Plain language report on river bed changes at Balclutha

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Cover photo: Imagery of the Clutha River showing movement of gravel bars from 2013 to 2024

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Non-technical summary

The bed level of a river can rise or fall depending on changes in channel shape, changes in river flow and changes in the supply of sediment from upstream. River bed adjustment to such changes can take many decades. For the Clutha River at Balclutha, all of these factors have come into play over the river's history, and they have been studied in a technical report "Clutha River Morphology Trends at Balclutha" prepared for Otago Regional Council in March 2025. This plain-language report accompanies, complements and summarises findings of the more detailed technical analysis.

Otago Regional Council (ORC) collected detailed surveys of the bed level of the Clutha River since 1994, and pre-1990s surveys have been compiled from historical records back to 1878. The National Institute of Water and Atmospheric Research (NIWA) has also measured river depth and flow near the Balclutha railway bridge since 1952. More recent satellite imagery collected by Sentinel-2 shows the patterns of channels and bars in the river. This study investigates these data to reveal how the level of the Clutha river bed near Balclutha has changed with time. In particular, it considers eleven locations near Balclutha where bed levels have been measured, 482 river depth and flow measurements near the Balclutha railway bridge, and seven satellite images that show gravel bars in the river. Bed levels are typically measured at points along a line across the river to produce what is known as a cross-section.

An important question related to the Clutha bed level, is whether the river is more or less likely to flood into Balclutha now than it has been in the past. This is revealed by NIWA's measurements near the Balclutha railway bridge, which show how the water level for a given flow has changed from the past to the present.

The overall finding on river bed changes near Balclutha is that there was an increase in bed level in the late 1800s. Little is known about river bed levels in the early 1900's, then there was a long-term trend of lowering of the river bed from the 1950s to about 2002 with less of a trend evident since 2002. This behaviour corresponds to an increase in alluvial sediment produced by gold mining and sluicing in the late 1800s and then a severe reduction in sediment supply following commissioning of the Roxburgh hydro dam in 1954. Cross-section levels measured since 1994, show that the average bed level is stable or falling at ten of the eleven cross-sections near Balclutha. The section at the State Highway Bridge shows a small rising trend in the average bed level. Since 1994, minimum bed levels (in other words, the deepest points in the river) have been stable or falling at all cross-sections except at the North end of Elizabeth Street where the surveyed low point is rising with time. This change has resulted from historic, upstream river training works which have moved the deepest part of the channel away from the bank.

The NIWA flow measurements at Balclutha show the channel flood capacity (the ability of the river to pass a flood through the channel without overtopping) has been increasing since 1952 for floods up to around 1600 cubic metres per second. River beds may lower during flood events, but the extent of bed lowering during floods is unknown at Balclutha. Assuming this effect has not reduced over time, the historic cross-section surveys do not indicate a reduction of flood capacity of the Balclutha reach.

However, there are recent reports that gravel bars are now more evident in the river at Balclutha, which could provide a barrier to flow which could cause reduced flood capacity. This apparent paradox could be explained because stable bars can become more visible and appear to be higher when the river water level falls alongside a bar. A field inspection may help confirm this explanation.

Effects of river gravel mining on the river cross is measured by the cross-section surveys. However, as extraction times and volumes are not all known, it is difficult to attribute the influence of gravel extraction on observed cross-section changes.

Ongoing monitoring and, in particular, measurement of river bed levels during future high flood flows, is strongly recommended. This monitoring would help to answer questions about any changes in ability of the channel to handle high floods and about how much the bed scours during a rising flood before refilling on a falling flood, which will bury the actual cross-section during the flood.

1 Introduction

1.1 Background

Since 1954, the Roxburgh Hydro dam has captured Clutha (Mata-Au) sediment and prevented gravel from moving downstream. This effect reduces the amount of sediment reaching Balclutha each year by about 90%[1]. Other factors that affect sediment in the river include gravel extraction, gold sluicing, the size and frequency of floods, river erosion, bank protection works and other changes in the river catchments between Roxburgh and Balclutha.

