vs Within-channel						
Combined banks	34.90	126.65	*+262.9*	45.23	125.54	*+177.6*
Within-channel	34.89	55.49	*+59.0*	41.65	101.47	*+143.6*
TOTAL	69.79	182.13	***+161.0***	86.88	226.62	***+160.8***

The pattern and rate of channel adjustments in *Upstream of Wairaki* subreach were greatly modified after flow regulation. The left bank upstream of Wairaki was essentially stable before 1969. However, areal adjustments since 1969 have been extremely significant, but rates of erosion and deposition crudely balance out. Summary rates of channel adjustment were relatively small along the right bank bend at the reach head (right bank (i)). Given its location, this point bar complex has been a zone of continuing deposition. Rate of accretion has increased by three times since 1969. In contrast, King-Allen bend (right bank (ii)) is a concave bank and represents an erosional site. Rate of erosion was roughly three times greater before 1969 than after 1969. Adjacent to the right bank compound

point bar immediately upstream of Wairaki confluence (right bank (iii)), the relationship between erosion and deposition has remained roughly constant both before and after 1969, although both erosion and deposition increased notably since 1969. The within-channel-upstream of confluence bend was characterised by erosion rather than deposition before 1969, but the erosion/sedimentation balance shifted clearly towards deposition since 1969. A similar pattern was evident in the within-channel zone adjacent to confluence bend, but in this instance the rate of erosion actually decreased after 1969.

While rates of channel adjustments in *Wairaki confluence zone* demonstrated no dramatic changes before and after 1969, the pattern of channel shifting in this zone has played a significant role in determining channel adjustments in *Downstream of Wairaki* subreach. Perhaps the most significant statistic indicated in Table 8.4 is the pronounced increase in the rate of erosion along both banks and in the within-channel zone downstream of Wairaki. Extremely high rates of removal along the left bank were associated with channel expansion during the flood of record in January 1984. Channel recovery following this event was rapid, and deposition rate was also very high after 1969. Deposition was dominant along the right bank prior to 1969, but erosion exceeded deposition since 1969. Indeed, while the rate of deposition has remained constant, erosion increased substantially. Summary rates of erosion and deposition in the within-channel zone before and after 1969 indicate the relative increase in erosion of mid-channel bars as the main channel has become better defined since 1969. However, deposition continued to be dominant over erosion. Rates of within-channel adjustment were notably higher in this reach compared to reaches upstream.

Rates of erosion and deposition were negligible in *Downstream of bedrock constriction* subreach, although deposition exceeded erosion along both banks and in the within-channel zone since 1969. As indicated elsewhere in Wairaki reach, erosion was dominant before 1969, but deposition has dominated since flow regulation.

Increases in the rate of erosion and deposition since 1969 largely reflect the greater detail that can be discerned from analysis of nine sets of photographs analysed since 1969 compared to just two sets of air photographs analysed prior to 1969. In assessment of rate of activity, much more reliable determinations can be assessed from specific sites of activity, as evaluated from erosion rates of particular banks. While summary rates of activity are suspect in absolute terms, the ratio between erosion and deposition provides a suitable guide to changes in the erosion/sedimentation regime. The ratio of erosion:deposition before 1969 was 0.80:1, identical to that demonstrated after 1969. Rates of both erosion and deposition increased by 2.61 x after 1969. While summary rates are remarkably similar, the distribution of erosion and deposition was modified before and after 1969, with a greater rate of increase in erosion along the banks relative to the within-channel zone. Rates of increase of deposition along banks and in the within-channel zone were roughly equal.

8.4 Lill Burn reach

Changes in channel morphology and alignment in Lill Burn reach are presented in Figure 8.3 and are summarised in Section 8.4.1. This is followed by assessment of rates of erosion and deposition in Lill Burn reach (Section 8.4.2).

8.4.1 Channel planform adjustments pre- and post-regulation

Planform adjustments in Wairaki reach between 1947-1969 and 1969-1992 are summarised in Table 8.5.

Table 8.5 Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	1947	1969	1992
Channel multiplicity			
Upstream of Lill Burn confluence	3	4	2
Downstream of Lill Burn confluence	5	5	5
Width of active channel zone (in m)			
Upstream of Lill Burn confluence	281	270	216
Downstream of Lill Burn confluence	525	460	383
Overall	417	376	309
Braided index			
Upstream of Lill Burn confluence	7.45	7.05	5.39
Downstream of Lill Burn confluence	19.21	16.48	9.92
Overall	13.61	11.99	7.76
Sinuosity	1.13	1.17	1.20

Planform adjustments in Lill Burn reach between 1947-1992 were similar to those demonstrated in Wairaki reach. While rate of channel changes were much greater after 1969, associated with flow regulation, the direction of adjustments was set in train prior to 1969. This was reflected by the decrease in width of the active channel and reduction in the braided index between 1947-1969, and the associated increase in sinuosity as the main channel weaved a more sinuous course around amalgamated bar sequences. Over the period of record the pattern of within-channel sedimentation changed. Between 1969-1992 bar complexes became bank-attached and Waiau River adopted a more sinuous course around compound point bars and bank-attached bars. Increase in sinuosity was much greater than evidenced in Wairaki reach. Between 1969-1992 the width of the active channel zone decreased from > 375 m to < 310 m, a reduction of almost 20 %. In the same interval the braided index decreased from almost 12 to < 8, a decrease of over 35 %. These adjustments were especially prominent downstream of Lill Burn confluence. Despite these channel changes, the number of channels remained consistent over the period of record.

Within-channel bars 2 km upstream of Lill Burn expanded in area and increased in number between 1947-1969. Since 1969 these bars accreted both laterally and downstream. Some bars amalgamated reducing channel multiplicity. These adjustments were relatively trivial, however, compared to channel changes at and around Lill

Burn confluence. Between 1947-1969 Lill Burn shifted to the north at the confluence, with extensive deposition along the southern bank. The sinuosity of Lill Burn increased, as bends 1 km upstream from the confluence expanded. Deflection of Lill Burn induced extensive erosion along the left bank of Waiau River, which shifted almost 200 m to the east. This greatly modified the pattern of within-channel sedimentation 500m upstream of Lill Burn, as bars realigned along the new channel orientation. After 1969, however, these bars amalgamated and a compound point bar formed. As channel multiplicity reduced, the width of the active channel zone diminished from > 310m to < 150 m and sinuosity increased. These changes were consistent with the increase in deposition rate associated with flow regulation, but relate also to adjustments at Lill Burn confluence.

Between 1969-1992 Lill Burn shifted 230 m to the south, as upstream bends expanded laterally. While erosion continued along the left bank of Waiau River, rate and extent of bank retreat were much lower than between 1947-1969. The focal point of erosion was 1 km further downstream along the left bank. While erosion initiated immediately upstream of the bedrock constriction between 1947-1969, land loss was much more extensive at this site between 1969-1992. This reflected modification in the pattern of within-channel sedimentation and channel alignment downstream of Lill Burn following flow regulation. In 1947 the within-channel zone was characterised by a large number of small bars, with a braided index of almost 20. Between 1947-1969 a compound point bar accreted laterally along the right bank immediately downstream of Lill Burn confluence, associated with the northerly shift of Lill Burn and concomitant left bank erosion of Waiau River. These processes modified the pattern of within-channel bars downstream of Lill Burn confluence, as the primary Waiau channel became better defined and shifted to the east. Sinuosity of this primary channel also increased, and a series of bars along the right bank upstream of the bedrock constriction amalgamated. Since 1969 bar stabilisation continued at an even greater rate, although the compound point bar immediately downstream of Lill Burn confluence was trimmed as Lill Burn shifted to the south. Between 1969-1992 many of the former mid-channel bars became bank-attached. Downstream of the bedrock constriction a compound point bar developed. While channel realignment and within-channel sedimentation were dominant between 1947-1969, bar amalgamation and bank-attachment were prominent between 1969-1992.

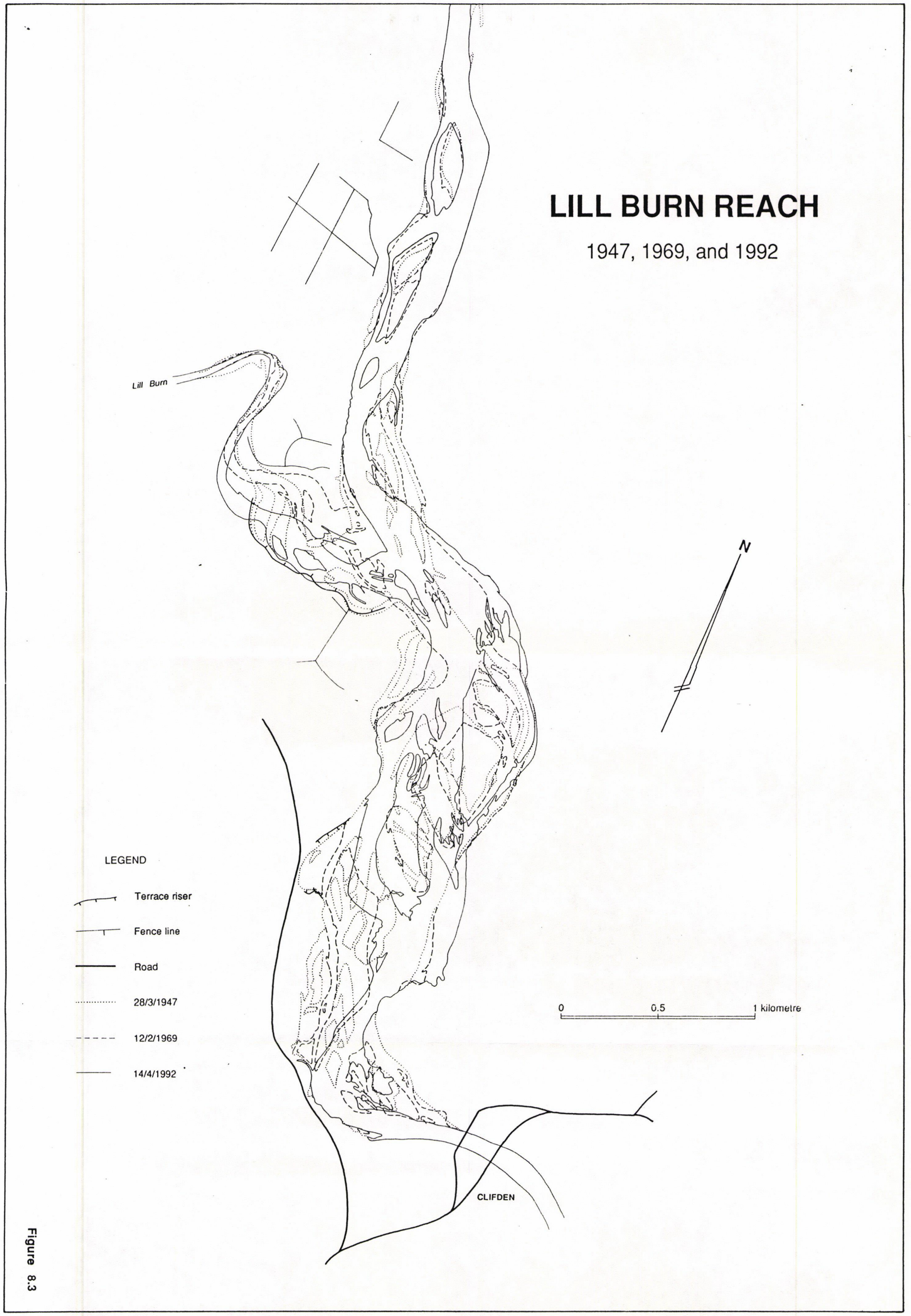

LILL BURN REACH
1947, 1969, and 1992
Lill Burn
N
LEGEND
Terrace riser
Fence line
Road
28/3/1947
12/2/1969
14/4/1992
0
0.5
1 kilometre
CLIFDEN

Figure 8.3

8.5 Downstream o'Clifden reach

Summary channel adjustments in Downstream o'Clifden reach in the photographic intervals pre- and post-1969 are shown in Figure 8.4. Adjustments in channel planform characteristics between 1947-1969 and 1969-1992 are presented in Table 8.7 and are discussed in Section 8.5.1. Summary rates of erosion and deposition are summarised in Section 8.5.2.

8.5.1 Channel planform adjustments pre- and post-regulation

Planform adjustments in Downstream o'Clifden reach are summarised in Table 8.7.

Table 8.7 Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	1947	1969	1992
Channel multiplicity	5	6	4
Width of active channel zone (in m)	428	386	333
Braided index	9.38	9.04	6.19
Sinuosity	1.25	1.39	1.49

Channel changes in Downstream o'Clifden reach essentially describe expansion of the most freely migrating bend along the course of Waiau River. As the bend has expanded significant bar amalgamation has occurred along the inside of the bend. As indicated in both Wairaki and Lill Burn reaches these adjustments were set on track between 1947-1969 but proceeded at a more dramatic rate between 1969-1992.

Perhaps the most significant statistic describing channel changes in Downstream o'Clifden reach is the increase in channel sinuosity. Bend expansion between 1947-1969 resulted in an increase in sinuosity from 1.25 to 1.39, an increase of > 11 %. Up to 210 m of bank retreat occurred along the concave bank, significantly increasing the width of the active channel zone. Numerous bars on the convex side of the bend amalgamated, resulting in a reduction of the braided index. The compound point bar downstream of the eroding bend amalgamated numerous units and expanded laterally by almost 300 m between 1947-1969.

Channel adjustments between 1969-1992 followed the direction of change evident between 1947-1969. While sinuosity continued to increase between 1969-1992, rate of change was actually lower than that recorded between 1947-1969 (an increase of 7.2 % compared to 11.2 %). However, channel multiplicity decreased between 1969-1992, as extent of braiding reduced and width of the active channel zone decreased from > 380m to 333 m (a decrease of almost 14 %). These adjustments affected all sections of Downstream o'Clifden reach. Linear bar features became attached to the left bank at the head of the reach, numerous bars amalgamated on the convex side of the eroding bend, and a series of small bars became bank-attached downstream of the eroding bend, locally straightening the channel. The primary bend tightened as erosion was focussed at the bend apex and translated downstream. Indeed, at the

8.4.2 Adjustments in the erosion/deposition regime pre- and post-regulation

Summary rates of erosion and deposition in Lill Burn reach pre- and post-regulation are presented in Table 8.6.

Table 8.6 Summary channel adjustments in Lill Burn reach before and after 1969

	Erosion			Deposition		
	Pre 1969	*Post 1969*	*% Change*	*Pre 1969*	*Post 1969*	*% Change*
	Areal adjustments in m^2/day			Areal adjustments in m^2/day		
Upstream of Lill Burn						
Left bank	11.11	18.44	*+66.0*	1.74	15.43	*+786.8*
Right bank	0.11	1.37	*+1145.5*	2.53	1.56	*+38.3*
Within-channel	3.97	3.87	*-2.5*	5.57	7.32	*+31.4*
Subreach total	**15.19**	**23.68**	***+55.9***	**9.84**	**24.31**	***+147.1***
Lill Burn confluence zone						
Right bank	11.43	40.35	*+253.0*	8.64	24.66	*+185.4*
Within-channel	0.76	6.82	*+797.4*	6.75	22.12	*+227.7*
Subreach total	**12.19**	**47.17**	***+287.0***	**15.39**	**46.78**	***+204.0***
Downstream of Lill Burn						
Left bank	3.40	21.35	*+527.9*	0.13	4.19	*+3123.1*
Right bank (i)	0.94	3.53	*+275.5*	7.55	5.10	*-32.5*
Right bank (ii)	0.60	5.37	*+795.5*	8.04	11.00	*+36.8*
Within-channel (i)	17.68	26.28	*+48.6*	14.16	52.85	*+273.2*
Within-channel (ii)	9.98	3.71	*-62.8*	13.73	13.57	*-1.21*
Subreach total	**32.60**	**60.24**	***+84.8***	**43.61**	**86.71**	***+98.8***
Downstream of bedrock constriction						
Left bank	0.19	10.80	*+5584.2*	0.89	14.21	*+1496.6*
Right bank	0.00	1.01	*?*	0.00	1.66	*?*
Within-channel	3.41	0.72	*-78.9*	8.10	0.89	*-89.0*
Subreach total	**3.60**	**12.53**	***+248.1***	**8.99**	**16.76**	***+86.4***
Banks vs Within-channel						
Combined banks	27.77	102.22	*+268.1*	29.52	77.81	*+163.6*
Within-channel	35.80	41.39	*+15.6*	48.32	96.76	*+100.2*
TOTAL	**63.57**	**143.61**	***+125.9***	**77.84**	**174.57**	***+124.3***

Prior to 1969 erosion was clearly dominant over deposition along the left bank in *Upstream of Lill Burn* subreach. This imbalance adjusted after 1969, when rates of erosion and deposition were significantly greater. Trivial rates of erosion and deposition were recorded along the right bank and in the within-channel zone. In both instances, however, rates of activity increased after 1969 and erosion exceeded deposition. In summary terms, erosion rate upstream of Lill Burn increased by almost 60 % from the period before 1969 to the period after 1969, while rate of deposition increased by almost 150 %, such that in the period after 1969 erosion and deposition were crudely balanced.

In *Lill Burn confluence zone* rates of erosion and deposition have increased significantly since 1969, but a balance was maintained both before and after flow regulation. Erosion was especially prominent along the banks, as Lill Burn shifted its position in the confluence zone.

As evidenced in Wairaki reach, the subreach in which channel adjustments were most pronounced following flow regulation was immediately downstream of Lill Burn confluence. In summary terms, rate of erosion in *Downstream of Lill Burn* subreach increased by almost 85 % after 1969, whereas rate of deposition increased by almost 100 %. Rates of activity were over twice those demonstrated in Upstream of Lill Burn subreach. Increase in erosion after 1969 occurred largely along banks, whereas the increase in deposition occurred primarily in the within-channel zone, especially adjacent to Bar complex 1 (within-channel (i)). Erosion dominanted over deposition along the left bank throughout the period of record, but extent of erosion greatly exceeded deposition after 1969. In contrast, deposition exceeded erosion along the right bank, as Waiau River shifted to the east. This pattern of change is largely explained by adjustments in Lill Burn confluence zone. Rates of erosion and deposition in the within-channel zone downstream of Lill Burn were significantly higher than observed elsewhere in Lill Burn reach. While erosion and deposition were roughly equivalent before 1969, deposition became dominant since 1969.

The history of channel adjustment in *Downstream of bedrock constriction* subreach is essentially the history of deposition and bar amalgamation of the left bank compound point bar and phases of erosion and destruction of this bedrock-constrained feature. Deposition exceeded erosion both before and after 1969, but rates of erosion and deposition were relatively low and the gap between erosion and deposition rates decreased after 1969.

Summary rates of increase of erosion and deposition after 1969 are remarkably similar in Lill Burn reach. While erosion rate increased by 126 %, deposition rate increased by 124 %. However, rate of erosion remained roughly constant in the within-channel zone, and was compensated for by a relatively greater rate of increase in erosion along banks. This is significant as it indicates localised trimming of land at the margins of the active channel zone at rates greater than pre-regulation.

downstream end of the bend flow in 1992 was actually oriented diagonally upstream, as the head of the compound point bar at the exit of the bend accreted upstream. This reflected a significant shift in bend character as the sinuous outline became firmly established. The reduction in mean flow of lower Waiau River stabilised this channel configuration.

8.5.2 Adjustments in the erosion/deposition regime pre- and post-regulation

Table 8.8 Summary channel adjustments in Downstream o'Clifden reach before and after 1969

	Erosion			Deposition		
	Pre 1969	*Post 1969*	*% Change*	*Pre 1969*	*Post 1969*	*% Change*
	Areal adjustments in m^2/day			Areal adjustments in m^2/day		
Left bank	0.00	0.55	*?*	2.10	8.50	*+304.8*
Right bank	15.43	11.31	*-26.7*	10.42	9.29	*-10.8*
Within-channel	9.64	17.08	*+77.2*	21.81	24.48	*+12.2*
Banks vs Within-channel						
Combined banks	15.43	11.86	*-23.1*	12.52	17.79	*+42.1*
Within-channel	9.64	17.08	*+77.2*	21.81	24.48	*+12.2*
TOTAL	**25.07**	**28.94**	***+15.4***	**34.33**	**42.27**	***+23.1***

Although rates of change along the left bank in Downstream o'Clifden reach were minimal throughout the period of record, rate of deposition greatly outstripped erosion since 1969. Summary rates of both erosion and deposition along the right bank were actually lower after 1969 than before 1969. In other words, the rate of erosion of the concave bank decreased following flow regulation. Deposition predominated over erosion in the within-channel zone both before and after 1969. However, while the rate of deposition remained roughly constant, the erosion rate almost doubled.

The dominant feature of summary erosion and deposition rates is the similarity of the increase of rates of activity after 1969, as erosion increased by 15 % and deposition increased by 23 %. While this tendency accords closely with trends observed in Wairaki and Lill Burn reaches, the pattern of changes was quite different, as erosion diminished along the banks after 1969 and increased in the within-channel zone, while rate of deposition was greatest along the banks.

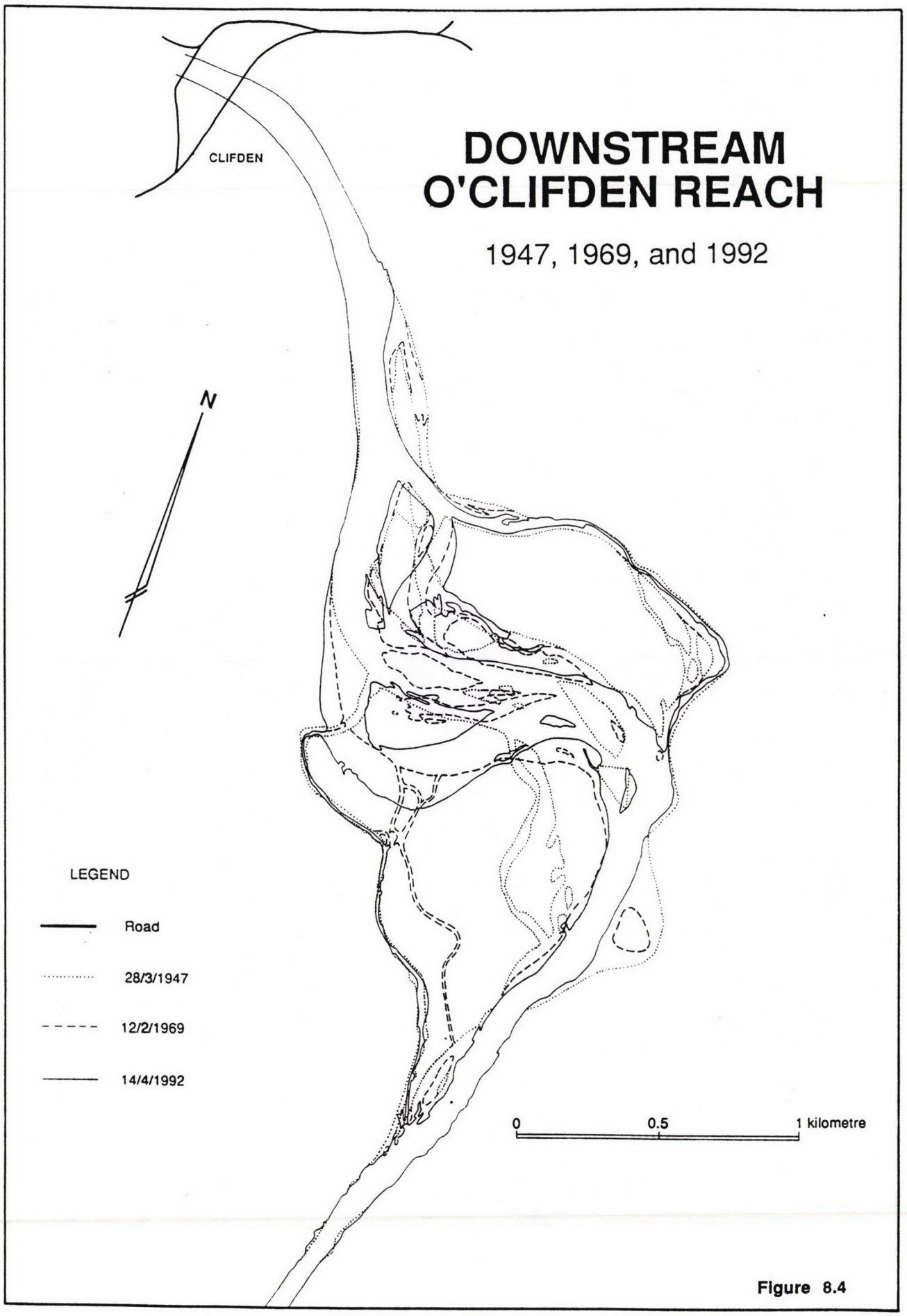

CLIFDEN
DOWNSTREAM
O'CLIFDEN REACH
1947, 1969, and 1992
N
LEGEND
Road
28/3/1947
12/2/1969
14/4/1992
0
0.5
1 kilometre

Figure 8.4

8.6 Tuatapere reach

Summary channel adjustments in Tuatapere reach in 1946. 1969 and 1992 are shown in Figure 8.4. Adjustments in channel planform characteristics between 1946-1969 and 1969-1992 are presented in Table 8.9 and are discussed in Section 8.6.1. Summary rates of erosion and deposition are summarised in Section 8.6.2.

8.6.1 Channel planform adjustments pre- and post-regulation

Planform adjustments in Tuatapere reach between 1946-1969 and 1969-1992 are summarised in Table 8.9.

Table 8.9 Summary channel planform adjustments in the periods pre and post regulation

Planform characteristic	1947	1969	1992
Channel multiplicity			
Tuatapere to mid-reach break	6	5	4
Mid-reach break to river mouth	8	6	4
Width of active channel zone (in m)			
Tuatapere to mid-reach break	521	521	403
Mid-reach break to river mouth	872	768	473
Overall	678	632	434
Braided index			
Tuatapere to mid-reach break	17.9	16.9	10.6
Mid-reach break to river mouth	32.6	24.3	10.0
Overall	24.4	20.2	10.3
Sinuosity			
Tuatapere to mid-reach break	1.09	1.12	1.07
Mid-reach break to river mouth	1.09	1.17	1.27
Overall	1.09	1.14	1.15

Tuatapere reach is divided into two sections, defined by the mid-reach transition point beyond which sinuosity increases markedly. *Tuatapere to mid-reach break* includes Upstream of Carr's and Carr's to mid-break subreaches, while *Mid-reach break to river mouth* includes Mid-break to bend break and Downstream of bend break subreaches. These two reaches are considered separately prior to an overall summary of planform adjustments in Tuatapere reach.

While the reduction in channel multiplicity, width of the active channel zone, and braided index in *Tuatapere to mid-break* reach following flow regulation are consistent with upstream reaches, the reduction in sinuosity is not! Mean width of the active channel zone was roughly constant between 1946-1969, but decreased from 520 m to 400 m between 1969-1992 (a decrease of > 20 %), while the braided index decreased from almost 17 km/km to < 11 km/km, a reduction of almost 40 %. Change in sinuosity reflected differences in the pattern of within-channel

sedimentation and flow alignment between 1969-1992 compared to 1946-1969. The large mid-channel complex in Upstream of Carr's subreach amalgamated in the period of record and between 1969-1992 a larger proportion of flow redirected down the left bank channel. Bar amalgamation started between 1946-1969, and resulted in reduction of the braided index. Within-channel deposition and increase in width of the active channel zone was coincident with erosion at Carr's property. In contrast, 500 m downstream of Tuatapere mid-channel bars became attached to the right bank between 1946-1969, reducing in width of the active channel zone. Erosion at Carr's property was significantly reduced between 1969-1992, as the mid-channel bar complex stabilised and flow realigned down the left bank channel. Even more dramatic, however, were adjustments immediately downstream of this mid-channel bar complex, in Carr's to Mid-break subreach.

In 1946 flow divided around a second large bar complex downstream of Carr's. By 1969 the right bank channel was clearly a secondary feature, while substantial erosion occurred along the left bank of Waiau River (see section 6.6.2). Between 1969-1992 the right bank channel was completely abandoned and the active channel zone narrowed substantially. The primary channel became better defined and adopted a notably straighter course.

Planform adjustments in *Mid-reach break to the river mouth* subreach between 1946-1992 were more extreme than in any other reach along the river. While many of the changes in the 4 km reach upstream from the mouth were set in-train between 1946-1969, rates of change were much greater between 1969-1992. Channel multiplicity halved over the period of record, from 8 channels in 1946 to 6 in 1969 to 4 in 1992. Numerous bars amalgamated as the pattern of within-channel sedimentation shifted from a complex assemblage of unit and compound bars in 1946 to larger, increasingly bank-attached bars in 1969. By 1992 bar styles were predominantly compound point bars, other than some mid-channel bars at the river mouth. The braided index decreased dramatically, from > 30 in 1946 to almost 25 in 1969, to just 10 in 1992, reductions of 25 % and almost 60 % respectively. As the sedimentation pattern altered, the width of the active channel zone decreased, and Waiau River adopted a more sinuous course. The primary channel was quite clearly defined by 1992. The active channel zone narrowed from over 870 m in 1946 to almost 770 m in 1969, but reduced significantly to < 475 m in 1992, reductions of almost 12 % and almost 40 % respectively. In contrast, sinuosity increased by over 7 % between 1946-1969 and 8.5 % between 1969-1992.

The shift towards a greater lateral component to channel adjustment clearly started prior to flow regulation, but the pattern of bends changed its alignment over the period of photographic record. 1.5 km upstream from the river mouth flow was aligned towards the left bank in 1946, but was redirected towards the right bank in 1992 as a bend developed with major erosion along the concave bank. Significant erosion also took place along the right bank at the river mouth, where width of the active channel zone actually increased from 650 m in 1946 to over 850 m in 1969 and 1992. Many of these adjustments in lower Tuatapere reach were likely associated with modifications to the gravel barrier system, as the river/coastal sediment budget responded to the altered flow regime of regulated Waiau River.

Channel adjustments in Tuatapere reach reflect the fact that this is the most alluvial stretch of the river, with the widest active channel zone and most extensive alluvial flats. All four variables used to characterise planform style

have been greatly modified in the period of photographic record. Between 1946-1992 channel multiplicity and the braided index have both been halved. By far the greater proportion of change in braided index occurred between 1969-1992. Associated with this reduction in braided index there was a shift in bar depositional style towards amalgamation and bank-marginal sedimentation, especially compound point bar development. This induced significant narrowing of the active channel zone from 678 m in 1946 to 630 m in 1969 to just 434 m in 1992. As bar style changed, so the overall sinuosity in Tuatapere reach increased from 1.09 to 1.15 in the period of record. Pattern of change in sinuosity differed markedly between the two subreaches. Sinuosity increased between 1946-1969 in both Tuatapere to Mid-reach break and Mid-reach break to river mouth subreaches, but between 1969-1992 Waiau River straightened in Tuatapere to Mid-reach break subreach but adopted an increasingly meandering outline in Mid-reach break to river mouth subreach.

TUATAPERE REACH

1946 - 1947, 1969, and 1992

TUATAPERE

Continuation on Map A

N

LEGEND

- Terrace riser
- Fence line
- Bridge
- 23/3/1946 and 28/3/1947
- 12/2/1969
- 14/4/1992

0 0.5 1 kilometre

A

Continuation on Map B

B

Te Waewae Bay

Figure 8.5

8.6.2 Adjustments in the erosion/deposition regime pre- and post-regulation

Summary rates of erosion and deposition in Tuatapere reach are presented in Table 8.10.

