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Trends in bed level and gravel storage in the Motueka River 1957–2001:

a progress report on results from analysis of river cross section data from the upper and lower Motueka River

Prepared for

Stakeholders of the
Motueka Integrated Catchment Management Programme

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Landcare Research

TDC Tasman District Council

CAWTHRON

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Trends in bed level and gravel storage in the Motueka River 1957–2001:

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Motueka Integrated Catchment Management
(Motueka ICM) Programme Report Series

by

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Cover Photo: Motueka River below Kohatu Bridge

PREFACE

An ongoing report series, covering components of the Motueka Integrated Catchment Management (ICM) Programme, has been initiated in order to present preliminary research findings directly to key stakeholders. The intention is that the data, with brief interpretation, can be used by managers, environmental groups and users of resources to address specific questions that may require urgent attentin or may fall outside the scope of ICM research objectives.

We anticipate that providing access to environmental data will foster a collaborative problem-solving approach through the sharing of both ICM and privately collected information. Where appropriate, the information will also be presented to stakeholders through follow-up meetings designed to encourage feedback, discussion and coordination of research objectives.

APPENDIX 8 LOWER MOTUEKA CHANGES IN CHANNEL STORAGE VOLUME BETWEEN 1957 AND 2001 III

Summary

There has been considerable debate about trends in mean bed levels and changes in gravel storage within the Motueka riverbed, and the influence of gravel extraction on those trends. Analysis of river cross section surveys was undertaken to investigate trends in mean bed levels and gravel storage in the Motueka River since 1957. Survey data were analysed for a 19 km reach of the upper Motueka between the Wangapeka confluence and Norths bridge (up to 30 cross sections, surveyed in 1960, 1988, 1995 and 2000), and a 13 km reach of the lower Motueka between the coast and Alexander Bluff bridge (up to 17 cross sections surveyed in 1957, 1960 and 1967/8, and up to 52 cross sections in 1978, 1982, 1984, 1990, 1997/8 and 2001). Trends in mean bed levels and gravel volumes stored in the riverbed were calculated using the "end area" method. Gravel storage changes were compared with the volume of gravel extracted from the riverbed to determine the influence of gravel extraction on observed trends in riverbed levels.

The data shows that on average both reaches of the river have degraded over the last 40 years. However, at individual cross sections bed levels exhibited very dynamic behaviour through time with considerable fluctuation between degradation and aggradation from one survey to the next. In addition, while the overall trend is one of degradation, there are few sub-reaches of the river that show consistent zones of degradation or aggradation across all survey periods.

Upper Motueka

In the upper Motueka cross sections there was an average net mean bed level change of –0.20 m between 1960 and 2000, with a range at individual cross sections from –1.15 m to +0.62 m. Average rates of mean bed level change have increased between 1960 and 2000 from –0.005 m/yr to –0.007 m/yr. The net change in the amount of gravel stored in the active channel of the entire reach between 1960 and 2000 was –715,475 m^3, and for the part of the reach from which gravel was extracted (CS2 (RD49260) and above) there was a net change of –728,138 m^3. During this time the average rate of gravel loss per year from the entire reach has progressively increased, from 16,667 m^3/yr (1960–88), 18,656 m^3/yr (1988–95), to 26,294 m^3/yr (1995–00). A similar trend was shown for the part of the reach from which gravel was extracted, increasing from 17,496 m^3/yr (1960–88), 17,409 m^3/yr (1988-95) to 23,279 m^3/yr (1995–00).

The net change in gravel storage (728,138 m^3) is 30% greater than the total amount of gravel extraction (560,747 m^3) and has exceeded gravel extraction volumes for 2 of the 3 inter-survey periods for which data is available (1960–88, 1995–2000). In contrast to the changes in gravel storage, the average rates of gravel extraction have remained fairly constant through time (13,500 m^3/yr between 1960 and 1988, 17,000m^3/yr between 1988 and 1995, 12,750 m^3/yr between 1995 and 2000). While the total amount of gravel extracted from the river between 1960 and 2000 is a substantial proportion of the total gravel loss (77%), there appears to be a significant component of gravel loss unrelated to gravel extraction suggesting factors other than gravel extraction play a secondary role in determining changes in gravel storage.

Lower Motueka

In the lower Motueka there was an average mean bed level change of –0.64 m (–0.015 m/yr) between 1957 and 2001, with a range from –1.17 m to –0.27 m. Between 1978 and 2001 average mean bed level change was –0.30 m (–0.070 m/yr). Rates of mean bed level change have fluctuated through time from +0.012 m/yr between 1957 and 1960, to –0.056 m/yr between 1982 and 1984. The net change in the amount of gravel stored in the active channel of the entire reach between 1957 and 2001 was –1,113,260 m^3. The average rate of change of gravel storage has varied from +10,859 m^3/yr between 1957 and 1960, to –103,300 m^3/yr between 1982 and 1984. There was no distinct trend through time, except that bed degradation peaked between 1982 and 1984 coinciding with a large flood in July 1983 (70-yr return period).

Throughout the 44-year length of record gravel storage loss has averaged c.–25,000 m^3/yr. The total amount of gravel lost from the reach between 1957 and 2001 (1,113,260 m^3) is very similar to the total amount of gravel extracted (1,067,835 m^3). Similarly, for the period between 1978 and 2001 (for which better data is available) channel storage loss (608,877 m^3) is very similar to gravel extraction (604,262 m^3). However, there were periods where gravel storage loss greatly exceeded extraction (1960–68 and 1982–84) and vice versa (1957–60, 1968–78). Both gravel extraction rates and gravel storage loss rates peaked between 1982 and 1984, although the gravel storage loss rate was more than twice the gravel extraction rate for this period, probably resulting from degradation

effects of the 1983 flood. As in the upper Motueka these trends suggest factors other than gravel extraction may play a secondary role in determining changes in gravel storage.

Recommendations

The observed trends in bed levels and gravel storage emphasise the importance of regularly repeating the cross section surveys. It is recommended that:

- the cross sections should continue to be surveyed every 4–5 years to monitor the mean bed level trends and their effect on river bed and bank stability.
- monitoring of the amount and location of gravel extraction, and archiving of survey results should be improved.
- mean bed level trends should be compared and correlated with flood events and channel management practices to determine the direct effects of floods and channel management on bed level trends, and to assess whether there is a relationship between costs of channel management and bed degradation.
- storage changes on the berms should be analysed to provide a complete sediment budget, and should incorporate a more precise analysis of channel change using a narrower active channel width and calculation of the contribution of bed degradation and channel widening to mean bed level change.
- air photo analysis should be used to provide confirmation of the channel changes suggested by the cross section survey results, and to assess how well the surveyed reaches reflect whole river behaviour.
- further work is needed to improve the estimates of the long-term rate of gravel supply to the river and to develop a hydraulic/sediment transport model to simulate past riverbed behaviour and predict future changes.

1. Introduction

The Motueka River (Fig. 1) has been subject to river control and river improvement works, and to gravel extraction for commercial and local uses for at least the last 50 years (Green 1982). In recent years there has been considerable interest in, and debate about, trends in mean bed levels and changes in gravel storage within the Motueka riverbed and the influence of gravel extraction on those trends (e.g. TDC 1993, 2000). The changes in gravel storage are also important in understanding sediment sources and fluxes within the Motueka catchment, a major aim of the Motueka Integrated Catchment Management research programme.

Gravel extraction has been controlled since the 1950s, initially by the Nelson Catchment Board and now by Tasman District Council (TDC). Controls were imposed in all the major Nelson rivers because of concerns that extraction might be causing excessive riverbed degradation, bank instability, increased flood peaks downstream, and lower groundwater levels (TDC 2000). Gravel extraction had increased dramatically from the 1950s to the mid 1980s, but has been progressively reduced since then as TDC recognised the low rate of gravel supply to the river and attempted to manage the gravel resource sustainably (Fig. 2). Allocations of gravel for extraction are currently set on an annual basis by TDC, pending completion of the "Rivers and Lakes" chapter of the Tasman Resource Management Plan, and take account of the need for gravel extraction in a broader context of river management.

River cross section surveys have been one of the primary methods for investigating trends in mean bed levels and changes in gravel storage, and surveys have been carried out on upper and lower Motueka River[1] reaches since at least 1957. While parts of this data have previously been analysed (TDC 1993; Howes 1994; Nottage 1994, 1995, 1996, 1997, 1998; Verstappen 1999, 2000), there has never been a comprehensive analysis of all the data, using a consistent methodology, to assess long-term trends in bed levels, or to assess the adequacy of the survey network to provide TDC with sufficient information to understand riverbed dynamics and manage gravel allocation sustainably and defensibly.

[1] Upper Motueka is the main stem reach from the Wangapeka confluence to Norths bridge; lower Motueka is the reach from the coast to Alexander Bluff bridge.

Several reports have previously been written for TDC on riverbed level variation, gravel availability, and sustainable gravel extraction rates including:

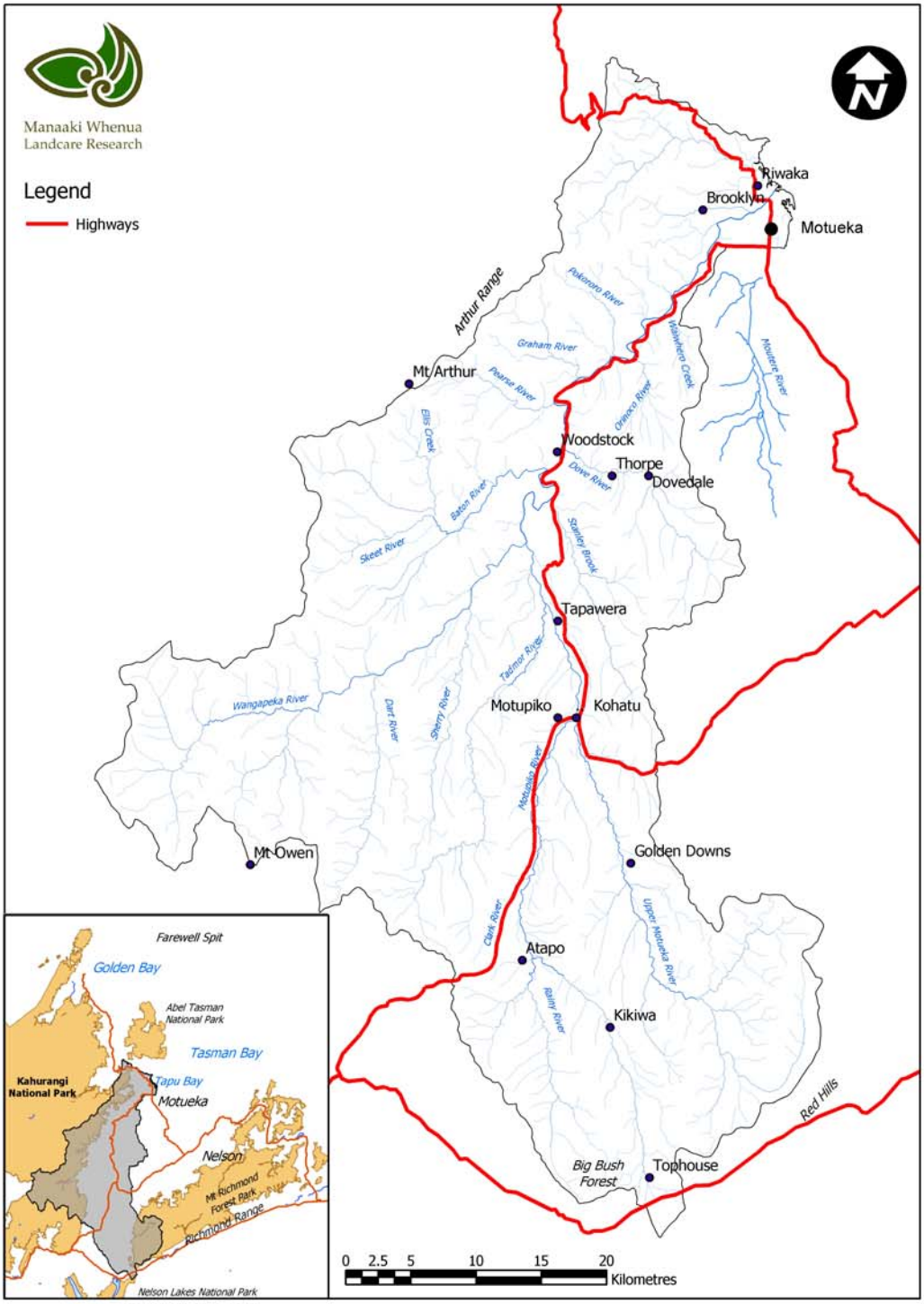
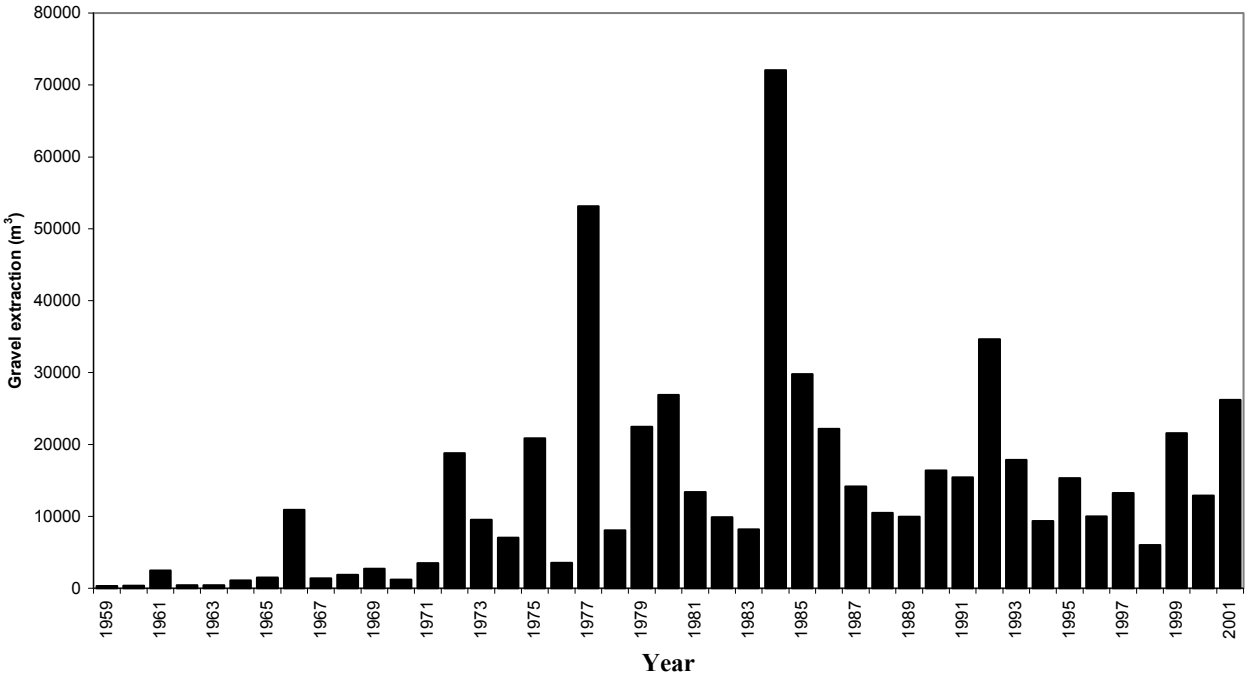


Fig. 1 Location diagram

(a) Upper Motueka



(b) Lower Motueka

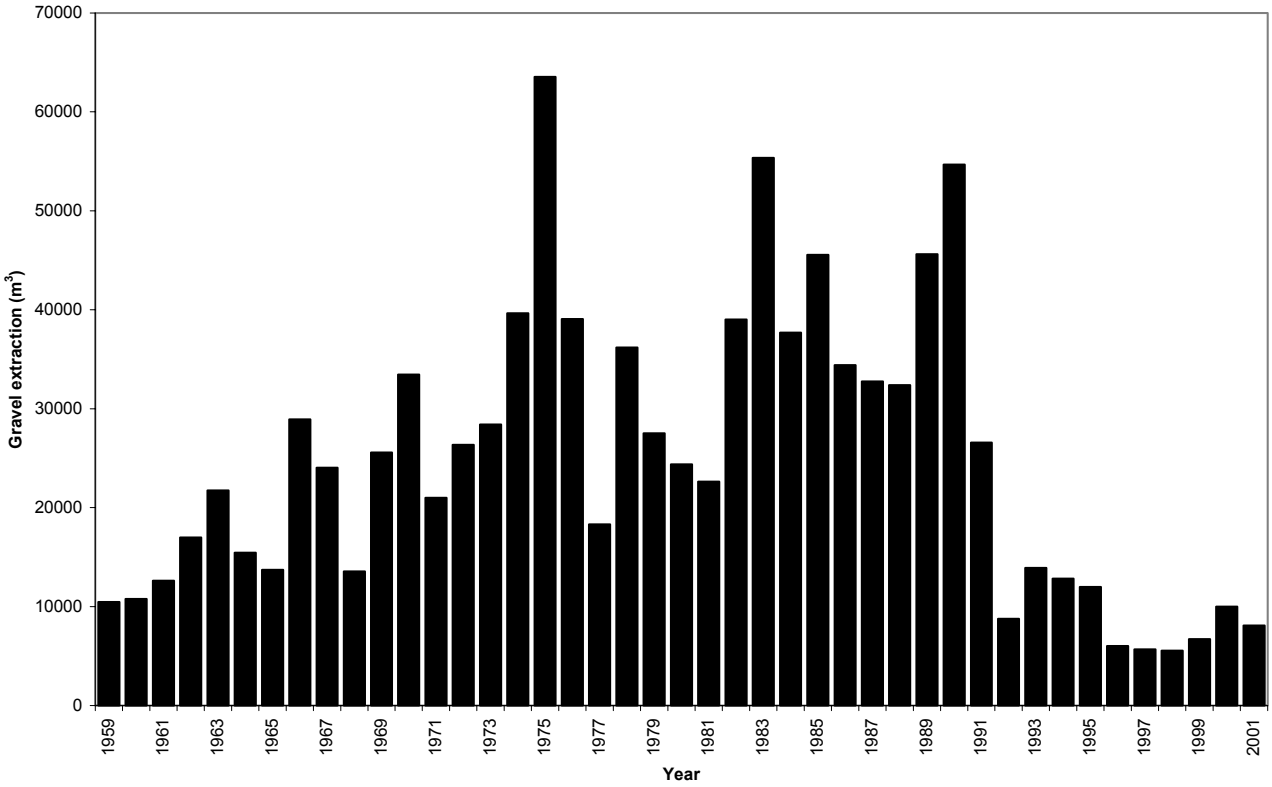


Fig. 2 Trends in gravel extraction between 1959 and 2001

- a series of internal reports written by TDC staff for Council meetings considering annual gravel allocations that summarise results of riverbed cross section surveys (e.g., Nottage 1994, 1995, 1996, 1997, 1998; Verstappen 1999, 2000).
- analysis of the lower Motueka River cross section data for the period 1957 to 1990, which was used to calculate the impact of bed level change on flood hazards (Howes 1994).
- a description of the geomorphic evolution of the Motueka spit and delta (Peterson 1997), from which the long-term supply of gravel to the coast was calculated at about 9000 m^3/yr (of which 7000–7600 m^3/yr accumulates in the delta and 1000–1500 m^3/yr is transported along the coast). Peterson suggests, from the volume of material trapped in the Motueka delta, that there has never been a large volume of gravel supplied to the coast or transported down the coast by long-shore drift. This provides the only assessment of the long-term rate of gravel supply.
- an analysis of the sources of gravel deposited within the Motueka catchment (Waterhouse 1996). Gravel composition varies systematically down the river as a function of the input of gravel from major tributaries. In the upper reaches of the river (above the Wangapeka confluence), clasts from the headwaters (ultramafic rocks and Maitai Group) and Moutere gravels dominate, but below the Wangapeka confluence clasts from the western tributary lithologies and granite are most common. The bulk of the clasts in the lower Motueka are from the western tributaries (more than half from the Baton and Wangapeka Rivers), with negligible amounts from the headwaters of the Motueka or from Moutere gravel. The inference from this finding is that changes in riverbed levels in the upper Motueka may have little influence on the lower Motueka.
- policy documents prepared by consultants (Williams 1995) or TDC staff (e.g. Fenemor 1997; TDC 1993, 2000) which outline the issues around river gravel extraction management, present summary data on riverbed trends, and consider gravel allocation options. The TDC public discussion paper (TDC 1993) suggests sustainable management of gravel resources needs to avoid or mitigate any adverse effects of gravel extraction, ensure the stability of the rivers and coast, encourage efficient use of gravel resources, and allocate the river gravel resource in a fair and reasonable manner in the best interests of the community. Policy options for future management of gravel extraction will be contained within the “Rivers and Lakes” chapter of the Tasman Resource Management Plan.

The major findings from these studies include:

- the rate of gravel supply to the Motueka River is low because rates of erosion are relatively low, and many rock types in the catchment produce little competent gravel;
- changes in riverbed levels in the upper Motueka may have little influence on the lower Motueka;
- both reaches of the river have consistently degraded;
- gravel extraction accounts for most (80–100%) of the gravel loss from the Motueka riverbed.

Similar issues of riverbed degradation or aggradation have been investigated using repetitive river cross section surveys on a number of other rivers in New Zealand, including the Wairau River in Marlborough (Noell 1992, Christensen 2001) and Waimakariri River in Canterbury (Griffiths 1979). These studies use a consistent approach to calculation of mean bed levels and changes in gravel storage (the "end-area" method – see Methods section) that is followed in this analysis of river cross section data for the Motueka River. Griffiths (1979) provides a conceptual basis for the analysis:

- river cross-sections can be divided into a "central gravel area" (or active channel) and "flanking berm areas". Volume changes are analysed separately in the active channel (assumed to be gravel) and berms (assumed to be dominantly sand and silt).
- mean bed level (MBL) is defined as the "area below a certain datum divided by a prescribed channel width", conceptually representing a horizontal line across the cross section such that there is as much riverbed above the line as below it. The prescribed width is the effective channel width bounding the flood carrying capacity of the channel. The MBL multiplied by cross-section width gives the end-area. The average of two adjacent end-areas multiplied by the distance between them gives the volume of material deposited or removed (i.e., the change in channel storage).
- Changes in channel bed and bank sediment storage are found by using the continuity equation

  $$\textit{Change in storage} = \textit{Inflow} - \textit{Outflow}$$

  The inflow term has two components (gravel entering the upstream end of the defined reach, gravel from bank and bed erosion) as does the outflow term (gravel passing out of the reach, extracted gravel).

Noell (1992) and Christensen (2001) discuss possible sources of errors in river cross section analysis, and their likely magnitude. The main sources of errors are identified as:

- survey errors. This is the misclose error associated with the survey procedure. The typical misclose error in the Wairau River surveys was ±25 mm, giving an error in mean bed level (MBL) of ± 15 mm. The maximum misclose error was ± 50 mm corresponding to MBL error of ± 30 mm.
- how well the surveyed cross-section represents the riverbed at each location, including the impact of localised high bars or scour holes, and the effect of localised variation in river channel orientation (i.e. where the river channel at the time of survey is oriented across the average downstream direction), and the effect of localised severe bank erosion at or between cross sections. This error is not readily quantifiable. However, aerial photos and site investigations can be used to assist the analysis by providing a wider picture of how the riverbed is behaving between the measured cross-sections.
- errors associated with calculation of changes in bed level and gravel volume storage. The end-area method assumes bed levels vary linearly between adjacent cross sections and linearly between successive surveys. Noell (1992) calculates the latter component of error as ±30/n mm, where n = number of years between surveys (with the error reducing as the interval between surveys increases).
- other errors including those associated with deposition of gravel outside the active channel, and complete avulsion[2] of channels between surveys.

Noell (1992) suggests for the Wairau River bed level changes >0.1 m/yr, and gravel volume changes >20,000 m^3/yr are likely to be significant.

In this analysis of Motueka River cross-sections a similar approach to Griffiths (1979), Noell (1992) and Christensen (2001) is adopted, except for exclusion of berms from the analysis since interest is primarily in changes in gravel storage. This report presents and analyses data on:

- river cross section surveys undertaken in the lower and upper Motueka since 1957 and 1960 respectively;
- trends in mean bed levels and gravel volumes stored in the riverbed;
- a comparison of the gravel volume changes with gravel extraction rates.

Specific objectives were to:

- compile all existing river cross-section data for the Motueka River and provide a comprehensive analysis of the data on riverbed levels using a consistent methodology;

[2] Movement of river channel to a completely new course

- calculate changes in mean bed levels and gravel storage through time;
- compare changes in gravel volumes stored in the Motueka River with the best available data on gravel extraction rates, and determine the influence of gravel extraction on observed trends in riverbed levels.

2. Study area description

The Motueka River is the largest catchment in the Nelson region draining an area of 2075 km^2. It flows for 112 km from the Red Hills on the southern end of the Richmond Range to the sea just north of Motueka township (Fig. 1). Most of the catchment is mountainous or hilly terrain with steep river and stream gradients, but there are two areas of extensive gravel deposition where river gradients are low: the Motueka-Riwaka plain near the coast, and the upper Motueka plains around Tapawera and Motupiko (extending up tributary valleys such as the Wangapeka, Tadmor, and Motupiko).

The main stem of the Motueka River can be divided into three river reaches:

- the lower Motueka flowing across the Motueka-Riwaka plain,
- the upper Motueka flowing across the upper Motueka plains from the Wangapeka confluence to the upper Motueka gorge,
- the middle Motueka between the two previous reaches, where the river is largely confined between granite ranges.

This report deals with river cross section data from the upper and lower Motueka reaches. No river cross-section surveys have been carried out in the middle Motueka (from Alexander Bluff bridge to the Wangapeka River), or for the upper Motueka between Norths bridge and the Motueka gorge. Both these river reaches also have significant volumes of gravel stored in their beds as floodplain and terraces.

The upper Motueka reach with cross section data extends from the Wangapeka confluence (RD[3]48160) to Norths Bridge (RD67243), c.3 km above the Motupiko confluence (Fig. 3a). In this distance of 19 km there are now 30 cross-sections with spacings between them ranging from 131 m

[3] River distance (m) from the coast (given a RD of 3500 by TDC)

to 1060 m, and an average spacing of 660 m. These cross sections were first surveyed in 1960 and a total of 6 surveys have been undertaken, the last in 2000 (Table 1). However, the 1973 survey only covered a few cross sections (4) and the 1962 survey data

Table 1 Cross section surveys undertaken in the Upper Motueka

Date	Number of sections surveyed
1960	23
1962	26
1973	4
1988	30
1995	30
2000	30

was considered to show less detail than other surveys, hence four surveys are included in the analysis (1960, 1988, 1995, 2000). The average river gradient in this reach is 0.0050, with a range from 0.0010 to 0.0067. There is a progressive lessening of the gradient towards the downstream end of the reach (Fig. 4).

The Lower Motueka reach extends from near Alexander Bluff bridge (CS1, RD16620) to the river mouth (CS54, RD3500), a distance of 13.1 km (Fig. 3b). There are now a total of 52 sections[4] in the reach with spacings ranging from 70 m to 470 m, and an average spacing of 250 m. Howes (1994) suggests the Lower Motueka River cross-section network dates back to 1949, however the earliest survey data located was dated 1957. Prior to 1978 a maximum of 15 cross sections were surveyed and the survey network only extended from CS53 (RD3850) to CS10 (RD14100, 2.5 km below Alexander Bluff bridge) limiting the precision of any analysis of mean bed levels and gravel volume changes. The survey network was reestablished in 1978 with 50 cross sections measured from CS54 (RD3500) at the coast to CS2 (RD16150) (slightly downstream of Alexander Bluff bridge). Since then additional cross sections have been established and there is now a total of 52 cross sections. Analysis of data prior to 1978 is limited by the small number of cross sections. Data is available for thirteen surveys in total, of which 9 are considered in this analysis[5] (Table 2). The average river gradient of this reach is 0.0019, with a range from 0.000 to 0.0081. The gradient is

[4] The cross sections are numbered 1 to 54 but there is no CS39 and CS50.
[5] Only one cross section was surveyed in 1965; the 1967 and 1968 surveys were treated as a single data set, as were the 1997 and 1998 data; the 1993 data have not been compiled.

very flat at the top of the reach and towards the coast, with the highest gradient in the middle of the reach (CS25). It tends to be highly irregular throughout the reach (Fig. 5).

Table 2 Surveys undertaken in the Lower Motueka

Date	Number of sections surveyed
1957	11
1960	15
1965	1
1967	13
1968	3
1978	50
1982	50
1984	51
1990	50
1993	40
1997	40
1998	7
2001	46

3. Methods

The general approach to analysis of cross section data comprised several steps:

- raw cross section survey data was located from various sources in TDC archives. This comprised a distance ("offset") measured along the cross section from a bench mark (BM), and an elevation ("RL") at each distance. Some cross sections had bench marks on the left and the right bank of the river, while others started at unstable locations (e.g. a cliff face) and only had one benchmark. Surveys traversed the berms, main channel, and back channel(s) of the river, although not all surveys covered the full width of each cross section.
- the data was compiled, and in many cases transformed (to take account of changes of bench marks, location of cross sections and length of cross section surveyed) to provide a common reference point for the subsequent analysis.
- the "clean" data from successive surveys at each cross section was plotted to identify the active channel width. This was held constant for calculating mean bed levels and changes in gravel storage through time.

- the changes in gravel storage were compared with figures on gravel extraction supplied by TDC.