Usually, when a dam cuts off sediment supply, a river starts to erode and cut deeper into its bed. This bed lowering tends to be more severe closer to the dam and decreases downstream. Over time, the rate of bed lowering generally slows down[2].

The Otago Regional Council (ORC) have commissioned NIWA to analyse and report on historical changes in river bed levels in the Clutha near Balcultha township, using data from bed level surveys, flow measurements and satellite imagery. The results of the analyses will be used to help understand any significant trends and to guide river management strategies into the future.

Bed levels are typically measured at points along a line across the river to produce what is known as a cross-section. All bed levels are presented with a common datum for which 100 m is the approximately mean sea level. Data from eleven cross-section locations have been used in this study. All cross-sections are viewed and discussed from a "looking downstream" point of view. Seven of the cross-sections are within the Clutha River and four are located on the two branches where the river splits, just downstream of Balclutha. Cross-section surveys for ten of the locations have been undertaken regularly since 1994 and, for the cross-section located near the railway bridge, data extend as far back as 1878.

While the analysis covers a long period, bed changes can occur between the dates of the cross-section measurements, particularly if there has been gravel extraction or flooding. Comprehensive gravel extraction data are not available, so the exact effects of gravel mining on the observed changes are not known. Moreover, areas of scour, or bed lowering, during a rising flood may refill on the falling flood and not be captured by a later cross-section survey. Consequently, the information on bed level changes reported here relates to the net change between the cross-section survey dates.

Local flood capacity of the river (the ability of the river to pass a flood through the channel without overtopping)depends on what happens downstream, the local cross-section and on localised flow influences from bars, river bends and bed material sizes. These effects are captured by making flow measurements during floods.

[1] Hicks DM, Walsh JM and Duncan MJ. (2000). Clutha River Sediment Budget. NIWA Client Report CHC00/45

[2] Grant, G. E., Fassnacht, H., McClure, E. M., & Klingeman, P. C. (2003). Downstream effects of the Pelton-Round Butte hydroelectric project on bedload transport, channel morphology, and channel-bed texture, lower Deschutes River, Oregon. Water Science and Application, 7, 175-176.

1.2 Scope of the work

The objectives of the study are to:

- Determine whether there is a significant trend in river bed levels at Balclutha in recent decades, beyond the expected range of typical bed level fluctuations or measurement uncertainties.
- Assess notable changes in the location, scale, or development of gravel bars or islands within this reach of the river.
- Identify the key factors driving any significant changes observed or, in the absence of such changes, to explore the reasons behind community perceptions of change in the river system.
- Evaluate whether the magnitude of any observed river bed level changes is sufficient to reduce the flood capacity within this reach of the river.

To address these objectives, we have undertaken the following steps:

- Collating all available ORC surveys and river bed cross-section data.
- Reviewing the raw survey data and refining it where discrepancies or mismatches with historical cross-section records were identified, ensuring consistency and accuracy.
- Overlaying and plotting the cross-sections to provide a clear visual representation of changes over time.
- Analysing historical changes in river bed levels by calculating the average bed level, the minimum bed level and changes in the higher parts (gravel bars) of each cross-section.
- Using satellite imagery over time to analyse changes in the extent of gravel bars.
- Investigating the record of flow measurements made at the NIWA flow recorder site at Balclutha.

2 Cross-section data and adjustments

Cross-section surveys of the Clutha River are made at fixed locations (Figure 2-1). Those covering the Balclutha township area are numbered C1 to C7, K12, K13, M12 and M11. More information on the cross-sections is provided in the report “Channel morphology and sedimentation in the Lower Clutha River” by Otago Regional Council (2008).