Table 8.10 Summary channel adjustments in Tuatapere reach before and after 1969

	Erosion			Deposition		
	Pre 1969	Post 1969	*% Change*	Pre 1969	Post 1969	*% Change*
	Areal adjustments in m^2/day			Areal adjustments in m^2/day		
Upstream of Carr's						
Left bank	0.04	9.31	*+23175.0*	2.50	2.14	*-14.4*
Right bank	4.97	4.14	*-16.7*	1.38	1.63	*+18.1*
Within-channel (i)	0.29	10.39	*+3482.8*	5.86	9.72	*+65.9*
Within-channel (ii)	16.14	17.42	*+7.9*	12.28	20.85	*+69.8*
Subreach total	**21.44**	**41.26**	***+92.4***	**22.02**	**34.34**	***+55.9***
Carr's to Mid-break						
Left bank	21.78	12.47	*-42.7*	0.37	1.04	*+181.1*
Right bank	0.00	3.47	*?*	1.29	8.53	*+561.2*
Within-channel	8.69	19.11	*+120.0*	11.95	33.65	*+181.6*
Subreach total	**30.47**	**35.05**	***-15.0***	**13.61**	**43.22**	***+217.6***
Mid-reach break to bend break						
Left bank	6.40	6.76	*+5.6*	7.67	4.59	*-40.2*
Right bank	0.66	6.70	*+915.2*	5.54	4.99	*-9.9*
Within-channel	23.63	20.61	*-12.8*	39.09	52.61	*+34.6*
Subreach total	**30.69**	**34.07**	***+11.0***	**52.30**	**62.19**	***+18.9***
Downstream of bend break						
Left bank	0.56	5.05	*+801.8*	6.35	12.35	*+94.5*
Right bank	22.82	10.80	*-52.7*	4.64	7.94	*+71.1*
Within-channel	4.49	18.05	*+302.0*	15.70	32.98	*+110.1*
Subreach total	**27.87**	**33.90**	***+21.6***	**26.69**	**53.27**	***+99.6***
Banks vs Within-channel						
Combined banks	57.22	58.69	*+2.6*	29.75	43.21	*+45.2*
Within-channel	53.24	85.58	*+60.7*	84.89	149.81	*+76.5*
TOTAL	**110.46**	**144.27**	***+30.6***	**114.63**	**193.02**	***+68.4***

In Upstream of Carr's subreach erosion and deposition rates were crudely balanced before 1969, but erosion exceeded deposition after 1969. While the extent of change was not pronounced, erosion was dominant along the banks but deposition was dominant in the within-channel zone. Rates of deposition along the left bank was low before and after 1969, but rate of erosion increased notably after 1969. In contrast, rate of erosion actually decreased along the right bank, but erosion still exceeded deposition. Upstream of Mid-channel Complex 1 (within-channel (i)) rate of erosion was negligible before 1969, but exceeded deposition since 1969. Erosion and deposition on Mid-channel complex 1 (within-channel (ii)) were roughly equal over the period of record. The slight emphasis on erosion before 1969 was compensated by the slight excess of deposition since 1969.

In *Carr's to mid-reach break* subreach the rate of erosion remained roughly constant before and after 1969, whereas rate of deposition increased by 3 x. The latter increase was largely accounted for by deposition in the within-channel zone. While erosion dominated along the left bank, rate of erosion declined by over 40 % after 1969. Waiau River has effectively shifted to the east over the period of the photographic record. Accordingly, negligible deposition occurred adjacent to the left bank, but deposition continued to dominate over erosion adjacent to the right bank after 1969. Rates of erosion and deposition were much greater in the within-channel zone, where erosion exceeded deposition both before and after 1969. Rates of both erosion and deposition increased by 2-3 x after 1969.

Rate of deposition was significantly higher in Mid-reach break to river mouth subreach than in Tuatapere to Mid-reach break subreach before and after 1969. While rate of deposition increased by just 19 % in *Mid-reach to bend break* subreach, the reach immediately upstream of the river mouth experienced an increase in deposition rate of almost 100 %. The ratio of erosion:deposition remained clearly tilted towards deposition in Mid-reach to bend break subreach. Before 1969, however, erosion and deposition were balanced in Downstream of Bend break subreach, but rate of erosion remained consistent after 1969 such that deposition dominated in this subreach.

In *Mid-break reach to bend break* subreach, summary rates of erosion and deposition were crudely equal along the left bank before and after 1969. Rate of deposition remained roughly constant before and after 1969 along the right bank, but rate of erosion increased significantly after 1969, when it slightly exceeded rate of deposition. Rates of channel adjustment in the within-channel zone were significant both before and after 1969. While deposition was dominant in both intervals, it was especially pronounced since 1969.

As Waiau River shifted to the west at the river mouth, deposition has dominated along the left bank whereas the right bank has eroded. Rate of adjustment along the right bank has adjusted markedly following flow regulation, as erosion rate decreased by over 50 % since 1969 whereas deposition rate increased by over 70 %. While erosion exceeded deposition, the pattern of adjustments has clearly altered. Deposition exceeded erosion in the within-channel zone before and after 1969, but the ratio of erosion:deposition has become less biased towards deposition after 1969.

Summary changes in erosion/sedimentation regime in Tuatapere reach after 1969 show a 30 % increase in rate of erosion and an increase of almost 70 % in rate of deposition. Given the magnitude of channel adjustments in this reach, this indicates a clear shift in regime towards depositional dominance. Adjustments have been markedly variable in the differing subreaches, reflecting the shift in the position of bends over the period of record. Relative rate of increase in erosion was greatest in Upstream of Carr's and Carr's to Mid-break subreaches. In Carr's to Mid-break and Downstream of Bend break subreaches there has been a significant shift to depositional dominance after 1969. This transition largely reflects an increase in within-channel sedimentation. Perhaps the most telling statistics regarding channel adjustments associated with flow regulation in Tuatapere reach, however, are the summary changes in erosion and deposition along banks and in the within-channel zone. While erosion increased by > 45 % along banks and in the within-channel zone after 1969, the increase in rate of erosion after 1969 was almost entirely accomodated by erosion in the within-channel zone. This implies, in relative terms at least, that margins of Waiau River have stabilised after flow regulation.

8.7 Comparison of rates of bank erosion before and after 1969

One of the major flaws in virtually all the preceding discussion of channel adjustments along Waiau River, and their relationship to either the flood history or the impacts of flow regulation, has been the limitation to areal analyses of channel changes determined from air photographs. The vertical dimension is clearly critical, but it has been assumed throughout this report that summary areal estimates provide a surrogate for the direction of change, at least in terms of the erosion:deposition balance. The one component of this study that can be used to test some of the report's findings is the volumetric assessment of removed material at nine sites of continual bank erosion throughout the period of record. Bank height at these sites, which are generally coincident with concave banks, was measured in the field, such that realistic estimates of erosion could be determined by combination with areal measurements from air photographs. Results of this analysis are presented in summary form before and after 1969 in Table 8.11.

Table 8.11 Summary comparison of volumetric removal of material at selected eroding bank, before and after 1969

	Volume of material removed (in $m^3 \times 10^5$)		
	Pre 1969	Post 1969	% Change
King-Allen bend, Wairaki	9.7	3.6	- 62.89 %
Left bank, Downstream of Wairaki confluence	11.62	11.68	+ 0.52 %
Left bank, Upstream of Lill Burn confluence	2.78	1.55	- 44.24 %
Left bank, Downstream of Lill Burn confluence	0.79	4.59	+ 481.01 %
Right concave bank, Downstream o'Clifden	1.49	1.02	- 31.54 %
Right bank, Carr's property, Tuatapere reach	3.9	0.97	- 75.13 %
Left bank, Carr's to mid-break, Tuatapere reach	4.6	2.64	- 42.61 %
Right bank, D/s of bend break, Tuatapere reach	0.21	1.52	+ 623.81 %
Right bank, river mouth	5.1	1.11	- 78.24 %

The primary findings of this study, which indicate a switch in erosion/sedimentation regime towards depositional dominance and reduction in the rate of bank erosion after 1969, are strongly supported by comparison of pre- and post-1969 estimates of material removed from the selected bank erosion sites. In six of the nine sites there was a decrease of > 30 % in the amount of material removed following flow regulation. Many of the adjustments previously reported have been associated with a change in mean flow. The history of bank erosion, however, is more likely associated with the history of extreme events. The reduced flow levels and peakedness of major floods on Waiau River as water is redirected to Deep Cove have seemingly reduced the rate of material removal from major bank erosion sites since 1969.

Notable reductions in volumetric removal of material were not evident at three sites. Approximately the same volume of material was removed from along the left bank downstream of Wairaki confluence between 1947-1969 and 1969-1992. The only sites at which volume of removed material was greater after 1969 were the left bank downstream of Lill Burn confluence and the right bank at the end of Downstream of Bend break subreach in Tuatapere reach. Erosion of banks downstream of major confluences is not a coincidental product of flow regulation. At both Wairaki and Lill Burn confluences the course of Waiau River was redirected as the local flow and sediment regime were altered, such that localised erosion ensued. The greater rate of erosion of a concave bank in Tuatapere reach reflected the increase in sinuosity upstream of the river mouth and the shift in the sequence of bends as they translate downstream.

8.8 Summary impacts of flow regulation on the erosion/sedimentation regime along Waiau River

The pattern of channel adjustments along Waiau River between 1946-1992 demonstrated pronounced spatial and temporal variability, determined primarily by the geographic setting of individual reaches and the timing of flood events. It is in this context that assessment of the impacts of flow regulation must be placed.

Summary channel adjustments between 1946-1992 were negligible along most of the course of Waiau River. For large sections of its course between Lake Te Anau and Te Waewae Bay the river is laterally constrained by either bedrock or outwash terraces and is unable to modify its boundary. Channel changes were restricted to those reaches in which the river has the space to shift laterally. Such reaches are relatively few in number, and major channel changes in the period of record only occurred in Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere reaches. The first three of these reaches are coincident with tributary confluences, whereas the latter two reaches are in lowland settings.

Channel changes in each laterally unconfined reach have been analysed in considerable detail in this report. Analysis of channel adjustments measured as areas of erosion and deposition from air photographic interpretations of channel outline indicated that rates of erosion and deposition were crudely balanced prior to flow regulation. The period immediately following flow regulation was characterised by depositional dominance. Between 1969-1974 the response of Waiau River to altered mean flow levels was immediate, as the river endeavoured to attain a new equilibrium condition. In general this was achieved rapidly, as channel adjustments in the latter half of the 1970's were not as dramatic as changes evident between 1969-1974. A depositional regime prevailed, however, until the major flood events between 1982-1984 induced substantial erosion along most of the river, although bank erosion was not as prevalent as expected. The channel zone was effectively flushed during these floods, but channel recovery between February-June 1984 was rapid. Impacts of the sustained high discharge condition in late 1988 differed significantly from reach to reach and even within-reach, as the erosion/sedimentation regime adjusted to local sediment availability, bar configuration and flow alignment in each subreach. Channel adjustments between 1984-1989 were most dramatic along the lower course of the river.

While the 1970's were a period of relatively low flows and no major floods, numerous major events occurred in the 1980's. In the two decades since flow regulation channel planform style in laterally unconfined reaches has been modified, as indicated in Table 8.12. Despite the flood events of the 1980's, the pattern of channel changes associated with flow regulation has been maintained by the present (1992) channel configuration. It must be stated, however, that many of these changes were set in train prior to 1969. Channel multiplicity has generally reduced, as have the width of the active channel zone and the braided index. In contrast, sinuosity has generally increased, albeit marginally, although some subreaches have straightened. It is interesting to note, however, that channel adjustments in Lower Redcliff reach were less dramatic than observed elsewhere, reflecting the relatively narrow channel zone at this location.

Table 8.12 Channel planform adjustments in laterally unconfined reaches after 1969

++	Major increase
+	Increase
o	Roughly constant
-	Decrease
- -	Major decrease

Reach	Channel multiplicity	Width of active channel zone	Braided index	Sinuosity
Lower Redcliff	o	-	-	+
Wairaki	-	- -	- -	+
Lill Burn	o	- -	- -	+
Downstream o'Clifden	-	- -	- -	+
Tuatapere (*1)	-	- -	- -	- +

*1 Sinuosity in Tuatapere reach decreased in the upper half of the reach but increased immediately upstream of the river mouth

Theoretical knowledge suggests that adjustments in the erosion/sedimentation regime should be most pronounced immediately downstream of impoundment structures and will migrate downstream over time. Lower Redcliff zone, as such, is the most likely reach in which adjustments in the erosion and sedimentation regime will be observed, as this is the most upstream of the laterally unconfined reaches, and as such is most prone to impacts of flow regulation associated with water extraction from Lake Manapouri and Lake Manapouri Control Structure. One of the most sensitive sites downstream of the structure is at tributary confluences, where the flow and sediment regime are modified. These implications are certainly substantiated along Waiau River, although it should be noted that Lake Manapouri Control Structure only modifies low flow conditions.

Summary adjustments of the erosion and deposition regime of Waiau River have been compiled for each laterally unconfined reach in Table 8.13. Although this table has been derived from areal assessments of channel changes, the relative rates of erosion and deposition in the periods before and after 1969 are key indicators of the influence of flow regulation on the sedimentation regime. Several features of Table 8.13 are significant. The only reach in which erosion rate diminished was Lower Redcliff reach. This was, coincidentally, the reach in which deposition rate increased most dramatically. The statistical similarity of rate of change of erosional and depositional adjustments in Wairaki, Lill Burn and Downstream o'Clifden reaches is remarkable. In all three reaches there is less than 10 % variability in the relative rates of change of erosion and deposition after 1969. This suggests that whatever balance in erosion and deposition was evident before 1969, it was maintained or reestablished after 1969. In other words, the erosion and depositional regime was either never significantly affected by flow regulation in these reaches or an equilibrium condition was subsequently regained.

Table 8.13 Summary channel adjustments before and after 1969: All reaches

	Erosion		%	**Deposition**		%
	Pre 1969	*Post 1969*	Change	*Pre 1969*	*Post 1969*	Change
	Areal adjustments in m^2/day			Areal adjustments in m^2/day		
Lower Redcliff	35.57	21.80	- 38 %	16.85	62.99	+ 274 %
Wairaki	69.79	182.13	+ 161 %	86.88	226.62	+ 161 %
Lill Burn	63.57	143.61	+ 126 %	77.84	174.57	+ 124 %
D/s o'Clifden	25.07	28.94	+ 15 %	34.33	42.27	+ 23 %
Tuatapere	110.46	142.54	+ 29 %	114.63	193.02	+ 68 %
TOTAL	302.46	519.02	+ 72 %	330.53	699.47	+ 112 %

The relative increase in rates of activity could be accounted for by the greater detail in assessment of channel changes that can be derived for the more frequent air photograph surveys flown in the period following flow regulation. It is interesting to postulate, however, on the downstream sequence in the percentage change in erosion and deposition rate after 1969. In crude terms, percentage changes in rates of erosion and deposition decline down-valley, although this trend does not apply for erosion in Lower Redcliff reach and is less applicable in Tuatapere reach. The potential implication is intriguing, however ... Could the downstream effects of flow regulation be isolated using this erosion/deposition relationship in differing reaches, whereby regulation impacts are most extreme at upstream sites and diminish dowstream?

The summary relationship between erosion and deposition in Tuatapere reach differs notably from other reaches described. Rate of increase of deposition after 1969 was greater than the rate of increase of erosion. Several factors could account for this imbalance. Tuatapere reach is the most alluvial reach along Waiau River, and may be most sensitive to change. As the lowland reach along the river course, it is the reach of sediment accumulation, and the sedimentation pattern may have been modified in association with flow regulation. A more likely explanation, however, is the nature of interaction between the river and the gravel barrier system. The 4 km subreach of Waiau River upstream of the river mouth has experienced the most dramatic change in planform style along the entire river course between 1946-1992. Channel adjustments have been especially pronounced since 1969, as the main channel has become better defined and the river has adopted a more sinuous outline. Changes to the rate of sediment movement through the lower course of Waiau River associated with flow regulation, possibly exaggerated by the modified sediment contribution from tributary catchments, may have changed the relationship between Waiau River and its barrier system, such that the planform geometry of Tuatapere reach has responded to an altered set of boundary conditions. Such notions await further enquiry.

9 Summary and implications

A) Significance of studies of channel adjustments

Any study of human impacts on rivers must have a sense of system dynamic and the pre-disturbance (ie. 'natural') condition of the landscape. This background information is available from a range of sources, including old maps and historical sources (including early expeditions and surveys), air photographs, oral histories provided by local residents, and the record of landscape-forming events preserved in the landscape. It in only when subsequent adjustments are placed in context of historical changes that the impacts of human activies can be assessed. Assessment of the history of channel adjustments and the erosion/sedimentation regime constitute primary base-line data with which a wide range of related ecological and human activities responses can be evaluated.

Impacts of flow regulation cannot be evaluated without direct reference to the pre-regulation condition of the river and the subsequent flood record. This study has performed an environmental audit which has assessed the impacts of modified flow regime on the channel character of Waiau River, by comparison of channel adjustments in the 23 year period prior to flow regulation and the 23 years period after regulation.

B) Character of Waiau River

Waiau River is typical of many New Zealand rivers in that it is highly sediment charged and has a fluctuating flow regime. The present character of the river is an artifact of regional history, driven by tectonic uplift of the South Island and the pervasive glacial deposits of the region. Waiau River has as much sediment available to move as it is able. Flood events of differing magnitude are required to initiate transportation of differing clast sizes. The history of channel adjustments directly reflects the history of gravel-transporting events, ie. the flood history. Modifications to the flow regime alter the capacity of the river to transport material, thereby inducing significant adjustments to channel character and alignment. Assessment of channel adjustments using the air photograph record provides an opportunity to assess the character and rate of channel adjustments to a range of differing flow conditions.

C) Flood history and regulation impacts on the discharge regime of Waiau River

Between 1964-1969 Waiau River had a mean discharge of around 560 m^3s^{-1}. In the period following flow regulation, mean flow has decreased to around 140 m^3s^{-1}. Regulation has not only reduced mean flow levels, but has also reduced the peakedness of extreme floods. High magnitude floods would be even greater but for the Manapouri scheme!

The flood history of Waiau River has been distinctly phased. Relative to the 1960's and 1970's, the 1980's were a period of high rainfall. The two floods of record occurred in January 1983 and January 1984, and had maximum instantaneous discharges of 3320 m^3s^{-1} and 1994 m^3s^{-1} respectively. The longest period of sustained flow levels > 1200 m^3s^{-1} occurred in October/November 1988. There were no major floods during the 1970's, although there were a number of peaked lower catchment events with maximum discharges of about 1000 m^3s^{-1}. The period following flow regulation was coincident with a period of infrequent low-moderate magnitude floods and no extreme events.

D) Relationship between channel adjustments and the flood record along Waiau River

The pattern of channel adjustments along Waiau River between 1946-1992 demonstrated pronounced spatial and temporal variability, determined primarily by the geographic setting of individual reaches and the timing of flood

events. Channel adjustments between 1946-1992 were negligible along most of the river course, as many sections of the river are constrained by either bedrock or outwash terraces. Adjustments were restricted primarily to reaches where the river has space to adjust laterally, namely: Lower Redcliff, Wairaki, Lill Burn, Downstream o'Clifden and Tuatapere reaches. There was pronounced spatial and temporal variability of adjustments both within- and between-reach, largely associated with tributary impacts.

Before 1969 Waiau River was a dynamic gravel-bed river in which erosion and deposition were crudely in balance. This can be viewed as an equilibrium condition. Between 1946-1969 the river became less multichannelled and more sinuous in laterally unconfined reaches. Accordingly, the braided index and the width of the active channel zone decreased. In general, bends migrated downstream, rather than laterally. The nature of channel changes since 1969 has essentially been consistent with those adjustments set in train before 1969, although rates of change have dramatically increased. A profound shift in the erosion/sedimentation regime occurred between 1969-1974, associated with the impacts of flow regulation. Between 1969-1974 discharge levels were quite high, but substantial channel changes occurred as *relative* change in discharge regime was pronounced. This resulted in substantial deposition along large sections of Waiau River as the channel contracted. The shift to depositional dominance between 1969-1974 was marked by rates of deposition roughly twice those recorded between 1963-1969. Indeed, between 1969-1974 and 1974-1978 deposition outstripped erosion by a ratio of at least 3:1 in all reaches. Although high deposition rates were maintained throughout the 1970's, the peak depositional interval differed among the four reaches. In Wairaki reach deposition was relatively higher in 1978-1980, in Lill Burn reach deposition was relatively high between 1980-1982, in Downstream o'Clifden reach deposition rate diminished consistently in the three intervals following 1969-1974, whereas in Tuatapere reach the relative proportion of deposition was notably greater between 1969-1974 but remained high between 1974-1978 and 1978-1980. These differences largely reflect sediment movement through the system, induced in large part by tributary sediment supply. Relatively high erosion rates in Lill Burn and Wairaki reaches between 1978-1980 seemingly reflect the short lived flood in May 1979 which had a maximum discharge of 1240 m^3s^{-1}.

Just as dramatic as the shift to a predominantly depositional regime after 1969 was the reversal to erosional dominance associated with the two floods of record in January 1983 and January 1984. In all four reaches the relative rate of erosion was greatest between 1982-1984. The relative significance of erosion between 1982-1984 varied spatially, and accounted for > 50 % of total erosion in Wairaki reach, but diminished downstream such that in Tuatapere reach the period 1982-1984 accounted for < 20 % of total erosion. Phases of erosion and deposition were interspersed during the 1980's, however, as channels responded rapidly to erosion during major floods. In contrast to the pattern of upstream dominance in the effectiveness of floods between 1982-1984, an opposite downstream trend was evident for geomorphic effectiveness of the sustained high discharge levels in late 1988. Over 30 % of total erosion in Tuatapere reach occurred between 1984-1989, but < 10 % of erosion in Wairaki reach occurred between 1984-1989.

Erosion rates at five of the nine sites of continual bank erosion studied were highest between 1963-1969. Sustained high discharge levels, such as those evident pre-regulation and in the immediately following regulation (1969-1974), were more effective in bringing about bank erosion than the major floods of the 1980's. In six of the nine sites there

was a decrease of > 30 % in the amount of material removed following flow regulation. The reduced peakedness of major floods on Waiau River, as water is redirected to Deep Cove, has seemingly reduced the rate of bank erosion.

The following factors are seen to account for the spatial variability in the effectiveness of flood events:

(i) The degree to which the river is able to shift laterally, conditioned by the width of the active channel zone.

(ii) Tributary confluence configuration, and the interaction of flows and sediment. Lower catchment floods may be highly effective as they rework deposits at the confluence zone.

(iii) The "condition" of the river system at the time of any individual event, recorded by the availability of materials of differing sizes and their distribution, greatly affects flood effectiveness. The sequence and magnitude of floods in any given interval will determine how much material is freely able has be moved, or how "flushed-out" the channel may be.

(iv) Stage of bend evolution and its relationship to channel alignment and the pattern of within-channel deposition. Sheltering of banks by within-channel bars may greatly decrease erosion rate, whereas choked channels may induce lateral erosion.

E) Channel responses to flow regulation: Theoretical expectations and observed trends

The response of Waiau River to altered mean flow levels between 1969-1974 was immediate, as the river endeavoured to attain a new equilibrium condition. In general this was achieved rapidly. Channel adjustments in the latter half of the 1970's were not as dramatic as changes between 1969-1974. A depositional regime prevailed until the major flood events between 1982-1984 and in late 1988 induced substantial erosion along most of the river. The channel zone was effectively flushed during these floods, but channel recovery was rapid. In the period following flow regulation, channel multiplicity has reduced, as have the width of the active channel zone and the braided index. In contrast, sinuosity has generally increased, albeit marginally. Many of these changes were set in train prior to 1969.

Theory suggests that adjustments in the erosion/sedimentation regime following flow regulation should be most pronounced immediately downstream of impoundment structures and will migrate downstream over time. Lower Redcliff zone, as such, is the most likely reach in which adjustments in the erosion and sedimentation regime will be observed, as this is the most upstream of the laterally unconfined reaches. This proved to be the case in this study, as the only reach in which erosion rate diminished after 1969 was Lower Redcliff reach. This was, coincidentally, the reach in which deposition rate increased most dramatically. Beyond the impoundment structure the most sensitive sites for subsequent channel adjustments are tributary confluences, where the flow and sediment regime are modified. This assertion is certainly substantiated along Waiau River, as channel adjustments have been pronounced at, and downstream of, Wairaki and Lill Burn confluences.

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

In Tuatapere reach, rate of increase of deposition after 1969 was greater than the rate of increase of erosion. The 4 km subreach of Waiau River upstream of the river mouth experienced the most dramatic change in planform style along the entire river. The main channel became better defined and the river adopted a more sinuous outline. Changes to the rate of sediment movement through the lower course of Waiau River, exaggerated by the modified sediment contribution from tributary catchments, may have changed the relationship between Waiau River and its barrier system, such that the planform geometry of Tuatapere reach has responded to an altered set of boundary conditions.

F) Implications and recommendations

(i) Areas of change in the past are the most likely areas of subsequent adjustment. Future channel changes are most likely to occur at tributary confluences or in the lowland reaches, especially the section upstream of the river mouth.

(ii) Bank erosion seemingly reflects sustained moderate to high flow levels, whereas flushing of the within-channel zone only occurs during major floods > 1500 m^3s^{-1}. Localised erosion downstream of tributary catchments was pronounced for lower catchment runoff events > 800 m^3s^{-1}. Discharge conditions between 500-800 m^3s^{-1} were primarily depositional, although localised erosion continued in alluvial reaches. Lower discharge stages are almost entirely depositional or ineffective in mobilising gravels. Since flow regulation has lowered mean flow levels and flood peaks, erosional impacts have been reduced. Assessment of future changes in channel outline should be limited to air photograph analysis every 10 years or following flood events > 2000 m^3s^{-1}. Analysis should be restricted to the primary tributary confluences and the lowland plain.

(iii) In Wairoa reach significant trimming of banks was observed in the period following flow regulation. A field measurement program is required to assess rates of bank erosion to differing flow releases through Lake Te Anau Control Structure.

(iv) A monitoring program is required to assess sediment build-up at the river mouth, determining the location, rate and character of materials that are accumulating and changes to the nature of material throughput to the gravel barrier system.

(v) The character of channel adjustments documented in this study has implications for a range of groups within Waiau River Working Party, as the river response to floods and flow regulation provides a sense of system dynamic over decadal timescales which should be integrated into other reports (eg. water quality, fisheries, aquatic habitat studies, etc).

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Appendix 1 Channel adjustments data

1.1 Areal extents of channel adjustments in each reach: Wairoa reach

1.1.1 Summary channel adjustments in Wairoa (Upper Waiau) reach: 15.02.57-18.03.65

	Left bank Erosion	Deposition	Right bank Erosion	Deposition
	in m^2 x 1000	in m^2 x 1000	in m^2 x 1000	in m^2 x 1000
Control Structure	0.00	0.00	0.00	0.00
Yerex	0.00	0.00	0.00	0.00
Queens	0.00	0.00	0.00	0.00
Horseshoe Bend	0.00	0.00	0.00	0.00
Rainbow	0.00	0.00	0.00	0.00
Balloon Loop	5.44	0.00	11.71	0.00
Boulder	0.00	0.00	0.00	0.00
D/s Boulder	0.00	0.00	0.00	0.00
TOTAL	5.44	0.00	11.71	0.00

1.1.2 Summary channel adjustments in Wairoa (Upper Waiau) reach: 18.03.65-25.02.77

	Left bank Erosion	Deposition	Right bank Erosion	Deposition
	in m^2 x 1000	in m^2 x 1000	in m^2 x 1000	in m^2 x 1000
Control Structure	0.00	0.00	0.00	0.00
Yerex	0.00	0.00	0.00	0.00
Queens	0.00	0.00	0.00	0.00
Horseshoe Bend	0.00	0.00	0.00	0.00
Rainbow	0.00	0.00	0.00	0.00
Balloon Loop	21.52	0.00	25.00	0.00
Boulder	0.00	0.00	0.00	0.00
D/s Boulder	0.00	0.00	0.00	0.00
TOTAL	21.52	0.00	0.00	0.00

1.1.3 Summary channel adjustments in Wairoa (Upper Waiau) reach: 25.02.77-14.04.92

	Left bank Erosion	Deposition	Right bank Erosion	Deposition
	in m^2 x 1000	in m^2 x 1000	in m^2 x 1000	in m^2 x 1000
Control Structure	26.83	2.00	0.00	13.67
Yerex	0.50	5.19	10.18	1.50
Queens	0.00	2.00	2.50	1.00
Horseshoe Bend	1.00	0.00	2.00	0.50
Rainbow	19.46	5.00	1.50	1.00
Balloon Loop	11.56	3.26	0.60	31.70
Boulder	4.49	0.00	0.00	0.00
D/s Boulder	27.85	2.60	15.55	10.36
TOTAL	91.69	20.05	32.33	59.73

1.1.4 Summary ratio of erosion:deposition, Wairoa reach

	Left bank	Right bank
1977-1992	4.57	0.34
Overall ratio erosion:depositon	1.55	

1.2 Areal extents of channel adjustments in each reach: Lower Redcliff reach

1.2.1 Summary channel adjustments in Lower Redcliff reach: 1954-1969

28.01.54 to 12.02.69	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	in m^2 x 1000
U/s of Redcliff	4.50	10.80	26.50	0.00		
U/s Bar 1					4.00	4.50
Bar 1					8.50	0.00
Bar 2					6.50	3.00
Confluence	15.70	8.40	0.00	0.50	1.20	18.50
D/s of Redcliff	20.30	0.00	4.50	4.00		
LB complex					68.70	33.80
RB complex					20.10	7.50
D/s complex					14.80	1.50
Reach section summary						
U/s of Redcliff	4.50	10.80	26.50	0.00	19.00	7.50
Confluence	15.70	8.40	0.00	0.50	1.20	18.50
D/s of Redcliff	20.30	0.00	4.50	4.00	103.60	42.80
Summary reach total	40.50	19.20	31.00	4.50	123.80	68.80
Reach section ratios of erosion:deposition						
U/s of Redcliff	0.42		?		2.53	
Confluence	1.87		0.00		0.06	
D/s of Redcliff	?		1.13		2.42	
Overall erosion:deposition	2.11		6.89		1.80	

1.2.2 Summary channel adjustments in Lower Redcliff reach: 1969-1982

12.02.69 to 12.08.82	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	in m^2 x 1000
U/s of Redcliff	0.00	24.70	2.30	36.30		
U/s Bar 1					1.00	5.60
Bar 1					17.80	9.00
Bar 2					5.00	18.80
Confluence	22.40	9.00	0.00	0.00	0.50	12.00
D/s of Redcliff	2.50	9.50	10.60	123.40		
LB complex					17.20	88.50
RB complex					0.00	(Bank)
D/s complex					4.00	16.50
Reach section summary						
U/s of Redcliff	0.00	24.70	2.30	36.30	23.80	33.40
Confluence	22.40	9.00	0.00	0.00	0.50	12.00
D/s of Redcliff	2.50	9.50	10.60	123.40	21.20	105.00
Summary reach total	24.90	43.20	12.90	159.70	45.50	150.40
Reach section ratios of erosion:deposition						
U/s of Redcliff	0.00		0.06		0.71	
Confluence	2.49		0.00		0.04	
D/s of Redcliff	0.26		0.09		0.20	
Overall erosion:deposition	0.58		0.08		0.30	

1.2.3 Summary channel adjustments in Lower Redcliff reach: 1982-1989

12.08.82 to 04.04.89	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
U/s of Redcliff	0.00	9.10	2.00	7.70		
U/s Bar 1					1.50	1.00
Bar 1					0.50	0.50
Bar 2					3.50	4.00
Confluence	8.00	14.00	0.00	0.00	0.00	5.00
D/s of Redcliff	0.00	2.00	2.90	4.50		
LB complex					31.50	3.50
RB complex					8.50	0.00
D/s complex					0.00	3.50
Reach section summary						
U/s of Redcliff	0.00	9.10	2.00	7.70	5.50	5.50
Confluence	8.00	14.00	0.00	0.00	0.00	5.00
D/s of Redcliff	0.00	2.00	2.90	4.50	40.00	7.00
Summary reach total	8.00	25.10	4.90	12.20	45.50	17.50
Reach section ratios of erosion:deposition						
U/s of Redcliff	?		0.26		1.00	
Confluence	0.57		0.00		?	
D/s of Redcliff	?		0.64		5.71	
Overall erosion:deposition	0.32		0.40		2.60	