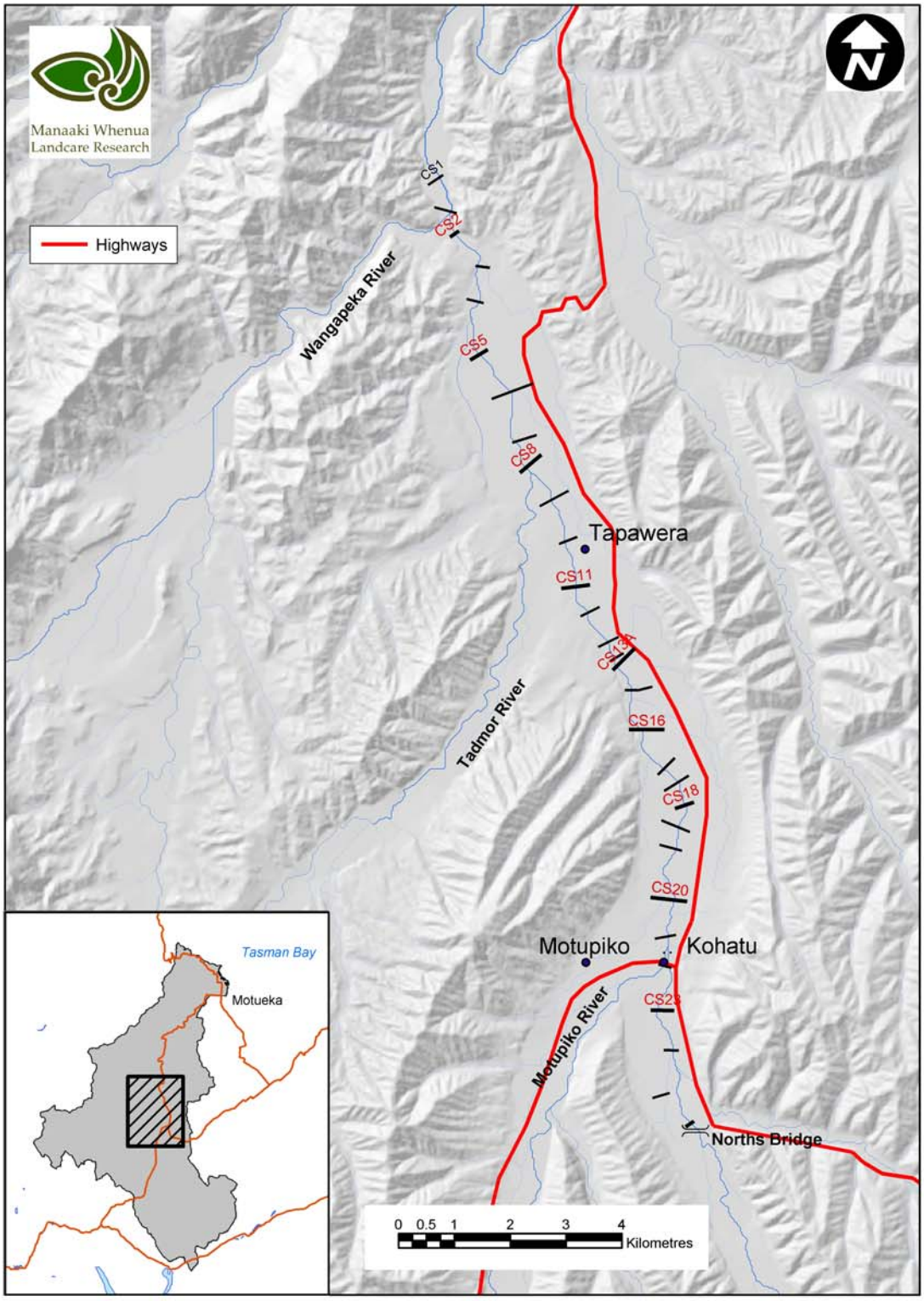


Figure 3a. Location of cross sections in upper Motueka reach.

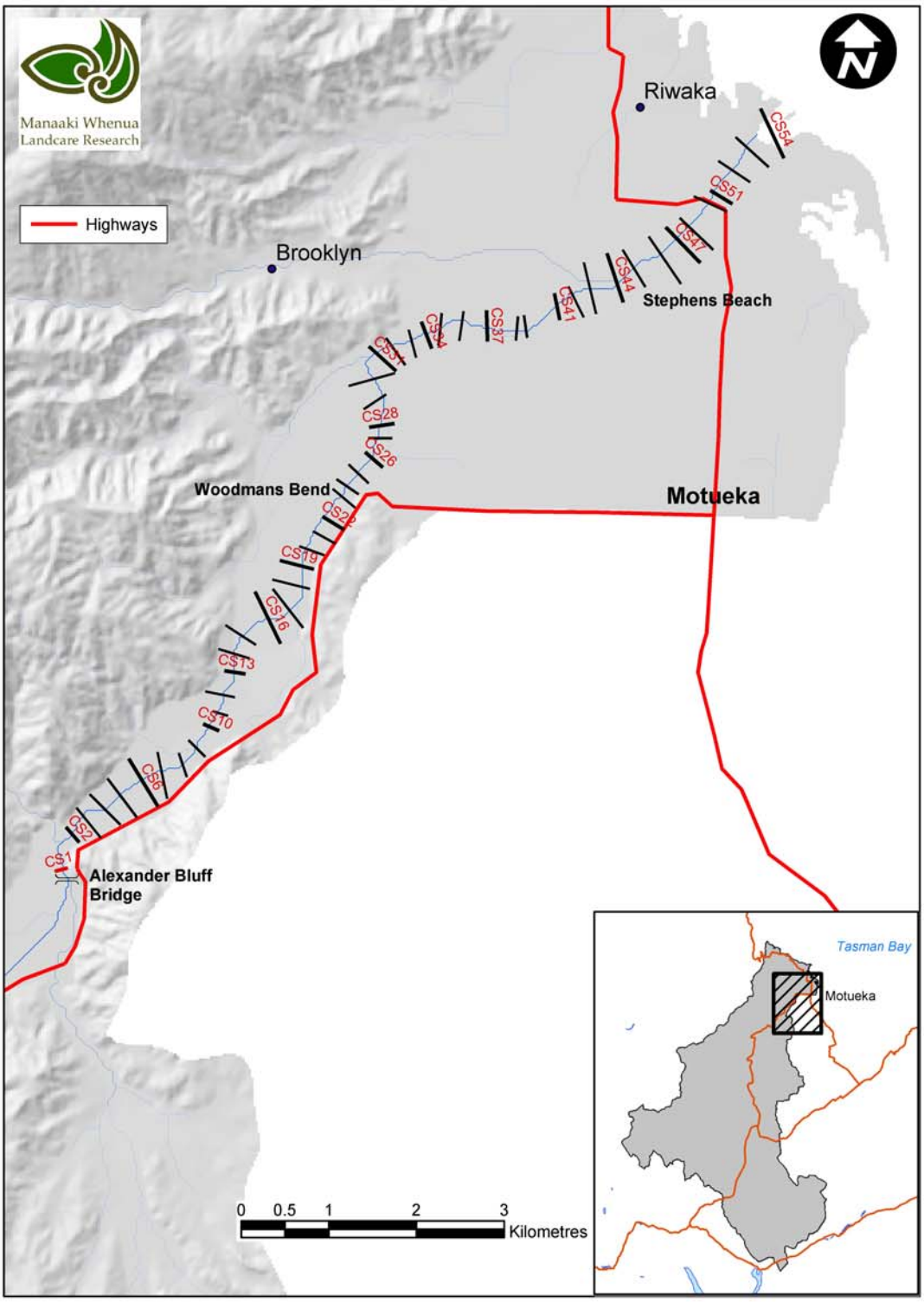


Figure 3b. Location of cross sections in lower Motueka reach.

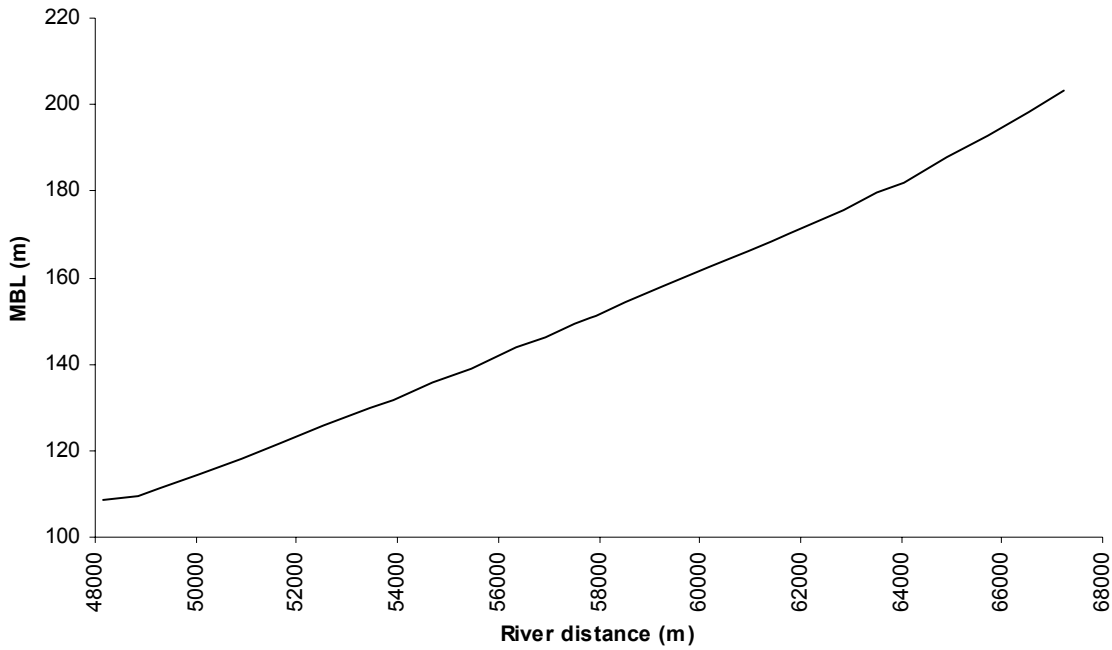


Fig. 4 Longitudinal profile of the upper Motueka River reach (based on mean bed level from the 2000 survey).

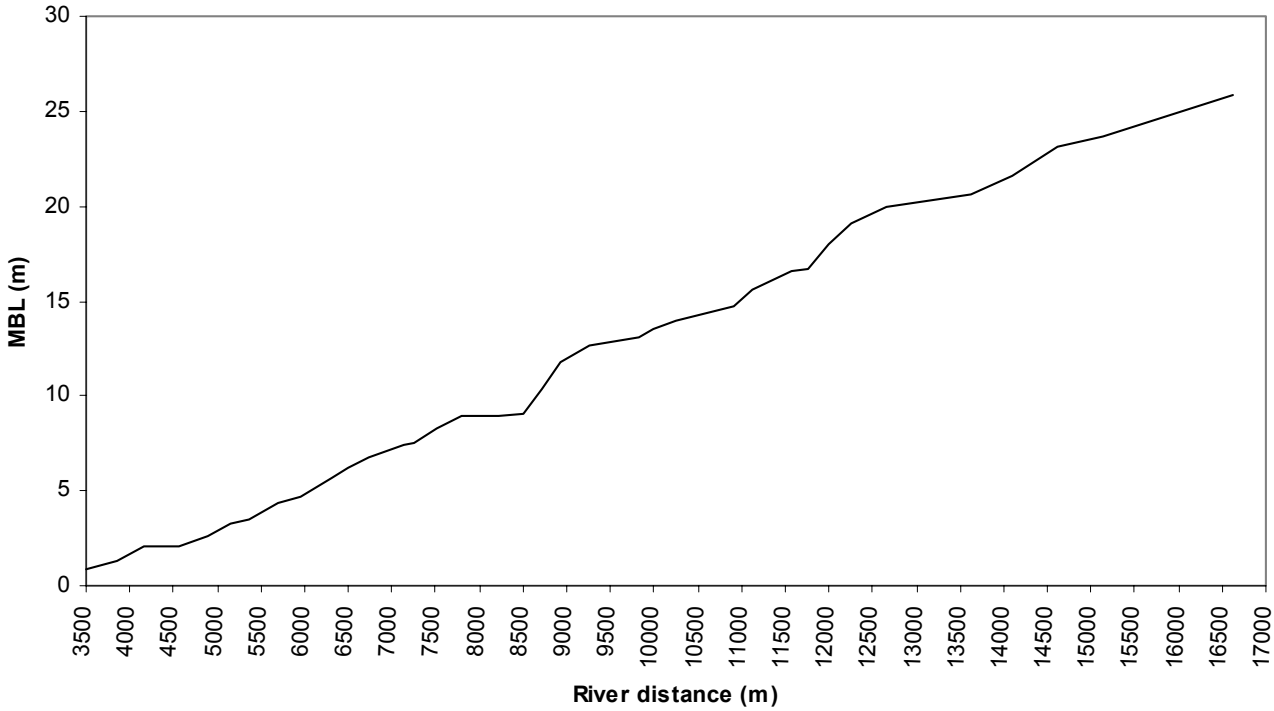


Fig. 5 Longitudinal profile of the lower Motueka River reach (based on mean bed level from the 2001 survey).

3.1 Raw data sources

Data sources comprised:

- river cross-section plans drawn at A1 size listing offset and RL, often with comments about vegetation or channel features.
- original survey figures in level books, containing the data from which the plans were drawn.
- bench mark cards showing a unique bench mark identifier, the date(s) the bench mark(s) was installed, the RL of the bench mark, the origin that was used to determine the RL, notes about changes to (or loss of) bench marks, and often a sketch of the cross section with the location of bench marks indicated. Location and elevation of bench marks is critical to comparing cross sections surveyed at different times. The bench mark cards for the upper Motueka provided information back to 1962 (and showed that all bench marks were converted from a Ministry of Works datum to a Lands and Survey datum), but for the lower Motueka only dated back to 1977.
- plans of cross section and bench mark locations, either on an air photo or map base.
- electronic files provided by Tasman District Council[6]. These included electronic data for recent surveys in the upper and lower Motueka (since 1988) and data compiled as part of the lower Motueka Flood Hazard study (Howes 1994).

Complete lists of data sources are given in Appendix 1.

3.2 Data transformation

After the raw cross section data were compiled, it was transformed (where necessary) to ensure common vertical and horizontal datums and provide a basis for comparing offsets and RLs along cross sections through time. This procedure was often difficult because many bench marks had been replaced or lost through time, fairly rudimentary records of these changes are available, and because the full length of each cross section was not always surveyed. The general procedure was:

1) The elevation (RL) measurements were adjusted with reference to bench mark elevations (from the bench mark cards). Different procedures were used in the upper and lower Motueka and these are detailed in Appendix 1 and 2.

[6] Provided by Eric Verstappen (TDC)

2) The cross sections were plotted to assess whether any offset adjustments were needed.
3) The offsets were adjusted along the cross section with reference to bench mark locations (from cross section plans or level books), or the location of the cross section relative to identifiable features (e.g. roads, houses) visible on aerial photo plans.

The details of the transformations made to each cross section are listed in Appendix 2.

The procedure for correcting the position of cross-sections from each survey year is illustrated in Fig. 6 (where both vertical and horizontal adjustments were required – CS2, upper Motueka) and Fig. 7 (where only horizontal adjustments were required – CS15, lower Motueka).

3.3 Data analysis

After all the surveys at each cross-section had been adjusted to overlay in their correct location, plots were prepared from which the active channel width was determined. From the survey data across the active channel, the mean bed level (MBL), change in MBL, and change in bed volume below the active channel from one survey to another was calculated. The rates of change in MBL and gravel volume per year were also calculated to allow comparison of changes that occurred over different intervals of time. The nature of the data imposed some limitations to data analysis and these are described at the end of this section.

3.3.1 Active channel width (ACW)

This is defined as the outer limits of major channel change during the entire survey period, and was kept constant through time for each cross-section. The active channel width[7] was taken to be the minimum distance between two stable banks i.e. the width between the inner-most common points that showed no (or very little) change through time (see Fig. 6–8). The position of the waters edge indicated on plans or in level books assisted identification of the main channel of the river and defining ACW.

[7] The upper Motueka analysis covers a longer time than previous analysis and therefore ACW (and hence gravel storage) tends to differ from previous analysis. For the lower Motueka ACW is similar to Howes (1994), since his analysis covered the period 1957–90, allowing direct comparison of results.

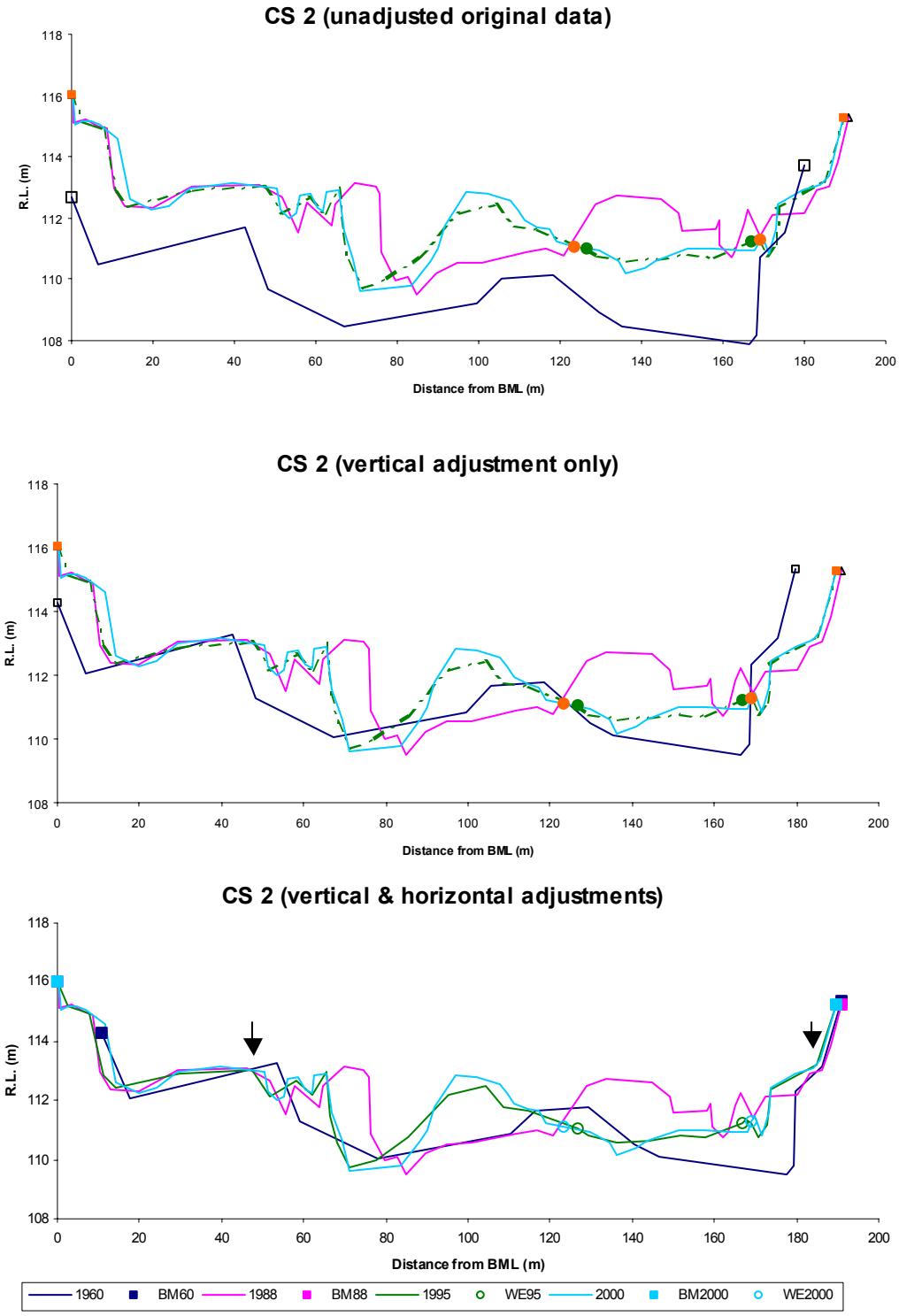


Figure 6 An example of a cross section correction where both vertical and horizontal adjustments were required (Upper Motueka CS2, RD49260). Note how the channel banks on both sides of the river, and the berms on the left side of the river align after adjustment. The arrows indicate the margins of the active channel used in the analysis; BM = bench mark, WE = waters edge (i.e. main channel)

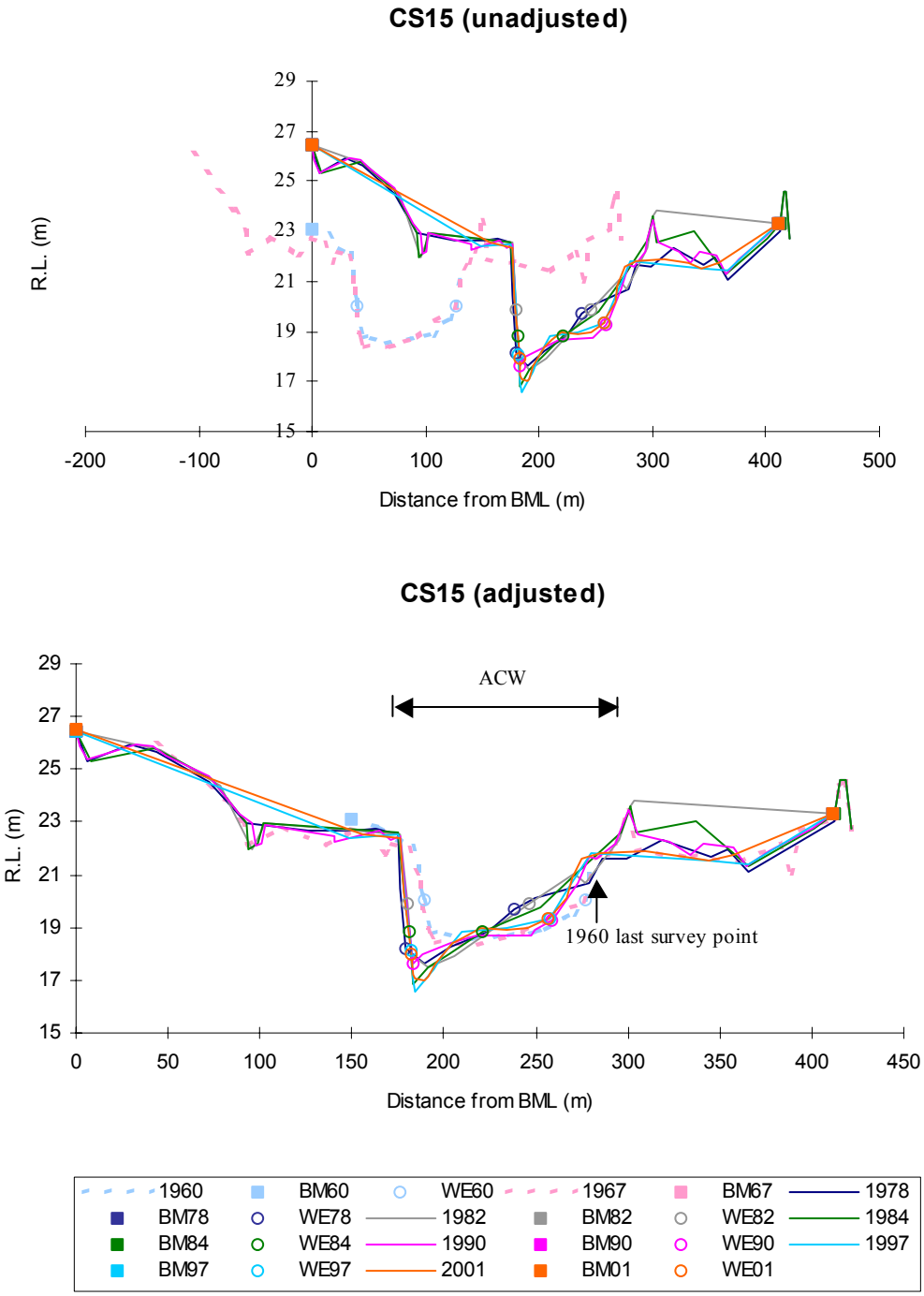


Fig. 7 An example of a cross section where only horizontal adjustment was required (Lower Motueka CS15, RD12910). Active channel width is indicated.

BM = bench mark, WE = waters edge (i.e. main channel)

3.3.2 Mean Bed Level (MBL) Calculation

The mean bed level represents "a horizontal straight line across the channel, positioned so there is as much bed above the line as below it" (Griffiths, 1979). The MBL of the active channel was found by dividing the end area of the cross section by the ACW as follows (see Table 3 and Fig. 8):

1. The RL of the active channel end points were found by interpolating between the RL of the points to the left and right of the end points of ACW.
2. The distance between adjacent survey points (dDist) was calculated (column 2). Survey points are shown as dots in Fig. 8.
3. The average RL between two adjacent points on the cross-section was calculated (column 4).
4. dDist was multiplied by the Average RL to give the average area under the plot between two neighbouring survey points (column 5). The total area under the cross section was calculated as the sum of all areas.
5. MBL was calculated by dividing the total area by the ACW.

For cross sections where survey data in some years did not extend for the full ACW, these were extended by merging data with the previous, or subsequent, survey that covered the full ACW. From inspection of the cross section plots, the year with the most similar data was used (with the aim of providing the most conservative estimate of change). For example, in Table 3 the 1960 data did not extend the full ACW so they were merged with 1967 data.

Net change in MBL was calculated as the difference in MBL at a cross section between the earliest (1957 for the lower Motueka and 1960 for the upper Motueka) and latest surveys (2001 for the lower Motueka and 2000 for the upper Motueka).

Table 3 is an example of a table used to calculate the MBL and Fig. 8 illustrates the process diagrammatically for lower Motueka CS15 in 1960.

3.3.3 Calculation of gravel volume

From the change in mean bed levels at adjacent cross sections and the distance between the cross sections the change in volume of gravel stored in the ACW between surveys was calculated by the "end-area" method.

Table 3 Mean bed level calculation table

Dist (m)	dDist (m)	RL (m)	Avg Level (m)	dDist*AL (m^2)	ACW (m)	MBL (m)
175		22.31				
183.76	8.76	22.09	22.20	194.46		
185.90	2.14	21.34	21.72	46.36		
188.34	2.44	20.26	20.80	50.75		
189.25	0.91	20.01	20.14	18.42		
193.52	4.27	18.76	19.39	82.79		
201.76	8.23	18.73	18.75	154.39		
215.48	13.73	18.55	18.64	255.86		
235.31	19.83	18.67	18.61	368.97		
250.86	15.56	18.82	18.75	291.63		
256.05	5.19	18.90	18.86	97.80		
265.81	9.76	19.36	19.13	186.70		
271.30	5.49	19.52	19.44	106.72		
276.79	5.49	20.01	19.77	108.52		
280.45	3.66	21.30	20.65	75.60		
283.19	2.75	21.60	21.45	58.88		
288.68	5.49	21.83	21.72	119.23		
292.95	4.27	22.18	22.01	93.97		
296	3.05	22.74	22.46	68.51		
	min BL	**18.55**		**2379.57**	**121**	**19.67**

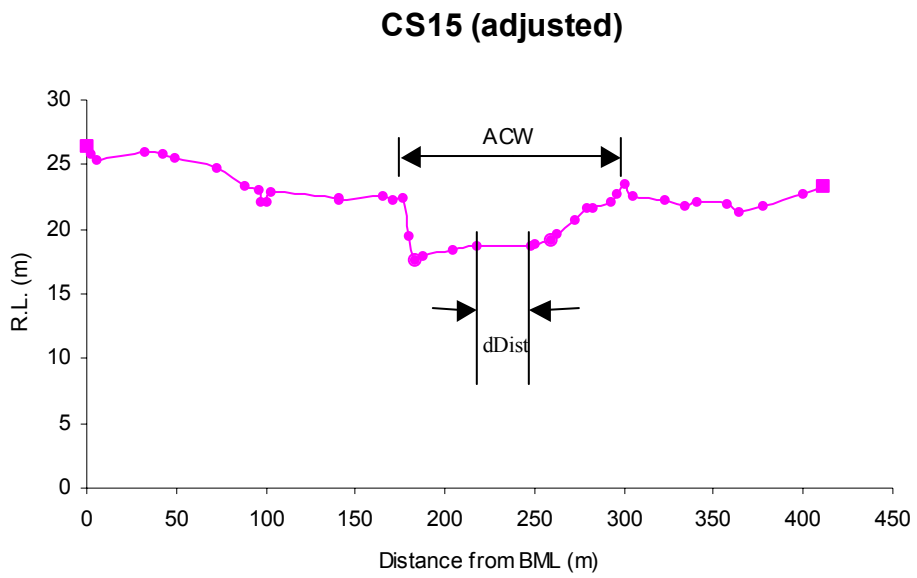


Fig. 8 Definition of terms used in mean bed level calculation

1 The change in mean bed level (dMBL) and cross sectional area (dA) at a cross section was calculated for consecutive surveys.

2 The change in cross sectional area (dA) at adjacent sections was averaged, and multiplied by the distance between cross sections to derive the bed volume change between adjacent sections (dV) between two survey periods.

$$dV = \frac{(dA_1 + dA_2)}{2} \times (Dist_1 - Dist_2)$$

where dV is the bed volume change

$\frac{(dA_1 + dA_2)}{2}$ is the average change in cross-sectional area

$Dist_1 - Dist_2$ is the distance between two river cross-sections

2. The bed volume change for the entire reach was calculated as the sum of volume changes between all cross sections.

The cumulative volume change for the reach was calculated as the difference in gravel volumes between the earliest (1957 for the lower Motueka and 1960 for the upper Motueka) and latest surveys (2001 for the lower Motueka and 2000 for the upper Motueka). For the upper Motueka this was calculated for the entire reach, and for the reach above CS2 (from which gravel has been extracted). For the Lower Motueka this was calculated for the 1957–2001 (for which only limited data is available and the calculation is less precise) and 1978–2001 (for which far more data is available and the calculation is more precise).

3.3.4 Rate of change of MBL and volume calculations

The rate of change of MBL and gravel volume per year was calculated for consecutive survey years to normalise the results for different lengths of time between surveys.