Although most of these cross-sections were surveyed between 1994 and 2024, different sections were surveyed at different times. Notably, cross-section C2, located at the present railway bridge, has survey records extending back to 1878. The years of cross-section surveys having reliable data are given in Table 2-1.

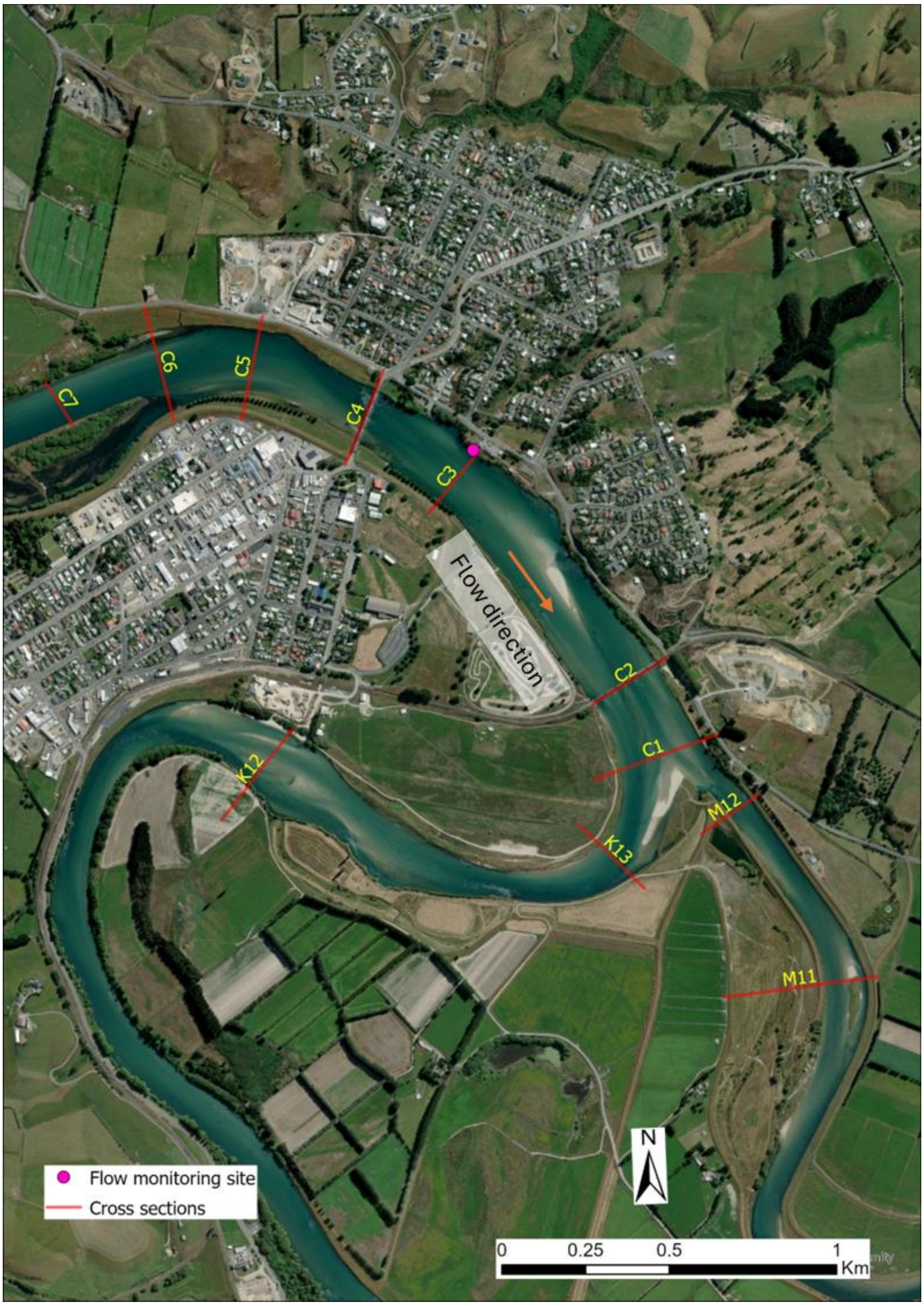


Figure 2-1: The location of cross-section surveys on the Clutha River at Balclutha together with the flow monitoring site. The flow monitoring site is near the North end of C3.