1.2.4 Summary channel adjustments in Lower Redcliff reach: 1989-1992

04.04.89 to 14.04.92	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
U/s of Redcliff	2.00	81.20	0.00	3.50		
U/s Bar 1					0.00	(Bank)
Bar 1					0.00	16.80
Bar 2					0.00	4.00
Confluence	1.00	2.50	0.00	0.00	9.50	0.00
D/s of Redcliff	4.00	2.00	3.50	1.50		
LB complex					10.00	5.80
RB complex					3.50	1.20
D/s complex					8.00	2.70
Reach section summary						
U/s of Redcliff	2.00	81.20	0.00	3.50	0.00	20.80
Confluence	1.00	2.50	0.00	0.00	9.50	0.00
D/s of Redcliff	4.00	2.00	3.50	1.50	21.50	9.70
Summary reach total	7.00	85.70	3.50	5.00	31.00	30.50
Reach section ratios of erosion:deposition						
U/s of Redcliff	0.02		?		?	
Confluence	0.40		0.00		?	
D/s of Redcliff	2.00		2.33		2.22	
Overall erosion:deposition	0.08		0.70		1.02	

1.3 Areal extents of channel adjustments in each reach: Wairaki reach

1.3.1 Summary channel adjustments in Wairaki reach: 1947-1963

28.03.47 to 10.03.63	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	1.00	0.50			41.53	0.00
Top bend			0.00	0.00		
King-Allen bend			11.88	1.55		
Opp conf bend			19.01	6.61		
Conf bend					59.91	8.26
Conf	32.64	77.89			32.23	21.18
D/s conf to b/rock	55.26	20.25	0.00	139.97	51.55	207.12
D/s bedrock	12.19	0.00	0.00	0.00	0.00	26.03
Reach section summary						
U/s of Wairaki	1.00	0.50	30.89	8.16	101.44	8.26
Confluence zone	32.64	77.89			32.23	21.18
D/s conf to bedrock	55.26	20.25	0.00	139.97	51.55	207.12
D/s of bedrock	12.19	0.00	0.00	0.00	0.00	26.03
Summary reach total	101.09	98.64	30.89	148.13	185.22	262.59
Reach section ratios of erosion:deposition						
U/s of Wairaki	2.00		3.79		12.28	
Confluence zone	0.42				1.52	
D/s conf to bedrock	2.73		?		0.25	
D/s of bedrock	?		?		?	
Overall erosion:deposition	1.02		0.21		0.71	

1.3.2 Summary channel adjustments in Wairaki reach: 1963-1969

10.03.63 to 12.02.69	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	0.00	18.90			1.00	0.00
Top bend			1.24	30.37		
King-Allen bend			84.50	0.00		
Opp conf bend			1.50	0.00		
Conf bend					0.00	4.65
Conf	3.41	3.61			3.50	12.60
D/s conf to b/rock	13.02	9.61	1.00	48.03	30.58	39.25
D/s bedrock	42.04	3.10	0.00	0.80	58.36	13.53
Reach section summary						
U/s of Wairaki	0.00	18.90	87.24	30.37	1.00	4.65
Confluence zone	3.41	3.61			3.50	12.60
D/s conf to bedrock	13.02	9.61	1.00	48.03	30.58	39.25
D/s of bedrock	42.04	3.10	0.00	0.80	58.36	13.53
Summary reach total	58.47	35.22	88.24	79.20	93.44	70.03
Reach section ratios of erosion:deposition						
U/s of Wairaki	?		2.87		0.22	
Confluence zone	0.94				0.28	
D/s conf to bedrock	1.35		0.02		0.78	
D/s of bedrock	13.56		?		4.31	
Overall erosion:deposition	1.66		1.11		1.33	

1.3.3 Summary channel adjustments in Wairaki reach: 1969-1974

12.02.69 to 31.05.74	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	0.00	9.61			0.00	86.46
Top bend			0.00	8.78		
King-Allen bend			18.80	0.00		
Opp conf bend			0.00	14.36		
Conf bend					3.80	48.65
Conf	0.00	0.00			0.00	0.00
D/s conf to b/rock	8.37	3.10	3.10	26.86	22.11	147.41
D/s bedrock	0.50	0.00	0.00	5.17	0.00	45.25
Reach section summary						
U/s of Wairaki	0.00	9.61	18.80	23.14	3.80	135.11
Confluence zone	0.00	0.00			0.00	0.00
D/s conf to bedrock	8.37	3.10	3.10	26.86	22.11	147.41
D/s of bedrock	0.50	0.00	0.00	5.17	0.00	45.25
Summary reach total	8.87	12.71	21.90	55.17	25.91	327.77
Reach section ratios of erosion:deposition						
U/s of Wairaki	?		0.81		0.03	
Confluence zone	0.00				0.00	
D/s conf to bedrock	2.70		0.12		0.15	
D/s of bedrock	?		?		?	
Overall erosion:deposition	0.70		0.40		0.08	

1.3.4 Summary channel adjustments in Wairaki reach: 1974-1978

31.05.74 to 11.02.78	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	3.00	0.00			2.50	25.52
Top bend			0.00	20.66		
King-Allen bend			0.00	0.00		
Opp conf bend			8.57	14.46		
Conf bend					0.00	0.00
Conf	0.30	28.10			0.00	0.00
D/s conf to b/rock	0.00	0.00	3.00	55.99	0.00	2.50
D/s bedrock	0.00	0.00	2.00	2.50	1.00	8.26
Reach section summary						
U/s of Wairaki	3.00	0.00	8.57	35.12	2.50	25.52
Confluence zone	0.30	28.10			0.00	0.00
D/s conf to bedrock	0.00	0.00	3.00	55.99	0.00	2.50
D/s of bedrock	0.00	0.00	2.00	2.50	1.00	8.26
Summary reach total	3.30	28.10	13.57	93.61	3.50	36.28
Reach section ratios of erosion:deposition						
U/s of Wairaki	?		0.24		0.10	
Confluence zone	0.01				0.00	
D/s conf to bedrock	0.00		0.05		0.00	
D/s of bedrock	0.00		0.80		0.12	
Overall erosion:deposition	0.12		0.14		0.10	

1.3.5 Summary channel adjustments in Wairaki reach: 1978-1980

11.02.78 to 14.04.80	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	0.00	60.12			0.20	39.05
Top bend			17.77	23.13		
King-Allen bend			0.00	0.00		
Opp conf bend			0.00	50.31		
Conf bend					0.00	1.50
Conf	33.06	25.52			0.00	10.85
D/s conf to b/rock	3.00	36.57	132.53	10.12	0.00	56.09
D/s bedrock	0.00	0.00	0.80	12.81	0.00	37.91
Reach section summary						
U/s of Wairaki	0.00	60.12	17.77	73.44	0.20	40.55
Confluence zone	33.06	25.52			0.00	10.85
D/s conf to bedrock	3.00	36.57	132.53	10.12	0.00	56.09
D/s of bedrock	0.00	0.00	0.80	12.81	0.00	37.91
Summary reach total	36.06	122.21	151.10	96.37	0.20	145.40
Reach section ratios of erosion:deposition						
U/s of Wairaki	?		0.24		0.00	
Confluence zone	1.30				?	
D/s conf to bedrock	0.08		13.10		?	
D/s of bedrock	0.00		0.06		?	
Overall erosion:deposition	0.30		1.57		0.00	

1.3.6 Summary channel adjustments in Wairaki reach: 1980-1982

14.04.80 to 12.08.82	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	0.00	13.33			0.00	2.70
Top bend			0.00	43.70		
King-Allen bend			0.00	0.00		
Opp conf bend			0.00	8.16		
Conf bend					0.00	3.50
Conf	12.19	11.47			3.00	38.94
D/s conf to b/rock	9.81	3.00	8.30	11.26	4.00	2.90
D/s bedrock	0.00	0.00	0.00	6.00	0.50	3.30
Reach section summary						
U/s of Wairaki	0.00	13.33	0.00	51.86	0.00	6.20
Confluence zone	12.19	11.47			3.00	38.94
D/s conf to bedrock	9.81	3.00	8.30	11.26	4.00	2.90
D/s of bedrock	0.00	0.00	0.00	6.00	0.50	3.30
Summary reach total	22.00	27.80	8.30	69.12	7.50	51.34
Reach section ratios of erosion:deposition						
U/s of Wairaki	?		?		?	
Confluence zone	1.06				0.08	
D/s conf to bedrock	3.27		0.74		1.38	
D/s of bedrock	0.00		?		0.15	
Overall erosion:deposition	0.79		0.12		0.15	

1.3.7 Summary channel adjustments in Wairaki reach: 1982-1984

12.08.82 to 07.02.84	Left bank EROSION	DEPOSITION	Right bank EROSION	DEPOSITION	Within-channel EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	157.20	0.00			75.20	3.00
Top bend			0.00	0.00		
King-Allen bend			0.00	0.00		
Opp conf bend			87.60	0.00		
Conf bend					0.00	0.00
Conf	45.80	0.00			0.00	0.00
D/s conf to b/rock	280.77	0.00	74.38	0.00	110.53	12.29
D/s bedrock	0.00	0.00	11.26	0.00	45.25	0.00
Reach section summary						
U/s of Wairaki	157.20	0.00	87.60	0.00	75.20	3.00
Confluence zone	45.80	0.00			0.00	0.00
D/s conf to bedrock	280.77	0.00	74.38	0.00	110.53	12.29
D/s of bedrock	0.00	0.00	11.26	0.00	45.25	0.00
Summary reach total	483.77	0.00	173.24	0.00	230.98	15.29
Reach section ratios of erosion:deposition						
	Left bank		Right bank		Within-channel	
U/s of Wairaki	?		?		25.07	
Confluence zone	?				0.00	
D/s conf to bedrock	0.00		?		8.99	
D/s of bedrock	?		?		?	
Overall erosion:deposition	?		?		15.11	

1.3.8 Summary channel adjustments in Wairaki reach: February-June 1984

07.02.84 to 21.06.84	Left bank EROSION	DEPOSITION	Right bank EROSION	DEPOSITION	Within-channel EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	3.50	121.27			6.50	48.96
Top bend			2.00	2.50		
King-Allen bend			0.00	0.00		
Opp conf bend			0.00	4.00		
Conf bend					0.00	19.11
Conf	6.50	12.29			4.00	4.40
D/s conf to b/rock	6.82	265.58	9.81	14.57	36.98	81.50
D/s bedrock	5.68	8.26	11.60	0.80	12.60	53.82
Reach section summary						
U/s of Wairaki	3.50	121.27	2.00	6.50	6.50	68.07
Confluence zone	6.50	12.29			4.00	4.40
D/s conf to bedrock	6.82	265.58	9.81	14.57	36.98	81.50
D/s of bedrock	5.68	8.26	11.60	0.80	12.60	53.82
Summary reach total	22.50	407.40	23.41	21.87	60.08	207.79
Reach section ratios of erosion:deposition						
U/s of Wairaki	0.03		0.31		0.10	
Confluence zone	0.53				0.91	
D/s conf to bedrock	0.03		0.67		0.45	
D/s of bedrock	0.69		14.50		0.23	
Overall erosion:deposition	0.06		1.07		0.29	

1.3.9 Summary channel adjustments in Wairaki reach: 1984-1989

21.06.84 to 04.04.89	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	5.40	20.35			1.50	2.50
Top bend			0.00	0.00		
King-Allen bend			12.91	0.00		
Opp conf bend			0.80	0.00		
Conf bend					2.30	0.00
Conf	8.78	5.00			2.00	23.45
D/s conf to b/rock	9.19	1.50	4.50	39.46	41.11	21.80
D/s bedrock	0.00	0.00	0.00	0.00	42.97	0.00
Reach section summary						
U/s of Wairaki	5.40	20.35	13.71	0.00	3.80	2.50
Confluence zone	8.78	5.00			2.00	23.45
D/s conf to bedrock	9.19	1.50	4.50	39.46	41.11	21.80
D/s of bedrock	0.00	0.00	0.00	0.00	42.97	0.00
Summary reach total	23.37	26.85	18.21	39.46	89.88	47.75
Reach section ratios of erosion:deposition						
U/s of Wairaki	0.27		?		1.52	
Confluence zone	1.76				0.09	
D/s conf to bedrock	6.13		0.11		1.89	
D/s of bedrock	0.00		0.00		?	
Overall erosion:deposition	0.87		0.46		1.88	

1.3.10 Summary channel adjustments in Wairaki reach: 1989-1992

04.04.89 to 14.04.92	Left bank		Right bank		Within-channel	
	EROSION	DEPOSITION	EROSION	DEPOSITION	EROSION	DEPOSITION
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
u/s of conf	10.12	4.00			3.50	0.00
Top bend			0.00	0.00		
King-Allen bend			4.13	0.00		
Opp conf bend			0.00	0.00		
Conf bend					1.50	0.00
Conf	?	?			?	?
D/s conf to b/rock	3.30	0.00	37.08	32.33	37.70	13.33
D/s bedrock	0.00	14.67	0.00	0.00	5.50	7.70
Reach section summary						
U/s of Wairaki	10.12	4.00	4.13	0.00	5.00	0.00
Confluence zone	?	?			?	?
D/s conf to bedrock	3.30	0.00	37.08	32.33	37.70	13.33
D/s of bedrock	0.00	14.67	0.00	0.00	5.50	7.70
Summary reach total	13.42	18.67	41.21	32.33	48.20	21.03
Reach section ratios of erosion:deposition						
U/s of Wairaki	2.53		?		?	
Confluence zone	?				?	
D/s conf to bedrock	?		1.15		2.83	
D/s of bedrock	?		0.00		0.71	
Overall erosion:deposition	0.72		1.27		2.29	

1.4 Areal extents of channel adjustments in each reach: Lill Burn reach

1.4.1 Summary channel adjustments in Lill Burn reach: 1947-1963

28.03.47 to 10.03.63	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	38.06	7.37	0.90	7.10	29.90	13.50
Confluence			74.20	30.60	3.80	31.70
Downstream of Lill Burn	10.64	0.00				
Bend d/s confl			7.50	54.83		
Bend to bedrock			1.30	32.19		
Bar complex 1					67.40	72.50
Bar complex 2					30.50	100.10
Downstream of bedrock	0.00	0.00	0.00	0.00	12.70	48.90
Reach section summary						
Upstream of Lill Burn	38.06	7.37	0.90	7.10	29.90	13.50
Confluence			74.20	30.60	3.80	31.70
Downstream of Lill Burn	10.64	0.00	8.80	87.02	97.90	172.60
Downstream of bedrock	0.00	0.00	0.00	0.00	12.70	48.90
Summary reach total	48.70	7.37	83.90	124.72	144.30	266.70
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	5.16		0.13		2.21	
Confluence			2.42		0.12	
Downstream of Lill Burn	?		0.10		0.57	
Downstream of bedrock	0.00		0.00		0.26	
Overall erosion:deposition	6.61		0.67		0.54	

1.4.2 Summary channel adjustments in Lill Burn reach: 1963-1969

10.03.63 to 12.02.69	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	50.65	6.55	0.00	13.10	1.80	31.00
Confluence			17.05	38.40	2.30	22.20
Downstream of Lill Burn	16.50	1.00				
Bend d/s confl			0.00	5.50		
Bend to bedrock			3.50	32.05		
Bar complex 1					73.80	40.60
Bar complex 2					49.20	9.55
Downstream of bedrock	1.50	7.09	0.00	0.00	14.50	15.80
Reach section summary						
Upstream of Lill Burn	50.65	6.55	0.00	13.10	1.80	31.00
Confluence			17.05	38.40	2.30	22.20
Downstream of Lill Burn	16.50	1.00	3.50	37.55	123.00	50.15
Downstream of bedrock	1.50	7.09	0.00	0.00	14.50	15.80
Summary reach total	68.65	14.64	20.55	89.05	141.60	119.15
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	7.73		?		0.06	
Confluence			0.44		0.10	
Downstream of Lill Burn	16.50		0.09		2.45	
Downstream of bedrock	0.21		0.00		0.92	
Overall erosion:deposition	4.69		0.23		1.19	

1.4.3 Summary channel adjustments in Lill Burn reach: 1969-1974

12.02.69 to 31.05.74	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	21.60	59.80	2.10	0.00	0.60	0.00
Confluence			10.40	13.80	1.30	54.10
Downstream of Lill Burn	27.55	0.00				
Bend d/s confl			0.00	4.30		
Bend to bedrock			0.00	11.90		
Bar complex 1					0.00	135.00
Bar complex 2					1.30	55.40
Downstream of bedrock	0.00	75.60	0.00	0.00	0.00	2.60
Reach section summary						
Upstream of Lill Burn	21.60	59.80	2.10	0.00	0.60	0.00
Confluence			10.40	13.80	1.30	54.10
Downstream of Lill Burn	27.55	0.00	0.00	16.20	1.30	190.40
Downstream of bedrock	0.00	75.60	0.00	0.00	0.00	2.60
Summary reach total	49.15	135.40	12.50	30.00	3.20	247.10
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	0.36		?		?	
Confluence			0.75		0.02	
Downstream of Lill Burn	?		?		0.01	
Downstream of bedrock	?		0.00		?	
Overall erosion:deposition	0.36		0.42		0.01	

1.4.4 Summary channel adjustments in Lill Burn reach: 1974-1977

31.05.74 to 25.02.77	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	8.40	0.00	0.30	0.00	0.00	21.40
Confluence			4.30	17.80	4.50	32.50
Downstream of Lill Burn	0.60	19.50				
Bend d/s confl			0.00	0.00		
Bend to bedrock			0.00	7.10		
Bar complex 1					0.30	14.60
Bar complex 2					7.10	12.80
Downstream of bedrock	3.50	2.80	0.00	0.00	0.00	0.00
Reach section summary						
Upstream of Lill Burn	8.40	0.00	0.30	0.00	0.00	21.40
Confluence			4.30	17.80	4.50	32.50
Downstream of Lill Burn	0.60	19.50	0.00	7.10	7.40	27.40
Downstream of bedrock	3.50	2.80	0.00	0.00	0.00	0.00
Summary reach total	12.50	22.30	4.60	24.90	11.90	81.30
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	?		?		?	
Confluence			0.24		0.14	
Downstream of Lill Burn	0.03		?		0.27	
Downstream of bedrock	1.25		0.00		0.00	
Overall erosion:deposition	0.56		0.18		0.15	

1.4.5 Summary channel adjustments in Lill Burn reach: 1977-1980

25.02.77 to 14.04.80	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	16.20	0.00	0.00	0.00	18.60	3.50
Confluence			29.90	6.40	38.50	13.40
Downstream of Lill Burn	0.00	0.00				
Bend d/s confl			1.50	1.40		
Bend to bedrock			1.00	2.00		
Bar complex 1					5.20	15.00
Bar complex 2					4.50	0.80
Downstream of bedrock	2.70	0.20	0.00	5.10	3.00	3.70
Reach section summary						
Upstream of Lill Burn	16.20	0.00	0.00	0.00	18.60	3.50
Confluence			29.90	6.40	38.50	13.40
Downstream of Lill Burn	0.00	0.00	2.50	3.40	9.70	15.80
Downstream of bedrock	2.70	0.20	0.00	5.10	3.00	3.70
Summary reach total	18.90	0.20	32.40	14.90	69.80	36.40
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	?		0.00		5.31	
Confluence			4.67		2.87	
Downstream of Lill Burn	0.00		0.74		0.61	
Downstream of bedrock	13.50		?		0.81	
Overall erosion:deposition	94.50		2.17		1.92	

1.4.6 Summary channel adjustments in Lill Burn reach: 1980-1982

14.04.80 to 12.08.82	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	0.00	1.50	0.00	0.00	0.00	9.30
Confluence			3.80	58.40	7.70	6.30
Downstream of Lill Burn	5.00	0.00				
Bend d/s confl			0.60	16.50		
Bend to bedrock			0.00	36.40		
Bar complex 1					1.50	74.20
Bar complex 2					1.00	40.80
Downstream of bedrock	17.50	1.70	0.00	2.50	2.00	1.20
Reach section summary						
Upstream of Lill Burn	0.00	1.50	0.00	0.00	0.00	9.30
Confluence			3.80	58.40	7.70	6.30
Downstream of Lill Burn	5.00	0.00	0.60	52.90	2.50	115.00
Downstream of bedrock	17.50	1.70	0.00	2.50	2.00	1.20
Summary reach total	22.50	3.20	4.40	113.80	12.20	131.80
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	?		0.00		?	
Confluence			0.07		1.22	
Downstream of Lill Burn	?		0.01		0.02	
Downstream of bedrock	10.29		?		1.67	
Overall erosion:deposition	7.03		0.04		0.09	

1.4.7 Summary channel adjustments in Lill Burn reach: 1982-1984

12.08.82 to 07.02.84	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	81.70	0.00	0.00	0.00	2.80	0.00
Confluence			109.00	6.60	0.00	1.00
Downstream of Lill Burn	108.40	0.00				
Bend d/s confl			25.50	0.00		
Bend to bedrock			0.00	0.00		
Bar complex 1					97.80	2.50
Bar complex 2					2.50	0.00
Downstream of bedrock	33.50	0.00	0.00	0.00	0.00	0.00
Reach section summary						
Upstream of Lill Burn	81.70	0.00	0.00	0.00	2.80	0.00
Confluence			109.00	6.60	0.00	1.00
Downstream of Lill Burn	108.40	0.00	25.50	0.00	100.30	2.50
Downstream of bedrock	33.50	0.00	0.00	0.00	0.00	0.00
Summary reach total	223.60	0.00	134.50	6.60	103.10	3.50
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	?		?		?	
Confluence			16.52		?	
Downstream of Lill Burn	?		?		40.12	
Downstream of bedrock	?		0.00		0.00	
Overall erosion:deposition	?		20.38		29.46	

1.4.8 Summary channel adjustments in Lill Burn reach: February-June, 1984

07.02.84 to 21.06.84	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	13.90	57.20	5.30	13.10	8.30	15.90
Confluence			7.20	12.20	2.00	20.80
Downstream of Lill Burn	1.50	9.60				
Bend d/s confl			2.00	19.60		
Bend to bedrock			0.00	12.50		
Bar complex 1					8.90	88.70
Bar complex 2					6.00	3.10
Downstream of bedrock	0.00	33.50	7.00	2.00	1.00	0.00
Reach section summary						
Upstream of Lill Burn	13.90	57.20	5.30	13.10	8.30	15.90
Confluence			7.20	12.20	2.00	20.80
Downstream of Lill Burn	1.50	9.60	2.00	32.10	14.90	91.80
Downstream of bedrock	0.00	33.50	7.00	2.00	1.00	0.00
Summary reach total	15.40	100.30	21.50	59.40	26.20	128.50
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	0.24		0.40		0.52	
Confluence			0.59		0.10	
Downstream of Lill Burn	0.16		0.06		0.16	
Downstream of bedrock	?		3.50		?	
Overall erosion:deposition	0.15		0.36		0.20	

1.4.9 Summary channel adjustments in Lill Burn reach: 1984-1989

21.06.84 to 04.04.89	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	6.10	0.00	3.80	0.00	0.00	2.30
Confluence			157.80	35.30	0.60	49.80
Downstream of Lill Burn	36.10	0.80				
Bend d/s confl			?	0.00		
Bend to bedrock			23.20	0.00		
Bar complex 1					86.70	20.20
Bar complex 2					1.00	0.00
Downstream of bedrock	33.40	3.40	0.00	3.50	0.00	0.00
Reach section summary						
Upstream of Lill Burn	6.10	0.00	3.80	0.00	0.00	2.30
Confluence			157.80	35.30	0.60	49.80
Downstream of Lill Burn	36.10	0.80	23.20	0.00	87.70	20.20
Downstream of bedrock	33.40	3.40	0.00	3.50	0.00	0.00
Summary reach total	75.60	4.20	184.80	38.80	88.30	72.30
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	?		?		?	
Confluence			4.47		0.01	
Downstream of Lill Burn	45.13		?		4.34	
Downstream of bedrock	9.82		?		0.00	
Overall erosion:deposition	18.00		4.76		1.22	

1.4.10 Summary channel adjustments in Lill Burn reach: 1989-1992

04.04.89 to 14.04.92	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Lill Burn	6.80	11.00	0.00	0.00	2.80	9.00
Confluence			16.20	56.40	2.60	7.70
Downstream of Lill Burn	0.00	5.30				
Bend d/s confl			0.00	1.00		
Bend to bedrock			20.90	22.40		
Bar complex 1					20.10	93.30
Bar complex 2					7.70	1.00
Downstream of bedrock	0.00	2.00	1.50	0.80	0.00	0.00
Reach section summary						
Upstream of Lill Burn	6.80	11.00	0.00	0.00	2.80	9.00
Confluence			16.20	56.40	2.60	7.70
Downstream of Lill Burn	0.00	5.30	20.90	23.40	27.80	94.30
Downstream of bedrock	0.00	2.00	1.50	0.80	0.00	0.00
Summary reach total	6.80	18.30	38.60	80.60	33.20	111.00
Reach section ratios of erosion:deposition						
Upstream of Lill Burn	0.62		0.00		0.31	
Confluence			0.29		0.34	
Downstream of Lill Burn	?		0.89		0.29	
Downstream of bedrock	?		1.88		0.00	
Overall erosion:deposition	0.37		0.48		0.30	

1.5 Areal extents of channel adjustments in each reach: Downstream o'Clifden reach

1.5.1 Summary channel adjustments in Downstream o'Clifden reach: 1947-1992

	Left bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
28.03.47 to 10.03.63	0.00	10.20	80.89	66.70	62.70	137.90
10.03.63 to 12.02.69	0.00	6.60	42.30	16.50	14.30	36.30
12.02.69 to 31.05.74	1.10	6.30	9.60	16.50	18.30	59.30
31.05.74 to 25.02.77	0.00	28.80	1.60	15.40	2.30	28.40
25.02.77 to 11.02.78	0.00	4.10	1.50	1.40	10.30	0.80
11.02.78 to 14.04.80	0.00	23.40	6.80	1.50	5.00	30.00
14.04.80 to 12.08.82	0.00	4.80	14.40	4.40	8.10	39.00
12.08.82 to 07.02.84	0.80	1.80	17.70	0.00	41.00	0.00
07.02.84 to 21.06.84	1.20	1.50	0.00	25.00	0.00	11.00
21.06.84 to 04.04.89	0.00	0.00	32.40	2.00	44.00	9.20
04.04.89 to 14.04.92	1.50	0.30	10.50	11.40	13.70	26.80

1.5.2 Summary rations of erosion:deposition in Downstream o'Clifden reach: 1947-1992

	Left bank	Right bank	Within-channel
28.03.47 to 10.03.63	?	1.21	0.45
10.03.63 to 12.02.69	?	2.56	0.39
12.02.69 to 31.05.74	0.17	0.58	0.31
31.05.74 to 25.02.77	?	0.10	0.08
25.02.77 to 11.02.78	?	1.07	12.88
11.02.78 to 14.04.80	?	4.53	0.17
14.04.80 to 12.08.82	?	3.27	0.21
12.08.82 to 07.02.84	0.44	?	?
07.02.84 to 21.06.84	0.80	?	?
21.06.84 to 04.04.89	0.00	16.20	4.78
04.04.89 to 14.04.92	5.00	0.92	0.51

nnel adjustments in each reach: Tuatapere reach

nnel adjustments in Tuatapere reach: 1946-1963

and 28.03.47 to 10.03.63

	Left Bank Erosion Deposition in m^2 x 1000		Right bank Erosion Deposition in m^2 x 1000		Within-channel Erosion Deposition in m^2 x 1000	
Upstream of Carr's						
U/s mid-channel complex					0.00	39.10
Mid-channel complex 1	0.00	17.80	36.50	8.00	83.70	83.60
tream of Carr's (Total)					83.70	122.70
's to mid break	0.00	17.80			49.90	38.90
eak to bend break	131.00	0.00			171.40	315.00
eam of bend break	33.20	17.70			35.70	84.40
	0.00	49.60				
reach total	164.20	85.10	36.50	8.00	340.70	561.00
ion ratios of erosion:deposition						
arr's			0.00	10.00		
ak	?		5.50	27.80		
l break	?		148.90	38.80		
d break	1.88					
	?		190.90	84.60		
ition	1.93					
		4.56			0.68	
		?			1.28	
		0.20			0.54	
		3.84			0.42	
		2.26			0.61	

djustments in Tuatapere reach: 1963-1969

	Left nk Erosion Deposition x 1000		Right bank Erosion Deposition in m^2 x 1000		Within-channel Erosion Deposition in m^2 x 1000	
	3.10					
0			5.00	3.50		
					2.40	9.90
					51.20	19.00
			53.60	28.90		
			22.70	61.00		
			26.10	11.70		
			1.80	46.80		
			104.20	148.40		
	1.43					
	?					
	?					
				1.85		
				0.37		
				2.23		
				0.04		
				0.70		

1.6.3 Summary channel adjustments in Tuatapere reach: 1969-1974

12.02.69 to 07.07.74	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	6.10	0.60	3.50	0.80		
U/s mid-channel complex					6.50	11.00
Mid-channel complex 1					18.60	94.90
Upstream of Carr's (Total)	6.10	0.60	3.50	0.80	25.10	105.90
Carr's to mid break	39.40	3.00	0.00	2.50	8.70	96.90
Mid break to bend break	5.40	24.40	3.70	1.00	9.30	204.00
Downstream of bend break	0.00	0.00	7.10	10.60	2.00	129.40
Summary reach total	50.90	28.00	14.30	14.90	45.10	536.20
Reach section ratios of erosion:deposition						
Upstream of Carr's	10.17		4.38		0.24	
Carr's to mid break	13.13		?		0.09	
Mid break to bend break	0.22		3.70		0.05	
Downstream of bend break	0.00		0.67		0.02	
Overall erosion:deposition	1.82		0.96		0.08	

1.6.4 Summary channel adjustments in Tuatapere reach: 1974-1975

07.07.74 to 03.03.75	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	0.00	0.00	0.00	2.00		
U/s mid-channel complex					0.00	0.20
Mid-channel complex 1					0.00	0.00
Upstream of Carr's (Total)	0.00	0.00	0.00	2.00	0.00	0.20
Carr's to mid break	0.00	0.00	0.00	0.00	2.00	1.00
Mid break to bend break	0.00	0.00	0.00	0.00	0.00	3.10
Downstream of bend break	0.00	22.90	0.00	0.00	0.00	7.90
Summary reach total	0.00	22.90	0.00	2.00	2.00	12.20
Reach section ratios of erosion:deposition						
Upstream of Carr's	0.00		?		?	
Carr's to mid break	0.00		0.00		2.00	
Mid break to bend break	0.00		0.00		?	
Downstream of bend break	?		0.00		?	
Overall erosion:deposition	0.00		0.00		0.16	

1.6.5 Summary channel adjustments in Tuatapere reach: 1975-1977

03.03.75 to 25.02.77	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	0.00	0.00	0.00	6.20		
U/s mid-channel complex					1.30	5.20
Mid-channel complex 1					0.00	15.40
Upstream of Carr's (Total)	0.00	0.00	0.00	6.20	1.30	20.60
Carr's to mid break	0.00	1.80	0.00	7.60	3.90	14.30
Mid break to bend break	2.20	6.90	0.00	1.00	2.90	8.50
Downstream of bend break	0.00	2.00	14.60	3.30	2.20	14.90
Summary reach total	2.20	10.70	14.60	18.10	10.30	58.30
Reach section ratios of erosion:deposition						
Upstream of Carr's	0.00		?		0.06	
Carr's to mid break	?		?		0.27	
Mid break to bend break	0.32		?		0.34	
Downstream of bend break	?		4.06		0.15	
Overall erosion:deposition	0.21		0.81		0.18	

1.6.6 Summary channel adjustments in Tuatapere reach: 1977-1978

25.02.77 to 11.02.78	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	0.00	2.50	0.50	0.00		
U/s mid-channel complex					0.00	14.00
Mid-channel complex 1					8.00	6.70
Upstream of Carr's (Total)	0.00	2.50	0.50	0.00	8.00	20.70
Carr's to mid break	9.90	0.00	0.00	0.00	0.00	6.50
Mid break to bend break	0.00	2.70	0.00	7.10	14.20	34.70
Downstream of bend break	0.00	0.70	3.30	4.30	15.80	14.60
Summary reach total	9.90	5.90	3.50	11.40	38.00	76.50
Reach section ratios of erosion:deposition						
Upstream of Carr's	?		?		0.39	
Carr's to mid break	?		0.00		?	
Mid break to bend break	?		?		0.41	
Downstream of bend break	?		0.77		1.08	
Overall erosion:deposition	1.68		0.33		0.50	