3.3.5 Limitations in MBL and volume calculations

There are some significant limitations to the analysis of the cross section data, primarily related to the number of cross sections surveyed each time. In some years not all cross-sections were surveyed. In the Upper Motueka, cross-sections 1A, 13A, 17A, and 18A were new cross sections established relatively recently. The Lower Motueka data had similar limitations, especially prior to

1978 when many cross sections were not surveyed and different cross sections were measured in different surveys.

The treatment of missing cross sections is outlined in Table 4, which is an extract of the MBL change and volume change calculation for years 1960 and 1988 for the Upper Motueka. The gaps in the "MBL 60" column are unsurveyed cross-sections. For example, CS18A was not

Table 4 Treatment of missing data

CS Dist	CS ID	dDist	MBL 60	MBL 88	dMBL 60-88	ACW	dA 60-88	dV 60-88	Bal 60-88
67243	26		203.68	203.20	-0.476	163.00	-77.66		
66547	25	696	198.92	198.78	-0.133	94.51	-12.62	-31416	-31416
65713	24	834	193.29	193.21	-0.080	169.02	-13.59	-10930	-42346
64905	23	808	187.88	187.81	-0.069	152.35	-10.46	-9719	-52065
64050	22	855	182.41	181.83	-0.582	167.75	-97.60	-46196	-98261
63525	21	525	179.79	179.61	-0.187	174.96	-32.78	-34225	-132486
62840	20	685	176.24	175.80	-0.435	161.65	-70.33	-35316	-167802
61780	19	1060	170.31	170.31	0.001	226.87	0.12	-37214	-205016
61405	18A	375		168.38		182.79			-205016
60965	18	440	165.78	165.99	0.211	110.73	23.35	9561	-195455
60560	17A	405		164.44		154.70			-195455
60205	17	355		162.48		133.64			-195455
59250	16	955	158.20	157.89	-0.314	157.30	-49.39	-22330	-217785
58512	15	738	154.93	154.90	-0.030	179.95	-5.37	-20207	-237992
58512	15	738		154.44		214.00			-237992
57953	14	559	151.17	151.10	-0.071	140.68	-9.95	-4284	-242276
57822	13A	131		150.36		115.50			-242276
57518	13	304	149.58	149.30	-0.283	175.43	-49.60	-12953	-255229
56924	12	594		146.71		186.09			-255229
56355	11	569	144.89	143.80	-1.089	214.27	-233.39	-164561	-419790
55470	10	885	139.95	139.06	-0.896	163.47	-146.44	-168076	-587866
54690	9	780	135.81	135.96	0.150	337.60	50.80	-37299	-625165
53915	8	775	131.71	131.66	-0.055	237.74	-12.98	14657	-610508
53445	7	470	129.78	129.74	-0.046	255.86	-11.88	-5840	-616348
52532	6	913	125.35	125.60	0.256	255.48	65.41	24439	-591909
51677	5	855	121.40	121.63	0.232	223.19	51.77	50097	-541812
50905	4	772	118.27	118.31	0.039	187.49	7.29	22800	-519012
50065	3	840	114.76	114.56	-0.199	126.19	-25.05	-7460	-526472
49260	2	805	110.81	111.65	0.844	137.45	115.96	36590	-489882

48860	1A	400		109.93		111.04		23192	-466689
48160	1	700				199.14			-466689

surveyed in 1960 so the change in MBL between 1960 and 1988 (dMBL 60-88) and the change in area (dA 60-88) for CS18A could not be found. Thus, the change in volume was estimated between CS18 and CS19 instead of CS18 and CS18A, which are adjacent sections. This same approach was also adopted to determine the rate of change of MBL and gravel volume.

Missing data in lower Motueka data was treated in the same way. However, because of the large amount of data involved, the analysis was separated into the 1957–1978 period and the 1978–2001 period.

4. Results

Results of the cross section analysis are summarised in Table 5 for the upper Motueka and in Table 6 for the lower Motueka. The MBL and gravel storage changes at each cross section are listed in Appendices 3–8. The results are discussed in terms of mean bed level change (both in absolute terms and as rates of change per year), and gravel volume changes within the active channel (also in absolute terms and as rates of change per year). The trends in mean bed level and gravel volume changes with distance down the river are illustrated in Figs. 9–12 for the upper Motueka and Figs. 13–17 for the lower Motueka. The gravel volume changes are compared with the amount of gravel estimated to have been extracted from the river over the same time period (Fig. 18). The results are presented with reference to cross section number; the equivalent river distances are given in Appendices 3 (Upper Motueka) and 5 (Lower Motueka).

4.1 Upper Motueka

4.1.1 1960 to 1988

The mean bed level change across all sections between 1960 and 1988 averaged –0.14 m, with values ranging from +0.84 m (CS2) to –1.09 m (CS11). The MBL trend over this relatively long time was characterised by a dominance of degradation from the upstream end at CS26 down to CS10 (Fig. 9), with the exceptions of CS18 (+0.21 m) and 19 (no change). Downstream of CS10 there was an alternation of degradation (by small amounts) and aggradation, with the greatest value of +0.84 m at CS2 just above the Wangapeka confluence.

The two cross sections where degradation was greatest (–1.09 m and –0.9 m) occurred at Tapawera Bridge at CS11 and CS10, respectively. Severe degradation also occurred at Norths Bridge (CS26) and Kohatu Bridge (CS22) with decreases in MBL of –0.48 m and –0.58 m, respectively. These sites of greatest degradation are associated with easy accessibility to the

Table 5 Summary data for Upper Motueka reach. Figures in brackets are ranges.

		60-88	88-95	95-00	60-00
Upper Motueka, whole reach	**Average change MBL (m)**	– 0.14 (– 1.09 to +0.84)	– 0.04 (– 0.25 to +0.29)	– 0.04 (– 0.37 to +0.24)	– 0.20 (– 1.15 to +0.62)
	Average rate of change MBL (m/yr)	– 0.005 (– 0.039 to +0.030)	– 0.005 (– 0.036 to +0.042)	– 0.007 (– 0.073 to +0.048)	–0.005 (–0.030 to +0.015)
	Net gravel volume change (m^3)	– 466,689	–130,591	–131,472	–715,475
	Net rate of gravel volume change (m^3/yr)	–16,667	–18,656	–26,294	–17,887
Upper Motueka, above CS2	**Net gravel volume change (m^3)**	– 489,882	–121,862	–116,394	–728,138
	Net rate of gravel volume change (m^3/yr)	–17,496	–17,409	–23,279	–18,203
	Gravel extraction (m^3)	378,102	118,931	63,714	560,747

Table 6 Summary data for lower Motueka reach. Figures in brackets are ranges.

	57-60	60-67/68	67/68-78	78-82	82-84	84-90	90-97/98	97/98-01	57-01	78-01
Average change MBL (m)	+0.04 (–0.46 to +0.34)	–0.20 (– 0.59 to +0.38)	–0.06 (– 0.58 to +0.53)	–0.03 (– 0.49 to +0.97)	–0.11 (– 0.89 to +0.43)	–0.07 (– 0.58 to +0.31)	–0.06 (– 0.46 to +1.02)	–0.01 (– 1.01 to +0.28)	–0.64 (–1.17 to – 0.27)	–0.30 (–0.93 to +0.29)
Average rate of change MBL (m/yr)	+0.012 (–0.154 to +0.113)	–0.027 (–0.084 to +0.054)	–0.006 (–0.053 to +0.048)	–0.007 (–0.123 to +0.241)	–0.056 (–0.443 to +0.213)	–0.012 (–0.096 to +0.051)	–0.009 (–0.066 to +0.146)	–0.004 (–0.253 to +0.069)	–0.015 (–0.027 to – 0.006)	–0.070 (–0.586 to +0.007)
Net gravel volume change (m^3)	+32,578	–389,522	–30,130	–81,032	–206,599	–234,421	–53,920	–33,141	–1,113,260	–608,877
Net rate of gravel volume change (m^3/yr)	+10,859	–51,936	–3013	–20,258	–103,300	–39,070	–6740	–11,047	–25,301	–26,473
Gravel extraction (m^3)	21,220	147,052	331,487	113,545	93,055	245,400	91,276	24,800	1,067,835	604,262

river. At most other sites bed degradation was generally <0.2 m. Aggradation, where it occurred, was <0.26 m except at CS2 at the downstream end of the reach above the Wangapeka confluence.

The bed level changes equate to an average rate of MBL change between 1960 and 1988 of –0.005 m/yr. The rate of change ranged from +0.030 m/yr increase to –0.039 m/yr decrease. Most of the upstream sections between CS26 and CS11 degraded, at rates less than –0.02 m/yr (Fig. 10). The rates of degradation at CS 10 and 11 were –0.039 and –0.032 m/yr. Below CS10 rates ranged from –0.007 m/yr to+0.03 m/yr.

Between 1960 and 1988 over the entire Upper Motueka reach from Norths Bridge to the Wangapeka River there was a net change in gravel storage of –467,000 m^3, equivalent to an average loss of 16,670 m^3/yr. There was a reduction in gravel volume between all cross sections except between CS19 and CS18, and from CS9 to CS3, and from CS 3 to CS1A. For the part of the reach from which gravel was extracted (CS2 and above) there was a net change in gravel storage of –490,000 m^3, equivalent to an average loss of 17,500 m^3/yr.

Over this period the reach can be split into two zones. The upper part of the reach from the upstream end at Norths Bridge (CS26) down to above the Tadmor confluence (CS9) was dominated by degradation, except between CS19 and CS18 that aggraded slightly (Fig. 11). Below the Tadmor confluence gravel deposition dominated from CS9 to CS1A, except for slight degradation between CS8 and CS7 and between CS4 and CS3. The greatest deposition of 50,100 m^3 was between CS6 and CS5.

The largest amounts of gravel lost in this 28-year period were 165,000 m^3 (or 5,880 m^3/yr) between CS12 and CS11, and 168,000 m^3 (or 6,000 m^3/yr) between CS11 and CS10. These cross sections are immediately upstream and downstream of Tapawera Bridge. Large losses also occurred downstream of the Kohatu bridge and Norths bridge.

4.1.2 1988 to 1995

Over this period the mean bed level change across all sections was –0.04 m with a range from +0.29 m to –0.25 m. There was more alternation between aggradation and degradation down the length of the reach (Fig. 9) than between 1960 and 1988. The majority of sections (20 out of 29) degraded, mostly by small amounts (<0.2 m), and there were three sections that aggraded by slightly larger amounts (0.17–0.29 m). During this period the cross sections that degraded the most (CS1A, 2, 6, 17A, 19, 20 and 24) did not occur at bridges. The only long zone showing consistent behaviour was from CS21 to CS14 with all cross sections degrading. Throughout the remainder of the reach degradation and aggradation alternated every 3 or 4 cross sections. The greatest aggradation in this 7-year period of +0.29 m was at CS13A and the greatest degradation was a reduction in MBL of –0.25 m. occurring at CS2. Only 9 out of 22 cross sections that were surveyed in 1960, 1988 and 1995 showed the same trend (of either degradation or aggradation) over both intervals of time (1960–88 and 1988–95).

On average MBL degraded between 1988 and 1995 at a rate of –0.005 m/yr, the same as in the previous period. The rate of change ranged from an increase of +0.042 m/yr to a decrease of –0.036 m/yr. Most sections degraded at rates of –0.05 to –0.25 m/yr (Fig. 10). The maximum degradation rate of –0.036 m took place at the downstream end at CS2, which in the previous period has aggraded rapidly (+0.30 m/yr).

During this 7-year period, the net change in gravel volume was much lower than the previous 28-year (1960–88) period at –130,600 m^3. However, the average loss rate was slightly higher than the previous period at –18,660 m^3/yr. For the part of the reach from which gravel was extracted (CS2 and above) there was a net change of –122,000 m^3 of gravel at a rate of 17,409 m^3/yr. During this period there were alternating zones of degradation (CS26–23, CS21–14, CS12–8, CS4–1) and aggradation (CS23–21 (downstream of Kohatu bridge), CS14–12 (upstream of Tapawera bridge), CS8–4 (downstream of Tadmor confluence) – see Fig. 11).

The largest gravel loss was between CS20 and CS19 (–32,900 m^3), with large losses also between CS25 and CS24, CS10 and CS9, CS3 and CS2. The greatest aggradation was between CS5 and CS4 (+16,074 m^3) in a zone between CS 4 and CS8 that also aggraded between 1960 and 1988. Significant aggradation also occurred between CS23 and CS21 (downstream of Kohatu bridge, an area previously subject to degradation). About two thirds

(14 out of 22) of the cross sections showed the same trend, of either aggradation or degradation, as in the 1960–88 period with the remainder showing the reverse trend.

4.1.3 1995 to 2000

During this 5-year period the mean bed level change across all sections was –0.04 m (the same value as 1988–95), with values ranging from +0.24 m to –0.37 m. Like the 1988–95 period there was marked fluctuation in MBL change between aggradation and degradation down the length of the reach (Fig. 9). Degradation and aggradation did not dominate for any long section of the river, instead they fluctuated often from one cross-section to the next.

The greatest degradation occurred at CS5, below the Tadmor confluence, CS12, just upstream of Tapawera Bridge, and CS1A , downstream of the Wangapeka confluence, with MBL reductions of 0.33 m, 0.37 m and 0.37 m, respectively. The greatest aggradation occurred at CS19 and CS14 with MBL increases of +0.16 m and +0.24 m, respectively. At most other cross sections bed level changes were <0.15 m.

The average rate of MBL change between 1995 and 2000 was –0.007 m/yr with a range from +0.048 to –0.073 m/yr. Compared to earlier rates of change, the rates of change between 1995 and 2000 showed much more fluctuation from one cross section to the next and the rates at individual cross sections tended to be higher (Fig. 10).

During this 5-year period the total gravel volume change was –131,500 m^3, which exceeded the loss during the previous 7-year period. The rate of loss was high at 26,294 m^3/yr. For the part of the reach from which gravel was extracted (CS2 and above) there was a net change of –116,000 m^3 of gravel at a rate of 23,279 m^3/yr.

About two thirds of the sections (19 out of 29) degraded with the remainder aggrading. Like the 1988-95 period there were no well-defined long zones of degradation or aggradation, but a fluctuation from aggradation to degradation along the whole reach (Fig. 11). The greatest

gravel loss (–27,500 m^3) occurred downstream of the Tadmor River between CS5 and CS4, which was the zone with the greatest aggradation in the previous survey period. Large gravel losses also occurred between CS26 and CS25, between CS13 and CS11, and between CS9 and CS8 (16,500–21,500 m^3). The greatest aggradation (+14,700 m^3) was between CS7 and CS6, downstream of the Tadmor River confluence and just upstream of where the greatest degradation occurred. At all other cross sections that aggraded, the volume of gravel aggradation was relatively small (<10,000 m^3).

4.1.4 Net change 1960–2000

Over the 40 year period from 1960 to 2000 the average mean bed level change for the entire reach was –0.20 m with a range from –1.15 to +0.62 m. Most sections (16 out of 22) that were surveyed at all 3 times have degraded (Fig. 12). Two zones show a consistent net change:

- from CS26 to CS19 (from Norths bridge to c.2.5 km below Kohatu) all cross sections have net degradation (although not all have degraded between all 4 surveys);
- from CS7 to CS5 (from c.1 km below Glen Rae Road to just above Bennets Road) all cross sections have aggraded (but none have aggraded between all 3 survey intervals).

In the remainder of the reach there is a fluctuation from net degradation to net aggradation. At only 4 out of 22 sections was there a consistent trend through the entire period, and at all those sites the trend was for degradation. There were no sections that aggraded for the 40 years, although there were 6 that aggraded in 2 out of the 3 survey intervals (3 of these had net degradation). Cross sections that had particularly high amounts of net degradation (>0.5 m) were CS26 and CS25 (downstream of Norths bridge), CS20 (1 km downstream of Kohatu), CS11 and CS10 (upstream and downstream of Tapawera bridge). The highest net aggradation was at CS2, just upstream of the Wangapeka confluence. The location of cross sections with the greatest bed level change (either degradation or aggradation) did not remain consistent through the 3 survey intervals.

There was an increasing rate of mean bed level change for the whole reach through the 3 survey intervals, from –0.004 m/yr between 1960 and 1988 to –0.007 m/yr between 1995 and 2000 (Table 5). Similarly the maximum rates of degradation and aggradation have increased (from –0.039 to –0.073 m/yr and +0.030 to +0.048 m/yr respectively).

The net change in the amount of gravel stored in the active channel of the entire reach between 1960 and 2000 was –715,475 m^3, and for the part of the reach from which gravel was extracted (CS2 and above) there was a net change of –728,138 m^3. During this time the rate of gravel loss per year from the entire reach has progressively increased (16,667 m^3/yr between 1960 and 1988, 18,656 m^3/yr between 1988 and 1995, 26,294 m^3/yr between 1995 and 2000). A similar trend was shown for the part of the reach from which gravel was extracted, increasing from 17, 496 m^3/yr to 23,279 m^3/yr. All cross sections above CS7 have lost gravel (Fig. 12), with the greatest loss between CS13 and CS9. Below there most cross sections have aggraded by small amounts.

Fig. 9 Upper Motueka mean bed level changes between 1960 and 2000

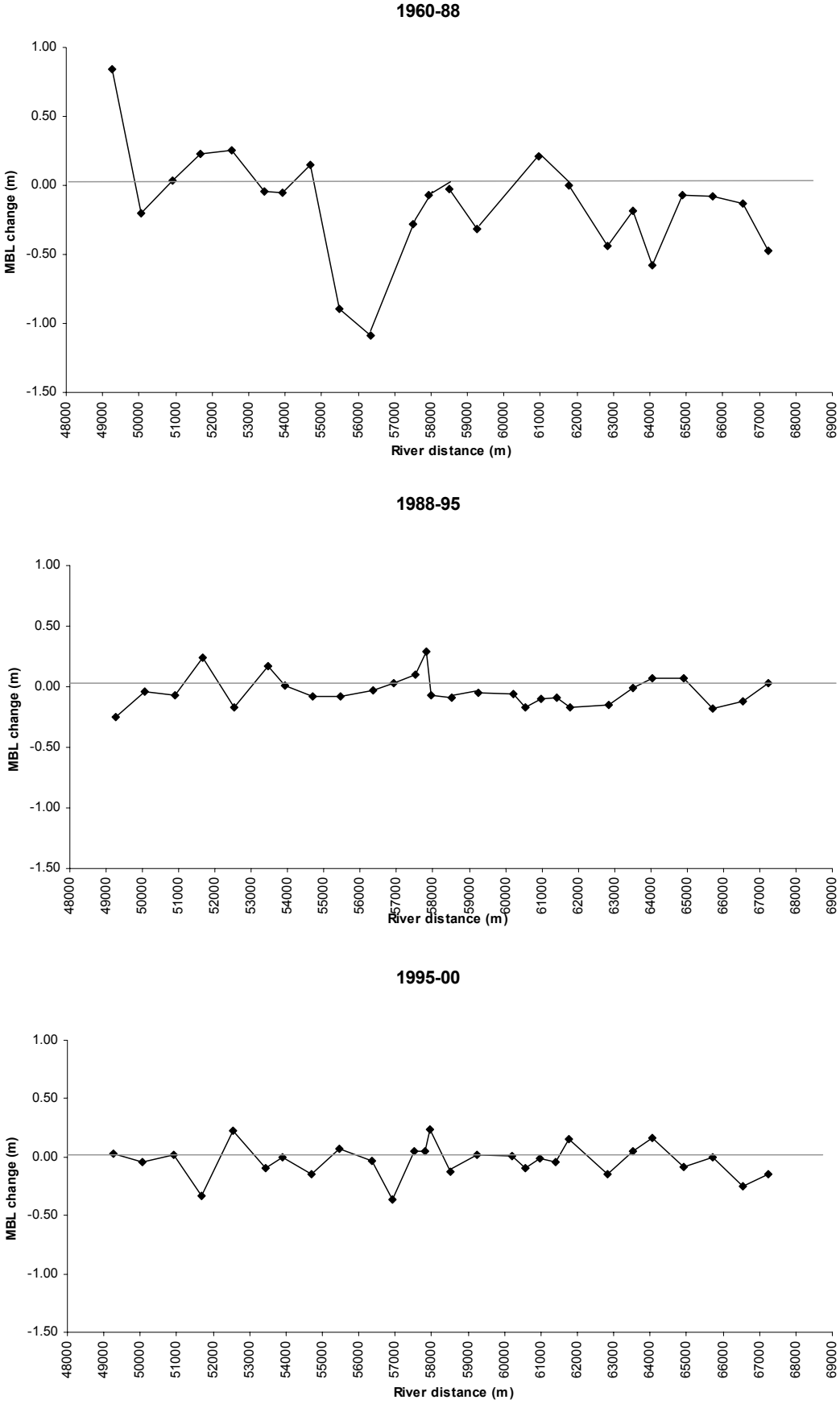
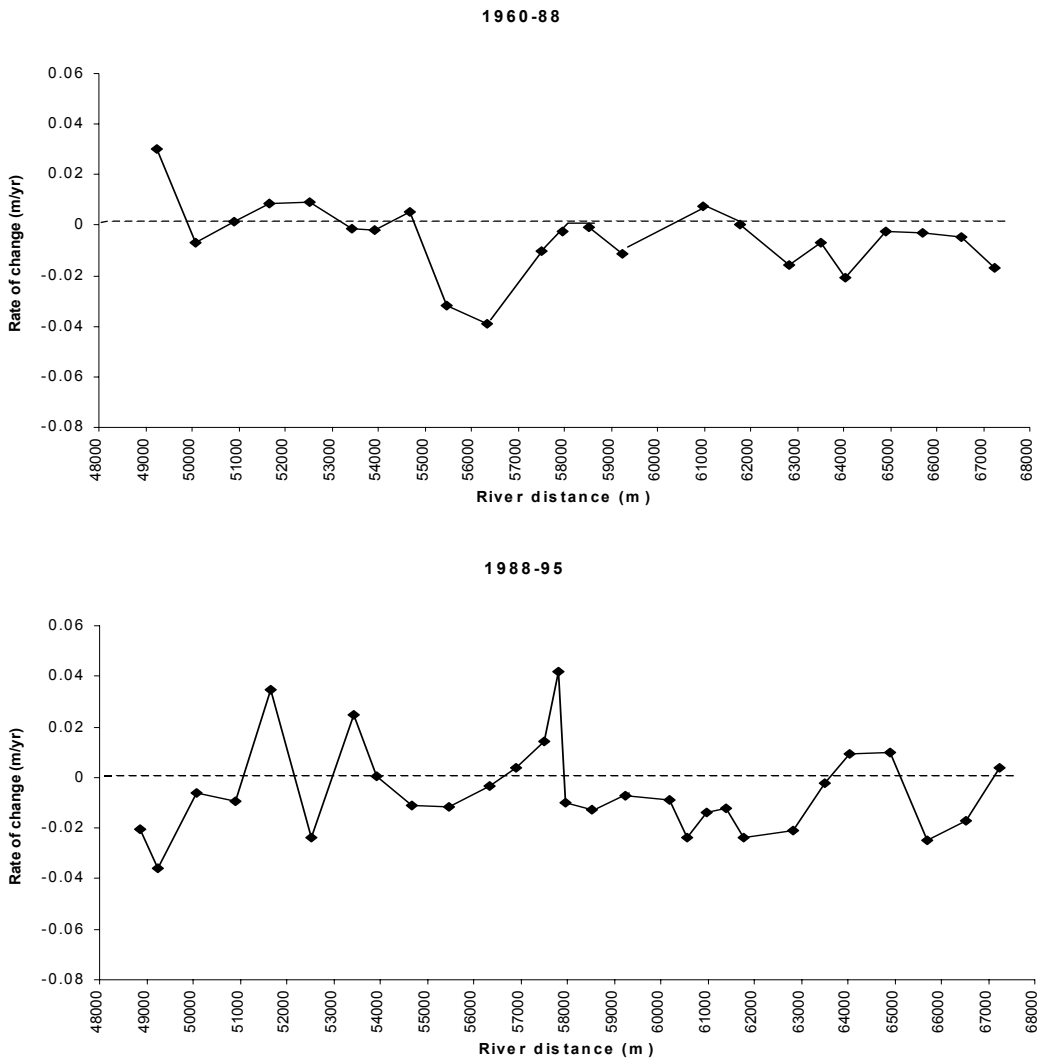


Fig. 10 Upper Motueka rate of mean bed level change between 1960 and 2000



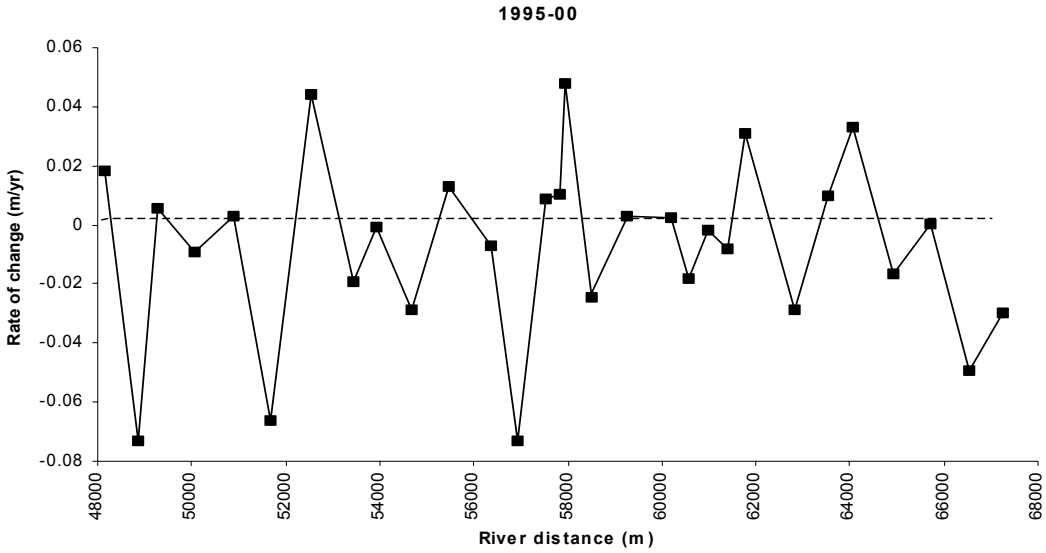
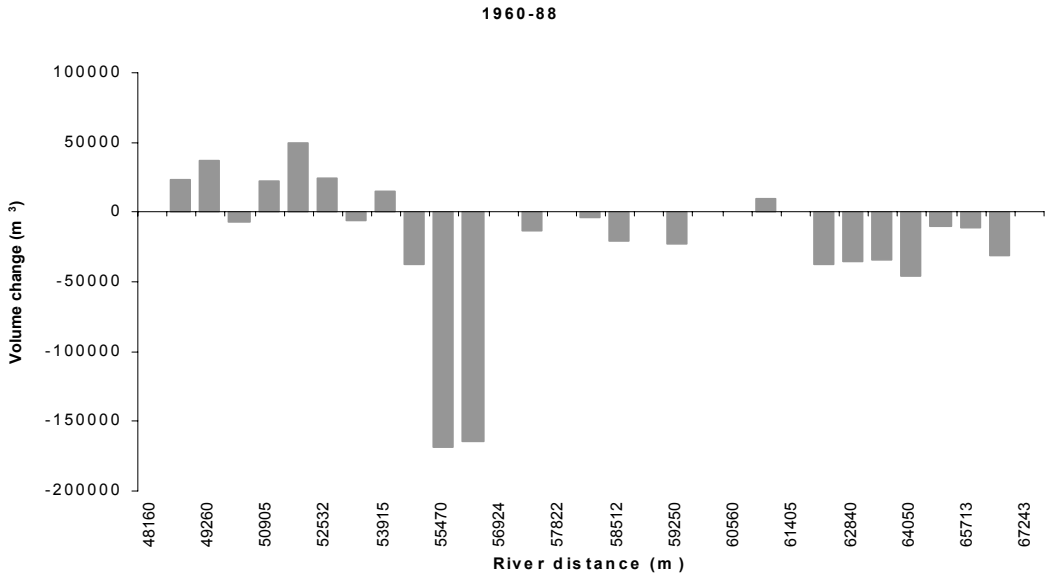