Table 2-1: Cross-section data from the Clutha River near Balclutha township. These data were used for the analysis of historical bed level changes.

Cross-section	Description	Number of surveys	Years*
K13	First downstream cross-section of Koau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
K12	Second downstream cross-section of Koau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
M12	First downstream cross-section of Matau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
M11	Second downstream cross-section of Matau branch	7	1994, 2002, 2005, 2014, 2019, 2020, 2024
C1	Most downstream cross-section before Clutha River splits into Matau Branch and Koau Branch	11	1994, 1995, 1996, 1997, 2001, 2002, 2005, 2014, 2019, 2020, 2024
C2	Cross-section near railway bridge	14	1878, 1893, 1939, 1994, 1995, 1996, 1997, 2001, 2002, 2005, 2014, 2019, 2020, 2024
C3	Cross-section next to flow monitoring site	9	1994, 1995, 1996, 2002, 2005, 2014, 2019, 2020, 2024
C4	Cross-section near Highway 1 bridge	8	1994, 1995, 1996, 1997, 2002, 2019, 2020, 2024
C5	Around 400m upstream of the Highway Bridge	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024
C6	North end of Elizabeth Street, Balclutha	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024
C7	Most upstream cross-section analysed	10	1994, 1995, 1996, 1997, 2002, 2005, 2014, 2019, 2020, 2024

* 2023 survey data are considered unreliable and are not listed here.

The cross-section data were aligned, and consistent start and end points were selected to compare measurements from different surveys. These results are shown in Appendix A with an example given in Figure 2-2 below, for the C1 cross-section. The grey vertical lines indicate the start and end points that are used to give consistent comparisons of bed level changes between the different surveys.