1.6.7 Summary channel adjustments in Tuatapere reach: 1978-1980

11.02.78 to 14.04.80	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	2.50	4.30	0.00	2.40		
U/s mid-channel complex					2.00	2.70
Mid-channel complex 1					1.60	19.40
Upstream of Carr's (Total)	2.50	4.30	0.00	2.40	3.60	22.10
Carr's to mid break	2.70	0.00	0.00	1.00	4.40	28.00
Mid break to bend break	6.70	0.00	0.00	0.00	2.30	69.20
Downstream of bend break	4.20	52.30	9.40	6.50	5.40	24.00
Summary reach total	16.10	56.60	9.40	9.90	15.70	143.30
Reach section ratios of erosion:deposition						
Upstream of Carr's	0.58		?		0.16	
Carr's to mid break	?		?		0.16	
Mid break to bend break	?		0.00		0.03	
Downstream of bend break	0.08		1.45		0.23	
Overall erosion:deposition	0.28		0.95		0.11	

1.6.8 Summary channel adjustments in Tuatapere reach: 1980-1982

14.04.80 to 12.08.82	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	2.60	0.80	7.00	0.00		
U/s mid-channel complex					2.30	2.60
Mid-channel complex 1					2.60	5.20
Upstream of Carr's (Total)	2.60	0.80	7.00	0.00	4.90	7.80
Carr's to mid break	9.80	0.00	0.00	1.60	8.20	29.50
Mid break to bend break	4.60	1.50	0.00	0.00	12.50	11.00
Downstream of bend break	4.50	4.20	1.70	5.60	11.00	32.60
Summary reach total	21.50	6.50	8.70	7.20	36.60	80.90
Reach section ratios of erosion:deposition						
Upstream of Carr's	3.25		?		0.63	
Carr's to mid break	?		?		0.28	
Mid break to bend break	3.07		?		1.14	
Downstream of bend break	1.07		0.30		0.34	
Overall erosion:deposition	3.31		1.21		0.45	

1.6.9 Summary channel adjustments in Tuatapere reach: 1982-1984

12.08.82 to 21.06.84	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	13.00	0.00	4.20	0.00		
U/s mid-channel complex					11.60	0.00
Mid-channel complex 1					7.20	4.90
Upstream of Carr's (Total)	13.00	0.00	4.20	0.00	18.80	4.90
Carr's to mid break	4.00	0.00	9.50	0.00	28.10	13.40
Mid break to bend break	14.00	0.00	1.90	0.00	66.60	21.40
Downstream of bend break	20.00	0.70	12.40	1.50	53.40	2.30
Summary reach total	51.00	0.70	28.00	1.50	166.90	42.00
Reach section ratios of erosion:deposition						
Upstream of Carr's	?		?		3.84	
Carr's to mid break	?		?		2.10	
Mid break to bend break	?		?		3.11	
Downstream of bend break	28.57		8.27		23.22	
Overall erosion:deposition	72.86		18.67		3.97	

1.6.10 Summary channel adjustments in Tuatapere reach: 1984-1985

21.06.84 to 08.10.85	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	0.00	0.00	2.70	1.50		
U/s mid-channel complex					7.70	6.80
Mid-channel complex 1					42.70	1.60
Upstream of Carr's (Total)	0.00	0.00	2.70	1.50	50.40	8.40
Carr's to mid break	9.60	0.00	2.00	0.00	26.90	13.90
Mid break to bend break	3.40	0.00	0.00	0.00	11.40	4.90
Downstream of bend break	0.00	18.70	8.10	1.20	34.30	14.90
Summary reach total	13.00	18.70	12.80	2.70	123.00	42.10
Reach section ratios of erosion:deposition						
Upstream of Carr's	0.00		1.80		6.00	
Carr's to mid break	?		?		1.94	
Mid break to bend break	?		0.00		2.33	
Downstream of bend break	?		6.75		2.30	
Overall erosion:deposition	0.70		4.74		2.92	

1.6.11 Summary channel adjustments in Tuatapere reach: 1985-1989

08.10.85 to 04.04.89	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	53.10	0.00	10.60	0.00		
U/s mid-channel complex					50.80	30.60
Mid-channel complex 1					48.50	20.30
Upstream of Carr's (Total)	53.10	0.00	10.60	0.00	99.30	50.90
Carr's to mid break	29.40	0.00	13.10	55.50	75.00	24.00
Mid break to bend break	17.00	0.00	49.00	30.70	45.10	15.20
Downstream of bend break	13.50	1.30	29.70	33.30	27.60	31.40
Summary reach total	113.00	1.30	102.40	119.50	247.00	121.50
Reach section ratios of erosion:deposition						
Upstream of Carr's	?		?		1.95	
Carr's to mid break	?		0.24		3.13	
Mid break to bend break	?		1.60		2.97	
Downstream of bend break	10.38		0.89		0.88	
Overall erosion:deposition	86.92		0.86		2.03	

1.6.12 Summary channel adjustments in Tuatapere reach: 1989-1992

04.04.89 to 14.04.92	Left Bank		Right bank		Within-channel	
	Erosion	Deposition	Erosion	Deposition	Erosion	Deposition
	in m^2 x 1000		in m^2 x 1000		in m^2 x 1000	
Upstream of Carr's	0.90	9.80	6.30	0.80		
U/s mid-channel complex					5.10	8.60
Mid-channel complex 1					17.20	6.80
Upstream of Carr's (Total)	0.90	9.80	6.30	0.80	22.30	15.40
Carr's to mid break	0.00	3.90	4.60	3.50	3.40	55.30
Mid break to bend break	3.50	3.10	1.70	2.10	8.90	70.10
Downstream of bend break	0.20	1.00	4.50	0.40	0.00	5.20
Summary reach total	4.60	17.80	17.10	6.80	34.60	146.00
Reach section ratios of erosion:deposition						
Upstream of Carr's	0.09		7.88		1.45	
Carr's to mid break	?		1.31		0.06	
Mid break to bend break	1.13		0.81		0.13	
Downstream of bend break	0.20		11.25		0.00	
Overall erosion:deposition	0.26		2.51		0.24	

Appendix 2 Summary channel adjustments in each reach over differing photographic intervals

2.1 Lower Redcliff reach

Year	Channel adjustments
1954-1969	Erosion was dominant along the right bank upstream of Redcliff, along the southern bank of Redcliff Creek at Waiau confluence zone and downstream of Redcliff. In contrast, deposition was dominant along the northern bank in the confluence zone. Rates of within-channel activity were greatest downstream of Redcliff, particularly along the left bank complex. Erosion was dominant over deposition in the within-channel zone.
1969-1982	Rate of deposition increased markedly between 1969-1982, whereas rate of erosion was reduced along both banks and in the within-channel zone. Deposition was especially pronounced along the left and right bank upstream of Redcliff, and along the right bank and within-channel zone downstream of Redcliff (where the right bank bar complex became bank-attached).
1982-1989	Erosion was negligible other than in the within-channel zone downstream of Redcliff (adjacent to the left bank bar complex). Deposition continued to dominate over erosion adjacent to the banks, but rate of deposition was much lower than in the period 1969-1982. Rate of erosion exceeded rate of deposition in the within-channel zone.
1989-1992	Deposition greatly exceeded erosion in this interval, as a mid-channel bar complex upstream of Redcliff became attached to the left bank. While deposition exceeded erosion in the within-channel zone upstream of Redcliff, erosion was dominant in the within-channel zone downstream of Redcliff.

2.2 Wairaki reach

Year	Channel adjustments
1947-1963	Extensive within-channel erosion occurred upstream of Wairaki confluence and in confluence bend, with lesser erosion in King-Allen bend and opposite confluence bend on the right bank. Deposition was pronounced along the right bank of Wairaki River at Waiau confluence, as Wairaki River eroded its left bank migrating over 100 m to the south. Downstream of Wairaki confluence the left bank eroded while extensive deposition occurred along the right bank and in the within-channel zone. Dean Burn confluence moved 500 m to the east.
1963-1969	Waiau River adopted a more sinuous course, with infilling of a chute channel on the compound point bar at the reach head and extensive erosion of the concave bank at King-Allen property. Significant deposition occurred in the within-channel zone and on the right bank opposite Wairaki confluence. The mid-channel bar complex downstream of the bedrock constriction was largely eroded, as was the left bank immediately downstream of this bar complex.
1969-1974	Deposition was dominant, especially in the within-channel zone. Extensive deposition occurred adjacent to the left bank complex and the right bank compound point bar upstream of Wairaki confluence. Downstream of Wairaki confluence the secondary channel adjacent to the right bank was largely infilled and a compound bar formed adjacent to the left bank. Diagonal bars were deposited downstream of the bedrock constriction. Erosion was localised to King-Allen bend and to the left bank of the bank-attached bar opposite Wairaki confluence.
1974-1978	Negligible erosion occurred, while deposition was highly localised and was prominent adjacent to the right bank compound point bar at the head of the reach, at the northern side of Wairaki confluence, and infilling a channel adjacent to Dean Burn confluence.
1978-1980	Deposition dominated over erosion other than along the northern margin of Wairaki confluence and along the left bank margin of the large bar complex opposite Wairaki confluence. Waiau River effectively shifted over 130 m to the west in this interval. Substantial deposition occurred along the right bank compound point bar and left bank compound point bar immediately upstream of Wairaki confluence, partially infilled the secondary channel along the left bank downstream of Wairaki confluence, and as depositional units attached to mid-channel complexes immediately upstream and downstream of the bedrock constriction.
1980-1982	Negligible erosion occurred other than along the right bank of Wairaki River at Waiau confluence and along the left bank immediately upstream of the bedrock constriction. Significant deposition occurred around the compound point bar at the entrance to the reach and at the northern side of Wairaki confluence zone.
1982-1984	Virtually no deposition was evident during this interval, while erosion was prominent. Erosion was pronounced along the left bank compound bar and right bank compound point bar upstream of Wairaki confluence, along the northern margin of Wairaki River itself, as channel reactivation along the right bank and especially along the left bank downstream of Wairaki confluence, and along bar margins downstream of the bedrock constriction. No erosion was evident along King-Allen bend.
February-June 1984	Channel recovery after the January 1984 flood was rapid, with extensive deposition adjacent to the left bank compound bar upstream of Wairaki confluence, along the left bank downstream of Wairaki confluence and adjacent to the mid-channel bar complexes downstream of the bedrock constriction. Localised erosion was restricted to Wairaki and Dean Burn confluence zones.
1984-1989	Erosion commenced along the right concave bank at King-Allen bend for the first time since 1974. Erosion was also prominent as dissection of the right bank bar complex downstream of Wairaki confluence and at the head of the mid-channel complex downstream of the bedrock constriction. Deposition was especially prominent at the southern (right bank) margin of Wairaki River at Waiau confluence.
1989-1992	Channel adjustments were restricted to the subreach between Wairaki confluence and the bedrock constriction. Erosion was prominent on the right bank opposite Wairaki confluence and along the left bank mid-way between the confluence and bedrock constriction. Deposition occurred along the left bank immediately downstream of Wairaki confluence and along the right bank immediately upstream of Dean Burn confluence.

2.3 Lill Burn reach

Year	Channel adjustments
1947-1963	Although deposition dominated over erosion, pronounced spatial variability in erosion and deposition was evident. Upstream of Lill Burn erosion was dominant, especially adjacent to the left bank opposite Lill Burn confluence and in the within-channel zone. Erosion was also dominant along the right bank at Lill Burn confluence, although deposition was prominent in the within-channel zone. Deposition was dominant downstream of Lill Burn confluence, with substantial addition of land adjacent to the right bank both at the compound bar at the head of this subreach and on the right bank compound bar immediately upstream of the bedrock constriction. Deposition was also prominent on the mid-channel complex bar downstream of the bedrock constriction.
1963-1969	Erosion continued to dominate over deposition upstream of Lill Burn confluence, with extensive erosion of the left bank opposite Lill Burn confluence. Significant within-channel deposition occurred as the mid-channel complex upstream of Lill Burn expanded upstream. Deposition was dominant at Lill Burn confluence, as the southern half of the active channel zone was effectively abandoned. Downstream of Lill Burn confluence erosion was dominant, with extensive erosion of land at the head of diagonally-aligned bar complexes. Substantial deposition occurred at the margins of the left bank compound bar opposite Lill Burn confluence and adjacent to the right bank mid-way between Lill Burn confluence and the bedrock constriction.
1969-1974	Erosion rate was greatly diminished in this interval, while deposition was extensive. Localised erosion continued, however, along the left bank opposite and downstream of Lill Burn confluence. Upstream of Lill Burn a major mid-channel bar became attached to the left bank, significant deposition occurred at Lill Burn confluence, the left bank compound bar opposite Lill Burn confluence expanded considerably and became effectively bank-attached, the right bank compound bar upstream of the bedrock constriction expanded laterally (constricting the main channel of Waiau River) and the mid-channel bar assemblage downstream of the bedrock constriction effectively formed a left bank compound point bar.
1974-1977	Negligible erosion was evident, and was largely restricted to the left bank opposite Lill Burn confluence. Rate of deposition was notably lower than in previous periods and was restricted to lateral expansion of a mid-channel bar at the head of the reach, within-channel deposition at Lill Burn confluence, and infilling of secondary channels on the left bank bar complex opposite Lill Burn confluence.
1977-1980	Negligible changes were evident, although erosion continued along the left bank opposite Lill Burn confluence and along the right bank of Lill Burn itself 500 m upstream of Waiau confluence. Rate of erosion exceeded deposition, which was restricted to a series of small units spread through the reach.
1980-1982	Virtually no erosion was evident, but extensive deposition occurred. Deposition was prominent along the northern side of Lill Burn confluence, at the downstream end of the right bank bar complex opposite Lill Burn, and infilling the secondary channel adjacent to the right bank immediately upstream of the bedrock constriction.
1982-1984	Extensive erosion occurred throughout the reach, especially adjacent to the main river banks. The chute channel on the left bank compound bar upstream of Lill Burn was reactivated, as was the secondary channel adjacent to the left bank opposite Lill Burn. The bar margin adjacent to the main channel also experienced significant erosion, as the channel shifted to the west. The compound point bar downstream of the bedrock constriction was extensively eroded.
February-June 1984	Channel recovery following the January 1984 flood was rapid throughout Lill Burn reach, as significant deposition occurred in each subreach. The left bank compound bar became bank-attached once more and dissection channels on the left bank bar complex opposite Lill Burn were largely abandoned. Land lost on the compound point bar downstream of the bedrock constriction was replaced.
1984-1989	Channel alignment was modified significantly, with erosion dominant. Lill Burn cut a new course to the south, with major erosion of the right bank point bar immediately downstream of Lill Burn confluence. Significant deposition occurred along the northern margin of the confluence. Flow realignment downstream of Lill Burn confluence resulted in extensive erosion along the tail of the left bank compound bar opposite the confluence. The left bank itself eroded during this interval, as the bend immediately upstream of the bedrock constriction effectively straightened. The compound point bar downstream of the bedrock constriction was largely dissected.
1989-1992	Erosion was highly localised and restricted primarily to the right bank downstream of Lill Burn confluence. Rate of deposition was significantly greater than that of erosion. The northern channel at Lill Burn confluence was largely infilled, and substantial within-channel deposition occurred downstream of Lill Burn confluence.

2.4 Downstream o'Clifden reach

Year	Channel adjustments
1947-1963	Sinuosity increased markedly, and extensive bank erosion occurred along the right concave bank as the major bend enlarged. There was associated deposition in the within-channel zone and on the compound point bar immediately downstream of the eroding bank.
1963-1969	Extensive erosion occurred along the right bank as the bend enlarged. Deposition was much less significant than in the previous interval, and was restricted to a series of small depositional units laid down adjacent to the bar complex.
1969-1974	Erosion was less extensive than in previous intervals, as deposition dominated. Numerous units were added to the bar complex as it expanded laterally, and the compound point bar downstream of the eroding bank experienced significant deposition at its head.
1974-1977	Erosion was negligible, while deposition was restricted to infilling of secondary channels on the bar complex and adjacent to the left bank.
1977-1978	Rates of adjustment were slow, but erosion dominated over deposition as bar margins were trimmed.
1977-1980	Erosion of the right concave bank recommenced, with three narrow strips of land removed. Deposition greatly exceeded erosion, however, as a secondary channel adjacent to the left bank at the reach entrance infilled, secondary channels on the major bar complex infilled and the compound point bar expanded laterally.
1980-1982	Erosion along the right concave bank was restricted to the upstream part of the bend, as sinuosity increased. The primary depositional zone was within the secondary channel adjacent to the left bank.
1982-1984	The January 1984 flood event induced significant erosion along the right concave bank. Extensive erosion also occurred along the margins of the bar complex, as a number of dissection channels were reactivated.
February-June 1984	No erosion was evident during this period, but extensive within-channel deposition did not occur. Rather, deposition was largely restricted to a long strip around the bend of the compound point bar.
1984-1989	Erosion was absolutely dominant during this period, with negligible deposition evident. Rate of erosion in the right concave bank was highest in the period of record, as the downstream end of the bend expanded significantly. Substantial trimming of bar margins occurred in the major bar complex, as the morphology of this bar became much simpler.
1989-1992	Narrow trimming of the right concave bank continued, but this period was characterised primarily by deposition of numerous small units.

2.5 Tuatapere reach

Year	Channel adjustments
1946-1963	Extensive rates of channel adjustments were evident, especially in the within-channel zone where deposition exceeded erosion. Along both banks, however, erosion exceeded deposition, reflecting the shifting nature of the main channel in this reach. Erosion was especially severe along the right bank at Carr's property, along the left bank in Carr's to mid-break subreach, and along the right bank at the river mouth. In the within-channel zone erosion was prominent in Upstream of Carr's and Mid-break to bend break subreach. Waiau River shifted over 100 m to the right in Upstream of Carr's reach and over 150 m to the left in Mid-break to bend break subreach. However, rates of deposition exceeded erosion in these subreaches, as bars left behind as the main channel shifted amalgamated.
1963-1969	Erosion continued to dominate over deposition along the banks, but overall areas of adjustment of erosion and deposition were similar. Erosion was localised, and was especially prominent at the head and tail of the mid-channel complex in Upstream of Carr's subreach, along the left bank in Carr's to mid-brace subreach and along the right bank at the river mouth. Although deposition was dominant in the within-channel zone, individual depositional units were small. Three substantial bars formed in the new channel position in Carr's to mid-break subreach, left bank compound bars in Mid-break to bend break subreach expanded laterally, and various mid-channel bars at the river mouth amalgamated.
1969-1974	Rates of erosion and deposition along banks diminished greatly in this period, but extensive deposition occurred in the within-channel zone. Erosion was focussed at the downstream end of Carr's to mid-break subreach, where a concave bank had developed and flow alignment had been modified. This resulted in local erosion of the right bank at the head of Mid-break to bend break subreach. Erosion also continued along the right bank at the river mouth. Deposition was extensive throughout the reach, but was especially prominent in Mid-break to bend break subreach. In Upstream of Carr's, Carr's to mid-break and Mid-break to bend break subreaches deposition generally took the form of lateral expansion units adjacent to compound point bars, as the main channel of Waiau River became better defined and adopted a more sinuous outline. Within-channel deposition at the river mouth amalgamated a series of smaller bars.
1974-1975	Negligible changes were evident, with no erosion recorded and deposition restricted to the left bank bar complex upstream of the river mouth.
1975-1977	Numerous small deposition units were spread throughout Tuatapere reach, but overall rate of deposition was low. Erosion was essentially restricted to the incipient right bank concave bank at the head of Mid-break to bend break subreach, reflecting flow realignment following deposition of the left bank compound point bar between 1969-1974.
1977-1978	Erosion and deposition were highly localised in this interval, but deposition was generally dominant. Bank erosion was restricted to the left concave bank at the downstream end of Carr's to mid-break subreach and the right concave bank at the head of Downstream of bend break subreach. Reworking of mid-channel forms took place at the downstream end of Mid-break to bend break subreach and the upstream end of Downstream of bend break subreach. Deposition was generally restricted to the within-channel zone. Numerous small units were deposited at the head of the mid-channel complex in Upstream of Carr's subreach. Downstream of this point, most within-channel deposition occurred as infilling and/or abandonment of secondary channels.
1977-1980	Erosion was restricted to trimming of the left bank at the downstream end of Carr's to mid-break subreach and along the right bank at the river mouth. Deposition was absolutely dominant over erosion. Numerous small depositional units were laid down at the margins of bar complexes in Upstream of Carr's and Carr's to mid break subreaches. Deposition was much more substantive in Mid-break to bend break and Downstream of bend break subreaches. Three mid-channel bars were accreted to the right bank in Mid-break to bend break subreach, whereas a large mid-channel bar became attached to the left bank at the head of Downstream of bend break subreach.
1980-1982	Deposition continued to dominate over erosion, especially in the within-channel zone. Erosion was primarily restricted to the left concave bank at the downstream end of Carr's to mid-break subreach, but notable trimming of mid-channel bars occurred downstream of this point. Deposition generally took the form of a series of small accretional units, although a series of smaller forms amalgamated opposite the concave bank at the downstream end of Carr's to mid-break subreach and numerous bar forms were deposited at the river mouth.

2.5 Tuatapere reach continued

1982-1984	Although extensive erosion occurred in this interval, associated with the January 1984 flood, erosion was generally restricted to the within-channel zone where numerous secondary channels were reactivated. Erosion was especially prevalent downstream of Upstream of Carr's subreach. Extensive trimming occurred in Carr's to mid-break subreach, while the main channel shifted over 80 m to the south in Mid-break to bend break subreach, with extensive erosion along the right bank. The narrow channel zone at the transition between Mid-break to bend break and Downstream of bend break subreaches experienced significant erosion during the January 1984 flood. The head of the compound point bar was eroded, as was the opposite concave bank. The left bank secondary channel at the head of Downstream of bend break subreach was reactivated, while the margins at the head this bar eroded adjacent to the main channel. The tail end of the bar complex at the river mouth also eroded severely.
1984-1985	Erosion continued to dominate during this interval, but the spatial distribution differed notably from that evident between 1982-1984. Flood channels in the large bar complex upstream of Carr's were reactivated, and significant erosional reworking of within-channel bars occurred in Carr's to mid-break subreach. Negligible changes were evident in Mid-break to bend break subreach, but erosion continued at the head of Downstream of bend break subreach. The lower half of this subreach was primarily depositional adjacent to the left bank bar complex, while a series of small bar forms in the middle of the main channel eroded.
1985-1989	Extensive erosion occurred throughout Tuatapere reach in this interval. The left bank channel adjacent to the large bar complex in Upstream of Carr's subreach enlarged substantially, as a greater proportion of flow was oriented down this channel. Significant erosion occurred at the head of this bar complex, while a diagonally-oriented flood channel reworked the bar complex adjacent to the right bank upstream of this bar complex. Realignment of flow in Upstream of Carr's subreach resulted in deposition adjacent to the right bank at the head of Carr's to mid-break subreach. Significant erosion occurred along the left bank and in the within-channel zone in the remainder of Carr's to mid-break subreach, as the channel effectively straightened. This shift in channel alignment induced a series of changes in Mid-break to bend break subreach. The sequence of bends expanded, as channel sinuosity increased. Up to 80 m of erosion occurred along the right concave bank at the head of Mid-break to bend break subreach, while the left bank downstream of this point eroded by over 50 m. The head of the compound point bar at the downstream end of this subreach eroded by almost 80 m. Downstream translation of bends effectively destroys the next compound point bar in sequence. Increase in the definition of the main channel, along with its altered alignment as sinuosity increased, resulted in erosion of the right concave bank at the head of Downstream of bend break subreach. A compound point bar started to form along the right bank downstream of this section, as the opposite left bank experienced significant erosion with almost 100m of bank retreat. Associated with the development of this sequence of bends, erosion was renewed along the right bank at the river mouth. Conversely, the bar complex adjacent to the left bank at the river mouth amalgamated into a much larger and simpler form than had previously been observed at this point.
1989-1992	Deposition dominated over erosion in this interval, especially in the within-channel zone in Carr's to mid-break and Mid-break to bend break subreaches. Localised erosion continued in Upstream of Carr's subreach, especially along the left bank channel. Trimming continued along the right bank in Carr's to mid-break subreach. This contrasts starkly with the pattern of erosion at the beginning of the period of photographic record. Substantial deposition occurred as within-channel bar forms adjacent to the left bank (ie. in the area of channel eroded during the period of record). Deposition in Mid-break to bend break subreach occurred as a mid-channel bar complex at the entrance to this subreach and as extension of the left bank compound point bar at the downstream end of this subreach.

Appendix 3 Hydrology data (i): Day counts for 50 m^3s^{-1} intervals using Tuatapere data for each photographic interval

3.1 Lower Redcliff reach

	15.02.57 to 12.02.69		12.02.69 to 12.08.82		12.08.82 to 04.04.89		04.04.89 to 14.04.92	
	1993 days	Cum %	4926 days	Cum %	2425 days	Cum %		Cum %
Discharge in cumecs								
500	170	46.91	121	11.04	31	7.42	7	2.28
550	147	38.38	126	8.59	26	6.14	5	1.62
600	128	31.01	91	6.03	22	5.07	5	1.14
650	106	24.59	56	4.18	12	4.16	1	0.67
700	85	19.27	44	3.05	9	3.67	1	0.57
750	68	15.00	17	2.15	11	3.30	1	0.48
800	61	11.59	17	1.81	10	2.85	0	0.38
850	30	8.53	11	1.46	7	2.43	0	0.38
900	29	7.02	13	1.24	5	2.14	0	0.38
950	27	5.57	8	0.97	10	1.94	1	0.38
1000	27	4.21	10	0.81	8	1.53	0	0.29
1050	9	2.86	9	0.61	4	1.20	1	0.29
1100	16	2.41	6	0.43	2	1.03	0	0.19
1150	9	1.61	7	0.30	1	0.95	1	0.19
1200	9	1.15	2	0.16	4	0.91	1	0.10
1250	9	0.70	4	0.12	5	0.74		
1300	2	0.25	0	0.04	4	0.54		
1350	0	0.15	2	0.04	3	0.37		
1400	0	0.15			2	0.25		
1450	2	0.15			2	0.16		
1500	0	0.05			0	0.08		
1550	0	0.05			1	0.08		
1600	0	0.05			0	0.04		
1650	0	0.05			0	0.04		
1700	1	0.05			0	0.04		
1750					0	0.04		
1800					0	0.04		
1850					0	0.04		
1900					0	0.04		
1950					0	0.04		
2000					0	0.04		
2050					0	0.04		
2100					0	0.04		
2150					1	0.04		
2200								

3.2 Wairaki reach

	10.03.63-12.02.69		12.02.69 to 31.05.74		31.05.74 to 11.02.78		11.02.78 to 14.04.80		14.04.80 to 12.08.82		12.08.82 to 07.02.84	
Discharge in cumecs	1993 days	Cum %	1933 days	Cum %	1352 days	Cum %	791 days	Cum %	850 days	Cum %	544 days	Cum %
500	170	46.91	75	19.40	10	3.70	14	6.70	22	7.77	12	11.95
550	147	38.38	84	15.52	8	2.96	18	4.93	16	5.18	3	9.74
600	128	31.01	54	11.17	12	2.37	9	2.66	16	3.29	4	9.19
650	106	24.59	42	8.38	4	1.48	4	1.52	6	1.41	4	8.46
700	85	19.27	35	6.21	3	1.18	4	1.01	2	0.71	4	7.72
750	68	15.00	13	4.40	3	0.96	0	0.51	1	0.47	7	6.99
800	61	11.59	15	3.72	2	0.74	0	0.51	0	0.35	7	5.70
850	30	8.53	7	2.95	1	0.59	2	0.51	1	0.35	4	4.41
900	29	7.02	10	2.59	3	0.52	0	0.25	0	0.24	3	3.68
950	27	5.57	5	2.07	1	0.30	1	0.25	1	0.24	6	3.13
1000	27	4.21	9	1.81	1	0.22	0	0.13	0	0.12	5	2.02
1050	9	2.86	8	1.35	1	0.15	0	0.13	0	0.12	2	1.10
1100	16	2.41	6	0.93	0	0.07	0	0.13	0	0.12	0	0.74
1150	9	1.61	6	0.62	1	0.07	0	0.13	0	0.12	0	0.74
1200	9	1.15	1	0.31			1	0.13	0	0.12	1	0.74
1250	9	0.70	4	0.26					0	0.12	1	0.55
1300	2	0.25	0	0.05					0	0.12	0	0.37
1350	0	0.15	1	0.05					1	0.12	0	0.37
1400	0	0.15									0	0.37
1450	2	0.15									0	0.37
1500	0	0.05									0	0.37
1550	0	0.05									1	0.37
1600	0	0.05									0	0.18
1650	0	0.05									0	0.18
1700	1	0.05									0	0.18
1750											0	0.18
1800											0	0.18
1850											0	0.18
1900											0	0.18
1950											0	0.18
2000											0	0.18
2050											0	0.18
2100											0	0.18
2150											1	0.18
2200												

3.2 Wairaki reach (continued)

	07.02.84 to 21.06.84		21.06.84 to 04.04.89		04.04.89 to 14.04.92	
	134 days	Cum %	1747 days	Cum %	1052 days	Cum %
Discharge in cumecs						
500	0	0	19	6.58	7	2.28
550	0	0	23	5.50	5	1.62
600	0	0	18	4.18	5	1.14
650	0	0	8	3.15	1	0.67
700			5	2.69	1	0.57
750			4	2.40	1	0.48
800			3	2.18	0	0.38
850			3	2.00	0	0.38
900			2	1.83	0	0.38
950			4	1.72	1	0.38
1000			3	1.49	0	0.29
1050			2	1.32	1	0.29
1100			2	1.20	0	0.19
1150			1	1.09	1	0.19
1200			3	1.03	1	0.10
1250			4	0.86		
1300			4	0.63		
1350			3	0.40		
1400			2	0.23		
1450			2	0.11		
1500						

3.3 Lill Burn reach

	10.03.63 to 12.02.69		12.02.69 to 31.05.74		31.05.74 to 25.02.77		25.02.77 to 11.02.78		11.02.78 to 14.04.80		14.04.80 to 12.08.82	
	1993 days	Cum %	1933 days	Cum %	1000 days	Cum %	340 days	Cum %	791 days	Cum %	850 days	Cum %
Discharge in cumecs												
500	170	46.91	75	19.40	8	4.00	2	2.94	14	6.70	22	7.77
550	147	38.38	84	15.52	6	3.20	2	2.35	18	4.93	16	5.18
600	128	31.01	54	11.17	9	2.60	3	1.76	9	2.66	16	3.29
650	106	24.59	42	8.38	3	1.70	1	0.88	4	1.52	6	1.41
700	85	19.27	35	6.21	2	1.40	1	0.59	4	1.01	2	0.71
750	68	15.00	13	4.40	3	1.20	0	0.29	0	0.51	1	0.47
800	61	11.59	15	3.72	2	0.90	0	0.29	0	0.51	0	0.35
850	30	8.53	7	2.95	1	0.70	0	0.29	2	0.51	1	0.35
900	29	7.02	10	2.59	2	0.60	1	0.29	0	0.25	0	0.24
950	27	5.57	5	2.07	1	0.40			1	0.25	1	0.24
1000	27	4.21	9	1.81	1	0.30			0	0.13	0	0.12
1050	9	2.86	8	1.35	1	0.20			0	0.13	0	0.12
1100	16	2.41	6	0.93	0	0.10			0	0.13	0	0.12
1150	9	1.61	6	0.62	1	0.10			0	0.13	0	0.12
1200	9	1.15	1	0.31					1	0.13	0	0.12
1250	9	0.70	4	0.26							0	0.12
1300	2	0.25	0	0.05							0	0.12
1350	0	0.15	1	0.05							1	0.12
1400	0	0.15										
1450	2	0.15										
1500	0	0.05										
1550	0	0.05										
1600	0	0.05										
1650	0	0.05										
1700	1	0.05										
1750												
1800												