Fig. 11 Upper Motueka gravel volume changes between 1960 and 2000



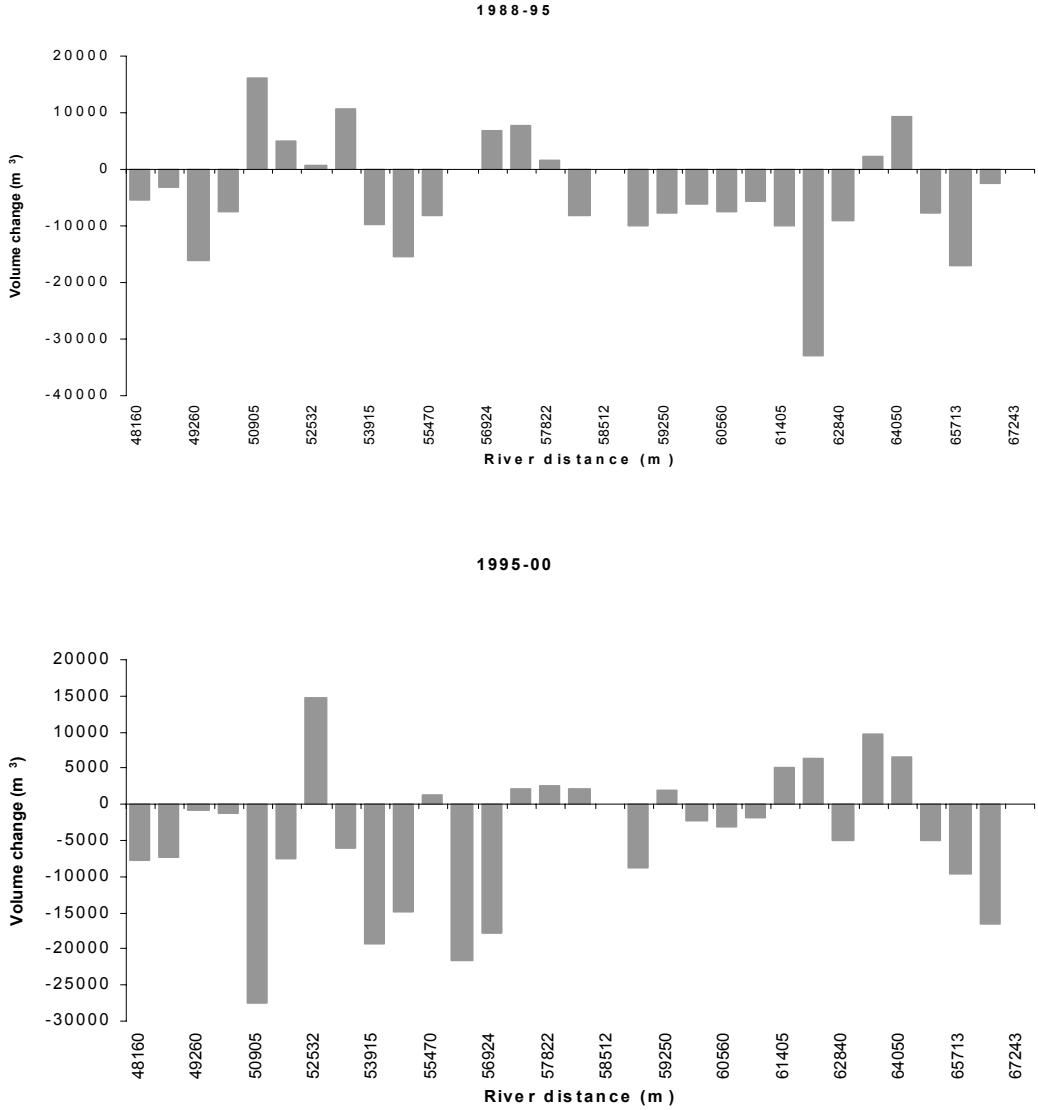
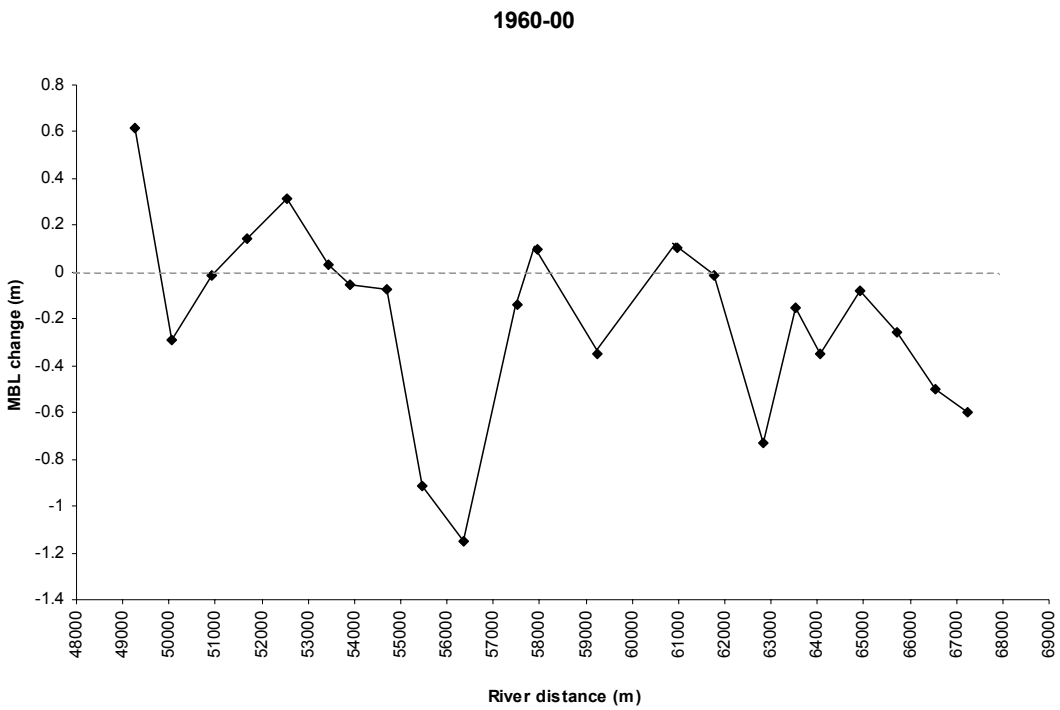
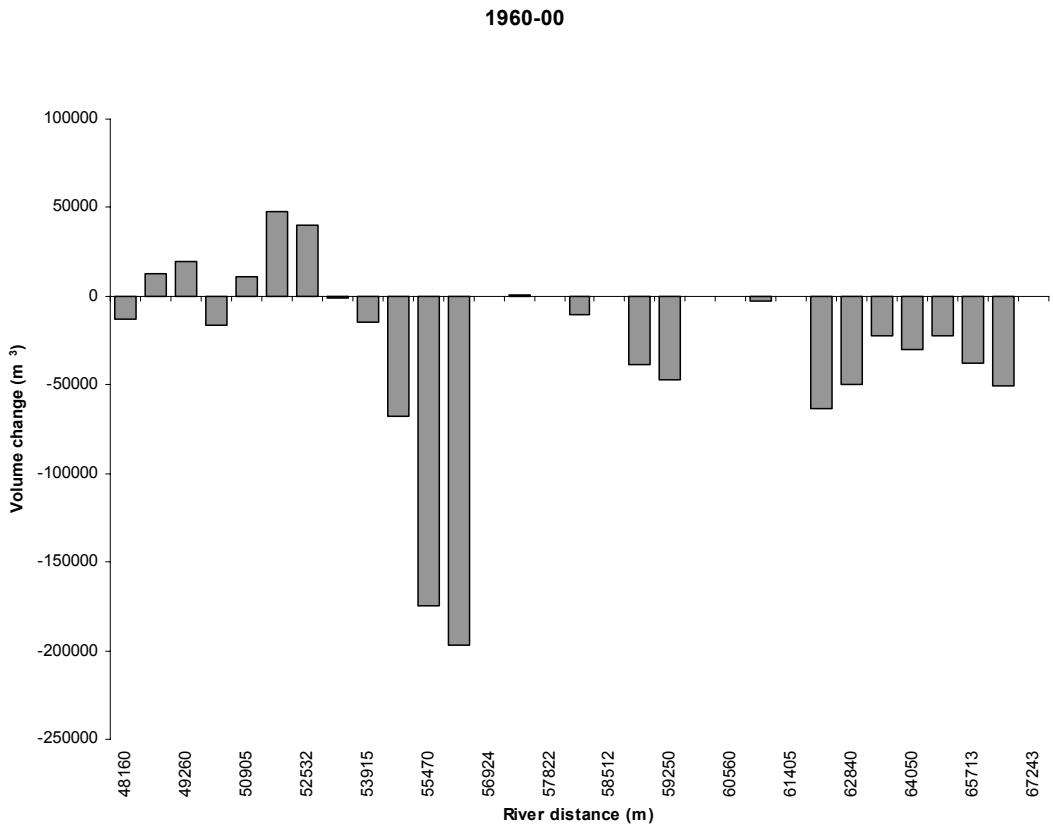


Fig. 12 Upper Motueka net mean bed level and gravel volume changes between 1960 and 2000





4.2 Lower Motueka

4.2.1 1957 to 1960

During this period only 10 cross sections, between CS10 and CS52 were surveyed at both times. The average MBL change was +0.04 m, with a range from –0.46 to +0.34 m. Aggradation dominated (at 7 of the 10 cross sections) for the cross sections surveyed (Fig. 13). The MBL change occurred over a 3-year period giving an average rate of MBL change of +0.012 m/yr. Rates of bed level change ranged from +0.113 m/yr to –0.154 m/yr. All 5 cross sections in the 4.7 km reach from CS24 to CS44 aggraded (Fig. 13). Downstream from this section degradation occurred at CS47 and CS49. However, the bed was aggrading again at CS52, 600 m from the river mouth.

The 1957 to 1960 period was the only one where the overall reach was aggrading, although that assessment is based on a small number of cross sections. The total change in bed volume was +32,578 m^3, and on average each section gained 3620 m^3 or 1200 m^3/yr. The maximum aggradation took place at the sections immediately upstream of Stephens Beach (Fig. 15), between CS37 and CS44, with a gain of 36,070 m^3 (12,020 m^3/yr). The sections upstream of here (from CS28) also aggraded by c.15–30,000 m^3. The greatest gravel loss was between CS10 and CS20 (–63,500 m^3, 21200 m^3/yr).

4.2.2 1960 to 1967/68

During this period only 6 cross sections, between CS15 and CS52 were surveyed at both times. The average MBL change was –0.20 m (–0.027 m/yr), with a range from +0.38 m (+0.054 m/yr) to –0.59 m (–0.084 m/yr). The bed degraded over the 3 km reach from CS15 to CS28 (Fig. 13), with progressively larger bed level decreases downstream (from –0.04 to –0.59 m), and also at the downstream end at CS52. CS33 was the only cross section to aggrade.

The total gravel volume change was –389,500 m^3, however this is based on analysis of a small number of cross section with large distances between them and is likely to

be inaccurate. The gravel volume analysis between adjacent cross sections suggests all the surveyed reaches were degrading even though MBL was increasing at CS33 (Fig. 15).

4.2.3 1967/68 to 1978

More data is available for this period with 14 cross sections, between CS15 and CS54, measured at both times. The overall MBL change between 1967/68 and 1978 was –0.06 m (–0.006 m/yr), with a range from +0.53 m (0.048 m/yr) to –0.58 m (–0.053 m/yr). Most (9) of the surveyed sections were degrading with highest rates in the upper and middle part of the reach (Figs. 13 and 14). The maximum degradation rate in this period was at CS33 where the aggradation rate was greatest in the previous period (1960–1967/68) and it had also aggraded between 1957 and 1960. This might imply that gravel extraction was taking place at this cross section. The highest rate of aggradation was towards the top of the reach at CS16, although most of the upper part was degrading.

The total net gravel volume change was very small at –30,130 m^3, although some of the changes between adjacent cross sections were large. There was a reduction in gravel volume, mostly by small amounts (<10,000 m^3) between all cross sections, except between CS15 and CS24 where aggradation occurred (Fig.15). The largest gravel losses were between CS33 and CS52 (–38,113 m^3 - probably influenced by the long distance between adjacent surveyed cross sections), and between CS53 and CS54. The greatest aggradation was between CS16 and CS18 (49,627 m^3).

4.2.4 1978 to 1982

This is the first interval for which comprehensive data is available (49 cross sections). The mean bed level change across all sections was –0.03 m with values ranging from +0.97 m to –0.49 m (Fig. 13). At the upstream end at CS1 there was aggradation of c.1 m. Downstream of this degradation and aggradation by small amounts (mostly

±0.2 m) alternated down the reach. The exception was a 3 km long reach between CS21 and CS35, which degraded consistently, and where the maximum MBL change of –0.49 m occurred.

The average rate of mean bed level change between 1978 and 1982 was –0.007 m/yr, with a range from +0.241 m/yr to –0.123 m/yr. The highest degradation rate was at CS23, near Woodmans Bend, and the highest aggradation rate was at CS1 at the upstream end (Fig. 14). Along the reach there were fluctuations typically within the range of ±0.05 m/yr.

Between 1978 and 1982, the lower Motueka reach lost a total of 81,000 m^3 of gravel at an average rate of 20,258 m^3/yr. The average loss per cross section was 1,690 m^3, or 422 m^3/yr. Degradation occurred at about two thirds of the cross sections (31 of 48), with the greatest loss (–18,000 m^3 or 4,500 m^3/yr) between CS21 and CS23 at Woodman's Bend (Fig. 15). The greatest aggradation (+11,200 m^3, 2,790 m^3/yr) occurred just downstream of Alexander Bluff Bridge at CS3. During this period there was a distinct zonation of zones of degradation (between CS3 and CS7, CS20 and CS36, CS45 and CS54) and aggradation (between CS7 and CS20, CS36 and CS40).

4.2.5 1982 to 1984

The mean bed level change across all sections was –0.11 m with a range from +0.43 m to –0.89 m. Most (38 of 49) cross sections degraded (Fig. 13), typically by small amounts (<0.2 m). There were three cross sections with large MBL change of –0.89 m (CS2), –0.67 m (CS9), and –0.61 m (CS37). The only cross section that aggraded substantially (+0.43 m) was at CS40, and two other nearby cross sections also aggraded.

The average rate of MBL change was the highest in the entire record at –0.056 m/yr, with a range from +0.213 m/yr to –0.443 m/yr (Fig. 14). This period also had the highest maximum degradation rate. Three cross sections (CS2, 0.443 m/yr, CS9, 0.336 m/yr, CS37, 0.303 m/yr) had particularly high degradation rates. Only one cross-section was aggrading rapidly (CS40, 0.213 m/yr).

The net loss of gravel from the lower Motueka reach between 1982 and 1984 was very large at 206,600 m^3, representing an average rate of 103,300 m^3/yr. The average loss per section was 4132 m^3 (2066 m^3/yr per section). Almost all cross sections degraded (Fig. 15), with particularly high degradation in the lower reaches of the river (below CS38) where most cross sections lost 5000–25,000 m^3. A few cross sections aggraded (between CS3 and CS5, CS34 and CS41), with only the area between CS37 and CS38 aggrading substantially (+15,508 m^3). It is interesting to note that the greatest degradation and aggradation both occurred within a 0.75 km reach.

4.2.6 1984 to 1990

During this period the mean bed level change across all sections was –0.07 m with a range from +0.31 m to –0.58 m. There was a dominance of degradation (at 30 of 49 cross sections). MBL changes alternated downriver between aggradation and degradation (Fig. 13). A major degradation zone extended from CS38 down to the river mouth, with values up to –0.58 m (at CS48). Between CS28 and CS37 most sections aggraded by small amounts (<0.25 m).

The average rate of MBL change was low at –0.012 m/yr, and the range also tended to be low (from +0.051 m/yr to–0.096 m/yr). Rates of change tended to increase in the downstream direction (Fig. 14).

Between 1984 and 1990, the total gravel volume change was –234,400 m^3 at a much lower rate (39,070 m^3/yr) than the previous period. The gravel volume

changes show a clear trend downriver from alternating minor degradation and aggradation between CS1 and CS31 (±<5000 m^3), to consistent aggradation between CS31 and CS38, and consistent and large degradation (>10,000 m^3) between CS38 and CS54 (Fig. 15).

4.2.7 1990 to 1997/98

The mean bed level change across all sections was low in this period (–0.06 m) with most (31 of 43) cross sections degrading. There was a very high range at individual values from +1.02 m to –0.46 m, but most were ±0.25 m. There was a tendency for aggradation, or little change, at the top of the reach (from CS1 to CS15), followed by a long zone in which degradation dominated (CS18 to CS46), and a zone near the coast (CS46 to CS54) where aggradation was characteristic (Fig. 13). The most striking feature was the large amount of aggradation at CS15 (+1.02 m).

The average rate of MBL change between 1990 and 1998 was –0.009 m/yr, with a range from +0.146 m/yr to –0.066 m/yr (Fig. 14). The rates of change tended to be quite low at most sites (±0.05 m/yr).

The net change in gravel storage is very small at –53,900 m^3, and the gravel loss rate is also very small (6740 m^3/yr). The gravel volume change ranged from +45,100 m^3 to –23,800 m^3, with most (27 of 42) sections degrading. There was a distinct zonation of areas of aggradation and degradation (Fig. 15) with aggradation dominating in the upper (between CS1 and CS18, with particularly high amounts of aggradation (+45,111 m^3) between CS14 and CS18) and lower (below CS46, near Stephens beach) parts of the reach, and degradation in the remaining 6.6 km of the reach. Degradation tended to increase downstream from CS18 to CS41 (–23,807 m^3 between CS40 and CS41), and then decreased downstream of here. Most cross sections had lost <10,000 m^3 of gravel.

4.2.8 1997/98 to 2001

During this period the mean bed level change across all sections was the lowest of any period at –0.01 m, with values ranging from +0.28 m to –1.01 m. Compared to other periods, the MBL change tended to be relatively small, except for severe degradation of –1.01 m at CS15 (this cross section had aggraded substantially (+1.02 m) in the previous period). There tended to be a fluctuation from degradation to aggradation along the reach (Fig. 13), with neither dominating for any great length of the river or overall (22 of 45 cross section degraded, the remainder aggraded). MBL change fluctuated within ±0.1 m at most cross sections. The greatest aggradation was at CS25 (+0.28 m). Many cross sections that had degraded in the previous period were now aggrading, and vice versa. There was very little change to cross sections upstream of CS15.

The average rate of MBL change between 1997/98 and 2001 was –0.004 m/yr, the lowest of all periods. The rate of change ranged from +0.069 m/yr to –0.253 m/yr. Excluding the severe and rapid degradation at CS15 the average rate of MBL change was slight aggradation (+0.002 m/yr). The rates of MBL change tended to be very low at most cross sections (±0.03 m/yr – Fig. 14).

This 3-year period had the smallest net gravel loss (–35,400 m^3) of any period. The average rate of loss was low (–11,047 m^3/yr), although not as low as the previous period. The gravel volume change ranged from +5,925 m^3 to –37,926 m^3, with a little over half (24 of 44) the cross sections degrading. The gravel volume changes between cross sections tended to be small (±5000 m^3), with the notable exception of the large gravel loss (–37,926 m^3) between CS15 and CS17, and between CS14 and CS15 (–12,885 m^3). With these two sections excluded, the net change across the entire reach was aggradation. There was a tendency for the upper part of the reach to be dominated by degradation and the lower part of the reach to be dominated by aggradation (Fig. 15). The maximum amount of aggradation between any cross sections was low (+5925 m^3).

4.2.9 Net change 1957 to 2001

For the 11 cross sections that were surveyed in both 1957 and 2001 (between CS10 and CS53) the average rate of net MBL change was –0.64 m, with a range from –1.17 m to –0.27 m (Fig. 16). None of the cross sections aggraded. There was a weak tendency for cross sections in the lower part of the reach to have a greater amount of degradation (often in the range –0.6 to –0.9 m) than those in the upper part of the reach (–0.2 to –0.4 m). The greatest degradation was at CS28. These changes equate to an average rate of change of –0.015 m/yr, with a range at individual cross sections from –0.006 m/yr to –0.027 m/yr.

The net change in gravel storage along the reach amounts to –1,113,260 m^3, however this is a minimum estimate and has high uncertainty since it is based on a small number of widely spaced cross sections between CS10 and CS53 that were surveyed in 1957. The data suggested there were no parts of the reach that aggraded during this time, with the highest losses (>100,000 m^3) between CS10 and 20, CS24 and CS28, CS28 and CS33, CS37 and CS44, CS44 and CS47 (Fig. 16).

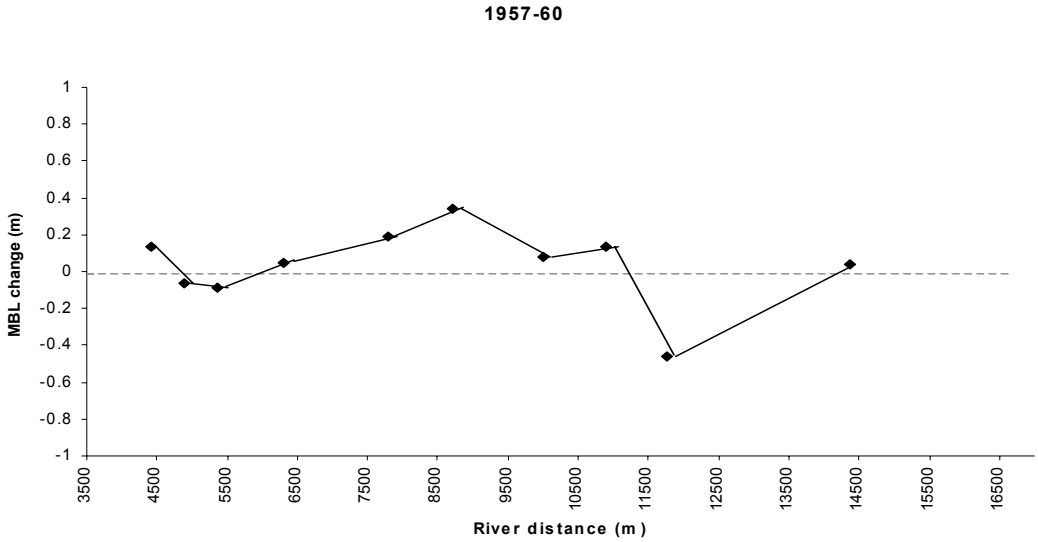
For the period 1978 to 2001, trends in MBL and gravel storage can be established from 44 cross sections. Over this period the average amount of MBL change was –0.30 m/yr, with a range at individual cross sections from +0.29 m to –0.93 m. Net change at the great majority of the cross sections (39 of 44) was for degradation (Fig. 16), with a tendency for the amount of degradation to increase downstream (rising from –0.2 to –0.4 m to –0.4 to –0.8 m) except for the 4 cross sections nearest to the coast which had lower amounts of degradation (–0.1 to –0.4 m). The greatest degradation occurred at CS23 (–0.87 m) and between CS41 and CS48 (mostly –0.7 to –0.9 m). The only significant aggradation was at CS2, CS16 and CS17 (+0.2 to +0.3 m).

The net change in gravel storage along the reach during this period was –608,877 m^3, at an average rate of 26,473 m^3/yr. There were only two areas where the reach

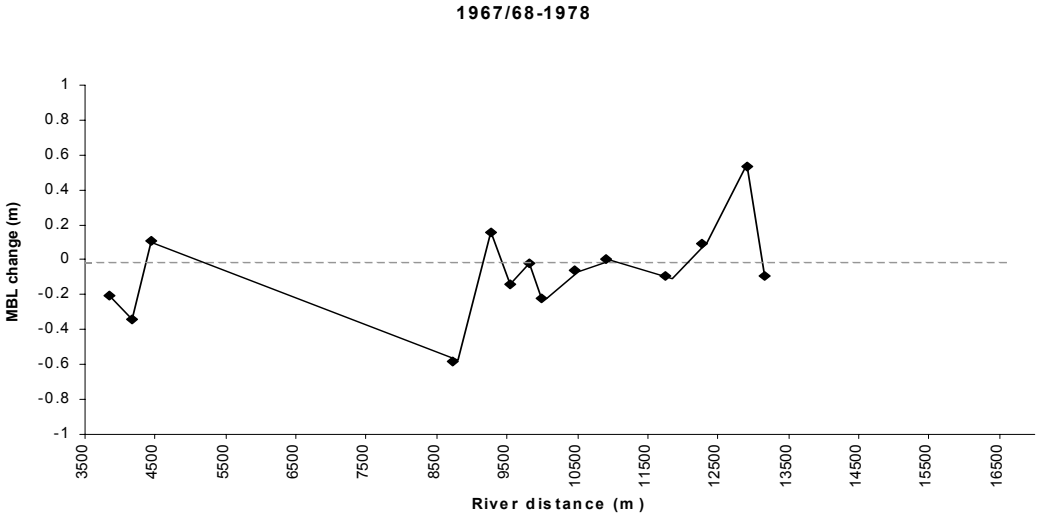
aggraded over this time (between CS2 and CS4, CS15 and CS20) with the remainder of the reach degrading (Fig. 16). In the upper part of the reach (above CS40), the amount of degradation between cross sections tended to be smaller (typically <–15,000 m^3) than in the lower part of the reach (typically –10,000 to –40,000 m^3). The greatest gravel loss was between CS41 and CS49.

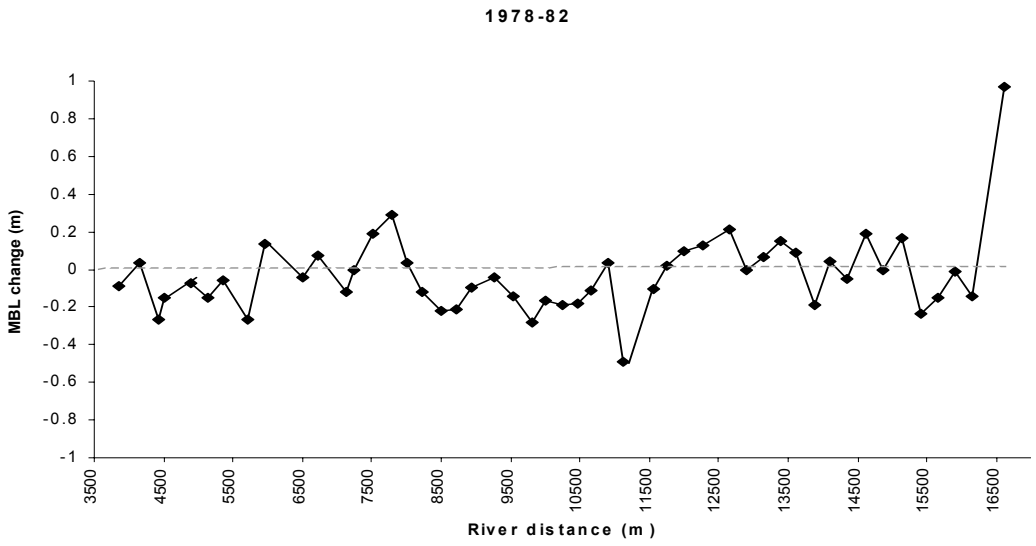
The trends in MBL at individual sections reveal some interesting patterns. Change in MBL at most cross sections fluctuated in successive surveys between aggradation and degradation (Appendix 6). Although the trend for the reach as a whole has been for degradation, no cross section has consistently degraded in all surveys. The data suggests a very dynamic riverbed in which storage and transport of gravel continually alternate within the active channel.