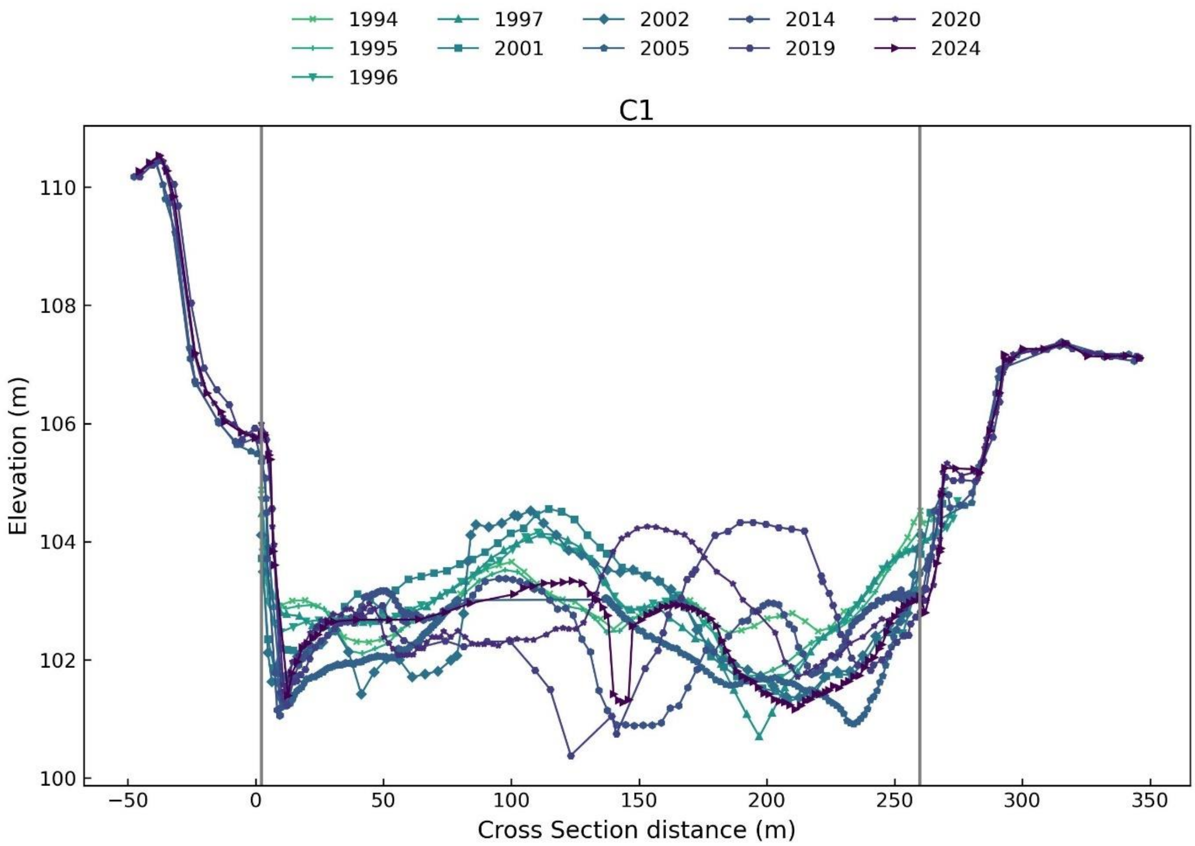


Figure 2-2: C1 cross-section profile for all surveyed years. Grey vertical lines indicate the start and end points used for analysis of bed level change. The sections are viewed looking downstream.

2.1 Cross-section data analysis

To monitor changes in the river bed, we have studied:

- The average level of the bed of the river between the start and end points.
- The area above average bed level divided by distance between the start and end points.
- The minimum bed level between the start and end points.
- The profile of the bed along the river.
- Changes in water level for different flows.

Assessing changes in the average level of the bed over time allows assessment of long-term river stability, showing whether the river bed is rising or falling between different cross-section survey dates.

The area above average bed level divided by distance between the start and end points of analysis indicates changes in high parts (gravel bars) of the channel.

Figure 2-3 shows an example of how these data can be used to identify gravel bars. The area above average bed level is shaded in red. This area is divided by the total width to give a consistent comparison between cross-sections. An increase over time means an increase in the range of bed level across a cross-section, which indicates the growth or enlarging of bars, or the formation of deeper channels.