3.3 Lill Burn reach (continued)

	12.08.82 to 07.02.84		07.02.84 to 21.06.84		21.06.84 to 04.04.89		04.04.89 to 14.04.92	
	544 days	Cum %	134 days	Cum %	1747 days	Cum %	1052 days	Cum %
Discharge in cumecs								
500	12	11.95	0	0	19	6.58	7	2.28
550	3	9.74	0	0	23	5.50	5	1.62
600	4	9.19	0	0	18	4.18	5	1.14
650	4	8.46	0	0	8	3.15	1	0.67
700	4	7.72			5	2.69	1	0.57
750	7	6.99			4	2.40	1	0.48
800	7	5.70			3	2.18	0	0.38
850	4	4.41			3	2.00	0	0.38
900	3	3.68			2	1.83	0	0.38
950	6	3.13			4	1.72	1	0.38
1000	5	2.02			3	1.49	0	0.29
1050	2	1.10			2	1.32	1	0.29
1100	0	0.74			2	1.20	0	0.19
1150	0	0.74			1	1.09	1	0.19
1200	1	0.74			3	1.03	1	0.10
1250	1	0.55			4	0.86	0	0
1300	0	0.37			4	0.63		
1350	0	0.37			3	0.40		
1400	0	0.37			2	0.23		
1450	0	0.37			2	0.11		
1500	0	0.37						
1550	1	0.37						
1600	0	0.18						
1650	0	0.18						
1700	0	0.18						
1750	0	0.18						
1800	0	0.18						
1850	0	0.18						
1900	0	0.18						
1950	0	0.18						
2000	0	0.18						
2050	0	0.18						
2100	0	0.18						
2150	1	0.18						
2200								

3.4 Downstream o'Clifden reach

	10.03.63 to 12.02.69		12.02.69 to 31.05.74		31.05.74 to 11.02.78		11.02.78 to 14.04.80		14.04.80 to 12.08.82		12.08.82 to 07.02.84	
	1993 days	Cum %	1933 days	Cum %	1352 days	Cum %	791 days	Cum %	850 days	Cum %	544 days	Cum %
Discharge in cumecs												
500	170	46.91	75	19.40	10	3.70	14	6.70	22	7.76	12	11.95
550	147	38.38	84	15.52	8	2.96	18	4.93	16	5.18	3	9.74
600	128	31.01	54	11.17	12	2.37	9	2.65	16	3.29	4	9.19
650	106	24.59	42	8.38	4	1.48	4	1.52	6	1.41	4	8.46
700	85	19.27	35	6.21	3	1.18	4	1.01	2	0.71	4	7.72
750	68	15.00	13	4.40	3	0.96	0	0.51	1	0.47	7	6.99
800	61	11.59	15	3.72	2	0.74	0	0.51	0	0.35	7	5.70
850	30	8.53	7	2.95	1	0.59	2	0.51	1	0.35	4	4.41
900	29	7.02	10	2.59	3	0.52	0	0.25	0	0.24	3	3.68
950	27	5.57	5	2.07	1	0.30	1	0.25	1	0.24	6	3.13
1000	27	4.21	9	1.81	1	0.22	0	0.13	0	0.12	5	2.02
1050	9	2.86	8	1.35	1	0.15	0	0.13	0	0.12	2	1.10
1100	16	2.41	6	0.93	0	0.07	0	0.13	0	0.12	0	0.74
1150	9	1.61	6	0.62	1	0.07	0	0.13	0	0.12	0	0.74
1200	9	1.15	1	0.31			1	0.13	0	0.12	1	0.74
1250	9	0.70	4	0.26					0	0.12	1	0.55
1300	2	0.25	0	0.05					0	0.12	0	0.37
1350	0	0.15	1	0.05					1	0.12	0	0.37
1400	0	0.15									0	0.37
1450	2	0.15									0	0.37
1500	0	0.05									0	0.37
1550	0	0.05									1	0.37
1600	0	0.05									0	0.18
1650	0	0.05									0	0.18
1700	1	0.05									0	0.18
1750											0	0.18
1800											0	0.18
1850											0	0.18
1900											0	0.18
1950											0	0.18
2000											0	0.18
2050											0	0.18
2100											0	0.18
2150											1	0.18
2200												

3.4 Downstream o'Clifden reach continued

	07.02.84 to 21.06.84		21.06.84 to 04.04.89		04.04.89 to 14.04.92	
	134 days	Cum %	1747 days	Cum %	1052 days	Cum %
Discharge in cumecs						
500	0	0	19	6.58	7	2.28
550	0	0	23	5.50	5	1.62
600	0	0	18	4.18	5	1.14
650	0	0	8	3.15	1	0.67
700			5	2.69	1	0.57
750			4	2.40	1	0.48
800			3	2.18	0	0.38
850			3	2.00	0	0.38
900			2	1.83	0	0.38
950			4	1.72	1	0.38
1000			3	1.49	0	0.29
1050			2	1.32	1	0.29
1100			2	1.20	0	0.19
1150			1	1.09	1	0.19
1200			3	1.03	1	0.10
1250			4	0.86		
1300			4	0.63		
1350			3	0.40		
1400			2	0.23		
1450			2	0.11		
1500						

3.5 Tuatapere reach

	10.03.63 to 12.02.69		12.02.69 to 07.07.74		07.07.74 to 03.03.75		03.03.75 to 25.02.77		25.02.77 to 11.02.78		11.02.78 to 14.04.80	
	1993 days	Cum %	1980 days	Cum %	229 days	Cum %	724 days	Cum %	351 days	Cum %	791 days	Cum %
Discharge in cumecs												
500	170	46.91	75	18.94	0	0	10	6.35	0	1.14	14	6.70
550	147	38.38	84	15.15	0	0	8	4.97	0	1.14	18	4.93
600	128	31.01	54	10.91	0	0	10	3.87	2	1.14	9	2.65
650	106	24.59	42	8.18	0	0	4	2.49	0	0.57	4	1.52
700	85	19.27	35	6.06			2	1.93	1	0.57	4	1.01
750	68	15.00	13	4.29			3	1.66	0	0.29	0	0.51
800	61	11.59	15	3.64			2	1.24	0	0.29	0	0.51
850	30	8.53	7	2.88			1	0.97	0	0.29	2	0.51
900	29	7.02	10	2.53			2	0.83	1	0.29	0	0.25
950	27	5.57	5	2.02			1	0.55			1	0.25
1000	27	4.21	9	1.77			1	0.41			0	0.13
1050	9	2.86	8	1.31			1	0.28			0	0.13
1100	16	2.41	6	0.91			0	0.14			0	0.13
1150	9	1.61	6	0.61			1	0.14			0	0.13
1200	9	1.15	1	0.30							1	0.13
1250	9	0.70	4	0.25								
1300	2	0.25	0	0.05								
1350	0	0.15	1	0.05								
1400	0	0.15										
1450	2	0.15										
1500	0	0.05										
1550	0	0.05										
1600	0	0.05										
1650	0	0.05										
1700	1	0.05										
1750												
1800												

3.5 Tuatapere reach continued

	14.04.80 to 12.08.82		12.08.82 to 21.06.84		21.06.84 to 08.10.85		08.10.85 to 04.04.89		04.04.89 to 14.04.92	
	850 days	Cum %	678 days	Cum %	474 days	Cum %	1275 days	Cum %	1052 days	Cum %
Discharge in cumecs										
500	22	7.76	12	9.59	10	6.75	9	6.51	7	2.28
550	16	5.18	3	7.82	7	4.64	16	5.80	5	1.62
600	16	3.29	4	7.38	10	3.16	8	4.55	5	1.14
650	6	1.41	4	6.79	0	1.05	8	3.92	1	0.67
700	2	0.71	4	6.20	2	1.05	3	3.29	1	0.57
750	1	0.47	7	5.61	1	0.63	3	3.06	1	0.48
800	0	0.35	7	4.57	1	0.42	2	2.82	0	0.38
850	1	0.35	4	3.54	0	0.21	3	2.67	0	0.38
900	0	0.24	3	2.95	0	0.21	2	2.43	0	0.38
950	1	0.24	6	2.51	1	0.21	3	2.27	1	0.38
1000	0	0.12	5	1.62			3	2.04	0	0.29
1050	0	0.12	2	0.89			2	1.80	1	0.29
1100	0	0.12	0	0.59			2	1.65	0	0.19
1150	0	0.12	0	0.59			1	1.49	1	0.19
1200	0	0.12	1	0.59			3	1.41	1	0.10
1250	0	0.12	1	0.44			4	1.18		
1300	0	0.12	0	0.30			4	0.86		
1350	1	0.12	0	0.30			3	0.55		
1400			0	0.30			2	0.31		
1450			0	0.30			2	0.16		
1500			0	0.30						
1550			1	0.30						
1600			0	0.15						
1650			0	0.15						
1700			0	0.15						
1750			0	0.15						
1800			0	0.15						
1850			0	0.15						
1900			0	0.15						
1950			0	0.15						
2000			0	0.15						
2050			0	0.15						
2100			0	0.15						
2150			1	0.15						
2200										

Appendix 4 Hydrology data (ii): Summary hydrologic data for each photographic interval

4.1 Lower Redcliff reach

Cumulative tally of number of days above differing discharge levels for each photographic interval, Lower Redcliff reach

	15.02.57 to 12.02.69	12.02.69 to 12.08.82	12.08.82 to 04.04.89	04.04.89 to 14.04.92
Discharge in cumecs				
> 500	935	121	31	24
> 750	299	106	80	5
> 1000	84	40	37	3
> 1250	14	6	18	
> 1500	1		2	
> 1750			1	
> 2000			1	

Cumulative percentage of days above differing discharge intervals for each photographic interval, Lower Redcliff reach

	15.02.57 to 12.02.69	12.02.69 to 12.08.82	12.08.82 to 04.04.89	04.04.89 to 14.04.92
Discharge in cumecs				
> 500	46.91	11.04	7.42	2.28
> 750	15.00	2.15	3.30	0.48
> 1000	4.21	0.81	1.53	0.29
> 1250	0.70	0.12	0.74	
> 1500	0.05		0.08	
> 1750			0.04	
> 2000			0.04	

Between 1964-1969 discharge levels in excess of 500 m^3s^{-1} were maintained on 47 % of days. This proportion diminished markedly over the period of record, with discharge levels in excess of 500 m^3s^{-1} on only 11 % of days between 1969-1982, 7.5 % of days between 1982-1989 and < 2.5 % of days between 1989-1992. Proportion of days in which discharge levels greater than 1250 m^3s^{-1} were exceeded shows a different temporal distribution, as the highest proportion of days was recorded between 1982-1989 (0.74 %). Discharge events above 1250 m^3s^{-1} were recorded on 14 days between 1964-1969, 18 days between 1982-1989, just 6 days between 1969-1982 and 0 days between 1989-1992. Discharge levels above 1500 m^3s^{-1} were achieved on just one day between 1964-1969 and two days between 1982-1989.

4.2 Wairaki reach

Cumulative tally of number of days above differing discharge levels for each photographic interval, Wairaki reach

	10.03.63 to 12.02.69	12.02.69 to 31.05.74	31.05.74 to 11.02.78	11.02.78 to 14.04.80	14.04.80 to 12.08.82	12.08.82 to 07.02.84	07.02.84 to 21.06.84	21.06.84 to 04.04.89	04.04.89 to 14.04.92
Discharge in cumecs									
> 500	935	375	50	53	66	65	0	115	24
> 750	299	85	13	4	4	38		42	5
> 1000	84	35	3	1	1	11		26	3
> 1250	14	5			1	3		15	
> 1500	1					2			
> 1750						1			
> 2000									

Cumulative percentage of days above differing discharge intervals for each photographic interval, Wairaki reach

	10.03.63 to 12.02.69	12.02.69 to 31.05.74	31.05.74 to 11.02.78	11.02.78 to 14.04.80	14.04.80 to 12.08.82	12.08.82 to 07.02.84	07.02.84 to 21.06.84	21.06.84 to 04.04.89	04.04.89 to 14.04.92
Discharge in cumecs									
> 500	46.91	19.40	3.70	6.70	7.77	11.95	0.00	6.58	2.28
> 750	15.00	4.40	0.96	0.51	0.47	6.99		2.40	0.48
> 1000	4.21	1.81	0.22	0.13	0.12	2.02		1.49	0.29
> 1250	0.70	0.26			0.12	0.55		0.86	
> 1500	0.05					0.37			
> 1750						0.18			
> 2000						0.18			

Between 1964-1969 almost 47 % of days had discharge levels beyond 500 m^3s^{-1} at Tuatapere. These high discharge levels have never subsequently been maintained consistently. Indeed, the highest average discharge in a subsequent interval was recorded between 1969-1974, when 19 % of days had discharge levels beyond 500 m^3s^{-1}. Between 1982-1984 and 1980-1982 discharge levels beyond 500 m^3s^{-1} were recorded on 12 % and 8 % of days respectively, while such flow levels were achieved on 7 % of days between 1978-1980 and 1984-1989, but less than 5 % of days for all other intervals.

The pattern of discharge variability differs for flow levels beyond 750 m^3s^{-1} as there were relatively few days with such levels between 1969-1974, 1978-1980 and 1980-1982. Accordingly, while 1963-1969 was the period with the most days beyond 750 m^3s^{-1}, with 15 % of days, 1982-1984 experienced the second highest percentage of days with discharge beyond 750 m^3s^{-1}, with 7 % of days. 4.4 % of days between 1969-1974 had flow levels beyond 750 m^3s^{-1}, while 2.4 % of days between 1984-1989 experienced such levels. All remaining intervals experienced discharge events > 750 m^3s^{-1} on less than 1 % of days.

Discharge levels beyond 1000 m^3s^{-1} were experienced on 4.2 % of days between 1963-1969, 2 % of days between 1982-1984, 1.8 % of days between 1969-1974 and 1.5 % of days between 1984-1989. Such levels were attaned on less than 0.5 % of days in all other time intervals.

The pattern of discharge variability is quite different for events greater than 1250 m^3s^{-1}, as the interval with the greatest number of days beyond this flow level was 1984-1989 (0.9 %). This reflects 15 days of record. In contrast, 14 days between 1963-1969 experienced flow levels beyond 1250 m^3s^{-1}, ie. 0.7 % of total days in that interval. Between 1982-1984 three days had flow levels beyond 1250 m^3s^{-1}, ie. 0.55 % of total days in that interval, while 5 days exceeded 1250 m^3s^{-1} between 1969-1974 (0.3 % of total days in that interval). Less than 0.2 % of days exceeded 1250 m^3s^{-1} in remaining intervals.

Extreme discharge events beyond 1500 m^3s^{-1} were restricted to the periods 1982-1984 and 1963-1969, which experienced 2 and 1 day above this flow level (ie. 0.4 and 0.05 % of total days respectively).

4.3 Lill Burn reach

Cumulative tally of number of days above differing discharge levels for each photographic interval, Lill Burn reach

	10.03.63 to 12.02.69	12.02.69 to 31.05.74	31.05.74 to 25.02.77	25.02.77 to 14.04.80	14.04.80 to 12.08.82	12.08.82 to 07.02.84	07.02.84 to 21.06.84	21.06.84 to 04.04.89	04.04.89 to 14.04.92
Discharge in cumecs									
> 500	935	375	40	63	66	65	0	115	24
> 750	299	85	12	5	4	38		42	5
> 1000	84	35	3	1	1	11		26	3
> 1250	14	5			1	3		15	
> 1500	1					2			
> 1750						1			
> 2000						1			

Cumulative percentage of days above differing discharge intervals for each photographic interval, Lill Burn reach

	10.03.63 to 12.02.69	12.02.69 to 31.05.74	31.05.74 to 25.02.77	25.02.77 to 14.04.80	14.04.80 to 12.08.82	12.08.82 to 07.02.84	07.02.84 to 21.06.84	21.06.84 to 04.04.89	04.04.89 to 14.04.92
Discharge in cumecs									
> 500	46.91	19.40	4.00	5.57	7.77	11.95	0	6.58	2.28
> 750	15.00	4.40	1.20	0.44	0.47	6.99		2.40	0.48
> 1000	4.21	1.81	0.30	0.09	0.12	2.02		1.49	0.29
> 1250	0.70	0.26			0.12	0.55		0.86	
> 1500	0.05					0.37			
> 1750						0.18			
> 2000						0.18			

Between 1964-1969 almost 47 % of days had discharge levels beyond 500 m^3s^{-1} at Tuatapere. These high discharge levels have never subsequently been maintained consistently. Indeed, the highest average discharge in a subsequent interval was recorded between 1969-1974, when 19.5 % of days had discharge levels beyond 500 m^3s^{-1}. Between 1982-1984 discharge levels beyond 500 m^3s^{-1} were recorded on 12 % of days, there were 8 % of days between 1980-1982, 6 % of days between 1977-1980 and 1984-1989, but less than 5 % of days for all subsequent intervals.

The pattern of discharge variability differs for flow levels beyond 750 m^3s^{-1} as there were relatively few days with such levels between 1969-1974, 1977-1980 and 1980-1982. Accordingly, while 1963-1969 was the period with the most days beyond 750 m^3s^{-1}, with 15 % of days, 1982-1984 experienced the second highest percentage of days with discharge beyond 750 m^3s^{-1}, with 7 %. 4.4 % of days between 1969-1974 had flow levels beyond 750 m^3s^{-1}, while 2.4 % of days between 1984-1989 and 1.2 % of days between 1974-1977 experienced such levels. All remaining intervals experienced dishcarge events > 750 m^3s^{-1} on less than 0.5 % of days.

Discharge levels beyond 1000 m^3s^{-1} were experienced on 4.2 % of days between 1963-1969, 2 % of days between 1982-1984, 1.8 % of days between 1969-1974 and 1.5 % of days between 1984-1989. This represents 84, 11, 35 and 26 days respectively. Such levels were attaned on less than 0.3 % of days in all other time intervals.

The pattern of discharge variability is quite different for events greater than 1250 m^3s^{-1}, as the interval with the greatest number of days beyond this flow level was 1984-1989 (0.9 %). This reflects 15 days of record. In contrast, 14 days between 1963-1969 experienced flow levels beyond 1250 m^3s^{-1}, ie. 0.7 % of total days in that interval. Between 1982-1984 3 days had flow levels beyond 1250 m^3s^{-1}, ie. 0.55 % of total days in that interval, while 5 days exceeded 1250 m^3s^{-1} between 1969-1974 (0.3 % of total days in that interval). Less than 0.2 % of days exceeded 1250 m^3s^{-1} in remaining intervals.

Extreme discharge events beyond 1500 m^3s^{-1} were restricted to the periods 1982-1984 and 1963-1969, which experienced 2 days and 1 day above this flow level (ie. 0.4 and 0.05 % of total days respectively).

4.4 Downstream o'Clifden reach

Cumulative tally of number of days above differing discharge levels for each photographic interval, Downstream o'Clifden reach

Discharge in cumecs	10.03.63 to 12.02.69	12.02.69 to 31.05.74	31.05.74 to 11.02.78	11.02.78 to 14.04.80	14.04.80 to 12.08.82	12.08.82 to 07.02.84	07.02.84 to 21.06.84	21.06.84 to 04.04.89	04.04.89 to 14.04.92
> 500	935	375	50	53	66	65	0	115	24
> 750	299	85	13	4	4	38		42	5
> 1000	84	35	3	1	1	11		26	3
> 1250	14	5			1	3		15	
> 1500	1					2			
> 1750						1			
> 2000						1			

Cumulative percentage of days above differing discharge intervals for each photographic interval, Downstream o'Clifden reach

Discharge in cumecs	10.03.63 to 12.02.69	12.02.69 to 31.05.74	31.05.74 to 11.02.78	11.02.78 to 14.04.80	14.04.80 to 12.08.82	12.08.82 to 07.02.84	07.02.84 to 21.06.84	21.06.84 to 04.04.89	04.04.89 to 14.04.92
> 500	46.91	19.40	3.70	6.70	7.77	11.95	0	6.58	2.28
> 750	15.00	4.40	0.96	0.51	0.47	6.99		2.40	0.48
> 1000	4.21	1.81	0.22	0.13	0.12	2.02		1.49	0.29
> 1250	0.70	0.26			0.12	0.55		0.86	
> 1500	0.05					0.37			
> 1750						0.18			
> 2000						0.18			

Between 1964-1969 almost 47 % of days had discharge levels beyond 500 m^3s^{-1} at Tuatapere. These high discharge levels have never subsequently been maintained consistently. Indeed, the highest average discharge in a subsequent interval was recorded between 1969-1974, when 19 % of days had discharge levels beyond 500 m^3s^{-1}. Between 1982-1984 discharge levels beyond 500 m^3s^{-1} were recorded on 12 % of days, 8 % of days between 1980-1982 had discharge levels beyond 500 m^3s^{-1} and there were 7 % of days between 1978-1980 and 1984-1989, but less than 5 % of days for all other intervals.

The pattern of discharge variability differs for flow levels beyond 750 m^3s^{-1} as there were relatively few days with such levels between 1969-1974, 1978-1980 and 1980-1982. Accordingly, while 1963-1969 was the period with the most days beyond 750 m^3s^{-1}, with 15 % of days, 1982-1984 experienced the second highest percentage of days with discharge beyond 750 m^3s^{-1}, with 7 %. 4.4 % of days between 1969-1974 had flow levels beyond 750 m^3s^{-1}, while 2.4 % of days between 1984-1989 and 1 % of days between 1974-1978 experienced such levels. All remaining intervals experienced dishcarge events > 750 m^3s^{-1} on less than 0.5 % of days.

Discharge levels beyond 1000 m^3s^{-1} were experienced on 4.2 % of days between 1963-1969, 2 % of days between 1982-1984, 1.8 % of days between 1969-1974 and 1.5 % of days between 1984-1989. This represents 84, 11, 35 and 26 days respectively. Such levels were attaned on less than 0.3 % of days in all other time intervals.

The pattern of discharge variability is quite different for events greater than 1250 m^3s^{-1}, as the interval with the greatest number of days beyond this flow level was 1984-1989 (0.9 %). This reflects 15 days of record. In contrast, 14 days between 1963-1969 experienced flow levels beyond 1250 m^3s^{-1}, ie. 0.7 % of total days in that interval. Between 1982-1984 3 days had flow levels beyond 1250 m^3s^{-1}, ie. 0.55 % of total days in that interval, while 5 days exceeded 1250 m^3s^{-1} between 1969-1974 (0.3 % of total days in that interval). Only one further day in the period of record exceeded 1250 m^3s^{-1} , between 1980-1982 (ie. 0.1 % of total days in that interval).

Extreme discharge events beyond 1500 m^3s^{-1} were restricted to the periods 1982-1984 and 1963-1969, which experienced 2 and 1 day above this flow level (ie. 0.4 and 0.05 % of total days respectively).

4.5 Tuatapere reach

Cumulative tally of number of days above differing discharge levels for each photographic interval, Tuatapere reach

	10.03.63 to 12.02.69	12.02.69 to 07.07.74	07.07.74 to 03.03.75	03.03.75 to 25.02.77	25.02.77 to 11.02.78	11.02.78 to 14.04.80	14.04.80 to 12.08.82	12.08.82 to 21.06.84	21.06.84 to 08.10.85	08.10.85 to 04.04.89	04.04.89 to 14.04.92
Discharge in cumecs											
> 500	935	375	0	46	4	53	66	65	32	83	24
> 750	299	85		12	1	4	4	38	3	39	5
> 1000	84	35		3		1	1	11		26	3
> 1250	14	5					1	3		15	
> 1500	1							2			
> 1750								1			
> 2000								1			

Cumulative percentage of days above differing discharge intervals for each photographic interval, Tuatapere reach

	10.03.63 to 12.02.69	12.02.69 to 07.07.74	07.07.74 to 03.03.75	03.03.75 to 25.02.77	25.02.77 to 11.02.78	11.02.78 to 14.04.80	14.04.80 to 12.08.82	12.08.82 to 21.06.84	21.06.84 to 08.10.85	08.10.85 to 04.04.89	04.04.89 to 14.04.92
Discharge in cumecs											
> 500	46.91	18.94	0	6.35	1.14	6.70	7.77	9.59	6.75	6.51	2.28
> 750	15.00	4.29		1.66	0.29	0.51	0.47	5.61	0.63	3.06	0.48
> 1000	4.21	1.77		0.41		0.13	0.12	1.62		2.04	0.29
> 1250	0.70	0.25					0.12	0.44		1.18	
> 1500	0.05							0.30			
> 1750								0.15			
> 2000								0.15			

Between 1964-1969 almost 47 % of days had discharge levels beyond 500 m^3s^{-1} at Tuatapere. Such discharge levels were never maintained post-regulation. Indeed, the highest average discharge in a subsequent interval was recorded between 1969-1974, when 19 % of days had discharge levels beyond 500 m^3s^{-1}. Discharge levels beyond 500 m^3s^{-1} were recorded on about 10 % of days between 1982-1984, 8 % of days between 1980-1982 and between 6-7 % of days between 1975-1977, 1978-1980 and 1984-1985 and 1985-1989 and on less than 2.5 % of days in all other intervals.

The pattern of discharge variability differs for flow levels beyond 750 m^3s^{-1}. Such levels were attained on relatively few days between 1969-1974, 1978-1980 and 1980-1982. Accordingly, while 1963-1969 was the period with the most days beyond 750 m^3s^{-1}, with 15 % of days, 1982-1984 experienced the second highest percentage of days with discharge beyond 750 m^3s^{-1}, with 5.6 %. 4.3 % of days between 1969-1974 had flow levels beyond 750 m^3s^{-1}, while 3 % of days between 1985-1989, 1.7 % of days between 1975-1977 and 0.6 % of days between 1984-1985 experienced such levels. Although all remaining intervals experienced discharge events > 750 m^3s^{-1} on less than 0.5 % of days, there were 5 days between 1989-1992 on which flow levels exceeded 750 m^3s^{-1}.

Discharge levels beyond 1000 m^3s^{-1} were experienced on 4.2 % of days between 1963-1969, 2 % of days between 1985-1989, 1.8 % of days between 1969-1974 and 1.6 % of days between 1982-1984. This represents 84, 26, 35 and 11 days respectively. Levels beyond 1000 m^3s^{-1} were attained on 3 days between 1975-1977 (0.4 % of days), 3 days between 1989-1992 (0.3 % of days) and 1 day between 1978-1980 and 1980-1982 (0.13 % and 0.12 % of days respectively).

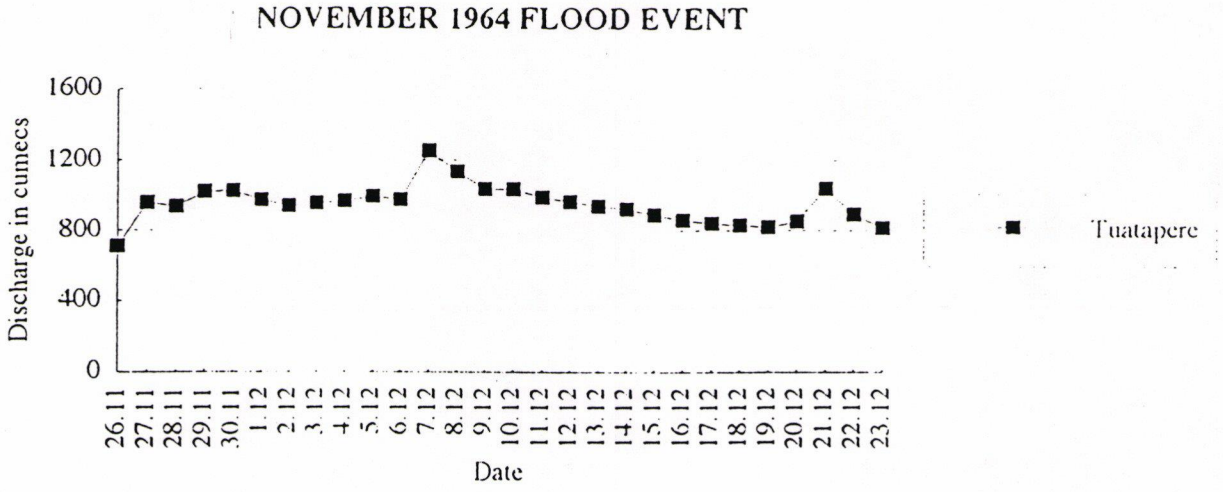
The pattern of discharge variability is quite different for events greater than 1250 m^3s^{-1}, as the interval with the greatest number of days beyond this flow level was 1985-1989 (1.2 %). This reflects 15 days of record. In contrast, 14 days between 1963-1969 experienced flow levels beyond 1250 m^3s^{-1}, ie. 0.7 % of total days in that interval. Between 1982-1984 3 days had flow levels beyond 1250 m^3s^{-1}, ie. 0.44 % of total days in that interval, while 5 days exceeded 1250 m^3s^{-1} between 1969-1974 (0.3 % of total days in that interval). Only one further day in the period of record exceeded 1250 m^3s^{-1}, between 1980-1982 (ie. 0.1 % of total days in that interval).

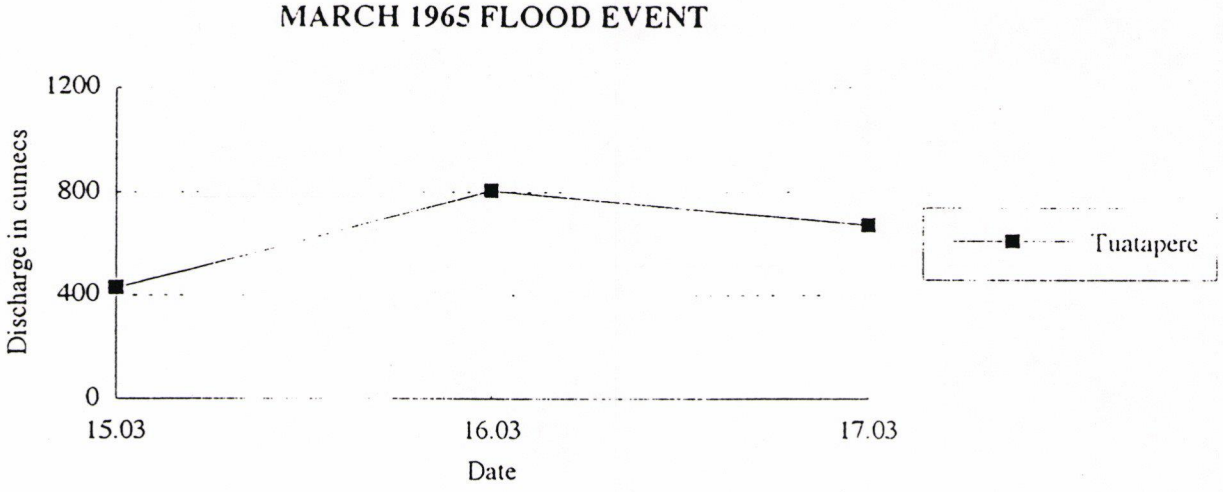
Extreme discharge events beyond 1500 m^3s^{-1} were restricted to the periods 1982-1984 and 1963-1969, which experienced 2 and 1 day above this flow level (ie. 0.3 and 0.05 % of total days respectively).