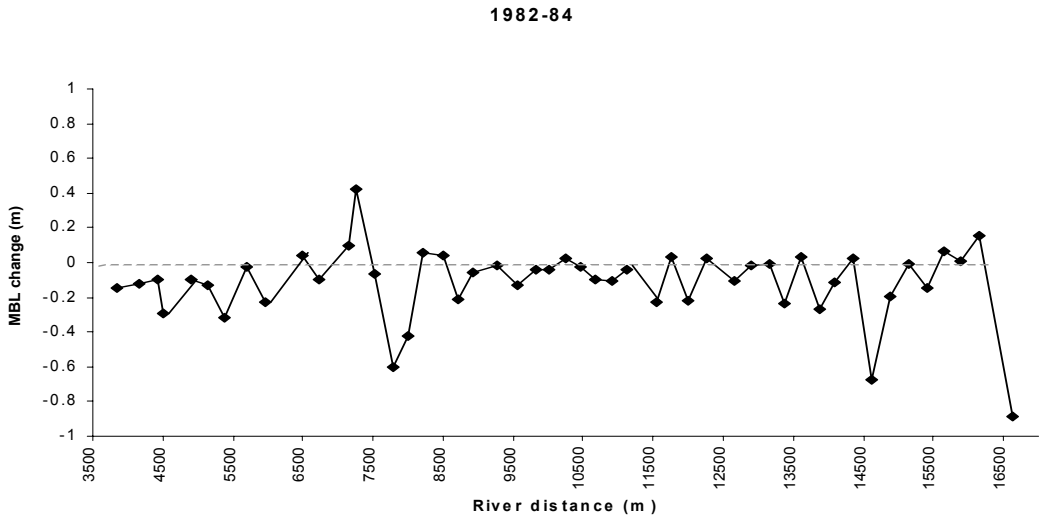
Fig. 13 Lower Motueka mean bed level changes between 1957 and 2001

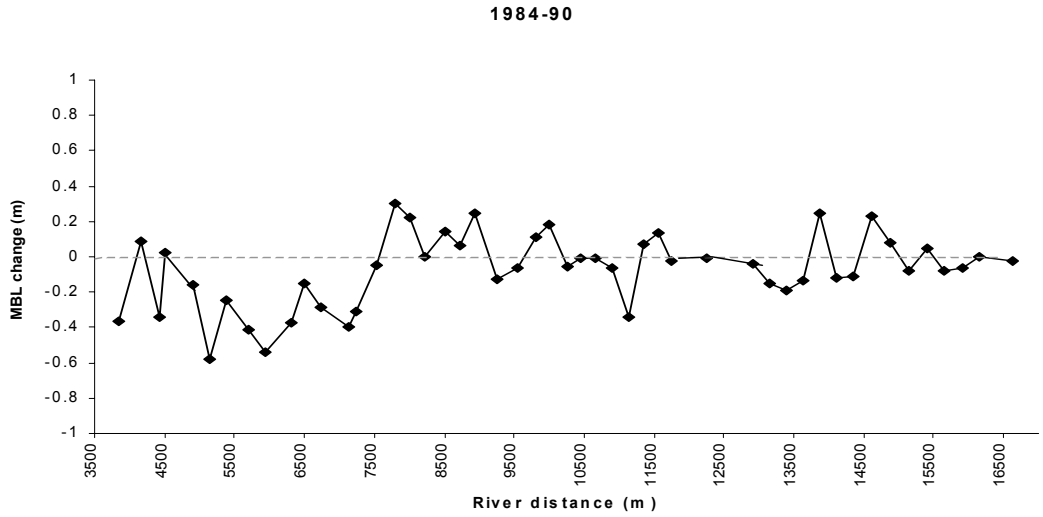



1960-67/68
MBL change (m)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
15500
16500
River distance (m)

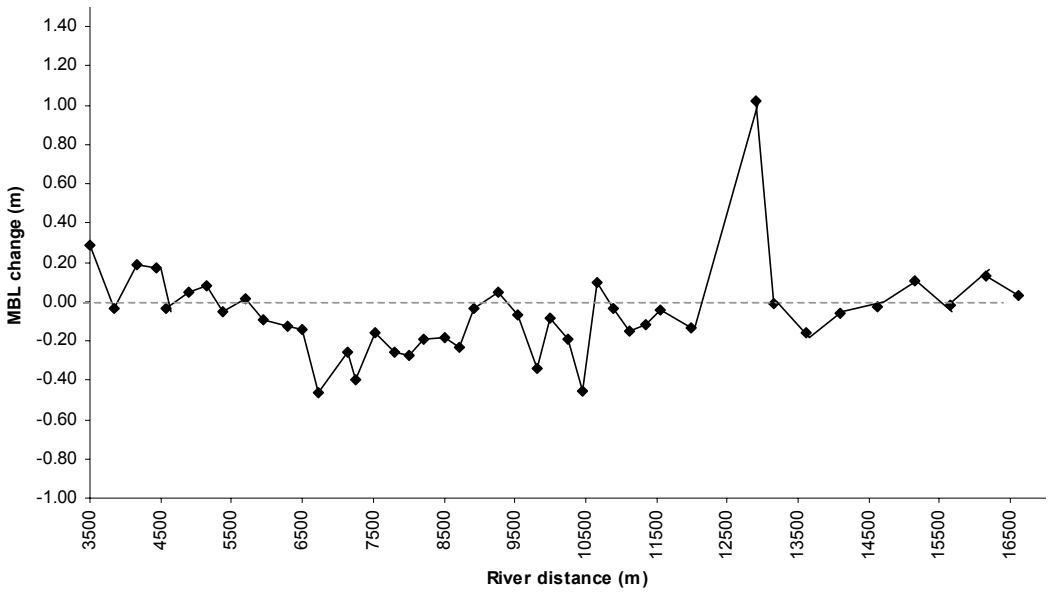

1967/68-1978
MBL change (m)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
15500
16500
River distance (m)


1978-82
MBL change (m)
River distance (m)


1982-84
MBL change (m)
River distance (m)


1984-90
MBL change (m)
River distance (m)

1990-98



1997/98-01

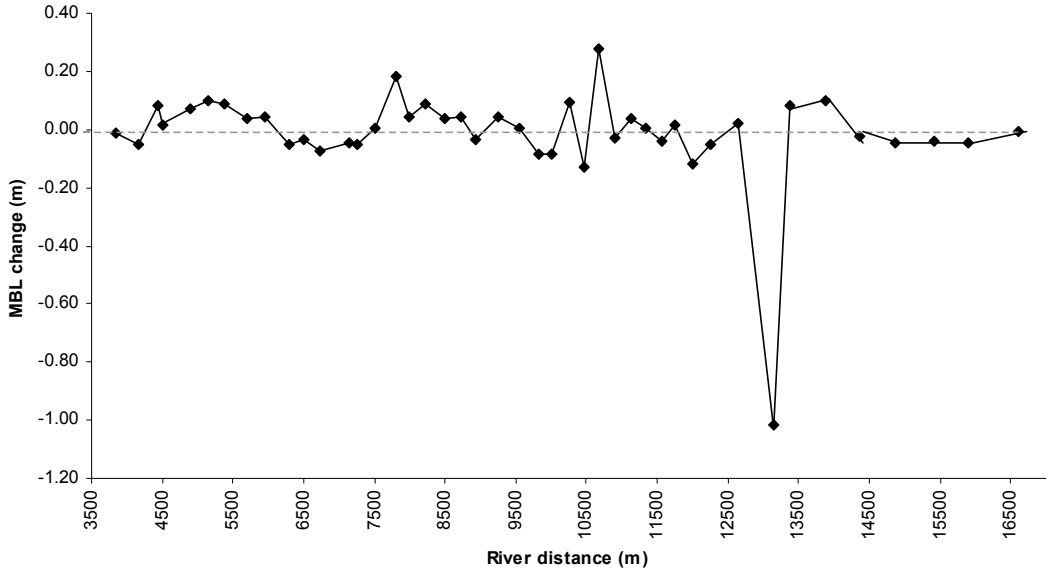
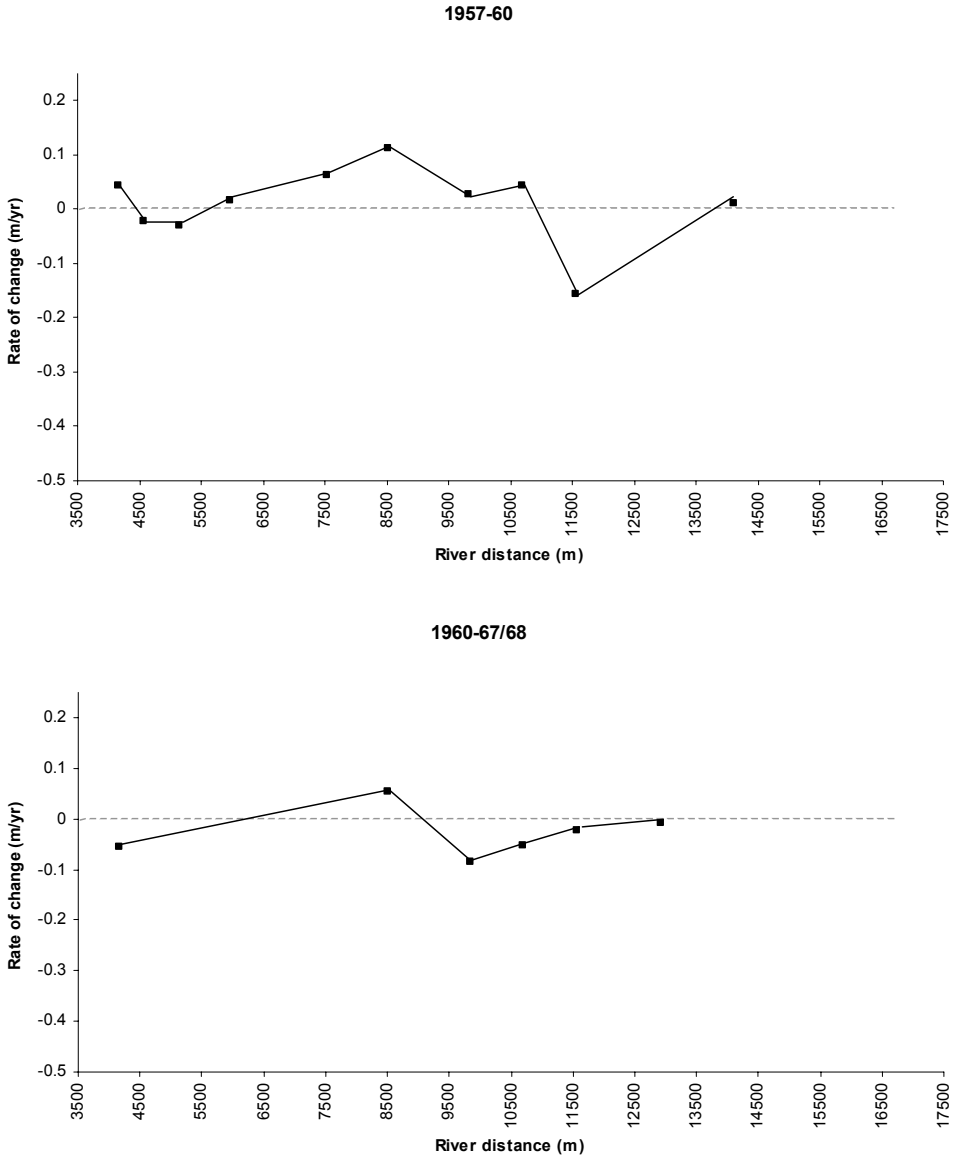
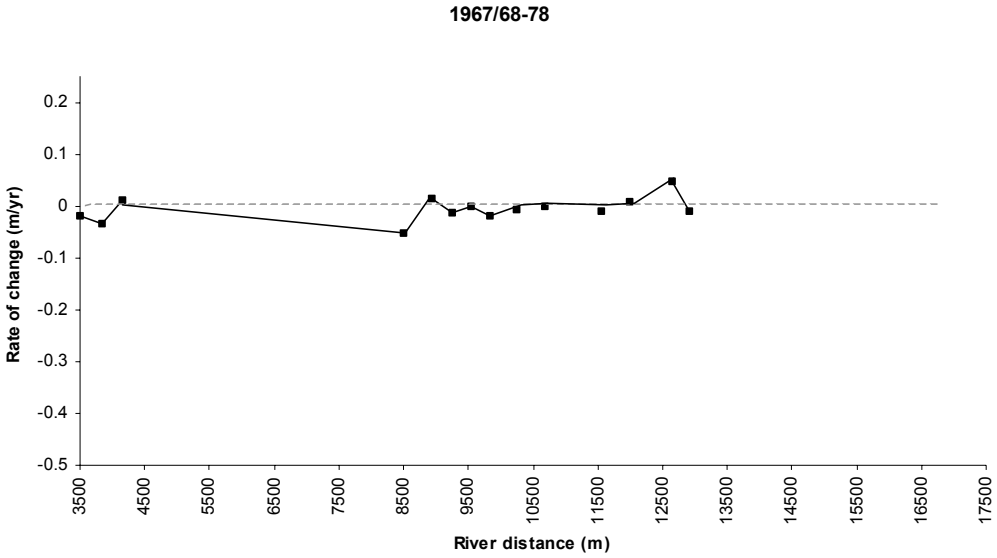
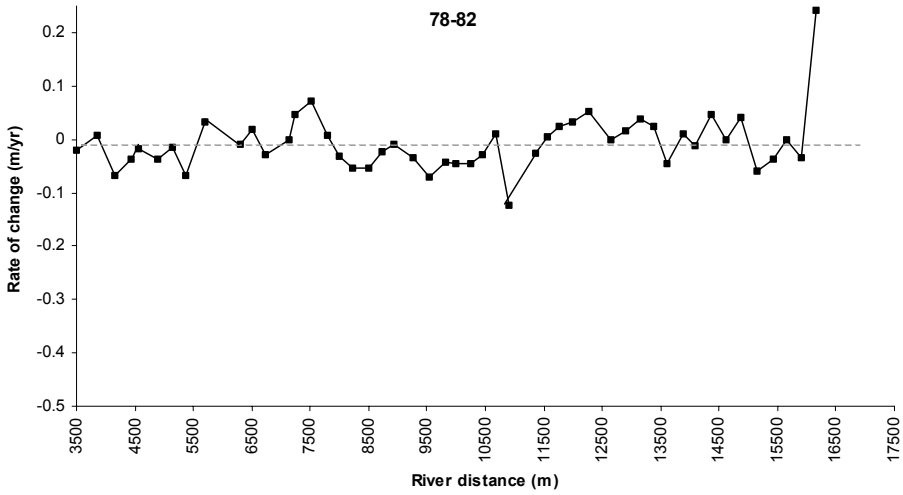
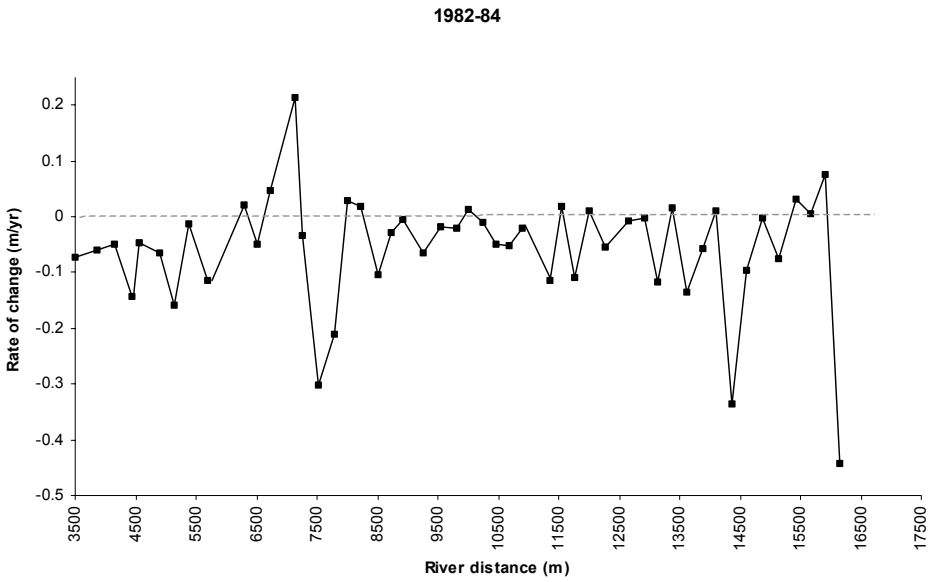


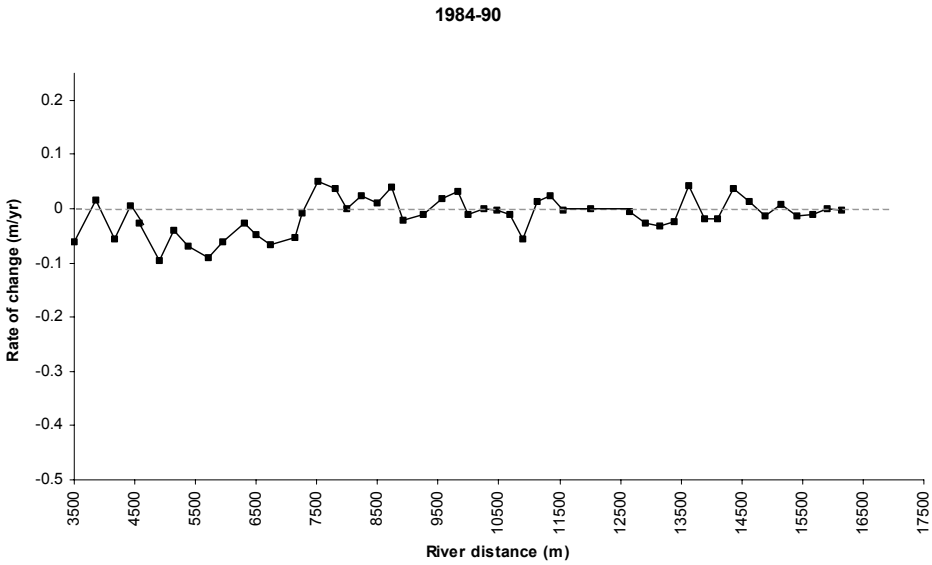
Fig. 14 Lower Motueka rate of mean bed level change between 1957 and 2001

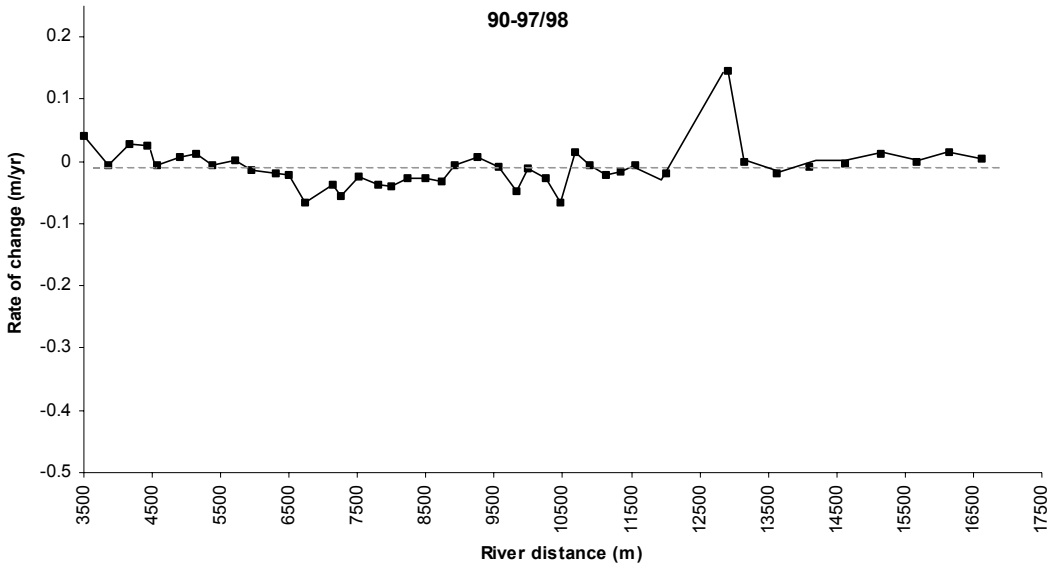



1967/68-78
Rate of change (m/yr)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
15500
16500
17500
River distance (m)


78-82
Rate of change (m/yr)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
15500
16500
17500
River distance (m)


1982-84
Rate of change (m/yr)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
15500
16500
17500
River distance (m)


1984-90
Rate of change (m/yr)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
15500
16500
17500
River distance (m)


90-97/98
Rate of change (m/yr)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
15500
16500
17500
River distance (m)

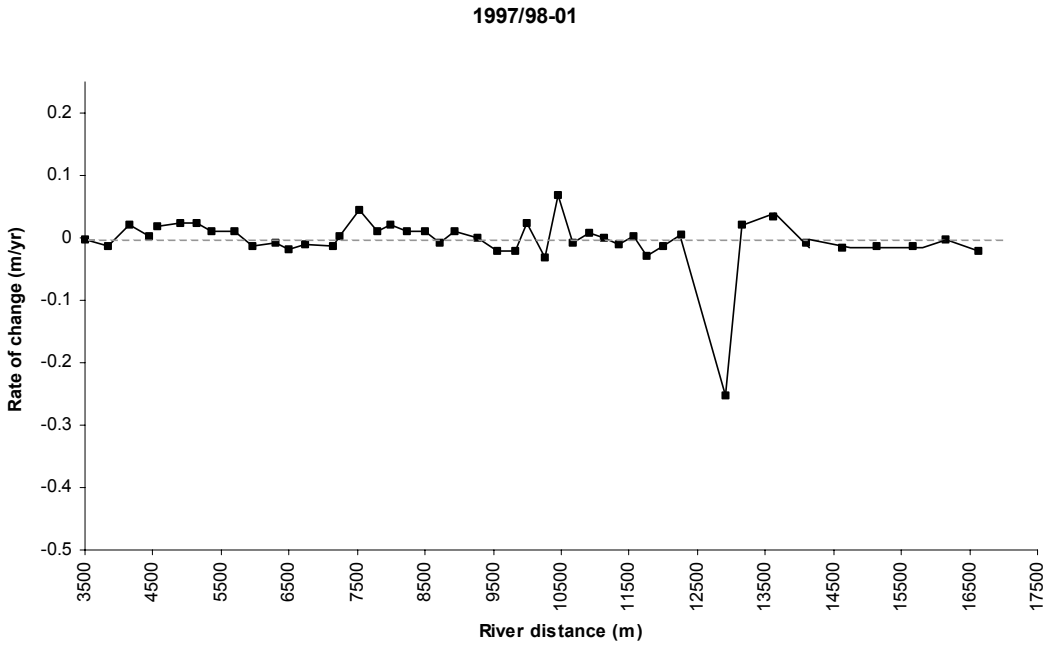
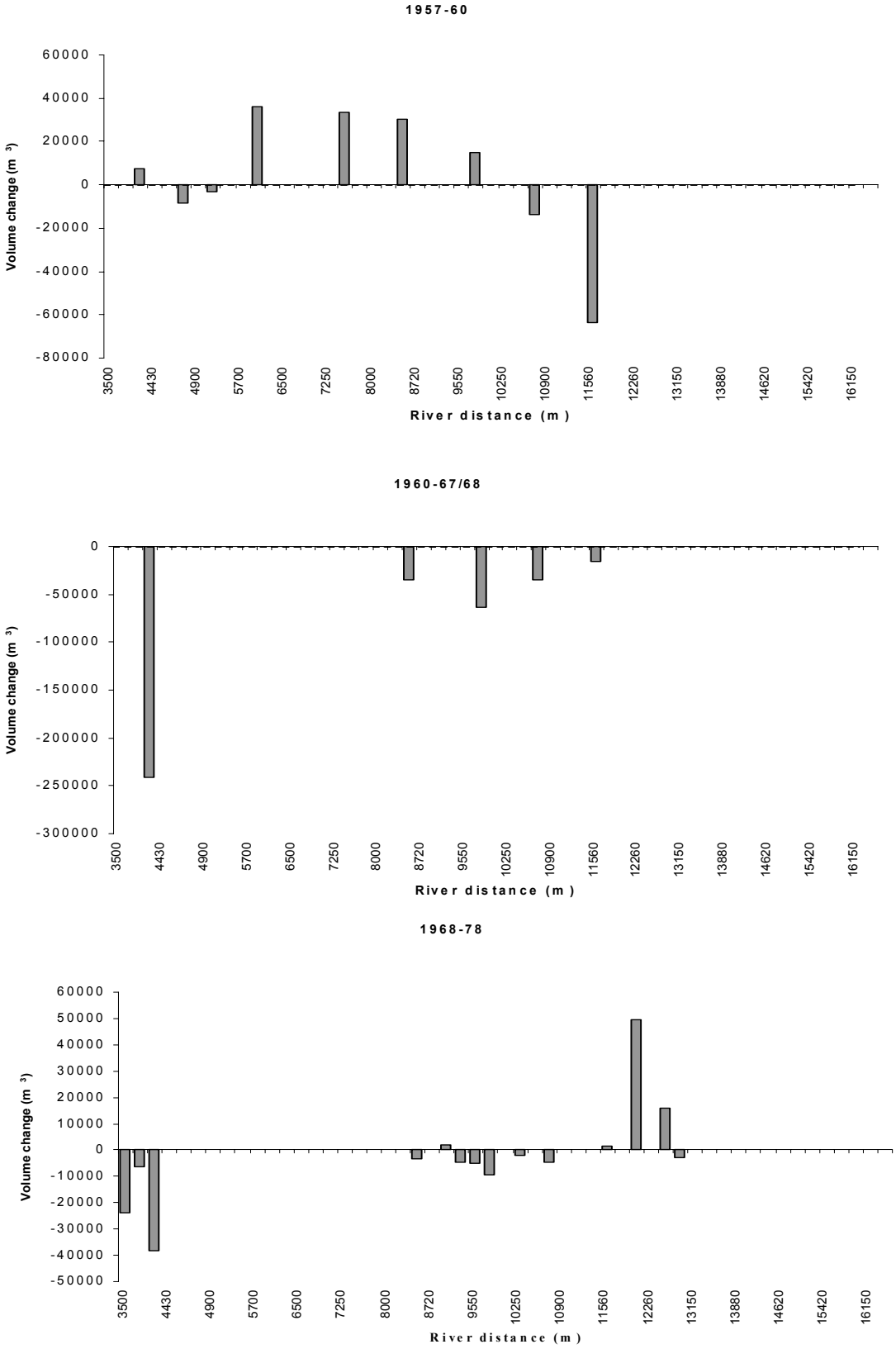
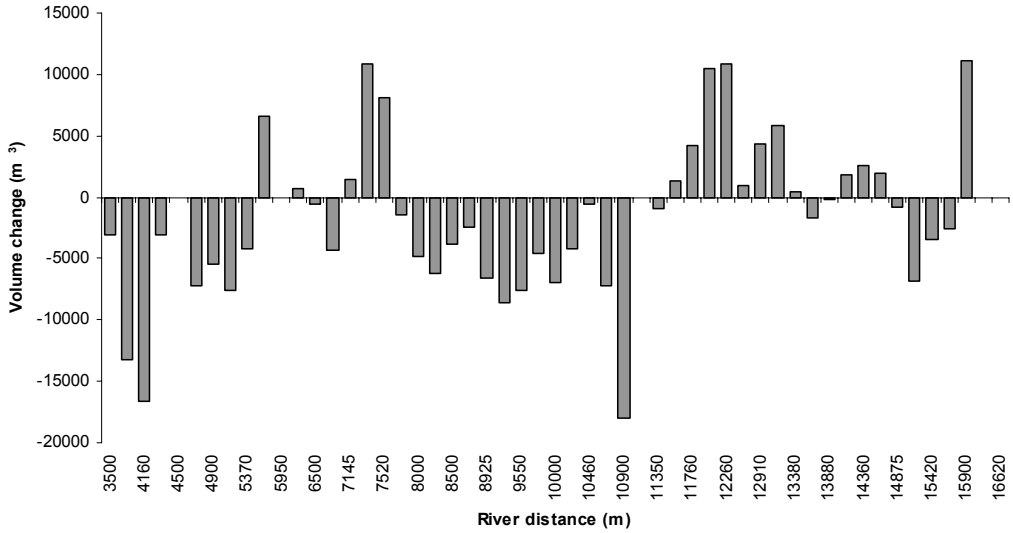

1997/98-01
Rate of change (m/yr)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
3500
4500
5500
6500
7500
8500
9500
10500
11500
12500
13500
14500
15500
16500
17500
River distance (m)

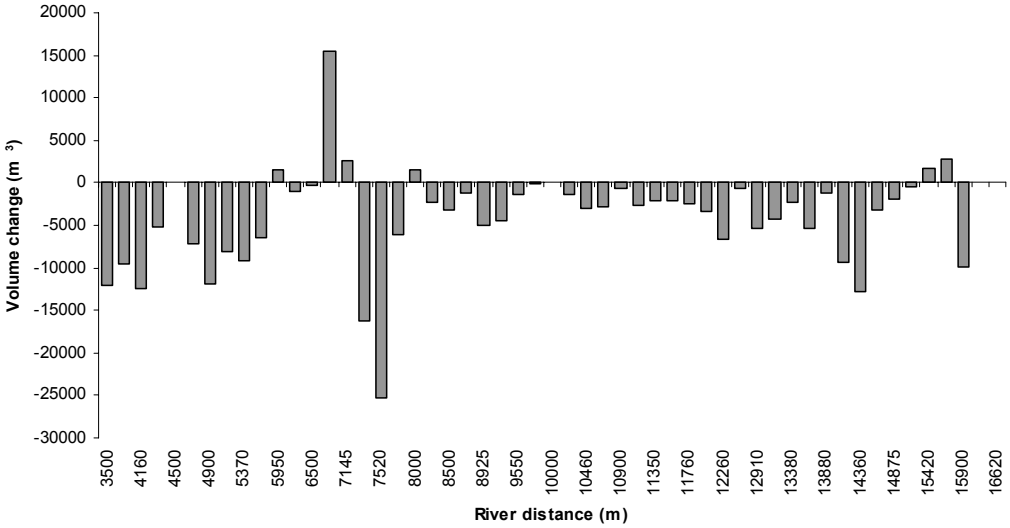
Fig. 15 Lower Motueka gravel volume changes between 1957 and 2001