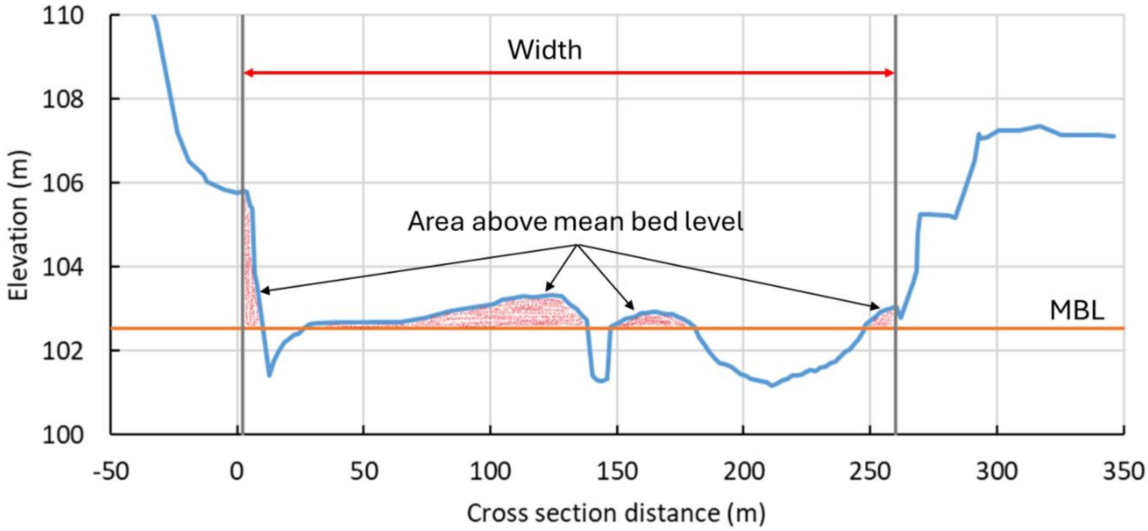


Figure 2-3: Illustration of area above average bed level for cross-section C1 in 2024.

The minimum bed level is the lowest point on the surveyed cross-section. Changes in the minimum bed level over time show any sediment build up or lowering in the deepest part of the channel.

The along-river distance between each cross-section is used to plot bed levels along the river. We report river distances relative to cross-section C1, with positive distances representing upstream cross-sections and negative distances representing downstream cross-sections.

3 Satellite imagery

Imagery from the Sentinel-2 satellite was used to study river bars in the area of interest. As river bars appear larger at lower flows and smaller at higher flows, comparison of river bar sizes and positions at different times should be made when there are similar flows in the river. Seven images from the period between 2016 and 2025 were selected based on two criteria:

- Cloud cover of less than 10% to ensure a clear view of the river and gravel bars, and
- Similar low-flow conditions, determined by selecting dates when there was satellite image acquisition and a low daily river flow apparent in the river flow record.

4 Clutha River flow data and analysis

Water level readings and streamflow measurements have been made at Clutha at Balclutha monitoring stations (NIWA site 75207; Figure 2-1) since 1952 (Figure 4-1). There was a period with several very high flows between 1994 and 1999.