APPENDIX 5: DAILY DISCHARGE PLOTS OF INDIVIDUAL FLOOD EVENTS

Figure 7.1 Flood events between 1963-1969

Mean daily discharges for events > 800 m^3s^{-1} at Tuatapere





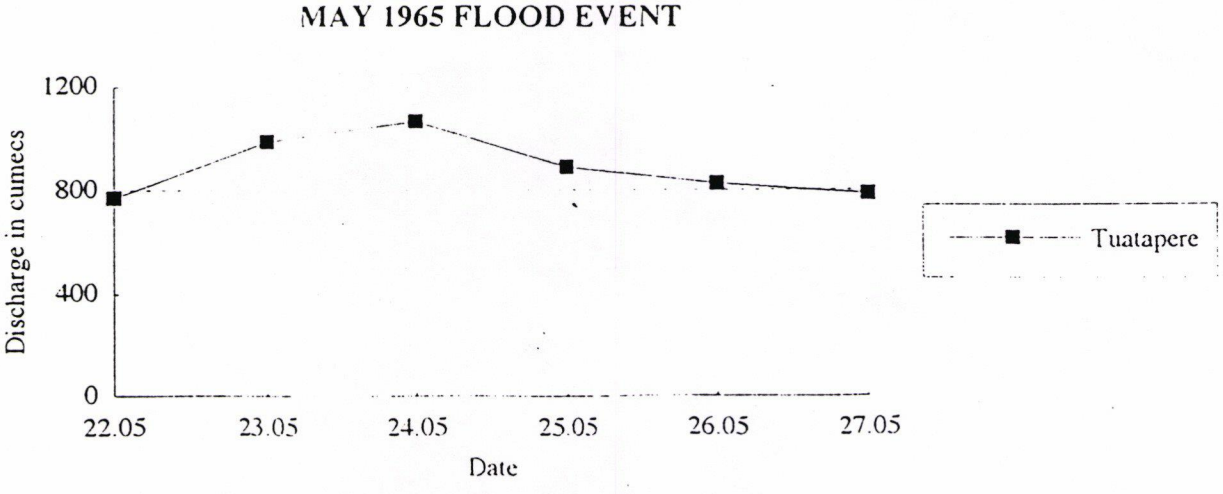


Figure 7.1 (Continued) Flood events between 1963-1969

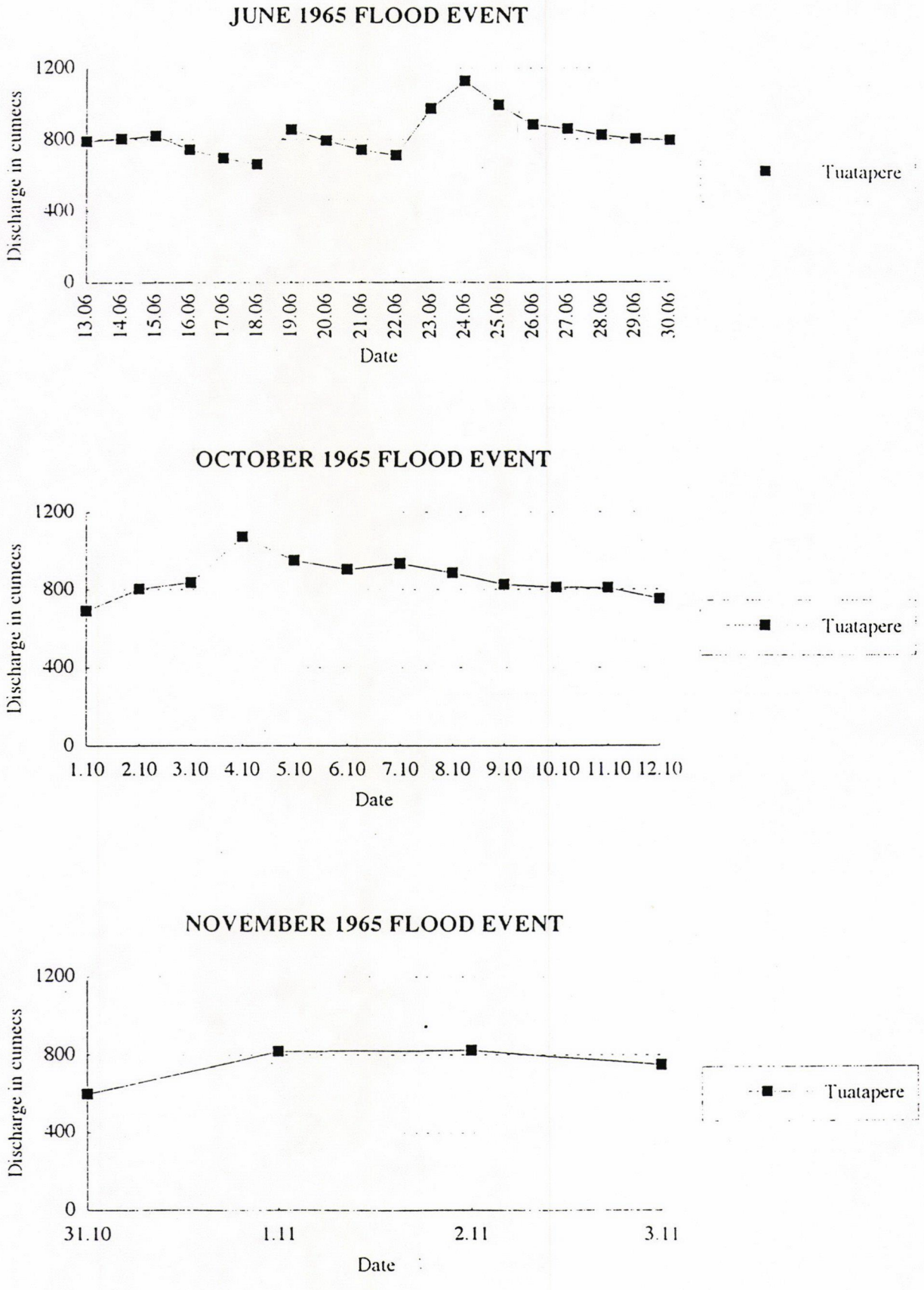
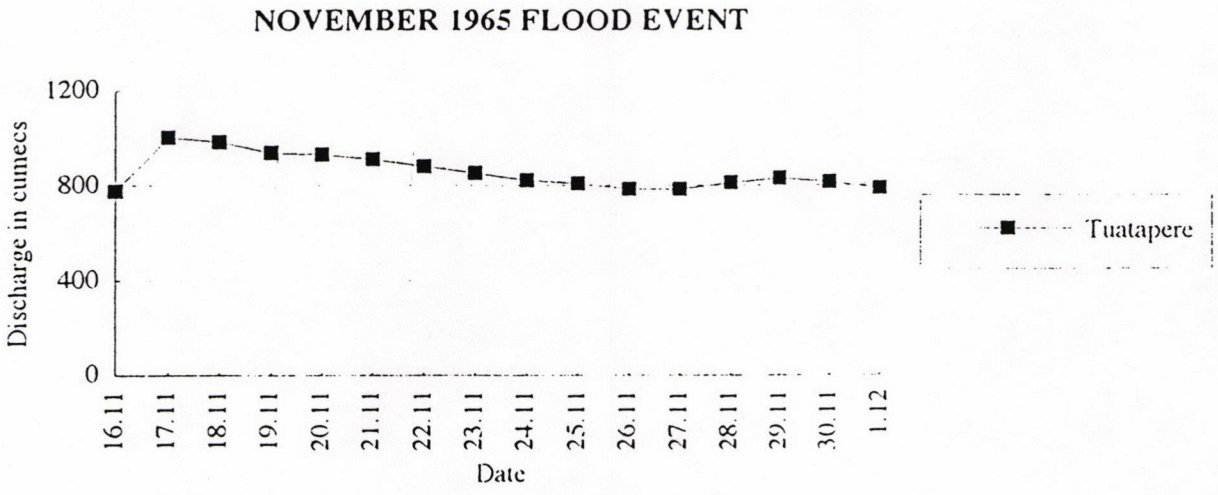
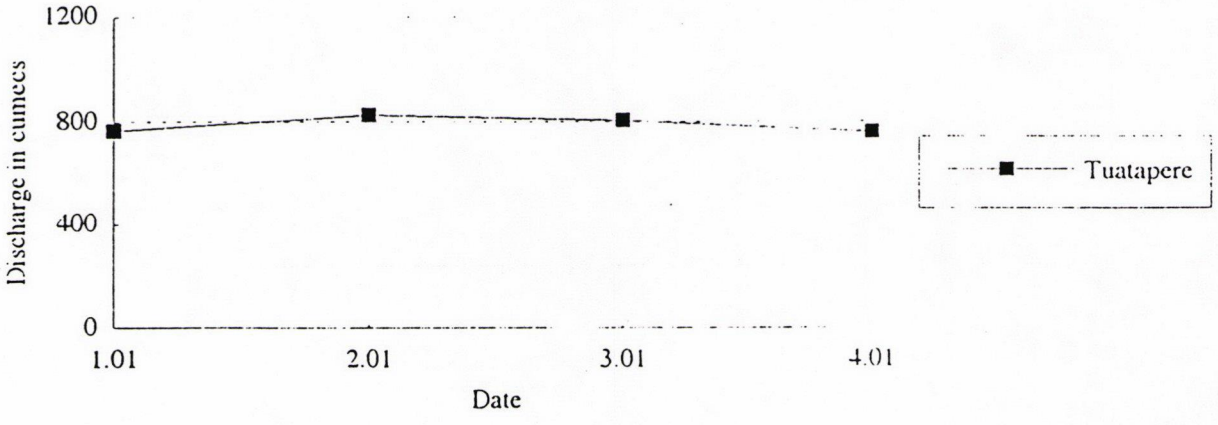


Figure 7.1 (Continued) Flood events between 1963-1969





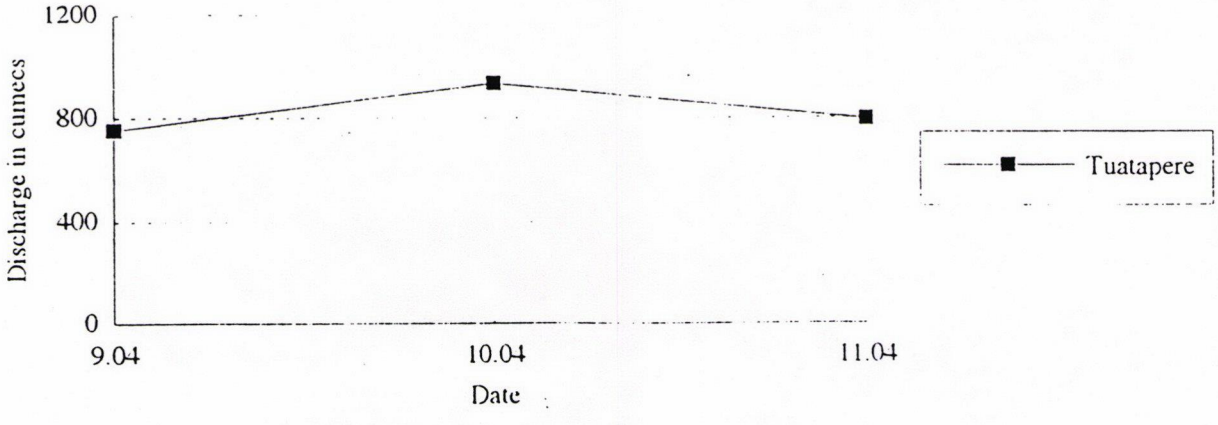


Figure 7.1 (Continued) Flood events between 1963-1969

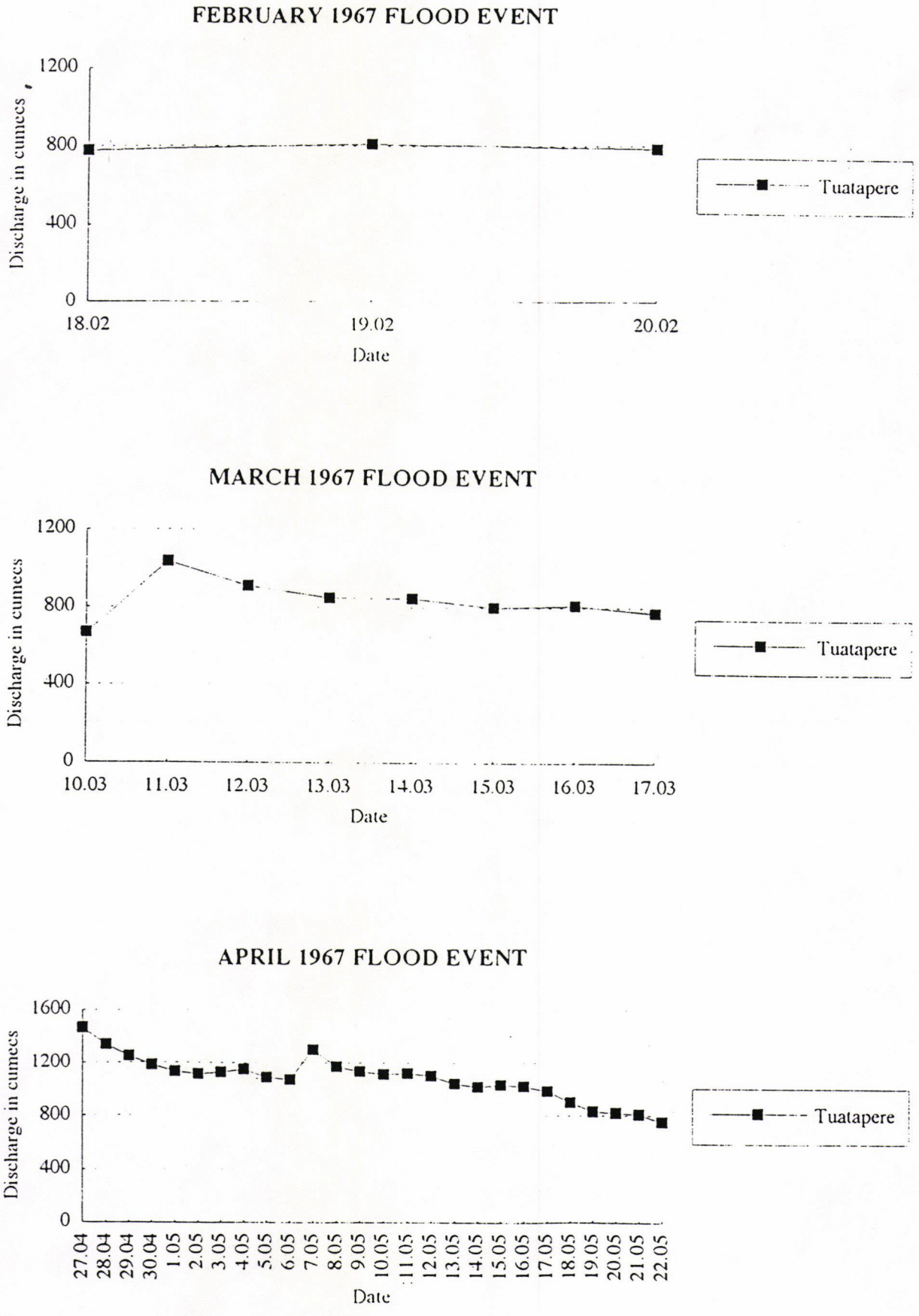


Figure 7.1 (Continued) Flood events between 1963-1969

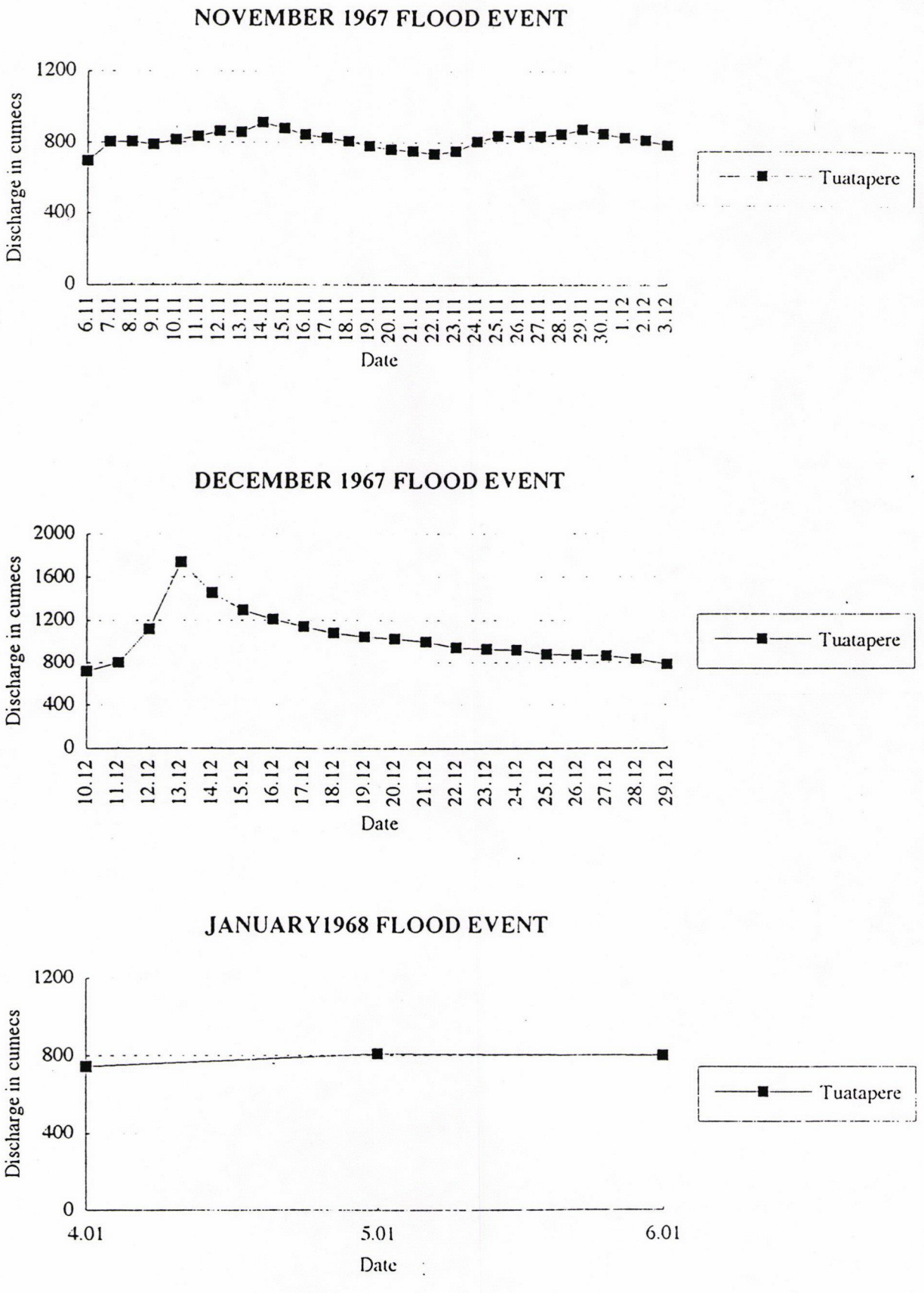
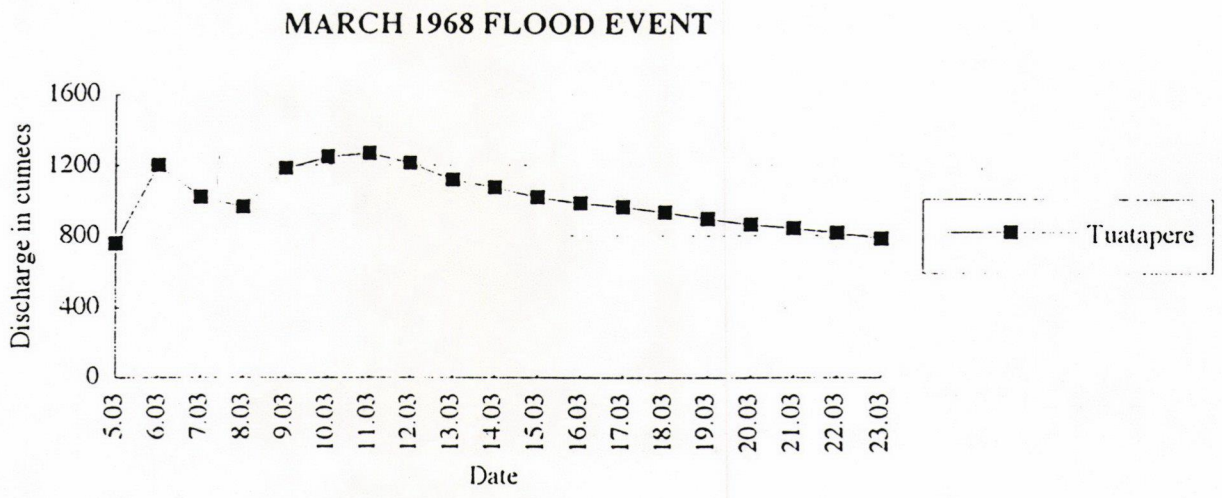
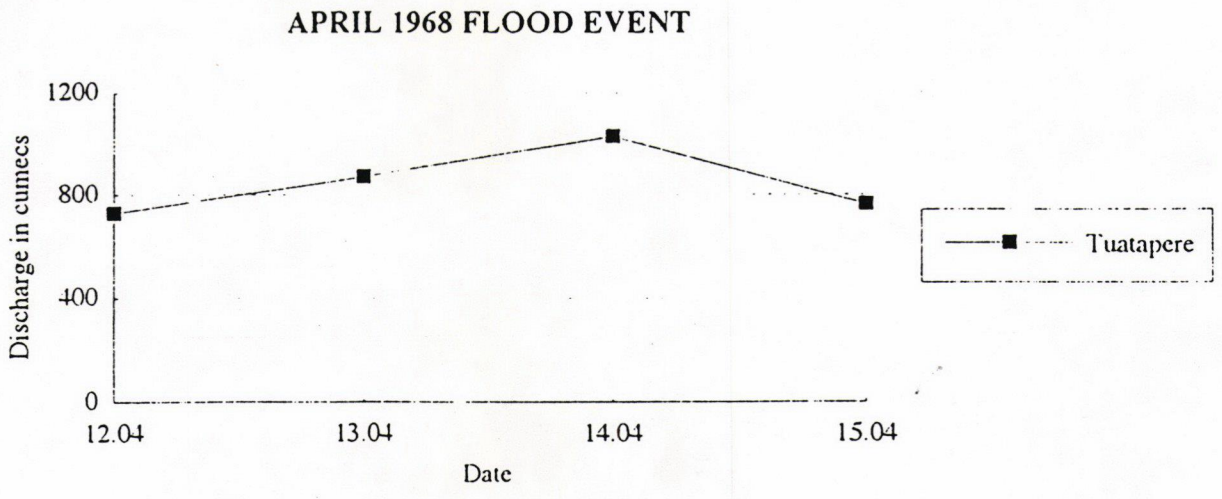


Figure 7.1 (Continued) Flood events between 1963-1969





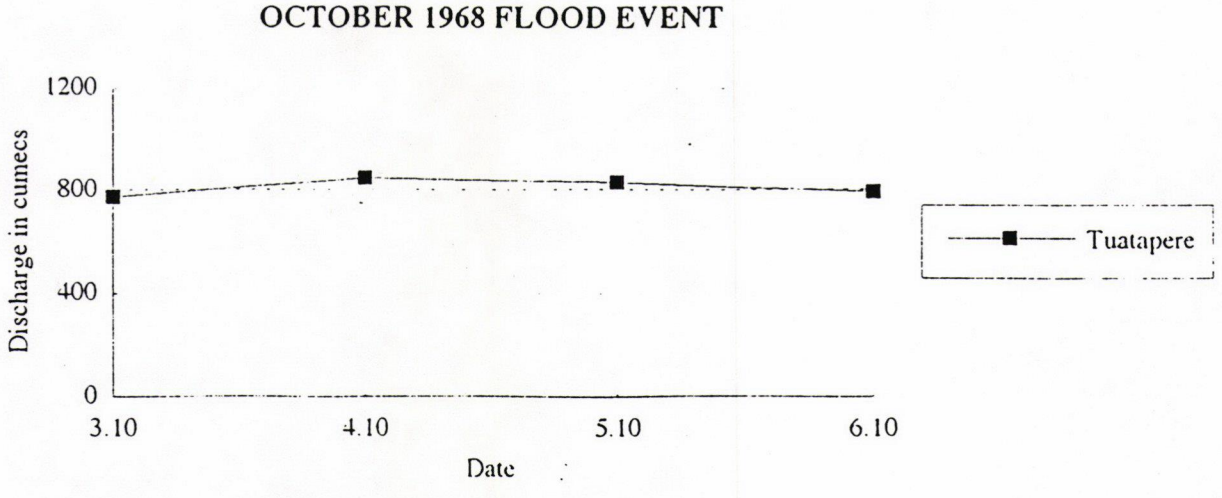


Figure 7.1 (Continued) Flood events between 1963-1969

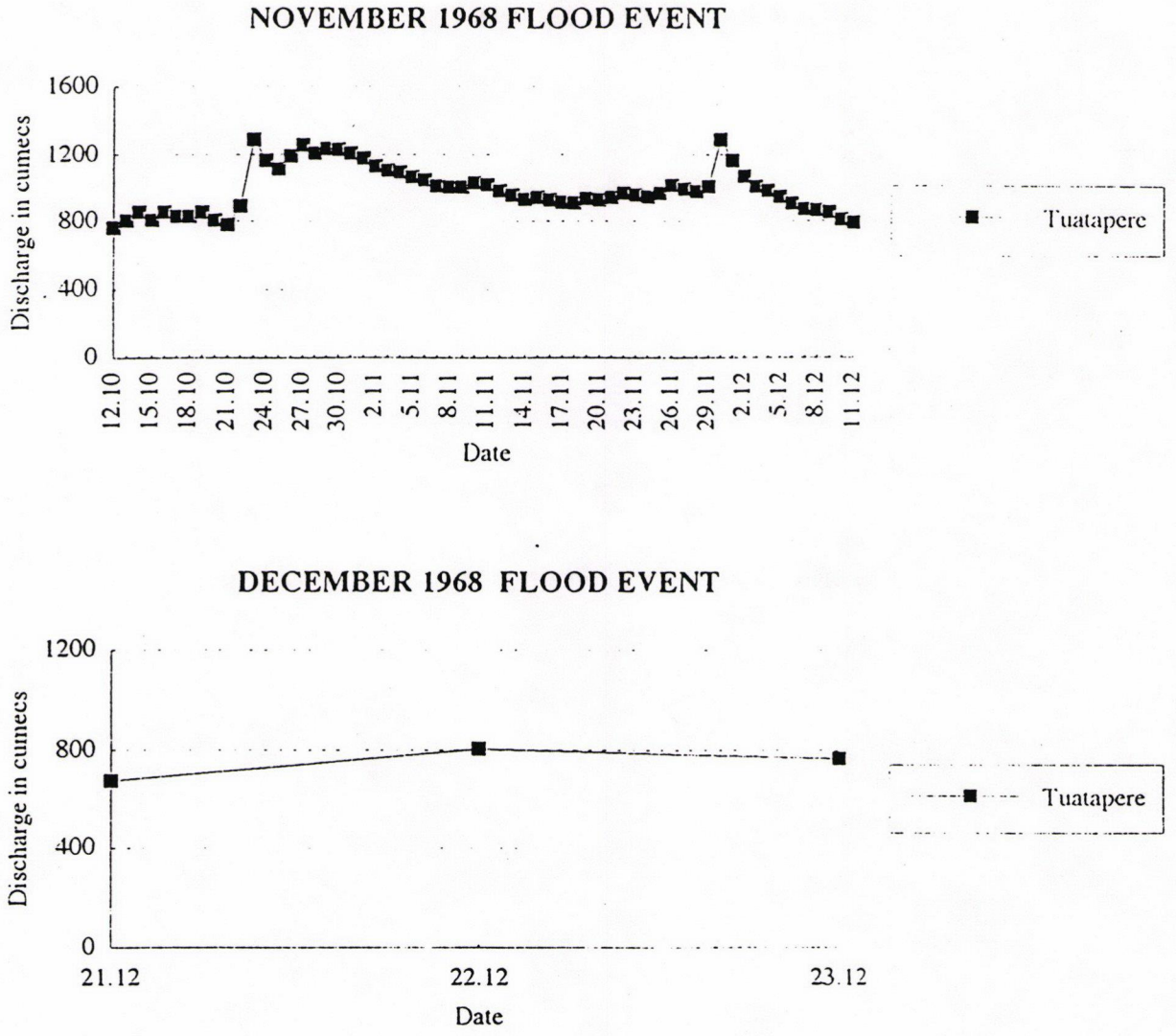
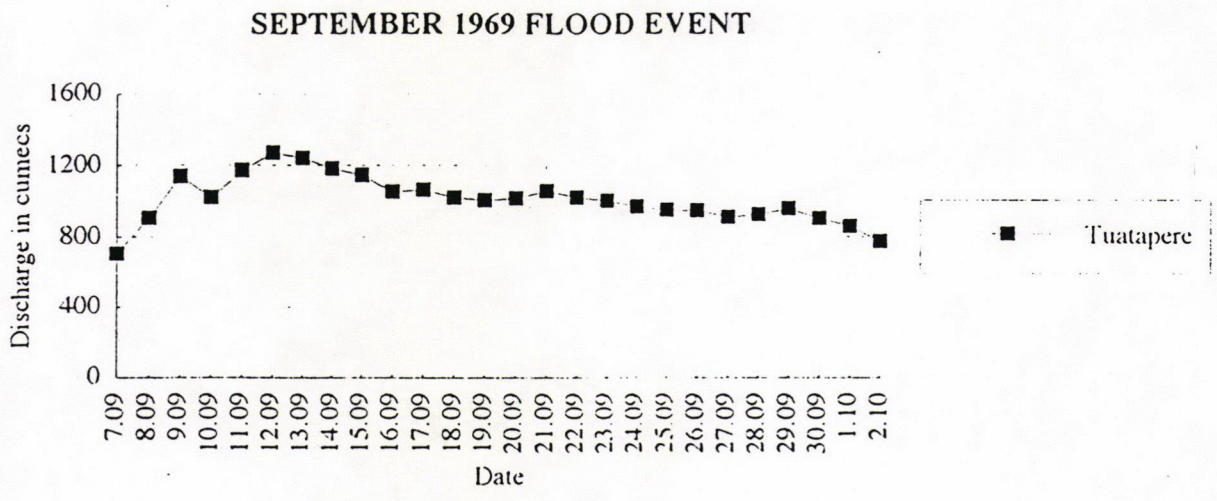
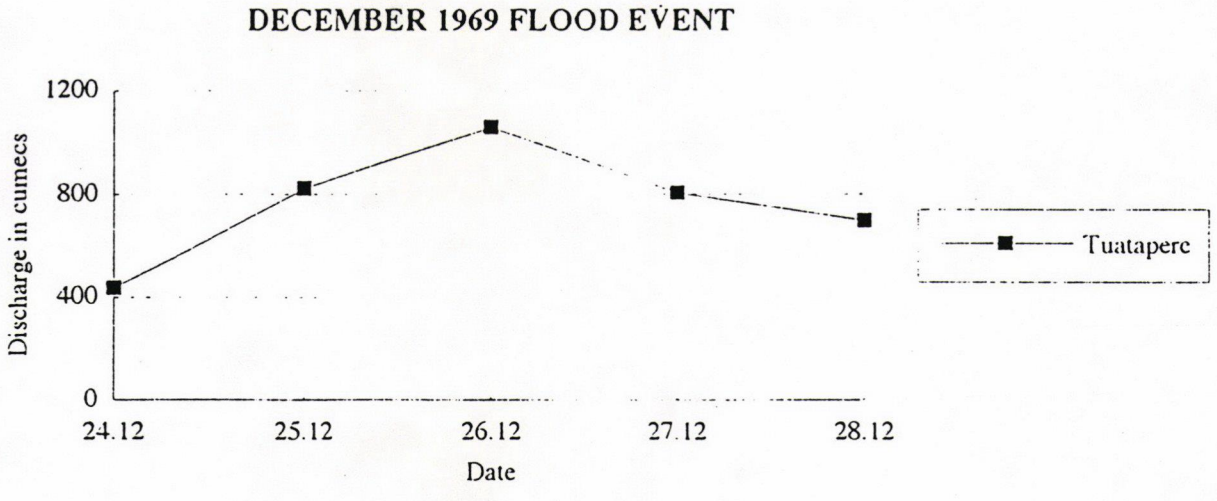


Figure 7.2 Flood events between February 1969 and May 1974

Mean daily discharges for events > 800 m^3s^{-1} at Tuatapere and/or >600 m^3s^{-1} at Sunnyside