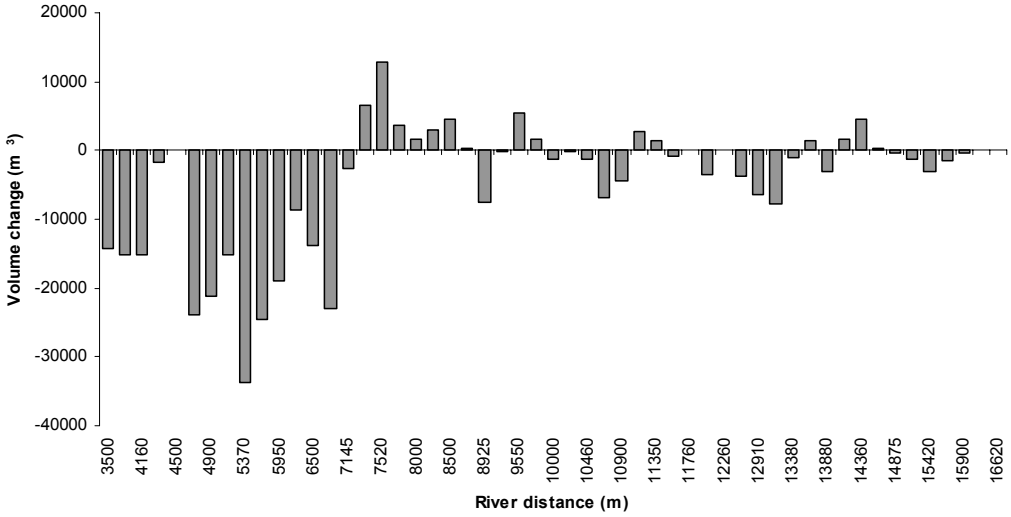
1978-82

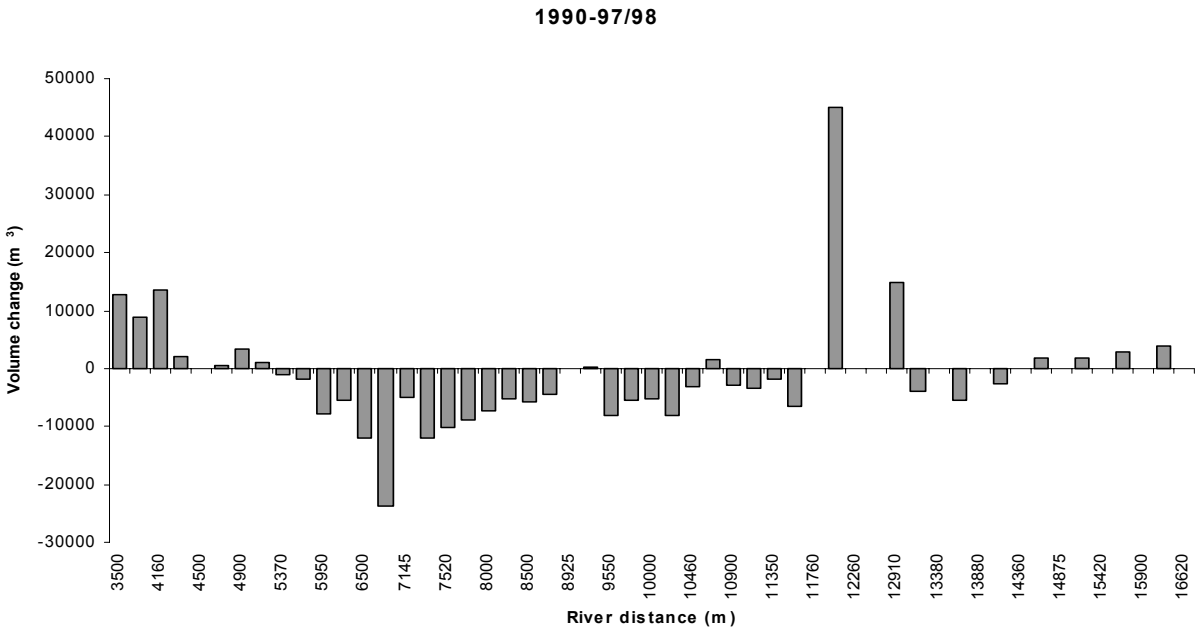


1982-84



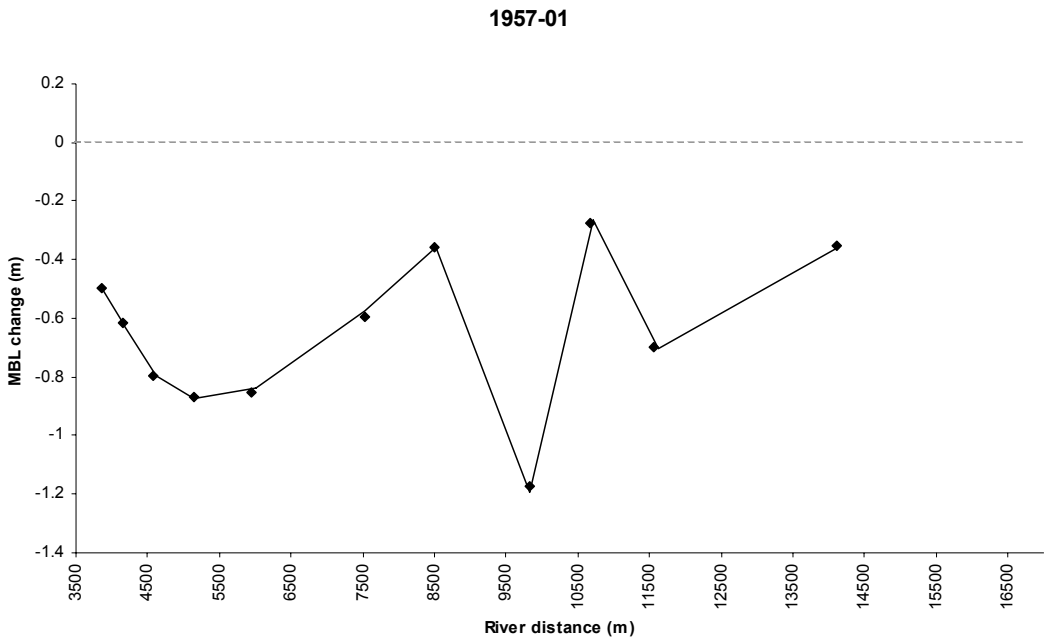
1984-90




1990-97/98
Volume change (m 3)
50000
40000
30000
20000
10000
0
-10000
-20000
-30000
3500
4160
4500
4900
5370
5950
6500
7145
7520
8000
8500
8925
9550
10000
10460
10900
11350
11760
12260
12910
13380
13880
14360
14875
15420
15900
16620
River distance (m)


1997/98-01
Volume change (m 3)
10000
5000
0
-5000
-10000
-15000
-20000
-25000
-30000
-35000
-40000
-45000
3500
4160
4500
4900
5370
5950
6500
7145
7520
8000
8500
8925
9550
10000
10460
10900
11350
11760
12260
12910
13380
13880
14360
14875
15420
15900
16620
River distance (m)

Fig. 16 Lower Motueka net mean bed level change between 1957 and 2001



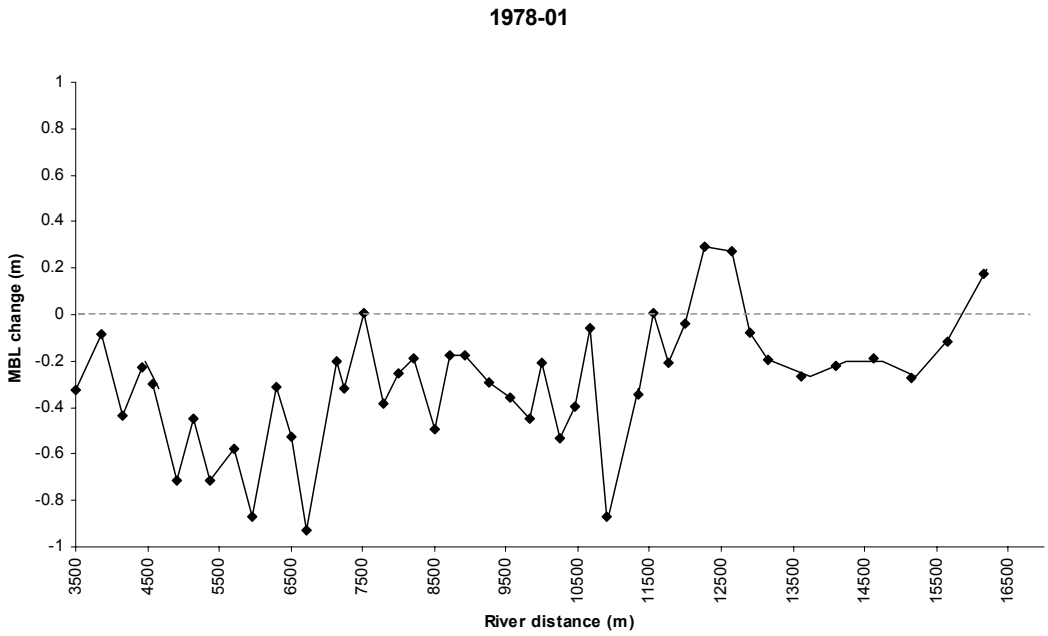
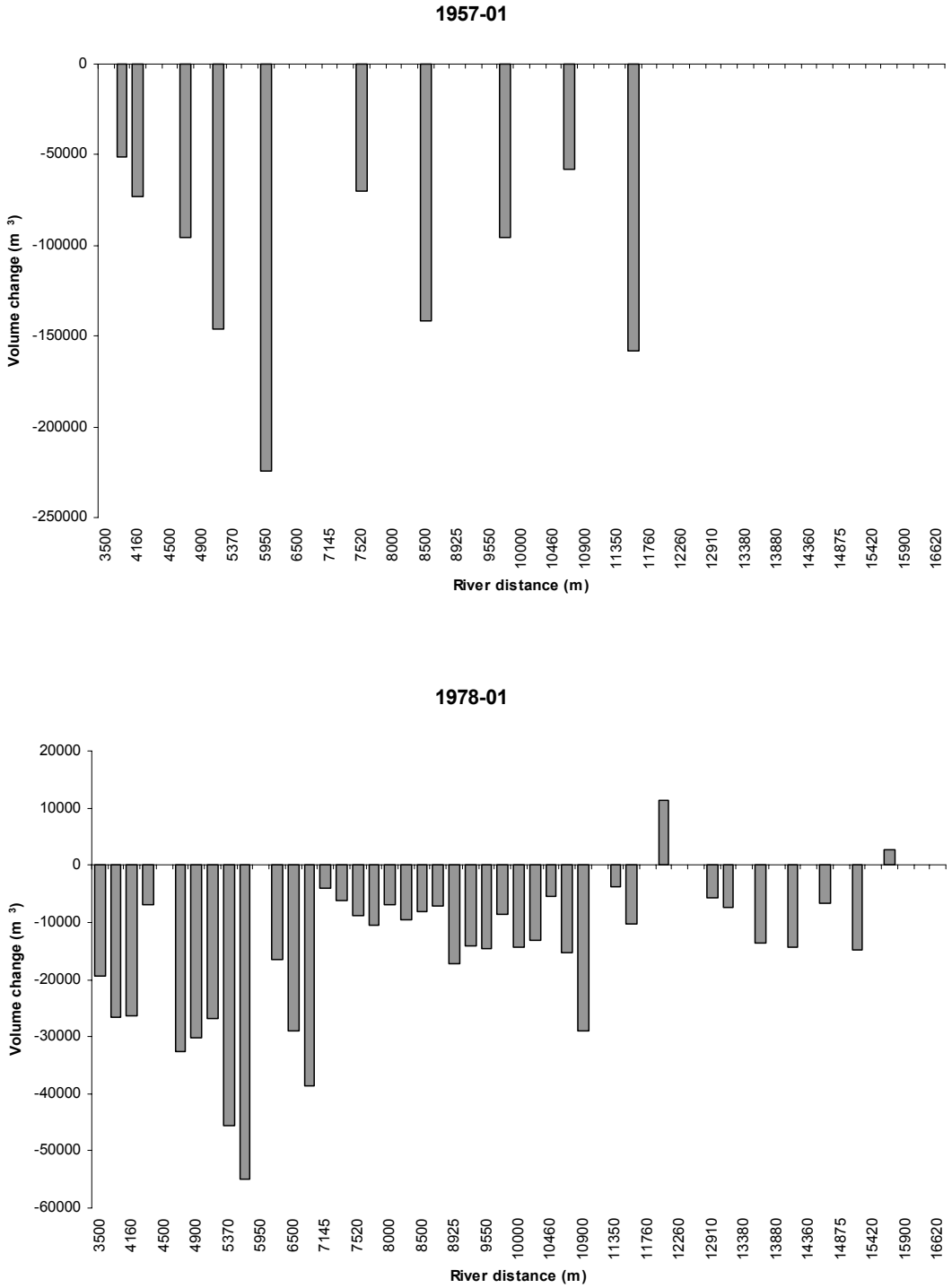


Fig. 17 Lower Motueka net gravel volume changes between 1957 and 2001

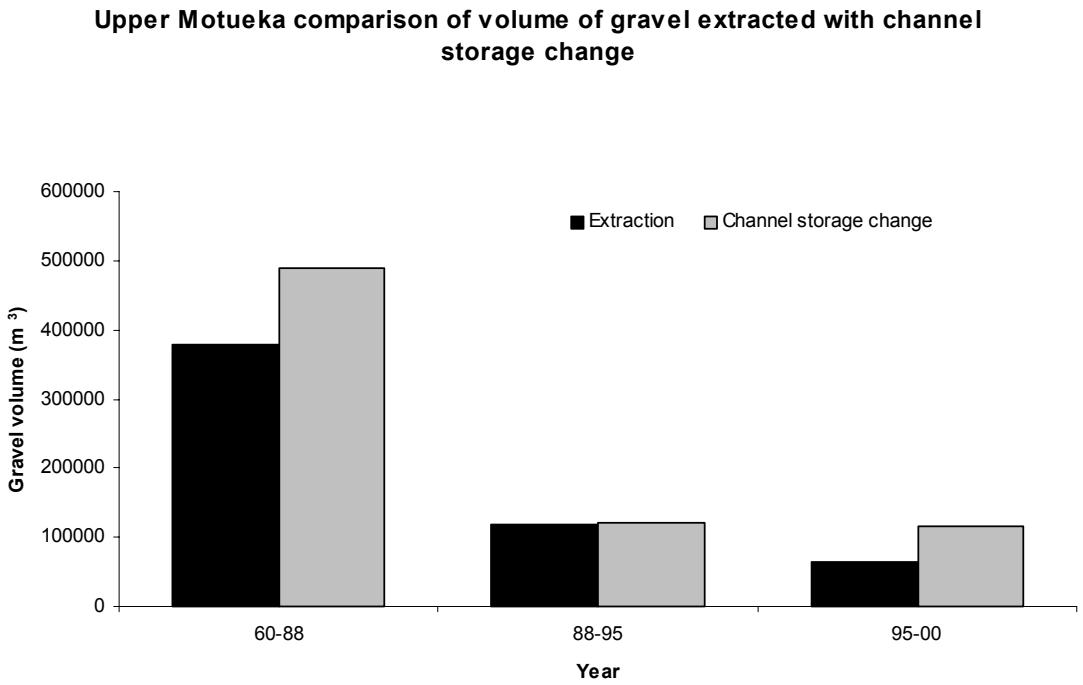


4.3 Comparison with gravel extraction

The comparison of the calculated changes in gravel storage within the active river channel with gravel extraction returns over the same time periods in the upper and lower Motueka is shown in Fig. 18. In the upper Motueka the calculated change in gravel storage (–728,000 m^3) is significantly greater than the total amount of gravel extraction (561,000 m^3). The channel storage change exceeded gravel extraction in 2 of the 3 periods, and was very similar in the other (1988–95). The rates of gravel loss from the upper Motueka reach have progressively increased through time from 17,496 m^3/yr between 1960 and 1988 to 23,279 m^3/yr between 1995 and 2000. By contrast the rates of gravel extraction were fairly constant between 1960 and 1988 (13,450 m^3/yr) and 1995 and 2000 (12,743 m^3/yr), and a little higher between 1988 and 1995. While the total amount of gravel extracted from the river between 1960 and 2000 is a substantial proportion of the total gravel loss (77%), there is a significant component of gravel loss unrelated to gravel extraction suggesting factors other than gravel extraction play an important role in determining changes in gravel storage.

In the lower Motueka over the entire period 1957–2001, the calculated change in gravel storage is very similar to the total amount of gravel extraction (c. 1,000,000 m^3). However in the individual time periods the two do not match closely except in the latter part of the record (since 1984). Between 1960 and 1968, and 1982 and 1984 channel storage change was far in excess of gravel extraction. However, this has been balanced in the other intervals (1957–60, 1968–78, and to a lesser extent 1978–82) when gravel extraction exceeded channel storage change. It is surprising that change in gravel storage matches gravel extraction as it might be expected that when channel storage loss exceeded gravel extraction then there would be a net loss of gravel from the river (unless it was being temporarily stored in areas between the surveyed cross sections) and would amount to an additional gravel loss.

For the period 1978–2001 for which more reliable estimates of channel storage change are available, the data suggest channel storage change (–609,000 m^3) was very similar to gravel extraction (604,000 m^3) from the riverbed. The most notable feature of the record in this period was that channel storage change (206,599 m^3) was well above extraction volumes (93,055 m^3) from 1982–84, coinciding with the severe flood



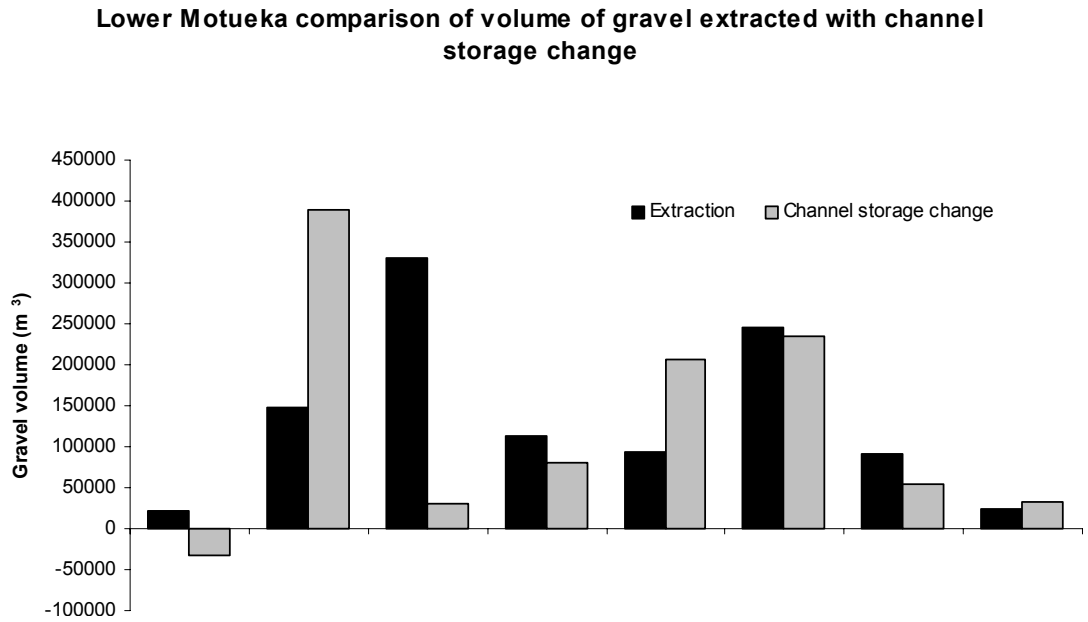


Fig. 18 Comparison of gravel volume changes with gravel extraction from the river (a) Upper Motueka (b) Lower Motueka (channel storage gain is shown as a negative value).

of July 1983 (70-year return period). However, this was balanced by gravel extraction exceeding channel storage change in the 1984–90 and 1990–98 periods.

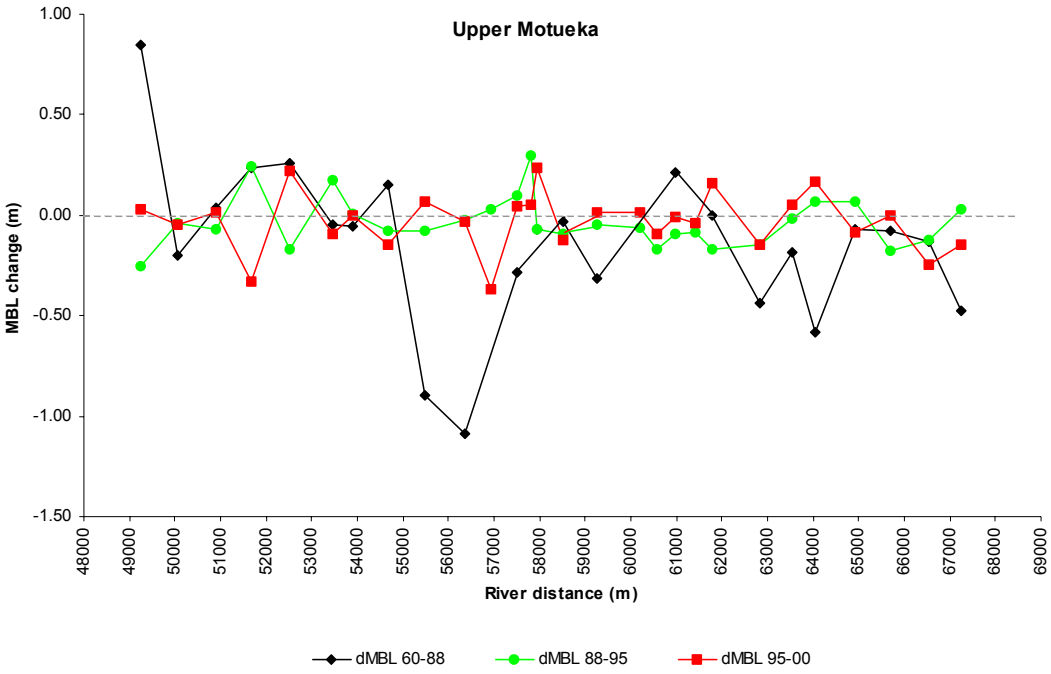
5. Discussion

The data clearly indicate the long-term trend in both reaches of the river has been for a reduction in MBL, averaging –0.20 m in the upper Motueka (1960–00) and –0.64 m in the lower Motueka (1957–01). The lower Motueka estimate is not very robust as it is based on a relatively small number of cross sections. However between 1978 and 2001 there was a MBL change of –0.30 m, and the rate of change is much higher than calculated for 1957–01 which might suggest the latter is a conservative estimate. Similarly both reaches of the river have shown a net decline in gravel storage. The extent of this loss per unit length of river is far greater in the lower Motueka (c.1,000,000 m^3 in a 13 km reach) than in the upper Motueka (c.730,000 m^3 in a 19 km reach).

In both reaches the trends in MBL at individual sections generally fluctuated in successive surveys between aggradation and degradation (Fig. 19). Although the trend for the reaches as a whole have been for degradation, no cross sections have consistently degraded in all surveys and there is little distinct spatial pattern of aggradation and degradation in successive surveys as occurs in some other gravel bed rivers such as the Waimakariri (Griffiths 1979) and Wairau (Noell 1992, Christensen 2001). The data suggests a very dynamic riverbed in which storage and transport of gravel continually alternate within the active channel. This may imply that gravel

transport occurs as sediment waves, as suggested by Griffiths (1979) for the Waimakariri River. The net trends (Figs. 12 and 17) show:

- in the upper Motueka, an increase in net gravel loss downstream before a switch to aggradation where the river gradient lessens near the Wangapeka confluence;
- in the lower Motueka, an initial increase in net gravel loss downstream before reducing near the coast.



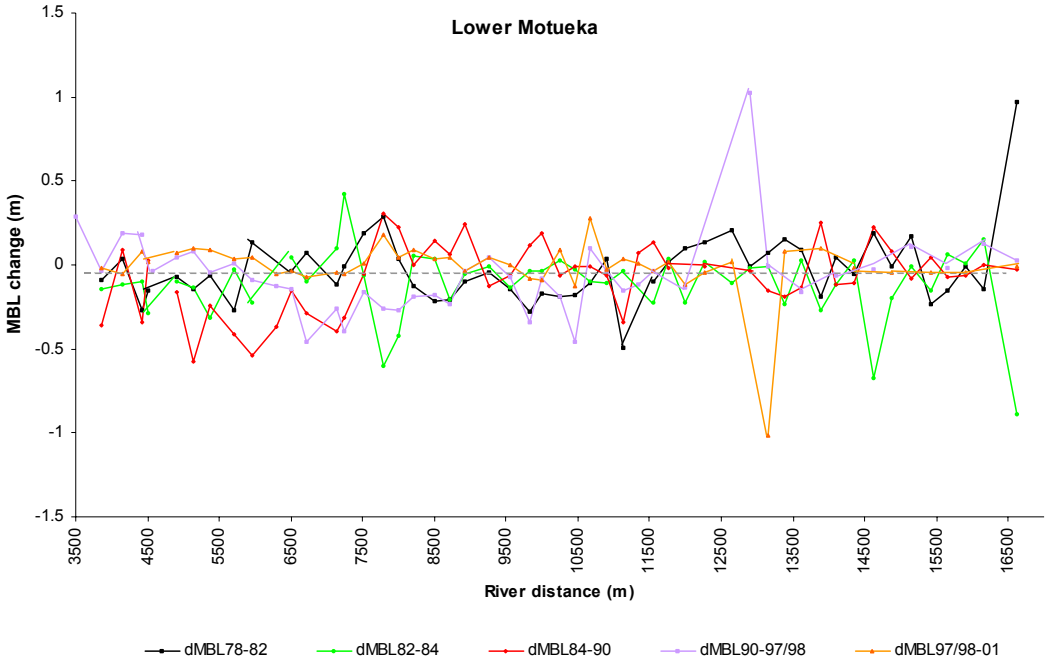


Fig. 19 Mean bed level changes in upper and lower Motueka reaches

There are a number of interesting features of the upper Motueka reach:

- the rate of MBL change and gravel loss from the whole reach has increased through time.
- the amount of gravel storage change (–728,000 m^3) is clearly in excess of gravel extraction (561,000 m^3), and the change in gravel storage can only partly be related to gravel extraction.

The channel storage change has exceeded gravel extraction in 2 of the 3 measurement periods (1960–88, 1995–00). While the rates of gravel loss from the river channel have progressively increased through time (from 17,496 m^3/yr between 1960 and 1988 to 23,279 m^3/yr between 1995 and 2000) the rates of gravel extraction have remained fairly constant (13–17,000 m^3/yr). Although the total amount of gravel extracted from the river between 1960 and 2000 is a substantial proportion of the total gravel loss (77%), the differences between trends in gravel extraction rates and channel storage loss rates suggest factors other than gravel extraction may play an important role in determining changes in gravel storage.

In the lower Motueka, there is little trend in rates of MBL and gravel storage change with time apart from the distinct peak between 1982 and 1984 coinciding with the large flood of July 1983. Gravel extraction returns suggest the highest rates of gravel extraction occurred in 1975, and rates were high throughout the 1970s, yet the period 1967/68–78 had one of the lowest rates of MBL and gravel storage change. Although the calculated change in gravel storage over the period 1957–2001 is very similar to the total amount of gravel extraction (c. 1,000,000 m^3), in individual time intervals the two do not match very well except in the latter part of the record (since 1984). Like the upper Motueka, there seems little direct correspondence between trends in channel storage and gravel extraction. Both gravel extraction rates and gravel storage loss rates peaked between 1982 and 1984, although the gravel storage loss rate was more than twice the gravel extraction rate for this period. As in the upper Motueka these trends suggest factors other than gravel extraction may play an important role in determining changes in gravel storage.

The calculated trends in MBL and gravel storage change are comparable with previous estimates made by TDC (Howes 1994; Nottage 1994, 1995, 1996, 1997, 1998; Verstappen 1999, 2000). In general, our estimates tend to be slightly higher than previous estimates (Table 13), probably because a wider active channel width has been used to account for channel change over the longer time period than previous analyses. In the upper Motueka especially, this has resulted in inclusion of significant

Table 13 Comparison of current estimates of gravel storage loss with previous estimates

	Time period	**Current estimate (m^3)**	**Previous estimate (m^3)**	**Reference**
Lower Motueka	1990-97	–53,920	–126,880	Verstappen (2000)
	1997–01	–33,141	–4500	Verstappen (2001)
	1957–90	–909,126	–1,053,250	TDC (1993)
Upper Motueka	1960–95	–611,744	–560,000	Verstappen (2000)

	1995–00	–116,394	–121,000	Verstappen (2000)
	1988–95	–121,862	–290,000	Verstappen (2000)
	1960–88	–489,882	–310,000	Fenemor (1997)
	1960–88	–489,882	–350,000	TDC (1993)

areas of berm within the defined ACW for more recent surveys particularly where the river channel is less constrained. A more accurate approach to estimating gravel storage changes would be to define active channel width based on each successive pair of surveys, and to incorporate analysis of the berms to caculate the total sediment storage change between surveys (including both gravel in the active channel and sand/silt on the berms).

The results support the view that gravel extraction has been a large component of gravel storage loss in both reaches, but suggest that other factors may also play an important role.

The results suggest a net rate of gravel loss from the lower Motueka of c.25,000 m^3/yr (1978–01), well in excess of Peterson's (1997) estimate of gravel supply to the coast in the last 5–6000 years (9000 m^3/yr). However, it is worth noting that Peterson's estimate is crude (based on the estimated volume of gravel in part of the delta, assumed position of the coastline at c.5500 yr BP, and very approximate estimates of the geometry of the delta) and no rationale is given for the estimate of the amount of gravel transported beyond the Motueka delta region (1000-1500 m^3/yr). The basis of this estimate needs to be examined more closely. Improved information on the geometry of the delta (including the entire Motueka-Riwaka plain), the age and rate of accumulation of the delta/plain sediments, and the changing position of the coastline would provide a better basis for estimating long-term gravel deposition.

Peterson's (1997) estimate of gravel supply as the proportion of total sediment yield may also be flawed. He estimates a suspended sediment yield of 96 t/km^2/yr for the

Motueka and calculates bedload as 10% of the sediment yield. Our current best estimate of the catchment sediment yield is 180 t/km^2/yr (M. Hicks pers. comm. 2002), which would suggest (using the same approach as Peterson) a gravel load of 20,750 m^3/yr. Hicks and Griffiths (1992) suggest bedload can range from 3–25% of the total load of low gradient rivers, which would be equivalent to a gravel load for the Motueka River between 6225 and 51,875 m^3/yr. It is imperative that better estimates of gravel transport capacity and long-term gravel load are developed to ensure that restrictions on gravel extraction are appropriate.

6. Conclusions

On average both the upper and lower Motueka River reaches of the river have degraded over the last 40 years. However, at individual cross sections bed levels exhibited very dynamic behaviour spatially and temporally, with considerable fluctuation between degradation and aggradation.

In the upper Motueka cross sections there was an average mean bed level change of –0.20 m between 1960 and 2000, with a range at individual cross sections from –1.15 m to +0.62 m. Average rates of mean bed level change have increased through time from –0.005 m/yr to –0.007 m/yr, equivalent to rates of gravel loss per year increasing from 16,667 m^3/yr to 26,294 m^3/yr. The net change in the amount of gravel stored in the active channel for the part of the reach from which gravel was extracted (CS2 and above) was –728,138 m^3. The change in gravel storage is significantly greater than the total amount of gravel extraction (561,000 m^3) and has exceeded gravel extraction in 2 of the 3 measurement periods (1960–88, 199500). In contrast to the changes in gravel storage, the rates of gravel extraction have remained fairly constant through time (13–17,000 m^3/yr). While the total amount of gravel extracted from the river between 1960 and 2000 is a substantial proportion of the total gravel loss (77%), the differences between trends in gravel extraction rates and channel storage loss rates suggest factors other than gravel extraction play an important secondary role in determining changes in gravel storage.

In the lower Motueka the average mean bed level change between 1957 and 2001was considerably higher at –0.64 m, with a range from –1.17 m to –0.27 m. Rates of mean bed level change have fluctuated through time from +0.012 m/yr between 1957 and 1960, to –0.056 m/yr between 1982 and 1984. There was no distinct trend through time, except that bed degradation peaked between 1982 and 1984 coinciding with the large flood of July 1983. The net change in the amount of gravel stored in the active channel of the entire reach between 1957 and 2001 was –1,113,260 m^3, and the rate of change of gravel storage varied from +10,859 m^3/yr between 1957 and 1960, to –103,300 m^3/yr between 1982 and 1984. Throughout the length of record it has averaged c. –25,000 m^3/yr. The total amount of gravel lost from the reach between 1957 and 2001 is very similar to the total amount of gravel extracted (1,113,260 m^3). However, there were periods where gravel storage loss greatly exceeded extraction (1960–68 and 1982–84) and vice versa (1957–60, 1968–78). Both gravel extraction rates and gravel storage loss rates peaked between 1982 and 1984, although the gravel storage loss rate was more than twice the gravel extraction rate.