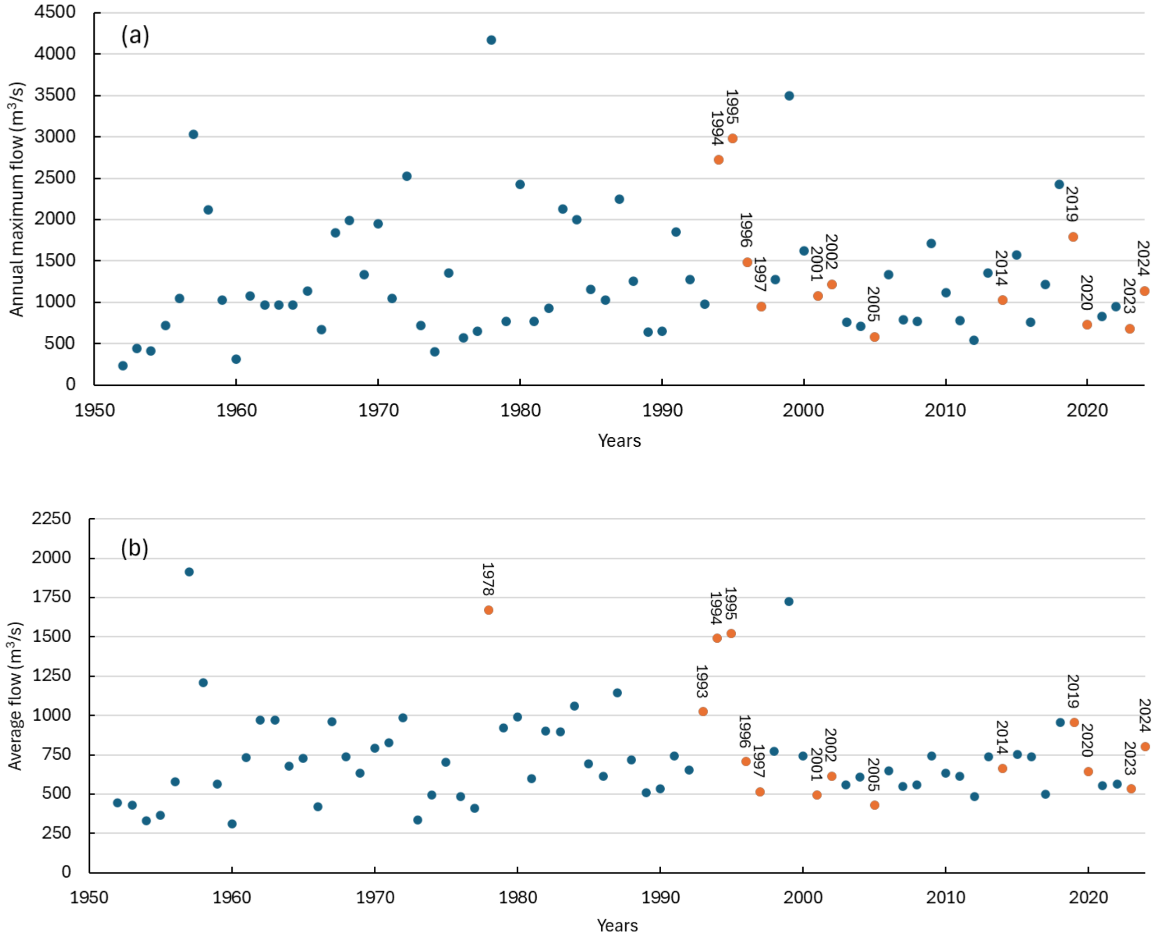


Figure 4-1: Annual maximum flow (a) and annual average flow (b) for the Clutha River at Balclutha monitoring site. Orange circles indicate years where surveys from some or all cross-sections were provided by ORC ease in bed level.

The Balclutha water level measurement data are collected to relate the water level to the corresponding river flow in cubic metres per second. While the data allow calculation of flow from a measured water level, they may also be used in reverse to calculate changes in water level over time, for a given flow. An increase in water level for a given flow could be due to increased vegetation and other types of flow-resisting roughness such as debris and gravel bars in the channel, or it could be due to general raising of the river bed. In either case, if over time there is an increase in the water level for a given high flow, this is an indication that the distance from the water surface to the top of the stopbanks (the freeboard), and consequently the flood capacity, is decreasing. Conversely, if over time there is a decrease in water levels for high flows, this would suggest an increase in flood capacity.

5 Results

5.1 Bed level changes

The changes in individual cross-sections can be compared by studying differences between successive surveys as shown for sections C2 and C4 in Figure 5-1 and Figure 5-2. Here, green areas indicate where the level of the bed has risen, and brown areas indicate where it has fallen.

5.1.1 Example cross-section changes

For section C2:

(a) from 1878 to 1994 the bed rose by around 2 metres on the left hand two-thirds of the channel and fell slightly on the right side.

(b) From the 1995 survey on, there is frequently a regular pattern of humps and hollows in the bed, probably caused by scour downstream of the railway bridge piers.

(d) By 2005 the bed troughs have filled, and a deep channel has developed on the right bank.

(e) By 2014 the bed has risen to the right of centre of the channel and fallen on the left side. The deep channel against the right bank persists.

(f) By 2020 the bed has become flatter across the channel and by 2024 there is evidence of new pier scour.