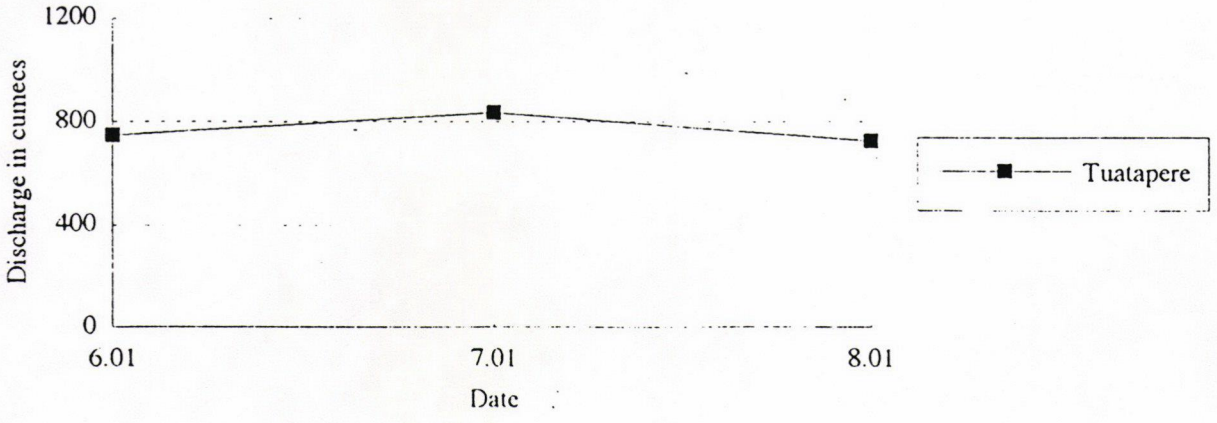
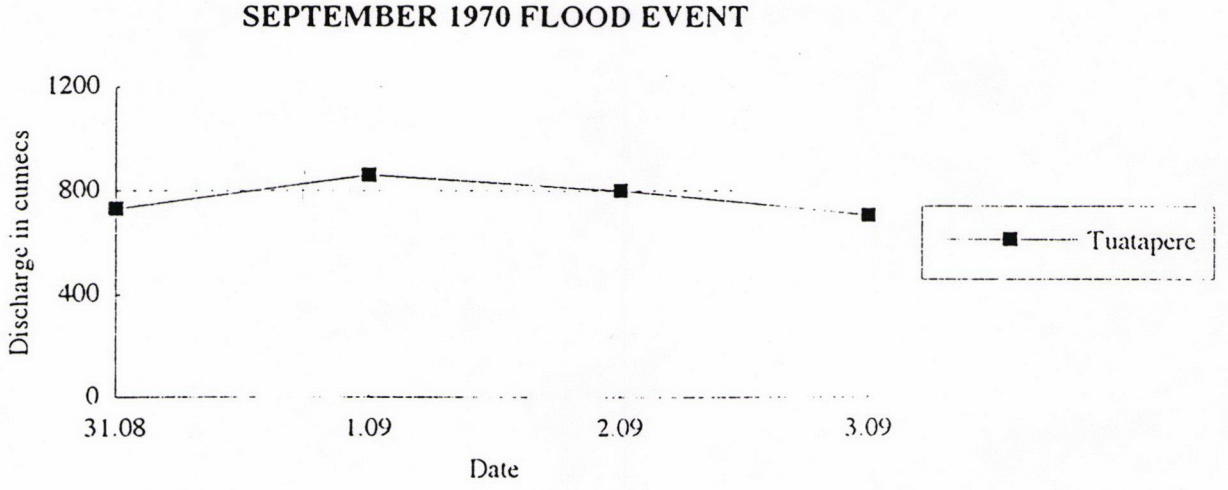
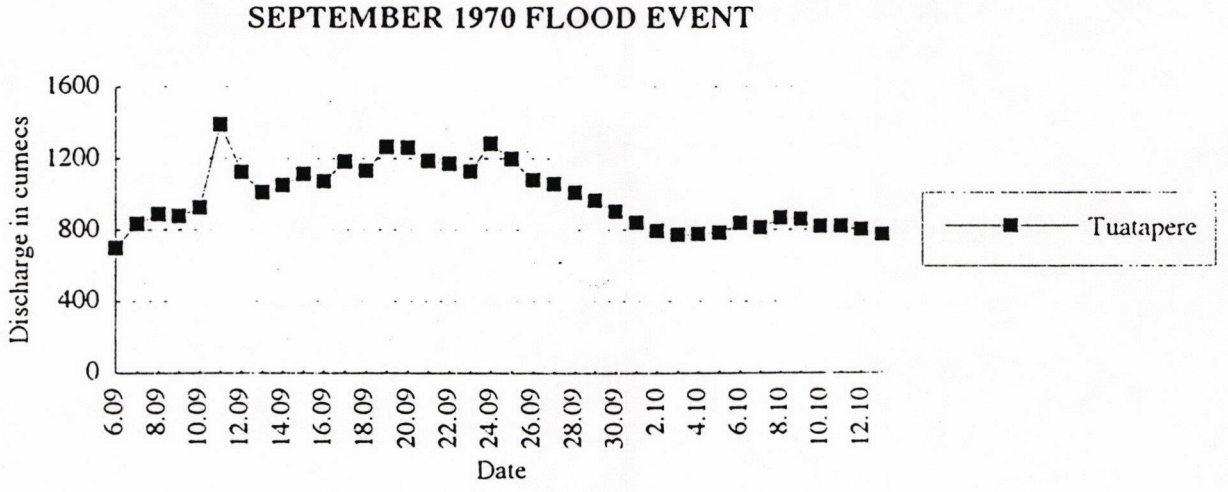


Figure 7.2 (continued) Flood events between February 1969 and May 1974





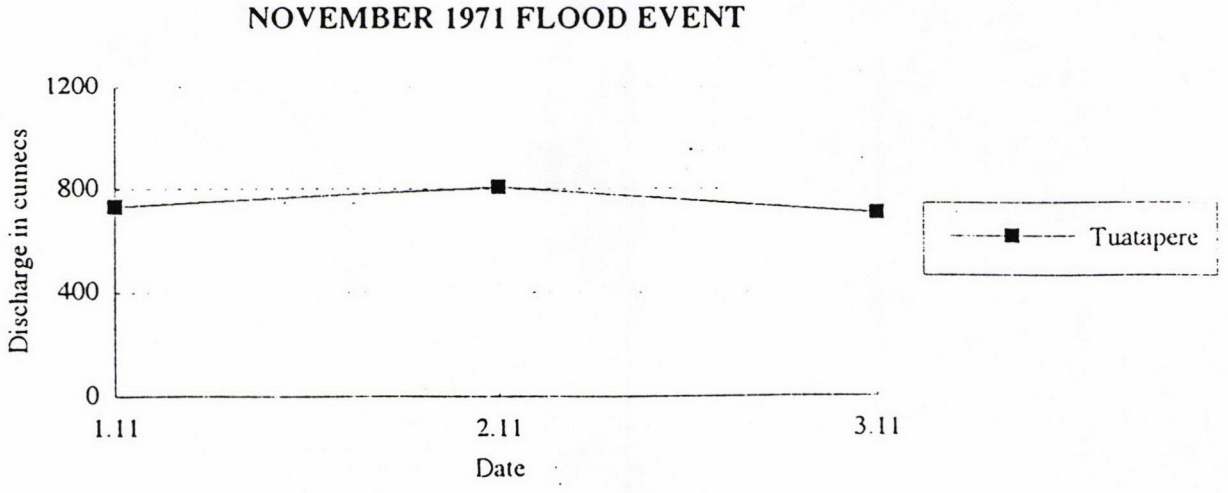


Figure 7.2 (continued) Flood events between February 1969 and May 1974

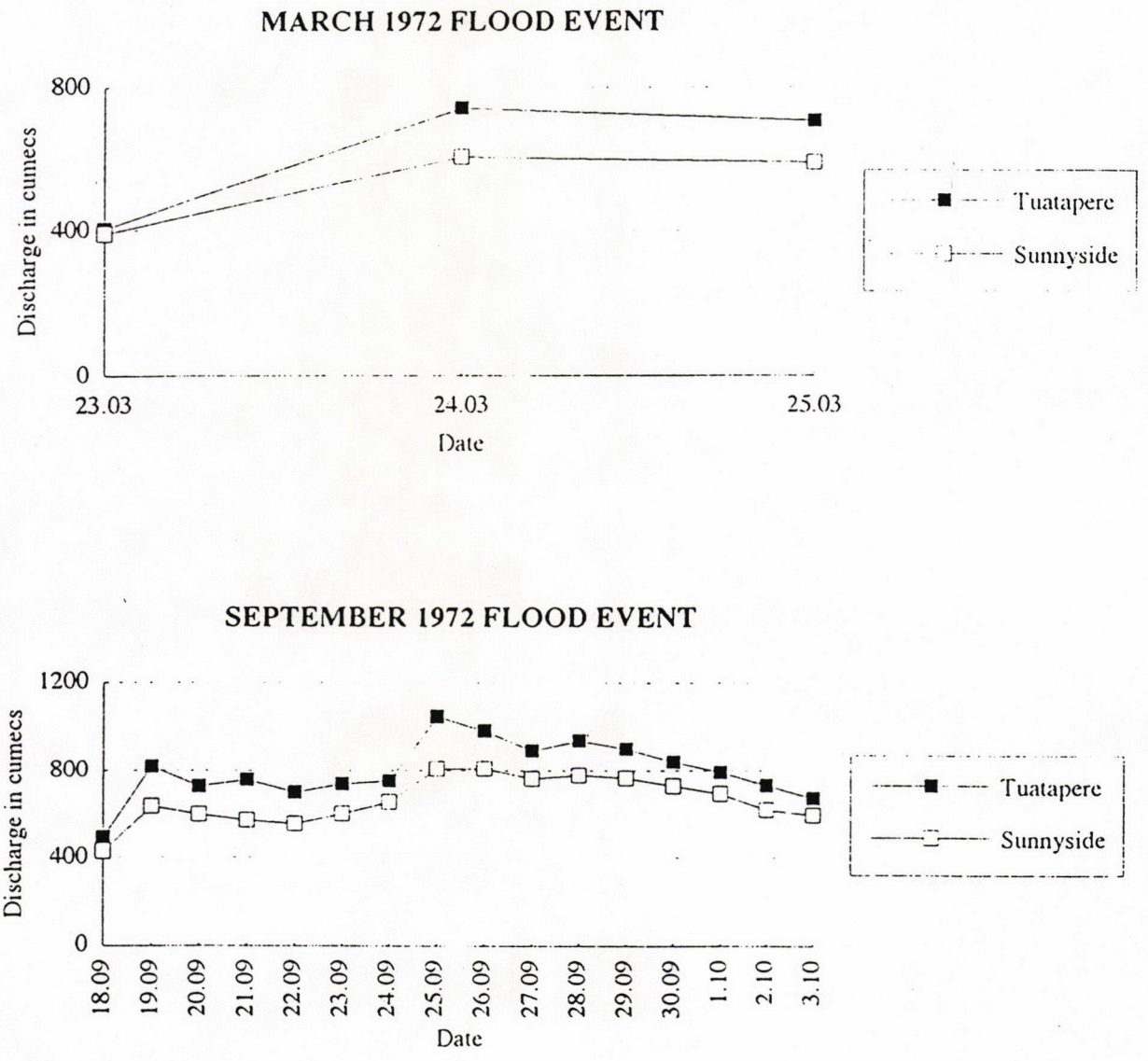
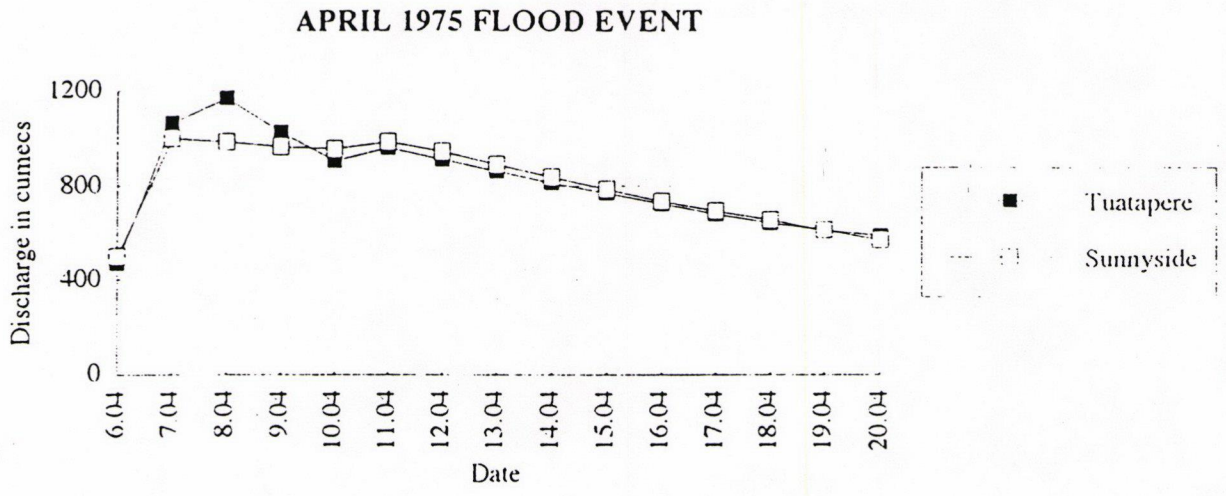
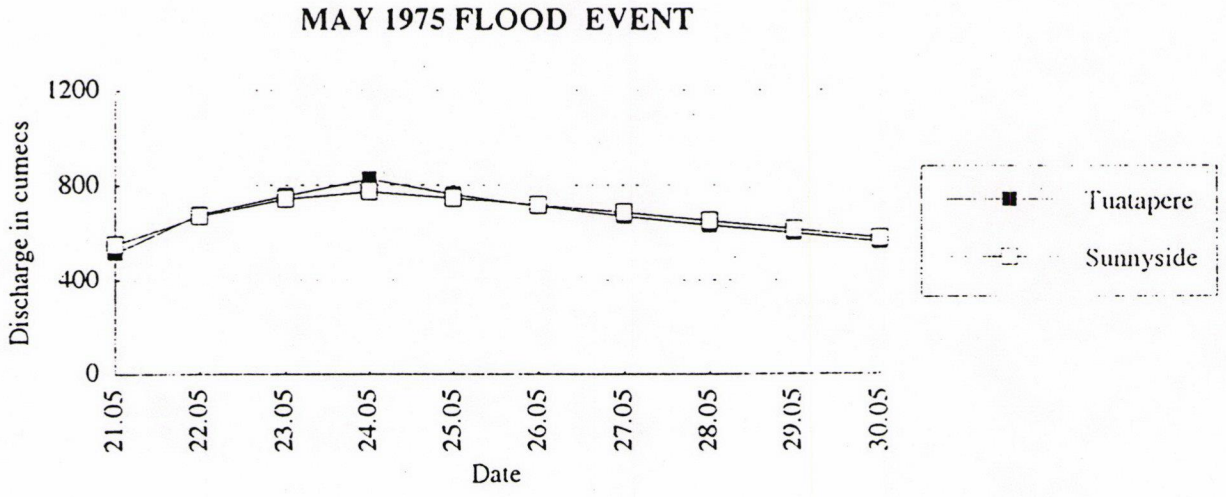


Figure 7.3 Flood events between May 1974 and February 1978

Mean daily discharges for events > 800 m^3s^{-1} at Tuatapere and/or >600 m^3s^{-1} at Sunnyside





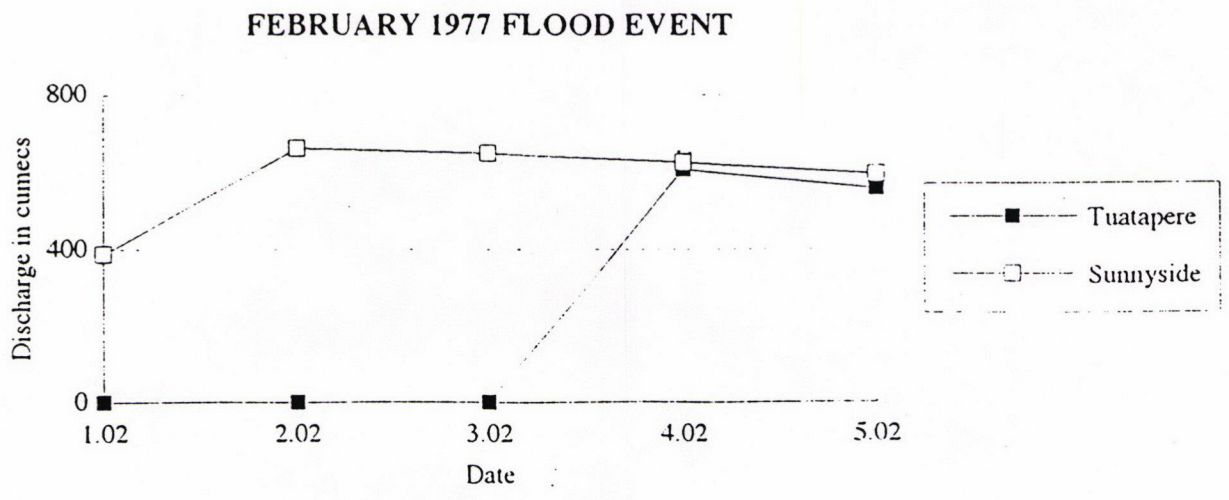


Figure 7.3 (continued) Flood events between May 1974 and February 1978

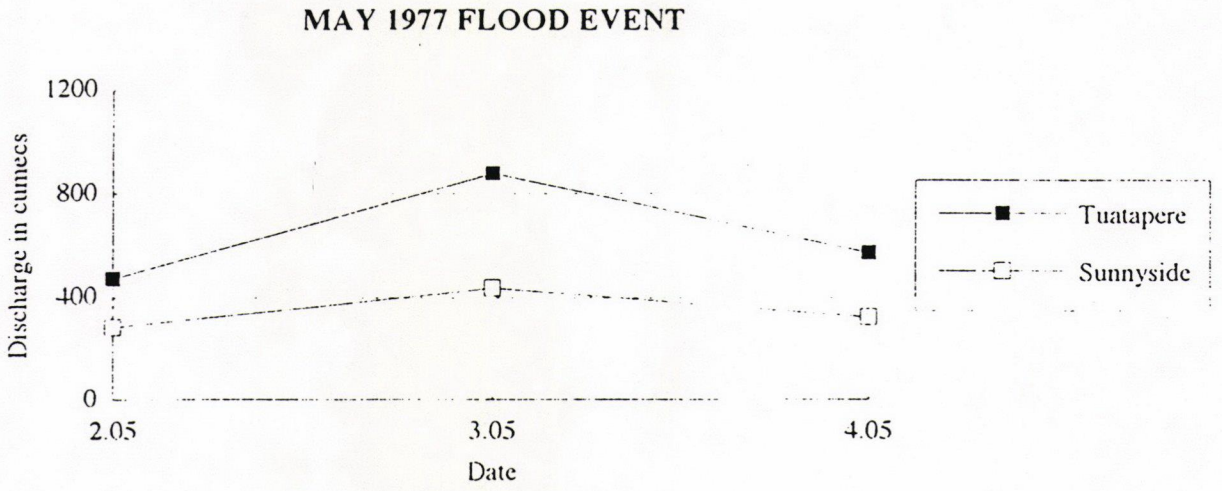
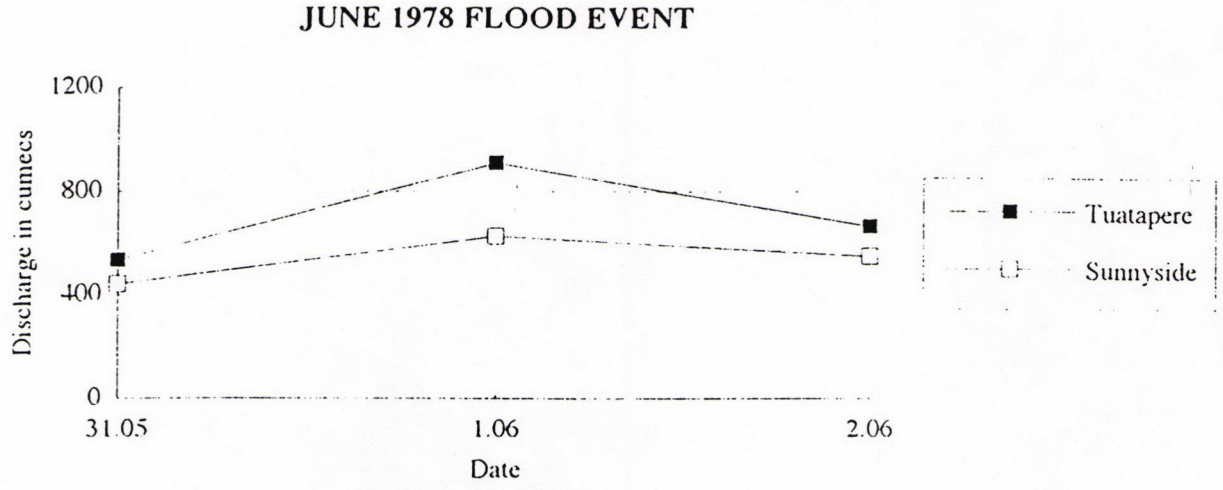
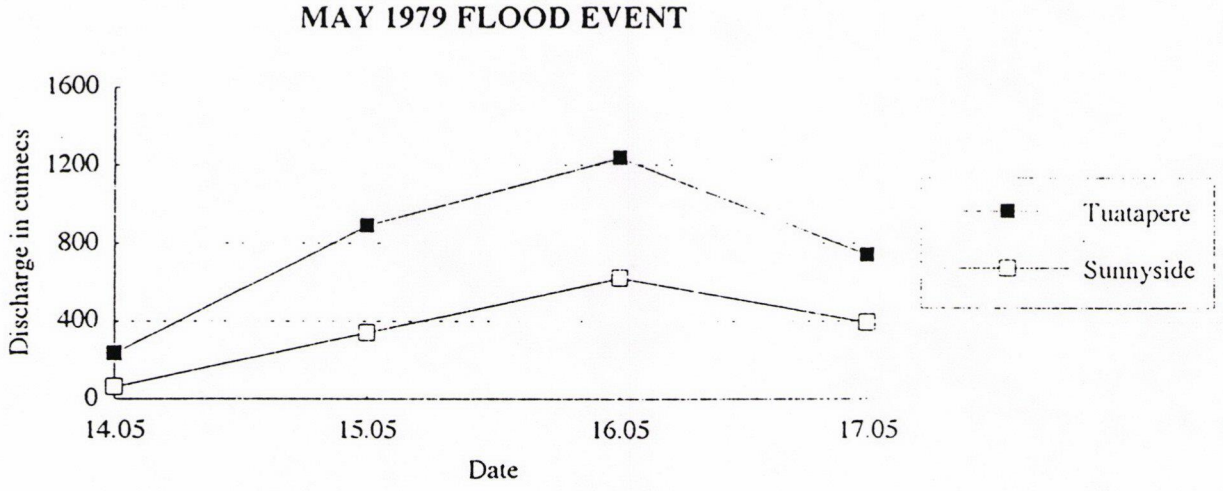


Figure 7.4 Flood events between February 1978 and April 1980

Mean daily discharges for events > 800 m^3s^{-1} at Tuatapere and/or >600 m^3s^{-1} at Sunnyside





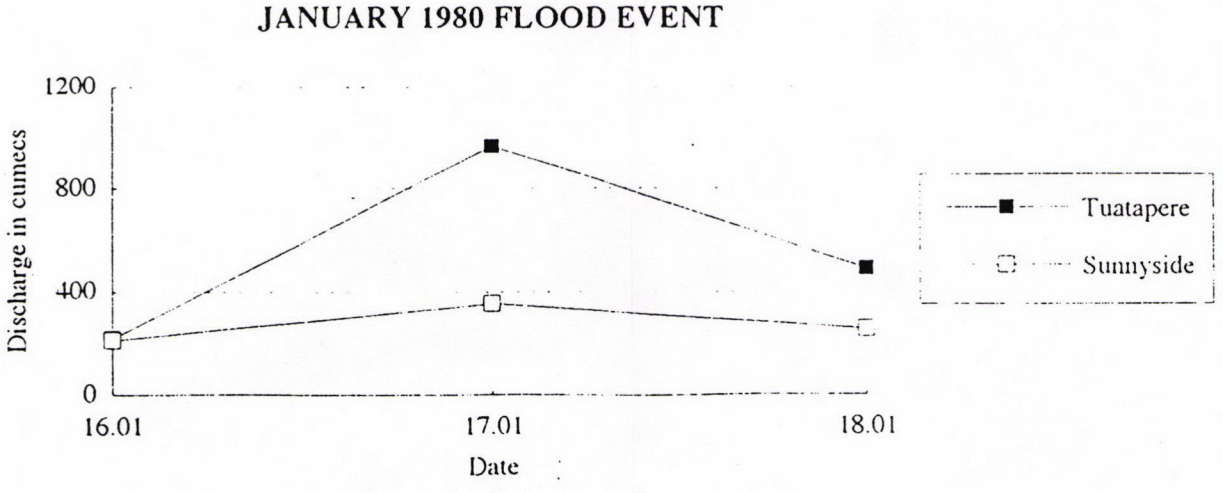


Figure 7.4 (continued) Flood events between February 1978 and April 1980

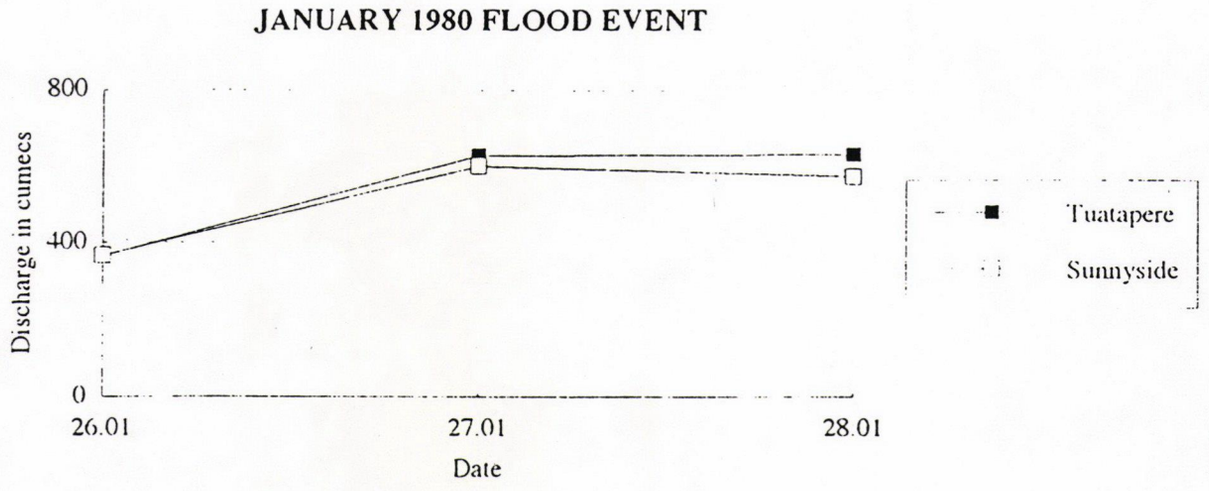
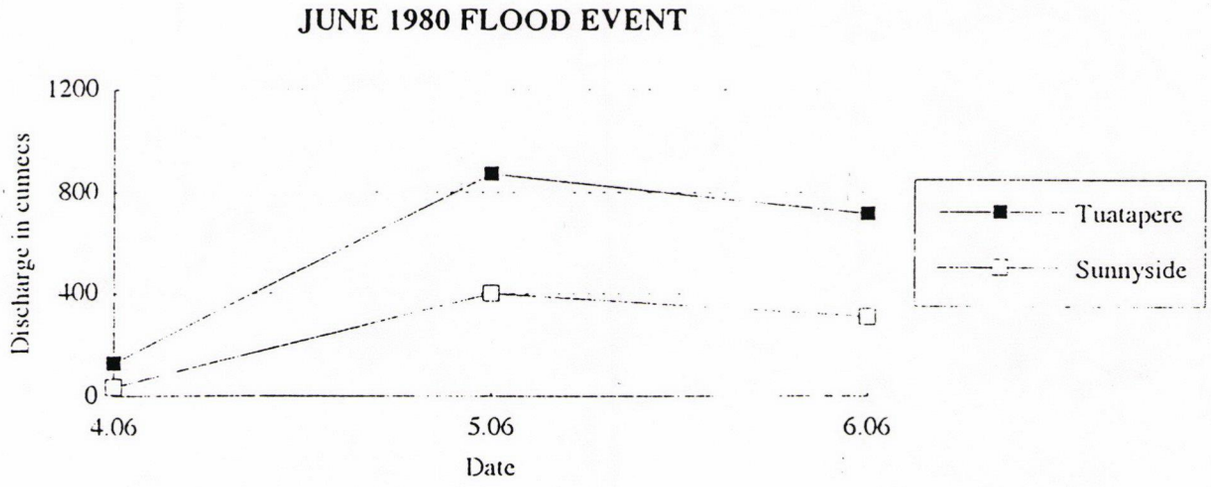
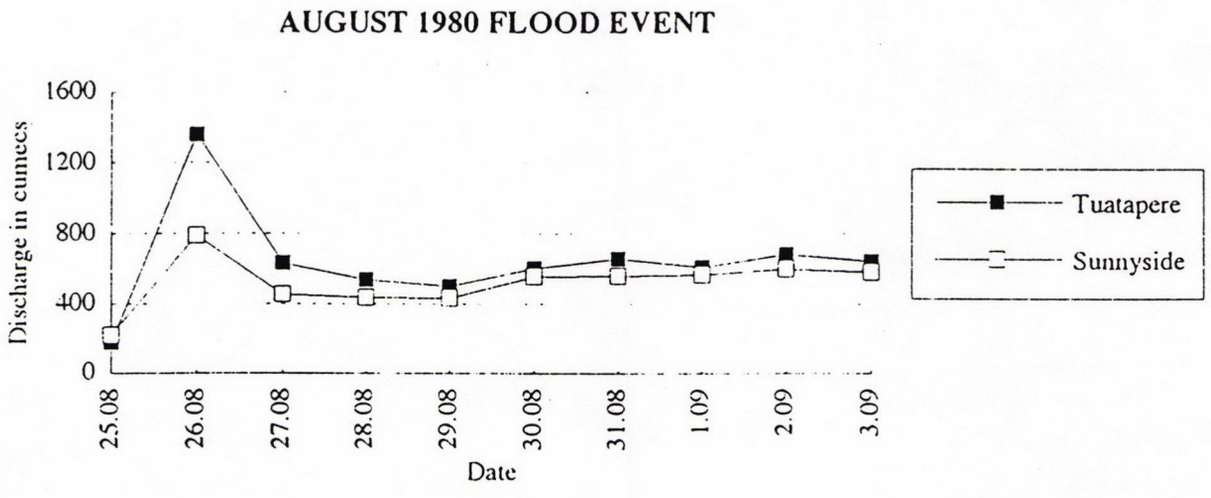


Figure 7.5 Flood events between April 1980 and August 1982

Mean daily discharges for events > 800 m^3s^{-1} at Tuatapere and/or >600 m^3s^{-1} at Sunnyside





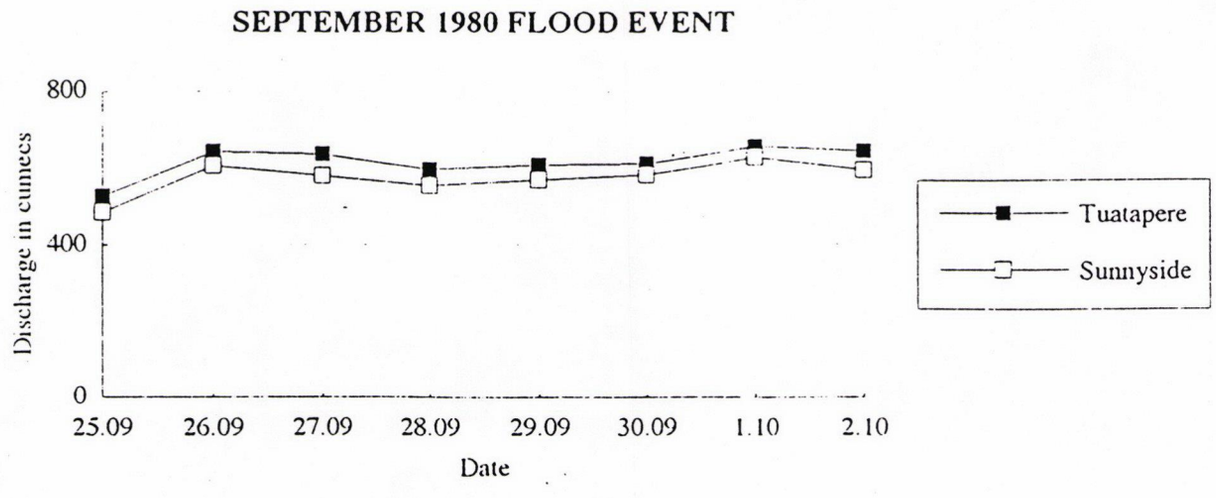
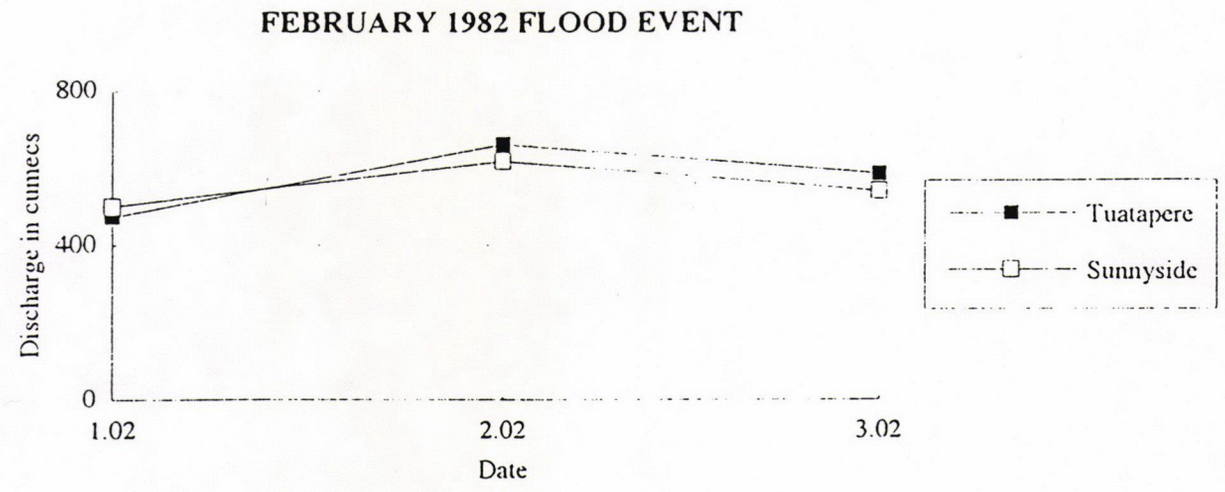