7. Recommendations

The present study has a number of limitations that should be addressed in the future:

- better monitoring of the amount of gravel extraction, and the locations of extraction sites, would allow improved evaluation of the influence of gravel extraction on observed bed level trends at individual cross sections.
- absence of data for the middle Motueka (between Alexander Bluff bridge and the Wangapeka confluence) and the upper Motueka above Norths bridge limits development of an understanding of the whole river system behaviour. While both reaches may have less gravel storage than the surveyed reaches, they do have substantial terraces and floodplains that provide sources and sinks for gravel transport.

- TDC needs to value these river cross section records and ensure they are carefully archived. Their value will increase as the length of record increases. The absence of drawn plans for early data from the lower Motueka River, and early bench mark records from the lower Motueka were significant constraints to this study.

Several components of the study remain to be completed:

- comparison of observed trends of MBL with channel management practices has not been initiated but would be worth investigating. For example, the river is considerably narrower than its natural course and this (along with other channel management practices) may have influenced sediment transport capacity. Mean bed level trends should be compared and correlated with flood events and channel management practices to determine the direct effects of floods and channel management on bed level trends, and to assess whether there is a relationship between costs of channel management and bed degradation.
- analysis of the 1993 data for the lower Motueka should be integrated with these results.
- analysis of storage changes on the berms is required to provide a complete sediment budget for the surveyed reaches. As part of this analysis ACW should be defined based on each successive pair of surveys (i.e., a different active channel width be used for each pair of surveys rather than a single ACW to encompass all surveys). This will provide a more precise approach to estimating gravel storage changes, and along with analysis of the berms will allow caculation of the total sediment storage change between surveys, including both gravel in the active channel and sand/silt on the berms.
- calculation of the contribution of the bed degradation and channel widening components in causing reduction in MBL is required to understand past change and predict likely future changes.
- analysis of air photos would provide a useful approach to confirming some of the changes suggested by these results (particularly major bank erosion), and

would provide an indication of how well the surveyed reaches reflect whole river behaviour.

It is clear from the observed trends that it is vital that ongoing cross section surveys continue to be carried out at least every 4–5 years to monitor the MBL trends and their effect on river bed and bank stability; accurate records of the amount and location of gravel extraction should also be maintained. If the degradation trend continues then this is likely to impact on channel and bank stability, with consequent effects on river training works. To fully understand the behaviour of the Motueka River and predict its future evolution, modelling of sediment transport capacity is required to calculate the theoretical gravel load of the river and to simulate past riverbed behaviour and predict future changes. It is also important that work is initiated to provide an improved estimate of the long-term rate of gravel transport, and to establish the magnitude of gravel transport to the coast.

8. Acknowledgments

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We owe an enormous debt of thanks to the staff of Nelson Catchment Board, Nelson Marlborough Regional Council and Tasman District Council for undertaking the cross section surveys over many years. Mark Holyoake (Montgomery Watson Harza, Richmond) provided valuable advice regarding the surveys and bench mark changes. We are grateful to Phil Howes for providing electronic copies of much of the lower Motueka data, and discussing his data compilation and results with us.

Eric Verstappen provided electronic copies of all the recent survey data, guided us through the intricacies of TDC's records system and previous analysis of parts of the data set. Eric and Andrew Fenemor reviewed an earlier draft of the manuscript. We acknowledge the previous analysis of part of the data carried out by Doug Nottage (formerly TDC). James Barringer prepared the maps.

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Appendix 1 Data sources used to compile Motueka River cross sections

1 Data sources for the Upper Motueka River

1.1 Plans

Hand-drawn and computer-drawn plans of surveyed river cross-section profiles contain the location of the cross section on the river, the location of benchmarks on the cross section, the offset and RL of each surveyed point, and additional notes on survey points (e.g. main channel, stopbank, gravel, silt, vegetation type).

List of upper Motueka River cross-section profile plans

Year of survey	Plan number	Sheet number
1960/62	5834	2–8
1988[8]	4260/1	1–1
1995	4547	1–9
1999/2000	4547/1	1–7

Plans on a topographic or aerial photo base show the locations of river cross-sections.

List of Upper Motueka River cross-section location aerial map plans

Date	Plan number	Sheet number	Scale	Description
1960	5834	1	1:7920	Hand drawn plan with BM locations
1989	4247	13–15,17	1:4000	Aerial halftones, flown 12.7.83, 8.7.86,

[8] All of the 1988 surveyed data has also been superimposed onto the 1995 surveyed data on plan 4547.

				includes BM location
1990	4260	1–4	1:4000	BM locations on 1989 aerial halftones

1.2 Level books

Level books contain the raw survey data, and were used to obtain the location of the water edge (i.e. main channel at the time of the survey) since this was not present on the drawn plans for 1960 and 1962. Some checks were carried to ensure the drawn plans accurately recorded the level book data.

List of level books with Upper Motueka survey data

Year of survey	Level book number
1960	89,91,93
1962	89,91,93
1973	135
1974	148
1988	241,244,246
1995	258

1.3 Electronic files

A series of EXCEL files were obtained from Eric Verstappen (TDC) comprising recent (1988, 1995, and 2000) raw survey data and his analysis of this data. These comprise:

- raw survey data for 1988, 1995, 2000 (88Survey.xls, 95Survey.xls, Upper Motueka 00.xls).
- survey data for active channel width and calculation of MBL for 1988, 1995, 2000 (Upper Motueka 1988calcs.xls, Upper Motueka1995calcs.xls, UpperMotueka2000 calcs.xls).
- analysis of recent survey data (1988, 1995, 2000) showing plots of bed volume change, MBL, MBL changes, and cumulative bed volume changes (UpperMotueka95-00 comparison.xls).
- a plot of MBL against river distance (RiverLongSectionTapawera Area88-95-00.xls).
- a summary table for 1995 and 2000 data containing distance between adjacent cross-sections, active channel width, and area and volume of degradation or aggradation (prepared by Mark Holyoake using a different calculation procedure, in UMQUANT95-001 MAH.XLS)

1.4 Benchmark Cards

Benchmark cards provide critical information on the location and height of local benchmarks established at each cross-section. These contain the following information on old (original) and new (replaced) benchmarks: date placed, provisional RL, origin of survey, final RL, origin of levels, date final RL adopted, level book number and page in which original survey data was recorded. The bench mark cards for the upper Motueka extend back to 1962 and show that all bench marks were converted from a Ministry of Works datum to a Lands and Survey datum. Copies of benchmark cards are held by TDC (Engineering section) and Mark Holyoake (Montgomery Watson Harza, Richmond).

2 Data sources for the Lower Motueka River

2.1 River cross-section plans

Unlike the Upper Motueka River, there were few river cross-section profiles on drawn plans for older surveys[9]. Small format computer-drawn plans of surveyed river cross-section profiles were located (containing the same information as for the upper Motueka).

List of lower Motueka River cross-section profile plans

Year of survey	Plan number	Sheet number
1960	2758	1–6
1966	2763	1–10
1978	3313–3338	1–26
1993	4721/1	1–11
1997	4721/2	1–7
1998	4721/2	1–2
2001	4721/3	1–8

Plans on an aerial photo base show the locations of river cross-sections and the benchmark locations.

List of Lower Motueka River cross-section location aerial map plans

Date	Plan no.	Sheet number	Scale	Description
1979	3313A&B	1–4	1:8000	Plan and longitudinal section,

[9] Phil Howes (Nelson City Council) used these plans in his lower Motueka flood hazard study but they appear to no longer be in TDC archives.

				BM locations
1988	4214	1–6, 7	1:4000	Strip foils with CS and BM locations
1996/97	4214/1	1–5	1:4000	BM and CS locations

2.2 Level books

Level books containing the raw survey data were used to obtain the location of bench marks and the water edge (i.e. main channel at the time of the survey) where these were not in the RICODA or EXCEL files. Some checks were carried to ensure the drawn plans and electronic files accurately recorded the level book data.

List of level books with lower Motueka survey data

Year of survey	Level book number
1957	66,79
1960	79
1967	109,110
1968	117
1978	165,186
1982	205,206
1984	217,219
1990	251,256
1993	257
1997	275

2.3 Electronic files

Survey data for the Lower Motueka from 1957 to 1990 prepared for the lower Motueka Flood Hazard Study (Howes 1994) were obtained from RICODA files and exported into EXCEL as LowerMot57.xls, LowerMot60.xls, LowerMot61.xls, LowerMot65.xls, LowerMot67.xls, LowerMot68.xls, LowerMot78.xls, LowerMot82.xls, LowerMot84.xls, LowerMot90.xls. Some checking of the electronic data was carried out by comparing with the data in level books or on drawn plans (given above).

Survey data from the last three surveys (1997, 1998, and 2001) were obtained from Eric Verstappen (TDC) as EXCEL files (LowerMot1997Survey_rawdata.xls, LowerMot1998Survey_rawdata.xls, LowerMot2001Survey_rawdata.xls). Some checking of the electronic data was carried out by comparing with the data in level books or on drawn plans.

2.4 Benchmark Cards

As in the upper Motueka benchmark cards provide critical information on the location and height of local benchmarks established at each cross-section and contain the same data. Unfortunately the bench mark cards for the lower Motueka only extend back to 1977. Howes (pers. comm. 2003) indicated that all the electronic data in RICODA files had been corrected for any bench mark changes and provided a formula for converting pre-1977 (Nelson Catchment Board imperial BM datum) RLs to post-1977 RLs (Nelson Catchment Board metric BM datum).

$$NCB\ (metric) = NCB\ (imp) - 44.57\ feet$$

(i.e. 44.57*0.305 = 13.59 m was subtracted from all the pre-1978 reduced RLs).

Appendix 2 Upper and lower Motueka cross-section offset and RL adjustments

1 Upper Motueka

1.1 Reduced level adjustments[10]

Most benchmarks in the upper Motueka were first placed in 1960 and then assigned a changed RL or replaced in 1988. The origins of levels used were the Ministry of Works (MoW) datum and Land & Survey (L&S) datum, in 1960 and 1988 respectively.

We were unable to determine the accepted difference between the MoW and L&S datums, but have calculated it from the available bench mark data by comparing RLs for cross section bench marks that have not been replaced or moved. The procedure used was:

1. Where both left (BML) and right benchmarks (BMR) were stable the difference between the RL in 1960 (MoW) and 1988 (L&S) was calculated for both. The average difference between the two was calculated and this average value used to correct RLs for that cross section.
2. Where only a single benchmark was stable the difference between the RL in 1960 (MoW) and 1988 (L&S) was calculated and used to correct RLs for that section.
3. For all remaining cross-sections where neither BM was stable the average of the values found by 1 and 2 above was used to correct RLs. This value was 1.63 m.
4. After a correction factor was found for each cross-section, the 1960 reduced levels were shifted up accordingly to match the post-1988 datum.

The values used to adjust RLs at each cross section are listed below (and in the file UpperMotueka_Benchmarks.xls.).

[10] These corrections correspond to the plots in the file UpperMotueka_Plot.xls

Correction factors for Upper Motueka benchmarks

BM	Year Final RL adopted		Difference between 1960 & 1988 RL (m)			Correction factor (m)
	1960	1988	BML	BMR	Average	
1L	Placed in 1995					
1R						
$2L_{60}$	112.61					1.62
$2L_{88}$		116.049				
$2R_{60}$	113.64	115.259		1.62	1.62	1.62
$3L_{60}$	116.61	118.256	1.65			1.63
$3R_{60}$	114.4	116.019		1.62	1.63	1.63
$4L_{60}$	119.63	121.266	1.64			1.69
$4R_{60}$	117.36	119.094		1.73	1.69	1.69
$5L_{60}$	120.83					1.61
$5L_{88}$		122.476				
$5L_{00}$						
$5R_{60}$	120.76	122.374		1.61	1.61	1.61
$6L_{60}$	124.52					1.63
$6L_{88}$		126.486				
$6R_{60}$	124.52					1.63
$6R_{88}$		126.324				
$7L_{60}$	129.24					1.63
$7L_{88}$		130.69				
$7R_{60}$	129.11					1.63
$7R_{88}$		130.454				
$8L_{60}$	131.17	132.814	1.64			1.63
$8R_{60}$	131.99	133.609		1.62	1.63	1.63
$8R_{88}$		132.084				
$9L_{60}$	136.41					1.66
$9L_{88}$		137.914				
$9R_{60}$	134.92	136.584		1.66	1.66	1.66

BM	Year Final RL adopted		Difference between 1960 & 1988 RL (m)			Correction factor (m)
	1960	1988	BML	BMR	Average	
$9R^{aux}_{88}$		136.334				
$10L_{60}$	139.12	140.744	1.62		1.62	1.62
$10R_{60}$	138.88					1.62
$10R_{88}$		140.274				
$11L_{60}$	143.97					1.63
$11L_{88}$		145.689				
$11R_{60}$	144.37					1.63
$11R_{88}$		145.454				
$12L_{60}$	Toe of bluff- no left benchmark value					
$12R_{60}$	146.28					1.63
$12R_{88}$		147.394				
$13L_{60}$	Toe of bluff- no left benchmark value					
$13R_{60}$	148.99					1.63
$13R_{88}$		150.184				
$14L_{60}$	Toe of bluff- no left benchmark value					
$14R_{60}$	150.34					1.63
$14R_{88}$		152.854				
$15L_{60}$	154.47					1.63
$15L_{88}$	Toe of bluff- no left benchmark value					
$15R_{60}$	154.59					1.63
$15R_{88}$		156.281				
$15R^{aux}_{88}$		156.064				
$16L_{60}$	Toe of bluff- no left benchmark value					
$16R_{60}$	157.21					1.63
$16R^{aux}_{60}$	157.32					
$16R_{88}$		158.765				
$16R^{aux}_{88}$		159.544				
$16R^{aux}_{95}$						
$17L_{60}$	162.21					1.63

BM	Year Final RL adopted		Difference between 1960 & 1988 RL (m)			Correction factor (m)
	1960	1988	BML	BMR	Average	
$17R_{60}$	161.65					1.63
$17R_{88}$		162.514				
$18L_{60}$	165.6					1.63
$18R_{60}$	165.76					1.63
$19L_{60}$	169.73					1.60
$19L_{88}$		170.888				
$19R_{60}$	170.11	171.709		1.60	1.60	1.60
$20L_{60}$	174.81					1.63
$20L_{88}$		178.048				
$20R_{60}$	175.56					1.63
$20R_{88}$		176.324				
$21L_{60}$	179.57					1.63
$21L_{88}$		180.555				
$21R_{60}$	178.55					1.63
$21R_{88}$		180.104				
$22L_{60}$	181.29					1.66
$22L_{88}$		182.957				
$22R_{60}$	182.06	183.719		1.66	1.66	1.66
$23L_{60}$	186.86					1.63
$23L_{88}$		188.539				
$23R_{60}$	186.81					1.63
$23R_{88}$		189.869				
$24L_{60}$	192.62					1.63
$24L_{88}$		194.449				
$24R_{60}$	192.22					1.63
$24R_{88}$		193.89				
$25L_{60}$	198.02					1.63
$25L_{88}$		200.233				
$25R_{60}$	197.78					1.63

BM	Year Final RL adopted		Difference between 1960 & 1988 RL (m)			Correction factor (m)
	1960	1988	BML	BMR	Average	
$25R_{88}$		199.665				
$26L_{60}$	203.1	204.638	1.54		1.54	1.63
$26R_{60}$	202.85					1.63
$26R_{88}$		205.415				
				Average	1.63	

1.2 Offset adjustments

After the 1960 RLs had been corrected to the same datum as the later data, the cross sections were plotted and inspected to determine if offsets also needed adjusting. The offset adjustment was based on either the established stability/instability of benchmarks, or the analysis of the location of sections from plans 5834 (1960) and 4247/4260 (1989/90). The location of the start and end of cross sections was determined with reference to identifiable features on the aerial photo plans (such as roads, buildings, trees)

CS1

There were two separate CS1, one placed in 1960 and surveyed in 1960 and 1962, the other placed in 1995 and surveyed in 1995 and 2000. Only data from the latter section is used in the analysis. BML95 and BMR95 have not been shifted or replaced so no horizontal adjustment was needed.

CS1A

No offset adjustment needed.

CS2

CS2 had benchmarks placed in 1960 and then replaced and extended in 1988. The 1960 offsets were shifted 10.95 m so the right bank of 1960 and later surveys tend to line up.

CS3

No offset adjustment needed.

CS4

No offset adjustment needed.

CS5

The BM card for CS5 showed that BMR60 had not been replaced so adjustments made for all the right benchmarks to coincide, shifting the offsets by 22.895 m.

CS6

This is a complicated cross-section where both BML60 and BMR60 were replaced in 1988. BMR88 was subsequently replaced in 1993. The location of the cross section was also moved by c.9 m. Cross-section plots on plans 4547 and 4547/1 showed the relative positions of sections between 1988 & 1995 and 1995 & 2000, respectively. The relative position of the 1960 and 1988 sections were labelled in plan 4260. The distance measured from the plan was 112 m therefore on the plot, BML60 and offsets were shifted 112 m. The 9 m offset between the old and the new cross-section lines was negligible so ignored.

CS7

No offset adjustment needed.

CS8

No offset adjustment needed.

CS9

BMR60 and BMR88 were at the same position since BMR60 was never replaced. So all right benchmarks coincided. BML60 however was replaced by BML88 at 15 m upstream of BML60 as suggested by Plan 4260. The plots were overlaid ignoring the fact that the 1960 cross-section line was not in exactly the same location as the later cross-section lines. This required BML to be offset by 9.945 m.

CS10

No offset adjustment needed.

CS11

Cross-section 11 is a complicated section where the correction made could contain a significant error. The left benchmark placed on a cliff face in 1960 was replaced twice in a new position in 1988 and then 1993 (assume to be due to erosion of cliff). The right benchmark placed in 1960 was repositioned in 1988.

No relative position of these benchmarks was given in any plans. Inspection of plans 5834 and 4260 suggest that the shorter 1960 CS line must be part of the longer 1988 CS line. Plan 5834 showed that BML60 was placed near bush. The position of BML60 was estimated on plan 4260 and superimposed onto the new section. Then the distance between the estimated BML60 and the BML88 was measured to be 152 m. The offsets of the 1960 section were then moved by 152 m.

CS12

The left bank was the toe of a bluff, and BMR60 was replaced at a new position by BMR88. There was no clear suggestion anywhere on plans of the relative positions of the benchmarks in different years. The toe of bluff was assumed to have eroded over the 40-year survey period therefore its position changed.

The approach to find the relative positions was by measuring distances from a point on the road (Motueka valley highway) taken as a stable reference point. The distance from BMR60 to the road and the distance from BMR88 to the road were measured off plans 5834 and 4260, respectively. The difference in these distances was therefore the offset between the two benchmarks. This calculation gave 100 m, which is a very large amount of erosion in 28 years, and should be checked by inspection of aerial photos.

CS13

Plans 5834 and 4260 suggested that cross section lines in 1960 and 1988 were the same. The left hand side was the toe of a bluff, and BMR60 was replaced by BMR88 at a new position. The relative position of the right benchmarks was again found by measuring distances off the plans 5834 and 4260, resulting in a shift of the offsets by 25 m.

CS13A

No offset adjustment needed.

CS14

The relative position of the right benchmarks was again found by measuring distances off the plans 5834 and 4260, resulting in a shift of the offsets by 28.58 m.

CS15

The benchmark card indicates that 15L placed in 1960 (i.e. BML60) was replaced in 1988 and called 15R (i.e. BMR88). This benchmark was bulldozed in 1995. The position of BMR60 was estimated from plans 5834 and 4260 and the offsets were shifted by 249.03 m.

An interesting feature to note was the major channel shift, which explained the large extension of the 1988 CS line. This validated our estimated position of the 1960 CS line.

CS16

The benchmark card indicates that the old 16R (i.e. BMR60) has gone. "The old 16R Aux is now called 16R (i.e. BMR88) and has been lowered approximately 0.18 m in the same position. A new benchmark Aux has been established approx 314 m back in fence line". Therefore, BMR60Aux was the same as BMR88. This helped locate the 1960 toe of bluff on the leftbank in plan 4260, which was found to be 80 m to the right of 1988 toe of bluff. This meant 80 m of erosion had occurred agreeing with our assumption. However, this should be checked by inspection of aerial photos.

CS17

The original BML60 was replaced at a new position in 1973. The relative position of the two benchmarks was unknown. The original BMR60 was also replaced at a new position in 1973. The benchmark card states that this benchmark "may have been repositioned to conform with stream alignment approx 60 m upstream of 1960 CS line". This 1973 right benchmark was again replaced in 1988, 246 m behind the old location.

A distance of 60 m was a large offset between cross-sections therefore the 1960 survey was omitted from this analysis. Consequently, no horizontal adjustment was required.

CS17A

No offset adjustment needed.

CS18

The benchmark card indicated that BML60 was replaced in 1973 at a new position. The relative position of the two benchmarks was unknown. Plans 5834 and 4260 suggested that the two benchmarks were reasonably close together, therefore we took the two BML to coincide on the plot.

CS18A

No offset adjustment needed.

CS19

The BM card indicated that BMR60 and BMR88 were at the same point therefore BMR60 was moved 146.87 m to coincide with BMR88 on the plot.

CS20

The BM card showed that both benchmarks had been relocated. From the positions of the BMs on plans 5834 and 4260 a shift to the offsets of 255.527 m was estimated.

CS21

All cross section lines were of similar length and the plans 5834 and 4260 suggested that the old and the new cross section lines were in the same place. Therefore, no adjustment was necessary.

CS22

No offset adjustment needed.

CS23

The BM card showed both the original 1960 benchmarks were replaced in 1988. Inspection of plans 5834 and 4260 suggested the left benchmark was replaced in a similar position to the old BM while the right BM was moved to a new location and the CS line was extended.

The difference in elevation between BML60 and the later BMLs may be due to silt deposition.

CS24

Although the BML60 was replaced twice, in 1988 and then in 1996, there was no note on the changing position of the BM. Therefore we assumed (from inspection of plans 5834 and 4260) that the position of BML remained the same. However, the CS line was extended in 1988 and BMR was moved, again this agreed with the plots.

CS25

Both BML60 and BMR60 were replaced in 1988 at a new location. The 1988 CS line was extended out but presumably still on the same line as the 1960 CS line. The location of BML60 in bush was superimposed onto the 1988 CS line in plan 4260. The distance between BML60 and BML88 was measured at 215.49 m and offsets shifted by this amount.

CS26

The original BML60 was replaced in 1996, and BMR60 was repositioned in 1962 to conform with stream alignment before being replaced in 1988 at a new position. From inspection of plans 5834 and 4260 an offset correction of 11.362 m was applied.

2 Lower Motueka

No adjustments were made to RLs in the lower Motueka as these had all been done previously by Howes (1994). Some offset adjustments were made to resolve the location of benchmarks and cross section features in different years.

CS54

1968 surveyed points were shifted by 72.905 m assuming that the 1968 BMR was the same as the 1984 BMR.

CS53

The 1968 offsets were shifted by 8.355 m so that the 1968 and the 1978/84 left stopbanks are coincident. Then the 1957 survey data were shifted by 94.43 m assuming that top of right bank in 1957 (originally at offset 193.065 m) is the same as that in 1968 (now at offset 287.495 m).

CS52, 51, 49, 48, 47, 46, & 45

No change was made to these sections; both left and right benchmarks of all years plot in the same (or very similar) position.

CS44

According to TDC plan 2758 sheet 4, the 1957 and 1960 sections offset the post-1978 sections by 800 ft so they were shifted by 800 ft (244 m).

CS43, 42

No change was made to these sections; both left and right benchmarks of all years plot in the same (or similar) position.

CS41

The 1982 stopbank was shifted by 7 m to align it with the 1984 stopbank.

CS40, 38, 37, 36, 35, 34, 33, 32, 31, 30

No change was made to these sections; both left and right benchmarks of all years fall on the same (or close) position.

CS29

From the plots, the 1967 and 1984 stopbanks are assumed to be the same and the centrelines adjusted to be coincident. The 1967 data was shifted by 7.48 m.

CS28, 27

No change was made to these sections; both left and right benchmarks of all years plot in the same (or similar) position.

CS26

Like CS29, from the plots it is assumed that the 1967 and 1984 stopbanks are the same. The 1967 offsets were shifted by 4.8 m.

CS25,24,23

No change was made to these sections; both left and right benchmarks of all years plot in the same (or similar) position.

CS22

TDC plan 2763 (sheet 4 of 10) suggests that the 1967 stopbank was realigned by 113 ft inside the 1957 stopbank. The 1967 stopbank was shifted by 113 ft (34.5 m).

CS21, 20, 19

No change was made to these sections; both left and right benchmarks of all years plot in the same (or similar) position.

CS18

The main channel in 1967 was shifted by 215.1 m to align with the post-1978 channels.

CS17

No change was made to these sections; both left and right benchmarks of all years plot in the same (or similar) position.

CS16

The 1967 right bank was shifted by 69.66 m to align with the 1984 right bank.

CS15

The 1960 and 1967 stopbanks were shifted by 149.6 m to align with the 1984 stopbank.

CS14, 13, 12, and 11

No change was made to these sections; both left and right benchmarks of all years plot in the same (or similar) position.

CS10

The 1957 and 1960 plots were shifted by 54.65 m to align the right benchmarks of all other years.

CS9, 8, 7, 6, 5, 4, 3, 2, 1

No change was made to these sections; both left and right benchmarks of all years plot in the same (or similar) position.

Appendix 3 Upper Motueka MBL changes between 1960 and 2000.

ACW = active channel width; MBL = mean bed level; * distance up river from the coast (m); # identifier for each cross section. A Two CS15 are listed as different channel widths were used in the analysis because of differences in the surveyed length of this cross section in 1960 and later surveys (1995, 2000).