Figure 7.5 (continued) Flood events between April 1980 and August 1982



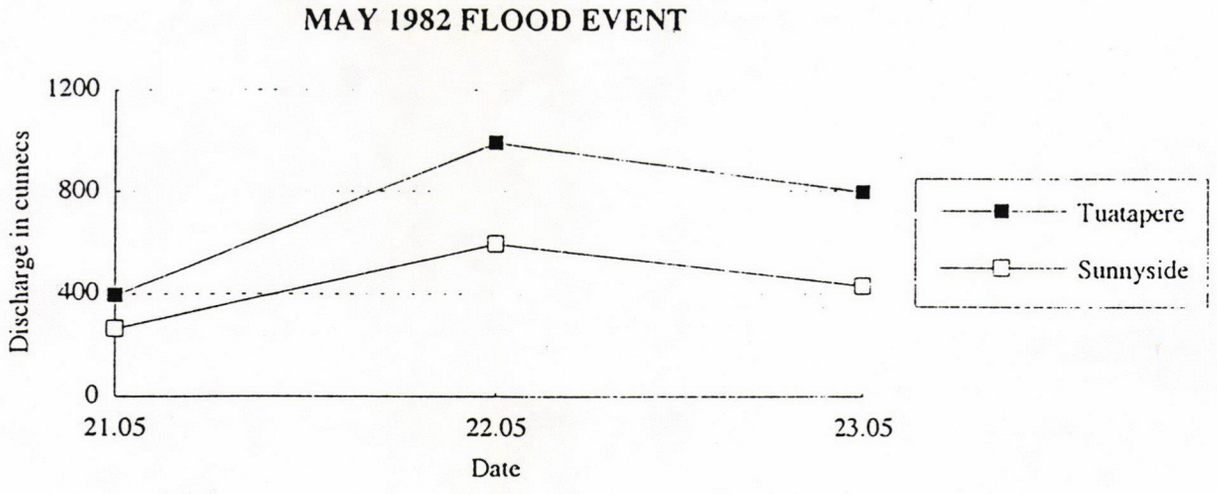
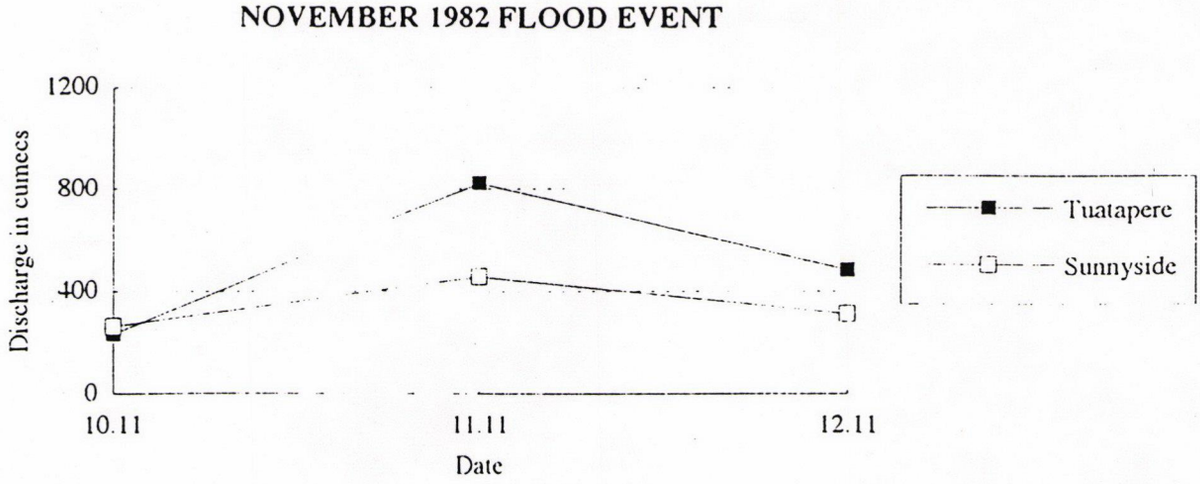
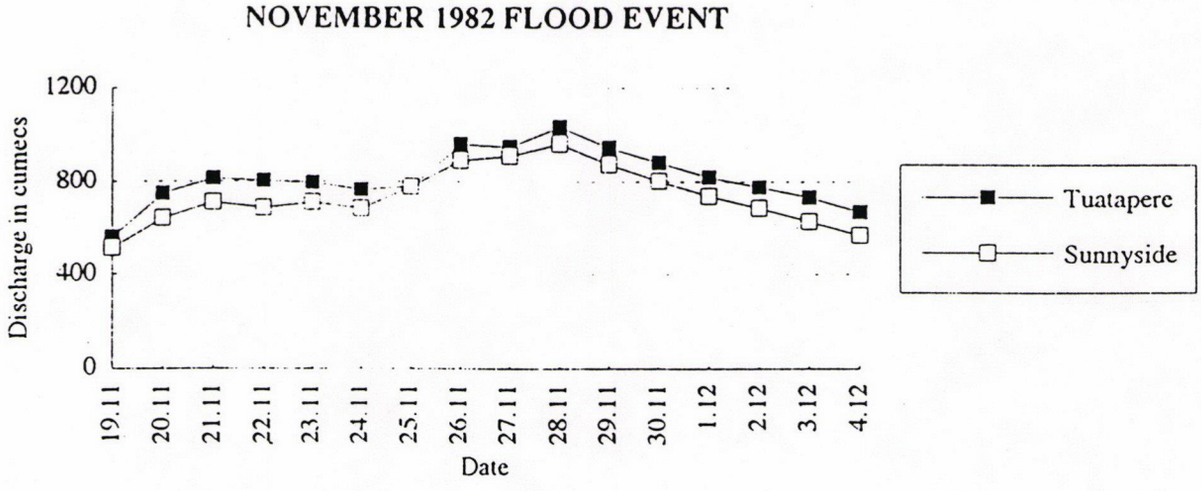


Figure 7.6 Flood events between August 1982 and February 1984

Mean daily discharges for events > 800 m^3s^{-1} at Tuatapere and/or >600 m^3s^{-1} at Sunnyside





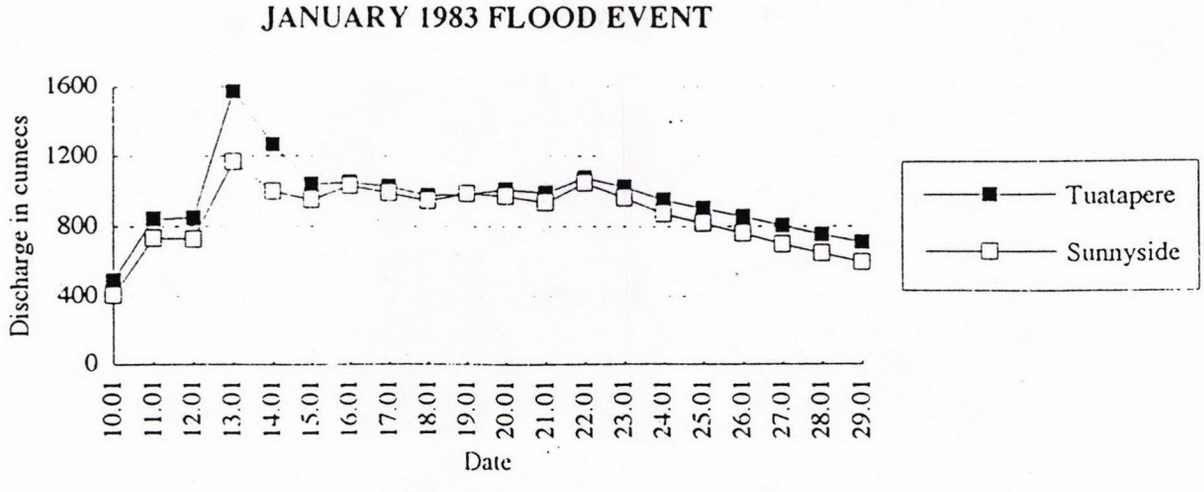


Figure 7.6 (continued) Flood events between August 1982 and February 1984

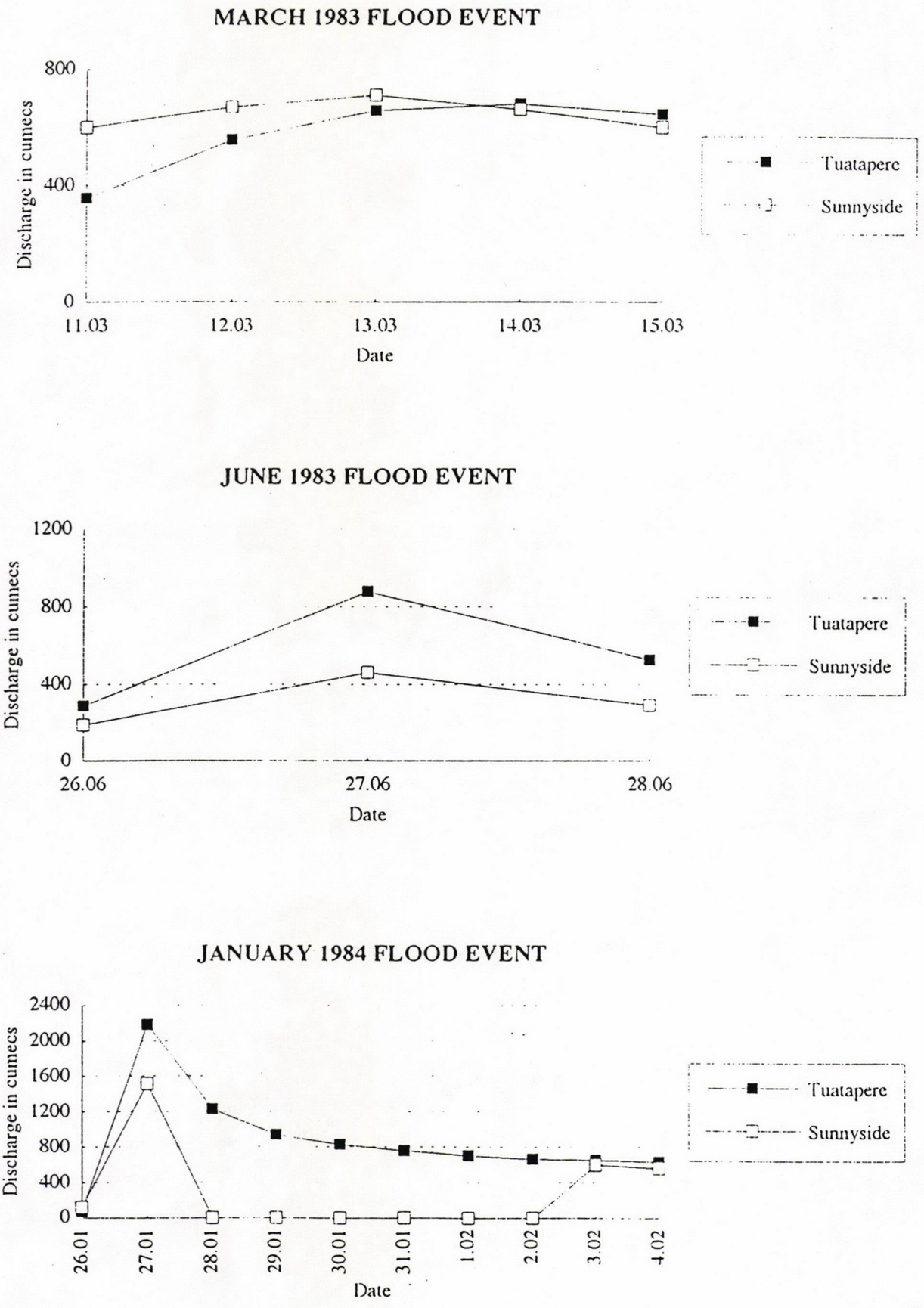
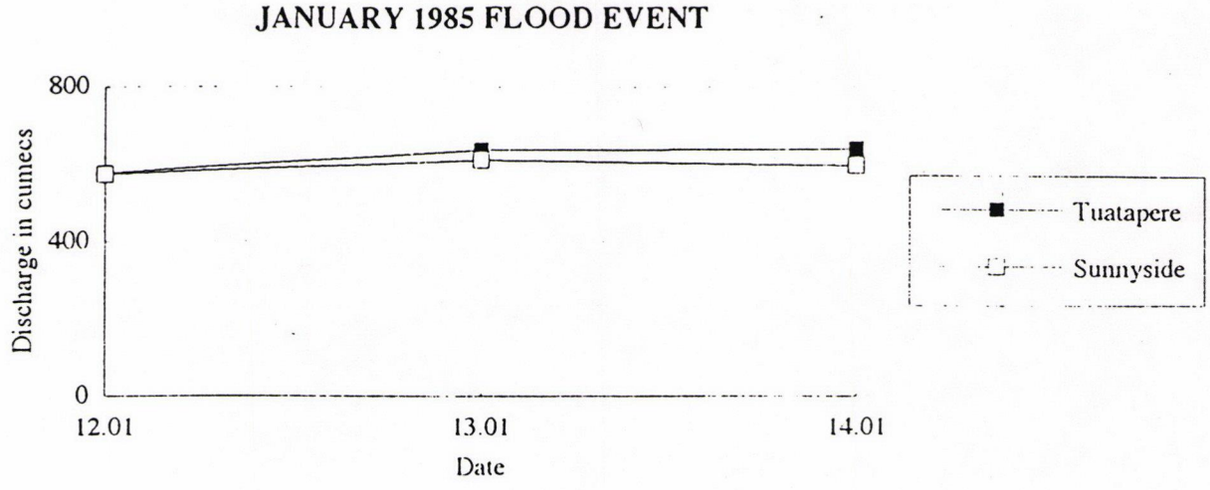
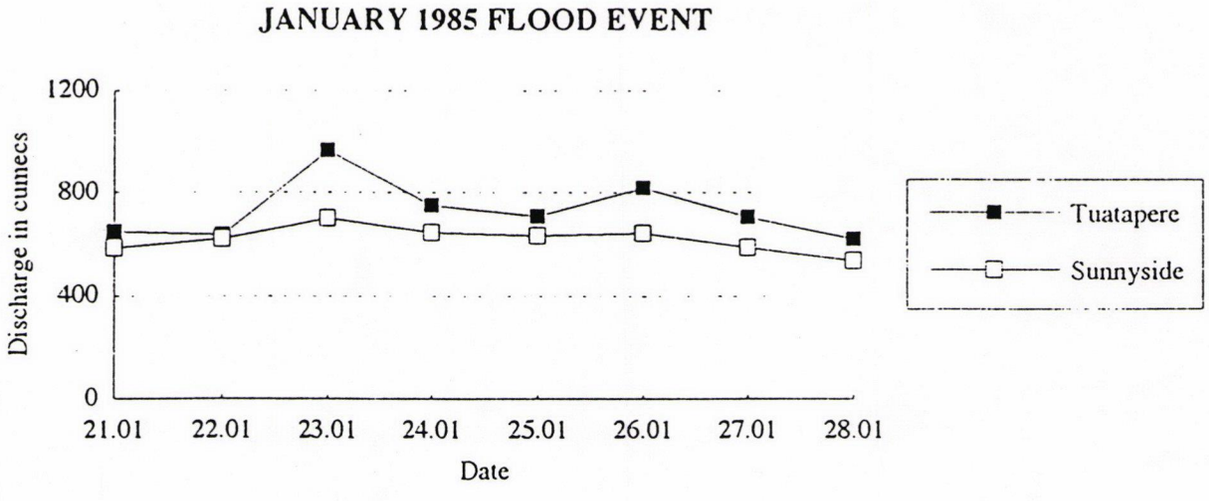


Figure 7.7 Flood events between February 1984 and April 1989

Mean daily discharges for events > 800 m^3s^{-1} at Tuatapere and/or >600 m^3s^{-1} at Sunnyside





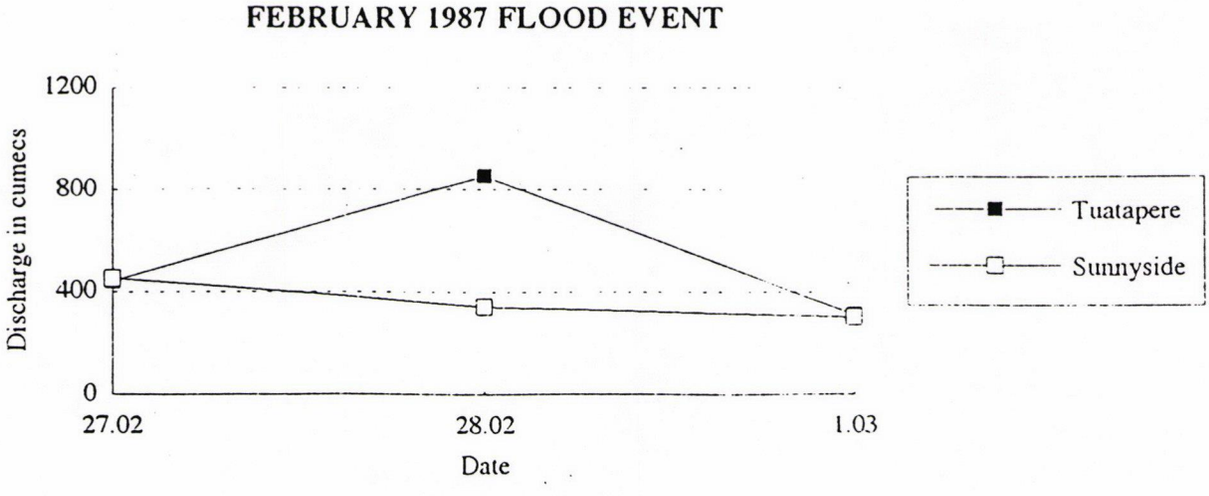
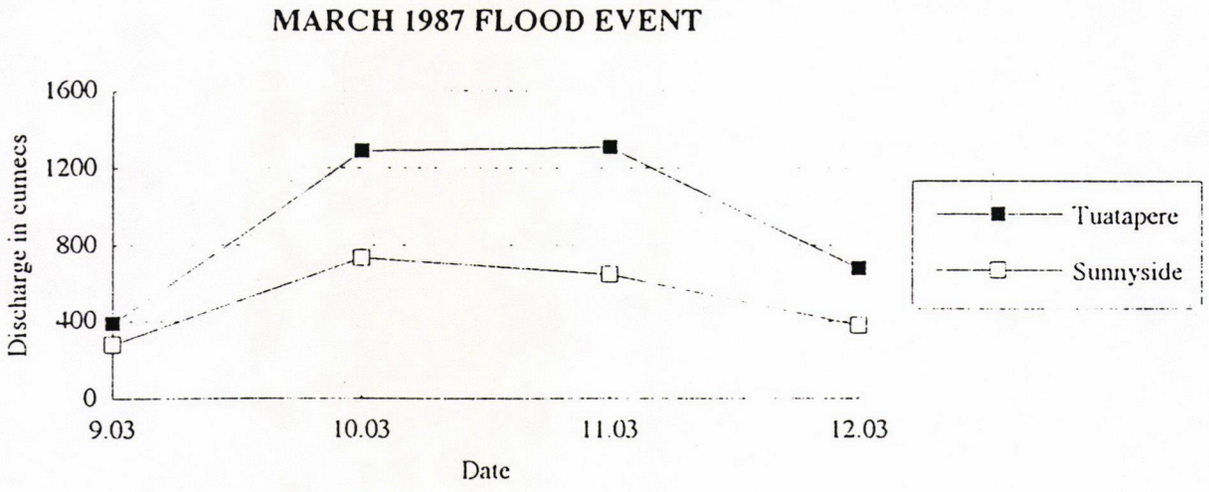
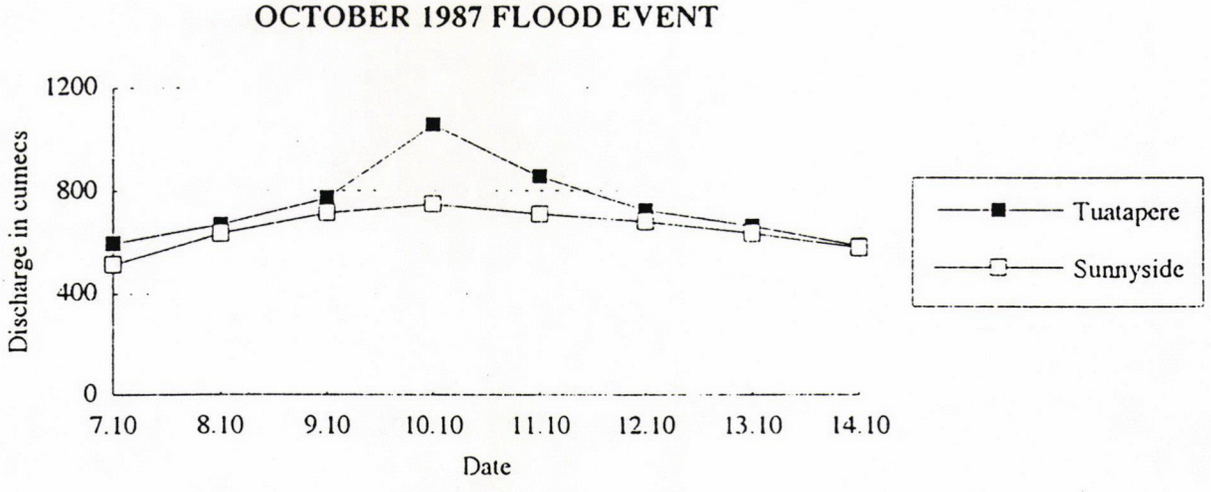


Figure 7.7 (continued) Flood events between February 1984 and April 1989





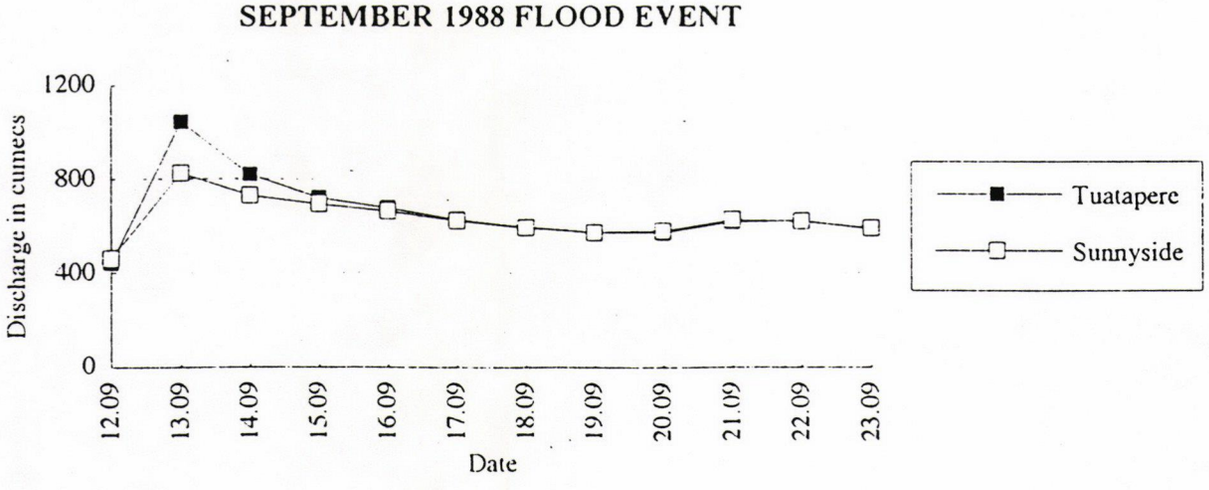


Figure 7.7 (continued) Flood events between February 1984 and April 1989

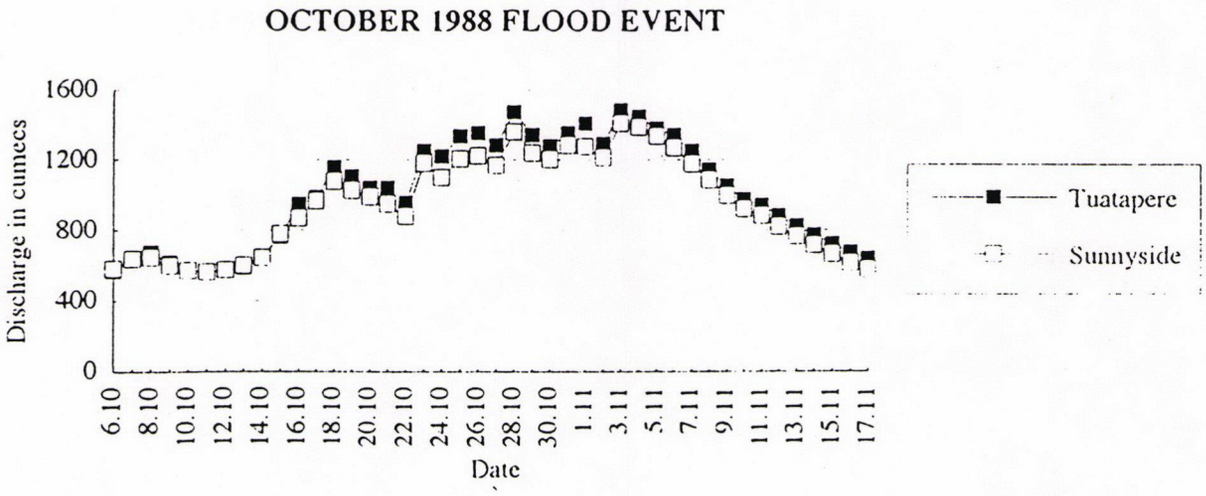
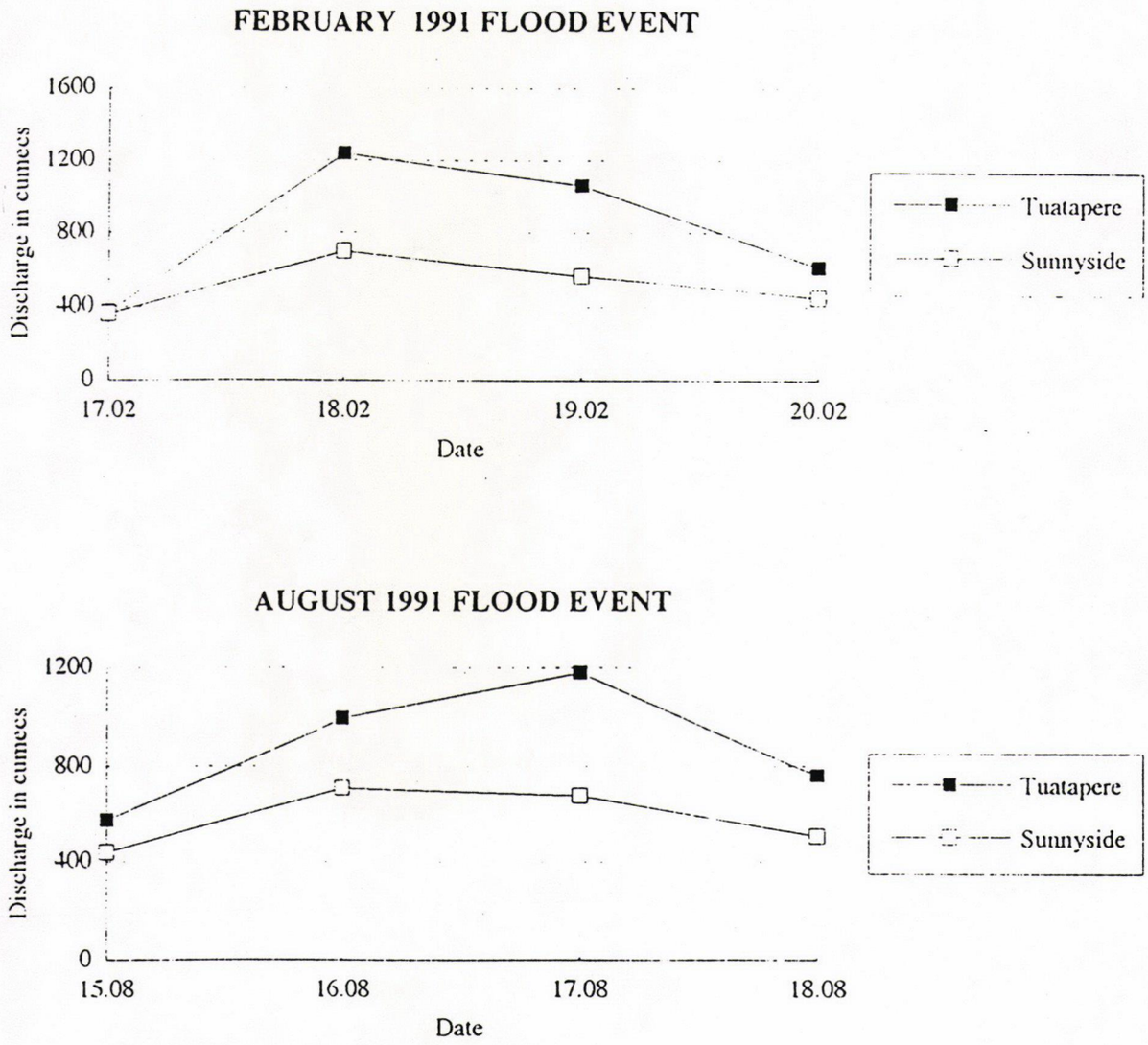


Figure 7.8 Flood events between April 1989 and April 1992

Mean daily discharges for events > 800 m^3s^{-1} at Tuatapere and/or >600 m^3s^{-1} at Sunnyside



APPENDIX 6 PROCEDURES USED TO DETERMINE PLANFORM CHARACTERISTICS

Channel planform characteristics for each laterally unconfined reach were determined from the earliest photograph of record along with the 1969 and 1992 channel outlines from tracings of Figures 8.1 to 8.5. Planform characteristics were determined from these tracing as follows:

Channel multiplicity

Maximum number of channels in each reach were determined by a simple count of channels in a cross section perpendicular to the orientation of the active channel zone.

Width of the active channel zone

Width of the active channel section was determined for cross-sections 250 m apart along the entire reach length, subdivided into subreaches where pertinent, and averaged from the number of cross-sections in each subreach and then overall. Each cross section was measured perpendicular to the orientation of the active channel zone.

Braided index

Braided inded was determined by measuring the length of all vegetated bars in each subreach and dividing by the length of the channel measured along the thalweg of the active channel zone.

Sinuosity

Sinuosity was measured as the stream length along the channel thalweg in each subreach divided by the straight-line distance between the upstream and downstream limits of the reach.