			Cross-section distance			MBL (m)				Change in MBL (m)				Change in MBL/yr (m/yr)		
CS Dist*	**CS ID#**	**Notes**	**left bank**	**right bank**	**ACW (m)**	**1960**	**1988**	**1995**	**2000**	**60-88**	**88-95**	**95-00**	**60-00**	**60-88**	**88-95**	**95-00**
67243	**26**	Norths Br.	11.5	174.5	163.0	203.7	203.2	203.2	203.1	-0.48	0.03	-0.15	-0.60	-0.017	0.004	-0.030
66547	**25**		215.5	310.0	94.5	198.9	198.8	198.7	198.4	-0.13	-0.12	-0.25	-0.50	-0.005	-0.017	-0.049
65713	**24**		19.8	188.8	169.0	193.3	193.2	193.0	193.0	-0.08	-0.18	0.00	-0.25	-0.003	-0.025	0.000
64905	**23**		0.0	152.3	152.3	187.9	187.8	187.9	187.8	-0.07	0.07	-0.08	-0.08	-0.002	0.010	-0.017
64050	**22**	d/s Kohatu. Br.	27.5	195.2	167.8	182.4	181.8	181.9	182.1	-0.58	0.07	0.17	-0.35	-0.021	0.010	0.033
63525	**21**		100.5	275.5	175.0	179.8	179.6	179.6	179.6	-0.19	-0.01	0.05	-0.15	-0.007	-0.002	0.010
62840	**20**		319.3	480.9	161.7	176.2	175.8	175.7	175.5	-0.44	-0.15	-0.14	-0.73	-0.016	-0.021	-0.029
61780	**19**		173.1	400.0	226.9	170.3	170.3	170.1	170.3	0.00	-0.17	0.16	-0.01	0.000	-0.024	0.031
61405	**18A**		171.4	354.2	182.8		168.4	168.3	168.3		-0.09	-0.04			-0.012	-0.008
60965	**18**		129.2	239.9	110.7	165.8	166.0	165.9	165.9	0.21	-0.10	-0.01	0.11	0.008	-0.014	-0.002
60560	**17A**		61.5	216.2	154.7		164.4	164.3	164.2		-0.17	-0.09			-0.024	-0.018
60205	**17**		51.9	185.5	133.6		162.5	162.4	162.4		-0.06	0.01			-0.009	0.002
59250	**16**		46.1	203.4	157.3	158.2	157.9	157.8	157.9	-0.31	-0.05	0.02	-0.35	-0.011	-0.007	0.003
58512	**15** A		249.0	429.0	180.0	154.9	154.9			-0.03				-0.001		
58512	**15** A		0.0	214.0	214.0		154.4	154.4	154.2		-0.09	-0.12			-0.013	-0.025
57953	**14**		0.0	140.7	140.7	151.2	151.1	151.0	151.3	-0.07	-0.07	0.24	0.10	-0.003	-0.010	0.048
57822	**13A**		0.0	115.5	115.5		150.4	150.7	150.7		0.29	0.05		0.000	0.042	0.010
57518	**13**		0.0	175.4	175.4	149.6	149.3	149.4	149.4	-0.28	0.10	0.04	-0.14	-0.010	0.014	0.009
56924	**12**		0.0	186.1	186.1		146.7	146.7	146.4		0.03	-0.37			0.004	-0.073

			Cross-section distance			MBL (m)				Change in MBL (m)				Change in MBL/yr (m/yr)		
CS Dist*	**CS ID#**	**Notes**	**left bank**	**right bank**	**ACW (m)**	**1960**	**1988**	**1995**	**2000**	**60-88**	**88-95**	**95-00**	**60-00**	**60-88**	**88-95**	**95-00**
56355	**11**	u/s Tapawera Br	187.8	402.1	214.3	144.9	143.8	143.8	143.7	-1.09	-0.03	-0.04	-1.15	-0.039	-0.004	-0.007
55470	**10**		16.1	179.6	163.5	140.0	139.1	139.0	139.0	-0.90	-0.08	0.07	-0.91	-0.032	-0.012	0.013
54690	**9**		78.2	415.8	337.6	135.8	136.0	135.9	135.7	0.15	-0.08	-0.14	-0.07	0.005	-0.011	-0.029
53915	**8**	d/s Tadmor	39.3	277.1	237.7	131.7	131.7	131.7	131.7	-0.05	0.01	0.00	-0.05	-0.002	0.001	-0.001
53445	**7**		12.0	267.9	255.9	129.8	129.7	129.9	129.8	-0.05	0.17	-0.10	0.03	-0.002	0.024	-0.019
52532	**6**		203.5	459.0	255.5	125.3	125.6	125.4	125.7	0.26	-0.17	0.22	0.31	0.009	-0.024	0.044
51677	**5**		93.3	316.5	223.2	121.4	121.6	121.9	121.5	0.23	0.24	-0.33	0.14	0.008	0.035	-0.066
50905	**4**		25.7	213.2	187.5	118.3	118.3	118.2	118.3	0.04	-0.07	0.02	-0.01	0.001	-0.010	0.003
50065	**3**		20.1	146.3	126.2	114.8	114.6	114.5	114.5	-0.20	-0.04	-0.05	-0.29	-0.007	-0.006	-0.009
49260	**2**		47.5	185.0	137.4	110.8	111.7	111.4	111.4	0.84	-0.25	0.03	0.62	0.030	-0.036	0.005
48860	**1A**	d/s Wangapeka	262.5	373.5	111.0		109.9	109.8	109.4		-0.14	-0.36			-0.020	-0.073
48160	**1**		58.0	257.1	199.1			108.6	108.7			0.09				0.019
									Average	**-0.14**	**-0.04**	**-0.04**	**-0.20**	**-0.005**	**-0.005**	**-0.007**
									Max	**0.84**	**0.29**	**0.24**	**0.62**	**0.030**	**0.042**	**0.048**
									Min	**-1.09**	**-0.25**	**-0.37**	**-1.15**	**-0.039**	**-0.036**	**-0.073**

Appendix 4 Upper Motueka changes in channel storage volume between 1960 and 2000

CS Dist	CS ID	Notes	1960-1988		1988-1995		1995-2000		1960-2000	
			Volume change (m^3)	Cumulative balance (m^3)	Volume change (m^3)	Cumulative balance (m^3)	Volume change (m^3)	Cumulative balance (m^3)	Volume change (m^3)	Cumulative balance (m^3)
67243	**26**	Norths Br.								
66547	**25**		-31416	-31416	-2484	-2484	-16566	-16566	-50466	-50466
65713	**24**		-10930	-42346	-17149	-19633	-9658	-26223	-37736	-88202
64905	**23**		-9719	-52065	-7699	-27332	-5072	-31295	-22490	-110692
64050	**22**	d/s Kohatu. Br.	-46196	-98261	9296	-18036	6467	-24828	-30433	-141125
63525	**21**		-34225	-132486	2247	-15789	9621	-15207	-22357	-163482
62840	**20**		-35316	-167802	-9144	-24933	-4954	-20161	-49414	-212896
61780	**19**		-37214	-205016	-32910	-57843	6392	-13770	-63732	-276628
61405	**18A**				-10051	-67894	5189	-8581		
60965	**18**		9561	-195455	-5780	-73674	-1871	-10452	-2954	-279582
60560	**17A**				-7433	-81107	-3049	-13502		
60205	**17**				-6086	-87193	-2248	-15750		
59250	**16**		-22330	-217785	-7730	-94923	1858	-13891	-47017	-326599
58512	**15**		-20207	-237992	-9989	-104912	-8819	-22710	-39015	-365615
57953	**14**		-4284	-242276	-8157	-113070	2042	-20668	-10399	-376014
57822	**13A**				1567	-111502	2596	-18073		
57518	**13**		-12953	-255229	7820	-103682	2114	-15958	1145	-374869
56924	**12**				6707	-96975	-17880	-33839		
56355	**11**	u/s Tapawera Br	-164561	-419790	-103	-97078	-21517	-55356	-197355	-572224
55470	**10**		-168076	-587866	-8268	-105346	1404	-53952	-174940	-747164

CS Dist	CS ID	Notes	1960-1988		1988-1995		1995-2000		1960-2000	
			Volume change (m^3)	Cumulative balance (m^3)	Volume change (m^3)	Cumulative balance (m^3)	Volume change (m^3)	Cumulative balance (m^3)	Volume change (m^3)	Cumulative balance (m^3)
54690	**9**		-37299	-625165	-15424	-120770	-14772	-68724	-67495	-814658
53915	**8**	d/s Tadmor	14657	-610508	-9729	-130500	-19267	-87991	-14340	-828998
53445	**7**		-5840	-616348	10580	-119919	-5988	-93979	-1248	-830246
52532	**6**		24439	-591909	592	-119327	14729	-79250	39760	-790486
51677	**5**		50097	-541812	4978	-114348	-7452	-86702	47623	-742863
50905	**4**		22800	-519012	16074	-98274	-27490	-114192	11384	-731478
50065	**3**		-7460	-526472	-7501	-105775	-1313	-115505	-16274	-747752
49260	**2**		36590	-489882	-16087	-121862	-888	-116394	19614	-728138
48860	**1A**	d/s Wangapeka	23192	-466689	-3174	-125036	-7355	-123748	12663	-715,475
48160	**1**				-5555	-130591	-7724	-131472		
Average change (m^3/yr)		**Whole reach**		**-16,667**		**-18,656**		**-26,294**		**-17,887**
		Above CS2		**-17,496**		**-17,383**		**-23,279**		**-18,203**

Appendix 5 Lower Motueka MBL between 1957 and 2001.

			Cross-section distance			MBL (m)								
CS Dist	**Cs ID**	**Notes**	**left bank**	**right bank**	**ACW (m)**	**1957**	**1960**	**1968/67**	**1978**	**1982**	**1984**	**1990**	**1997/98**	**2001**
16620	**1**	Alexander Bluff Bridge	20	97	77					25.8		25.9	25.9	25.8
16150	**2**		47	160	113				25.9	26.8	25.9	25.9	26.0	26.0
15900	**3**		72	214	142				25.8	25.6	25.8	25.8		
15660	**4**		67	266	199				26.1	26.1	26.1	26.1	26.1	26.0
15420	**5**		145	321	176				25.1	25.0	25.0	25.0		
15140	**6**		209	304	95				24.0	23.8	23.6	23.7	23.8	23.7
14875	**7**		181	276	95				23.0	23.2	23.2	23.1		
14620	**8**		86	208	122				23.4	23.4	23.2	23.2	23.2	23.2
14360	**9**		117	229	112				22.5	22.6	22.0	22.2		
14100	**10**		58	178	120	21.9	22.0		21.8	21.7	21.7	21.6	21.6	21.6
13880	**11**		34	153	119				21.7	21.8	21.7	21.5		
13620	**12**		179	278	99				20.9	20.7	20.4	20.7	20.5	20.6
13380	**13**		0	244	244				21.7	21.8	21.8	21.7		
13150	**14**		86	273.852	187.852				21.0	21.2	20.9	20.7	20.7	20.8
12910	**15**		175	296	121		19.7	19.6	19.5	19.6	19.6	19.4	20.5	19.4
12650	**16**		53	307	254			19.2	19.7	19.7	19.7	19.6		20.0
12260	**17**				272				18.8	19.0	18.9		19.1	19.1
12000	**18**		223	405	182			17.9	18.0	18.1	18.2	18.2	18.0	18.0
11760	**19**				114				16.9	17.0	16.7		16.8	16.7
11560	**20**		86	204	118	17.2	16.8	16.6	16.5	16.5	16.6	16.6	16.5	16.5
11350	**21**		10	118	108				15.9	15.8	15.5	15.7	15.6	15.5
11130	**22**		19	148	129			16.2			15.7	15.7	15.6	15.6
10900	**23**	Woodman's Bend	104	244	140				15.6	15.1	15.1	14.7	14.7	14.7
10670	**24**		56	229	173	15.9	16.0	15.7	15.7	15.7	15.6	15.5	15.6	15.6
10460	**25**		134	236	102				14.3	14.2	14.1	14.1	13.6	13.9
10250	**26**		33	192	159			14.5	14.5	14.3	14.3	14.3	14.1	14.0
10000	**27**		112	259	147				13.7	13.5	13.6	13.5	13.4	13.5
9825	**28**		111	263	152	14.3	14.4	13.8	13.6	13.4	13.3	13.5	13.2	13.1
9550	**29**		161	268	107			12.5	12.4	12.2	12.1	12.2	12.2	12.1

			Cross-section distance			MBL (m)								
CS Dist	**Cs ID**	**Notes**	**left bank**	**right bank**	**ACW (m)**	**1957**	**1960**	**1968/67**	**1978**	**1982**	**1984**	**1990**	**1997/98**	**2001**
9260	**30**		180	383	203			13.0	12.9	12.8	12.6	12.6	12.6	12.6
8925	**31**		35	294	259			11.8	12.0	12.0	11.9	11.8	11.8	11.8
8720	**32**		10	155	145				10.6	10.5	10.4	10.6	10.4	10.4
8500	**33**		9	106	97	9.4	9.7	10.1	9.5	9.3	9.1	9.1	9.0	9.0
8220	**34**		27	137	110		9.8		9.1	8.9	9.0	9.1	8.9	8.9
8000	**35**		33	198	165				9.7	9.5	9.6	9.6	9.3	9.4
7800	**36**		57	223	166				9.3	9.4	8.9	9.2	8.9	8.9
7520	**37**	Douglas Rd	108	290	182	8.9	9.0		8.3	8.5	7.9	8.2	8.1	8.3
7250	**38**		79	227	148		8.6		7.9	8.1	8.0	7.9	7.5	7.5
7145	**40**		74	210	136		8.1		7.6	7.6	8.0	7.7	7.4	7.4
6725	**41**		68.8	282	169		7.9		7.6	7.5	7.6	7.2	6.8	6.7
6500	**42**		16	208	192				6.8	6.9	6.8	6.5	6.3	6.3
6300	**43**		218	421	203				6.0	6.0	6.0	5.9	5.8	5.7
5950	**44**		294	502	208	5.5	5.5		5.5		5.2	4.8	4.7	4.6
5700	**45**	Stephens Beach	219	442	223				4.9	5.1	4.8	4.3	4.3	4.4
5370	**46**		145	351	206				4.2	3.9	3.9	3.5	3.4	3.5
5150	**47**		116	333	217	4.2	4.1		3.8	3.7	3.4	3.1	3.2	3.3
4900	**48**		109	311	202				3.3	3.2	3.1	2.5	2.5	2.6
4570	**49**		174	353	179	2.9	2.8		2.4	2.3	2.2	2.0	2.0	2.1
4430	**51**		95	293	198				2.2	2.1	1.8	1.8	2.0	2.0
4160	**52**		27	375.22	348.22	2.6	2.8	2.3	2.5	2.2	2.1	1.8	1.9	2.0
3850	**53**		69	300	231	1.8		1.8	1.4	1.5	1.3	1.4	1.4	1.3
3500	**54**	River mouth	169	452	283			1.4	1.2	1.1	1.0	0.6	0.9	0.9

Appendix 6 Lower Motueka MBL change between 1957 and 2001.

			Change in MBL (m)							
CS dist	**CS ID**	**Notes**	**57-60**	**60-67/68**	**67/68-78**	**78-82**	**82-84**	**84-90**	**90-97/98**	**97/98-01**
16620	**1**	Alexander Bluff Bridge							0.03	-0.06
16150	**2**					0.97	-0.89	-0.02	0.13	-0.01
15900	**3**					-0.14	0.15	0.00		
15660	**4**					-0.01	0.01	-0.06	-0.02	-0.04
15420	**5**					-0.15	0.06	-0.08		
15140	**6**					-0.23	-0.15	0.05	0.11	-0.04
14875	**7**					0.17	-0.01	-0.08		
14620	**8**					-0.01	-0.19	0.08	-0.03	-0.04
14360	**9**					0.19	-0.67	0.23		
14100	**10**		0.04			-0.05	0.02	-0.11	-0.06	-0.02
13880	**11**					0.04	-0.12	-0.12		
13620	**12**					-0.19	-0.27	0.25	-0.16	0.10
13380	**13**					0.09	0.03	-0.14		
13150	**14**					0.15	-0.24	-0.19	-0.01	0.08
12910	**15**			-0.04	-0.09	0.07	-0.01	-0.15	1.02	-1.01
12650	**16**				0.53	-0.01	-0.02	-0.04		
12260	**17**					0.21	-0.11			0.02
12000	**18**				0.10	0.13	0.02	0.00	-0.14	-0.05
11760	**19**					0.10	-0.22			-0.12
11560	**20**		-0.46	-0.15	-0.09	0.02	0.03	-0.02	-0.04	0.01
11350	**21**					-0.10	-0.23	0.14	-0.12	-0.04
11130	**22**							0.07	-0.15	0.00
10900	**23**	Woodman's Bend				-0.49	-0.04	-0.34	-0.03	0.04
10670	**24**		0.13	-0.35	0.00	0.04	-0.11	-0.06	0.10	-0.03
10460	**25**					-0.11	-0.10	-0.01	-0.46	0.28
10250	**26**				-0.06	-0.18	-0.02	0.00	-0.19	-0.13

			Change in MBL (m)							
CS dist	**CS ID**	**Notes**	**57-60**	**60-67/68**	**67/68-78**	**78-82**	**82-84**	**84-90**	**90-97/98**	**97/98-01**
10000	**27**					-0.19	0.03	-0.06	-0.08	0.09
9825	**28**		0.08	-0.59	-0.22	-0.17	-0.04	0.18	-0.34	-0.09
9550	**29**				-0.02	-0.28	-0.04	0.11	-0.07	-0.08
9260	**30**				-0.14	-0.14	-0.13	-0.06	0.04	0.00
8925	**31**				0.16	-0.04	-0.01	-0.13	-0.04	0.04
8720	**32**					-0.09	-0.06	0.25	-0.23	-0.04
8500	**33**		0.34	0.38	-0.58	-0.21	-0.21	0.07	-0.18	0.04
8220	**34**					-0.22	0.04	0.14	-0.19	0.04
8000	**35**					-0.12	0.06	0.00	-0.27	0.09
7800	**36**					0.03	-0.42	0.22	-0.26	0.04
7520	**37**	Douglas Rd	0.19			0.29	-0.61	0.31	-0.16	0.18
7250	**38**					0.19	-0.07	-0.05	-0.40	0.01
7145	**40**					-0.01	0.43	-0.31	-0.26	-0.05
6725	**41**					-0.12	0.09	-0.40	-0.46	-0.05
6500	**42**					0.08	-0.10	-0.29	-0.14	-0.07
6300	**43**					-0.04	0.04	-0.15	-0.13	-0.03
5950	**44**		0.05					-0.37	-0.09	-0.05
5700	**45**	Stephens Beach				0.14	-0.23	-0.54	0.01	0.04
5370	**46**					-0.27	-0.03	-0.41	-0.05	0.04
5150	**47**		-0.09			-0.06	-0.32	-0.25	0.08	0.09
4900	**48**					-0.15	-0.13	-0.58	0.04	0.10
4570	**49**		-0.06			-0.08	-0.10	-0.16	-0.04	0.07
4430	**51**					-0.15	-0.29	0.03	0.18	0.02
4160	**52**		0.13	-0.42	0.11	-0.27	-0.10	-0.34	0.19	0.08
3850	**53**				-0.34	0.03	-0.12	0.09	-0.04	-0.05
3500	**54**	River mouth			-0.20	-0.09	-0.15	-0.36	0.29	-0.01
		Average	**0.04**	**-0.20**	**-0.06**	**-0.03**	**-0.11**	**-0.07**	**-0.06**	**-0.01**
		Max aggradation	**0.34**	**0.38**	**0.53**	**0.97**	**0.43**	**0.31**	**1.02**	**0.28**
		Max degradation	**-0.46**	**-0.59**	**-0.58**	**-0.49**	**-0.89**	**-0.58**	**-0.46**	**-1.01**

Appendix 7 Lower Motueka rate of MBL change between 1957 and 2001

			Change in MBL/yr (m/yr)							
CS Dist	**Cs ID**	**Notes**	**57-60**	**60-67/68**	**67/68-78**	**78-82**	**82-84**	**84-90**	**90-97/98**	**97/98-01**
16620	**1**	Alexander Bluff Bridge							0.004	-0.021
16150	**2**					0.241	-0.443	-0.004	0.016	-0.003
15900	**3**					-0.035	0.076	0.000		
15660	**4**					-0.002	0.006	-0.011	-0.002	-0.014
15420	**5**					-0.038	0.032	-0.013		
15140	**6**					-0.058	-0.075	0.008	0.013	-0.014
14875	**7**					0.042	-0.004	-0.014		
14620	**8**					-0.002	-0.097	0.013	-0.003	-0.015
14360	**9**					0.047	-0.336	0.038		
14100	**10**		0.013			-0.013	0.011	-0.018	-0.008	-0.007
13880	**11**					0.011	-0.058	-0.020		
13620	**12**					-0.047	-0.135	0.041	-0.020	0.034
13380	**13**					0.023	0.015	-0.023		
13150	**14**					0.038	-0.118	-0.031	-0.001	0.020
12910	**15**			-0.006	-0.009	0.017	-0.003	-0.025	0.146	-0.253
12650	**16**				0.048	-0.001	-0.008	-0.006		
12260	**17**					0.052	-0.055			0.005
12000	**18**				0.009	0.033	0.011	-0.001	-0.019	-0.012
11760	**19**					0.025	-0.110			-0.030
11560	**20**		-0.154	-0.021	-0.009	0.005	0.017	-0.003	-0.006	0.003
11350	**21**					-0.026	-0.114	0.023	-0.016	-0.010
11130	**22**							0.012	-0.021	0.001
10900	**23**	Woodman's Bend				-0.123	-0.020	-0.057	-0.005	0.009

			Change in MBL/yr (m/yr)							
CS Dist	**Cs ID**	**Notes**	**57-60**	**60-67/68**	**67/68-78**	**78-82**	**82-84**	**84-90**	**90-97/98**	**97/98-01**
10670	**24**		0.045	-0.050	0.000	0.009	-0.053	-0.010	0.014	-0.007
10460	**25**					-0.028	-0.048	-0.002	-0.065	0.069
10250	**26**				-0.006	-0.045	-0.012	-0.001	-0.028	-0.032
10000	**27**					-0.047	0.013	-0.010	-0.012	0.024
9825	**28**		0.028	-0.084	-0.020	-0.042	-0.020	0.031	-0.048	-0.022
9550	**29**				-0.002	-0.070	-0.019	0.019	-0.010	-0.021
9260	**30**				-0.013	-0.036	-0.065	-0.010	0.006	0.000
8925	**31**				0.014	-0.010	-0.006	-0.021	-0.005	0.011
8720	**32**					-0.024	-0.028	0.041	-0.033	-0.009
8500	**33**		0.113	0.054	-0.053	-0.053	-0.105	0.011	-0.026	0.011
8220	**34**					-0.055	0.019	0.024	-0.027	0.009
8000	**35**					-0.031	0.029	-0.001	-0.039	0.021
7800	**36**					0.008	-0.211	0.037	-0.037	0.011
7520	**37**	Douglas Rd	0.065			0.072	-0.303	0.051	-0.023	0.045
7250	**38**					0.048	-0.033	-0.008	-0.057	0.001
7145	**40**					-0.001	0.213	-0.052	-0.037	-0.013
6725	**41**					-0.029	0.047	-0.066	-0.066	-0.011
6500	**42**					0.019	-0.049	-0.048	-0.021	-0.019
6300	**43**					-0.010	0.022	-0.025	-0.018	-0.009
5950	**44**		0.017					-0.062	-0.013	-0.013
5700	**45**	Stephens Beach				0.034	-0.114	-0.090	0.002	0.010
5370	**46**					-0.067	-0.013	-0.068	-0.007	0.010
5150	**47**		-0.029			-0.015	-0.158	-0.041	0.012	0.023
4900	**48**					-0.037	-0.066	-0.096	0.006	0.024

			Change in MBL/yr (m/yr)							
CS Dist	**Cs ID**	**Notes**	**57-60**	**60-67/68**	**67/68-78**	**78-82**	**82-84**	**84-90**	**90-97/98**	**97/98-01**
4570	**49**		-0.021			-0.019	-0.048	-0.027	-0.005	0.018
4430	**51**					-0.038	-0.145	0.005	0.025	0.004
4160	**52**		0.045	-0.053	0.011	-0.067	-0.049	-0.057	0.027	0.020
3850	**53**				-0.034	0.008	-0.060	0.015	-0.005	-0.013
3500	**54**	River mouth			-0.020	-0.022	-0.073	-0.060	0.041	-0.003
		Average	**0.012**	**-0.027**	**-0.006**	**-0.007**	**-0.056**	**-0.012**	**-0.009**	**-0.004**
		Maximum	**0.113**	**0.054**	**0.048**	**0.241**	**0.213**	**0.051**	**0.146**	**0.069**
		Minimum	**-0.154**	**-0.084**	**-0.053**	**-0.123**	**-0.443**	**-0.096**	**-0.066**	**-0.253**

Appendix 8 Lower Motueka changes in channel storage volume between 1957 and 2001

CS Dist	CS ID	Notes	1957-1960		1960-1967/68		1967/68-1978		1978-1982	
			Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance
			(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
16620	**1**	Alexander Bluff Bridge								
16150	**2**									
15900	**3**								11166	11166
15660	**4**								-2574	8592
15420	**5**								-3412	5181
15140	**6**								-6851	-1670
14875	**7**								-816	-2487
14620	**8**								1935	-552
14360	**9**								2610	2058
14100	**10**								1875	3933
13880	**11**								-130	3803
13620	**12**								-1711	2092
13380	**13**								457	2549
13150	**14**								5812	8361
12910	**15**						-2698	-2698	4379	12740
12650	**16**						16110	13412	888	13628
12260	**17**								10836	24463
12000	**18**						49627	63038	10484	34947
11760	**19**								4207	39155
11560	**20**		-63499	-63499	-15173	-15173	1351	64389	1379	40534
11350	**21**								-905	39629
11130	**22**									
10900	**23**	Woodman's Bend							-17996	21633
10670	**24**		-13962	-77461	-34782	-49955	-4653	59736	-7203	14429
10460	**25**								-526	13904

CS Dist	CS ID	Notes	1957-1960		1960-1967/68		1967/68-1978		1978-1982	
			Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance
			(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
10250	**26**						-1893	57843	-4188	9716
10000	**27**								-7005	2711
9825	**28**		15149	-62312	-63321	-113276	-9236	48607	-4620	-1909
9550	**29**						-4972	43635	-7613	-9523
9260	**30**						-4447	39188	-8559	-18082
8925	**31**						2042	41230	-6626	-24708
8720	**32**								-2490	-27198
8500	**33**		30040	-32272	-34875	-148152	-3375	37855	-3761	-30958
8220	**34**								-6224	-37182
8000	**35**								-4856	-42038
7800	**36**								-1472	-43510
7520	**37**	Douglas Rd	33394	1122					8085	-35425
7250	**38**								10883	-24543
7145	**40**								1447	-23096
6725	**41**								-4301	-27397
6500	**42**								-586	-27983
6300	**43**								657	-27326
5950	**44**		36070	37192						
5700	**45**	Stephens Beach							6636	-20690
5370	**46**								-4190	-24880
5150	**47**		-3298	33894					-7560	-32440
4900	**48**								-5391	-37832
4570	**49**		-8667	25227					-7152	-44984
4430	**51**								-3065	-48050
4160	**52**		7351	32578	-241370	-389522	-38113	-258	-16656	-64706
3850	**53**						-6148	-6406	-13288	-77995
3500	**54**	River mouth					-23723	-30130	-3037	-81032

CS Dist	CS ID	Notes	1957-1960		1960-1967/68		1967/68-1978		1978-1982	
			Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance
			(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
Average change (m^3/yr)			**10859**		**-51936**		**-3013**		**-20258**	

CS Dist	Cs ID	Notes	1982-1984		1984-1990		1990-1997/98		1997/98-2001		1957-2001		1978-2001	
			Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance
			(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
16620	**1**	Alexander Bluff Bridge												
16150	**2**						3957	3957	-1384	-1384				
15900	**3**		-9811	-9811	-348	-348								
15660	**4**		2870	-6941	-1544	-1892	2778	6736	-2351	-3735			2759	2759
15420	**5**		1620	-5321	-3127	-5020								
15140	**6**		-425	-5747	-1232	-6251	1827	8563	-3292	-7027			-14892	-12133
14875	**7**		-1976	-7722	-439	-6691								
14620	**8**		-3106	-10829	252	-6438	1831	10393	-2467	-9494			-6617	-18750
14360	**9**		-12848	-23676	4594	-1845								
14100	**10**		-9420	-33096	1631	-214	-2715	7679	-2066	-11561			-14272	-33022
13880	**11**		-1231	-34327	-2975	-3189								
13620	**12**		-5277	-39604	1367	-1822	-5532	2147	1790	-9770			-13699	-46721
13380	**13**		-2317	-41921	-1030	-2852								
13150	**14**		-4230	-46151	-7853	-10705	-4035	-1888	5925	-3845			-7272	-53993
12910	**15**		-5382	-51533	-6438	-17143	14704	12815	-12885	-16730			-5622	-59616
12650	**16**		-603	-52136	-3683	-20826								
12260	**17**		-6579	-58715					-37926	-54656				
12000	**18**		-3354	-62069	-3479	-24305	45111	57926	-398	-55055			11296	-48320
11760	**19**		-2536	-64606					-2702	-57757				-
11560	**20**		-2106	-66711	-723	-25028	-6485	51441	-1190	-58947	-158278	-158278	-10157	-58477

CS Dist	Cs ID	Notes	1982-1984		1984-1990		1990-1997/98		1997/98-2001		1957-2001		1978-2001	
			Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance
			(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
11350	**21**		-2150	-68861	1316	-23712	-1798	49643	-266	-59214			-3804	-62280
11130	**22**		-2700	-71561	2683	-21030	-3494	46149	-392	-59606				
10900	**23**	Woodman's Bend	-645	-72206	-4428	-25458	-2771	43379	652	-58953			-29089	-91369
10670	**24**		-2740	-74946	-6759	-32216	1437	44815	-6	-58959	-57669	-215947	-15272	-106641
10460	**25**		-2946	-77892	-1258	-33474	-3084	41731	2428	-56532			-5385	-112026
10250	**26**		-1419	-79310	-200	-33674	-8116	33616	795	-55736			-13127	-125153
10000	**27**		29	-79282	-1173	-34847	-5331	28285	-850	-56587			-14330	-139483
9825	**28**		-192	-79473	1697	-33150	-5549	22736	52	-56535	-95404	-311350	-8612	-148095
9550	**29**		-1398	-80871	5514	-27636	-8093	14643	-3048	-59583			-14639	-162734
9260	**30**		-4442	-85313	-92	-27728	218	14861	-1240	-60824			-14115	-176850
8925	**31**		-4988	-90301	-7555	-35283	-107	14754	1919	-58904			-17357	-194206
8720	**32**		-1165	-91467	336	-34947	-4463	10291	605	-58299			-7177	-201384
8500	**33**		-3140	-94607	4620	-30327	-5677	4614	-93	-58392	-141300	-452651	-8051	-209435
8220	**34**		-2273	-96880	3093	-27235	-5369	-755	1179	-57213			-9595	-219030
8000	**35**		1495	-95385	1669	-25565	-7226	-7981	2000	-55213			-6918	-225947
7800	**36**		-6063	-101448	3606	-21959	-8825	-16806	2141	-53073			-10613	-236560
7520	**37**	Douglas Rd	-25237	-126685	12916	-9043	-10189	-26996	5642	-47431	-70136	-522786	-8785	-245345
7250	**38**		-16208	-142894	6518	-2525	-11940	-38936	4563	-42868			-6185	-251529
7145	**40**		2520	-140374	-2609	-5135	-4954	-43890	-318	-43186			-3915	-255445
6725	**41**		15508	-124866	-22972	-28107	-23807	-67697	-3069	-46254			-38641	-294085
6500	**42**		-301	-125167	-13736	-41843	-11895	-79592	-2479	-48734			-28998	-323084
6300	**43**		-978	-126146	-8611	-50454	-5386	-84978	-2122	-50856			-16441	-339524
5950	**44**		1557	-124589	-18883	-69336	-7863	-92841	-3125	-53981	-224187	-746973		
5700	**45**	Stephens Beach	-6360	-130949	-24632	-93968	-1986	-94828	-236	-54217			-54891	-394416
5370	**46**		-9248	-140196	-33773	-127740	-1110	-95938	2819	-51399			-45502	-439918
5150	**47**		-8096	-148293	-15153	-142894	937	-95001	3041	-48358	-146339	-893312	-26833	-466750
4900	**48**		-11879	-160171	-21217	-164111	3411	-91590	4896	-43462			-30180	-496930
4570	**49**		-7214	-167385	-23949	-188060	423	-91167	5308	-38153	-95987	-989299	-32584	-529514

CS Dist	Cs ID	Notes	1982-1984		1984-1990		1990-1997/98		1997/98-2001		1957-2001		1978-2001	
			Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance	Volume change	Cumulative balance
			(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
4500	**50**													
4430	**51**		-5205	-172590	-1630	-189690	1973	-89194	1090	-37063			-6838	-536352
4160	**52**		-12340	-184930	-15261	-204951	13616	-75577	4165	-32899	-72990	-1062289	-26476	-562827
3850	**53**		-9574	-194504	-15139	-220090	8949	-66629	2492	-30407	-50971	-1113260	-26560	-589388
3500	**54**	River mouth	-12095	-206599	-14331	-234421	12708	-53920	-2734	-33141			-19490	-608877
Average change (m3/yr)				**-103300**		**-39070**		**-6740**		**-11047**		**-25301**		**-26473**