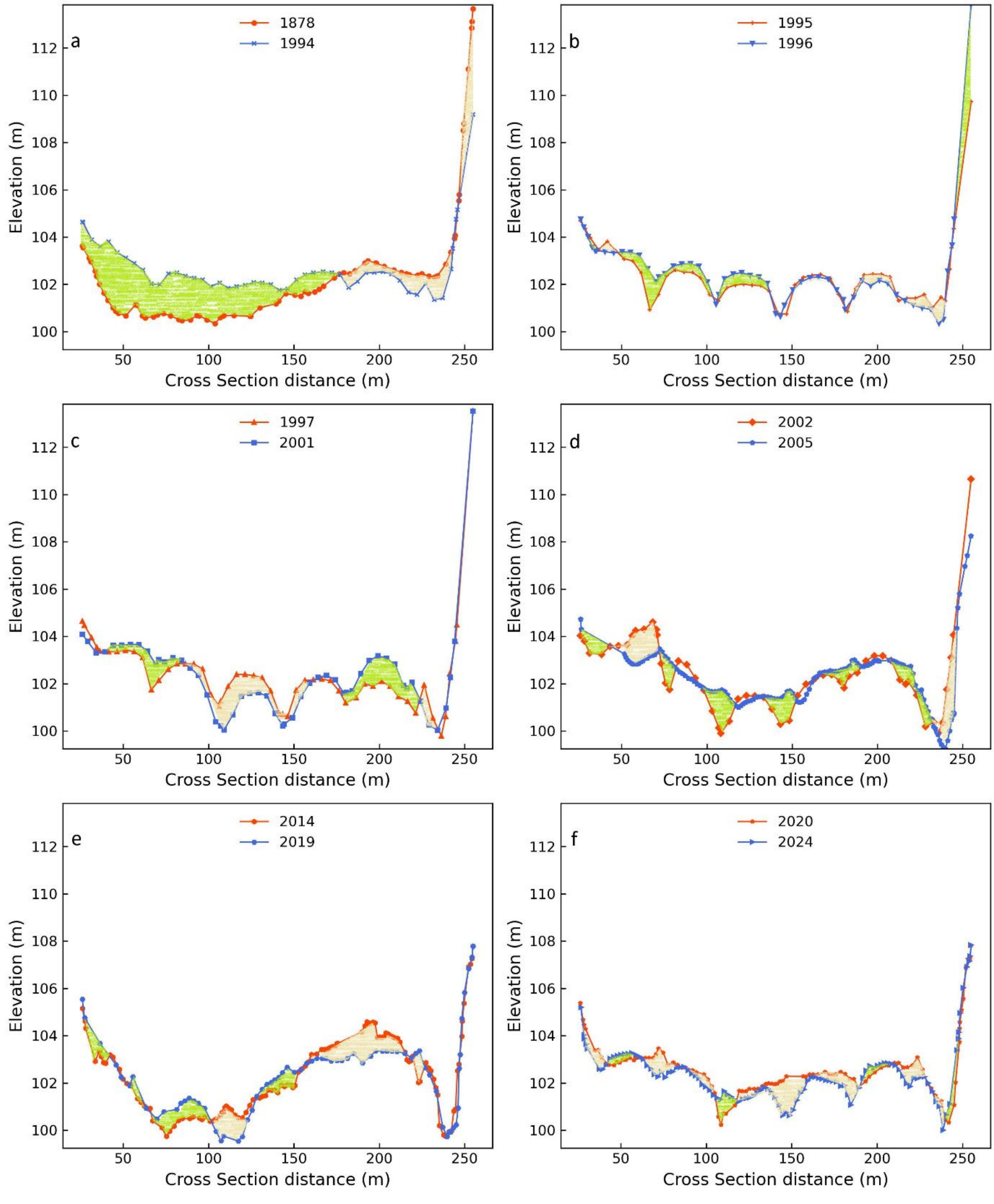


Figure 5-1: Changes in the bed at Section C2 from 1878. Brown areas indicate bed lowering, green areas indicate an increase in bed level.

For section C4 shown below:

(a) Between 1994 and 1995 there was lowering of more than 3 metres forming a channel in the centre of the bed.

(b) This lowering continued through 1996 – 1997.

(c) From 2002 to 2019 the channel deepened to the left of centre and filled from the centre to the right side.

(d) Between 2019 and 2020 the channel had refilled somewhat but again deepened to the left of centre and the bed rose to the right of centre by 2024.

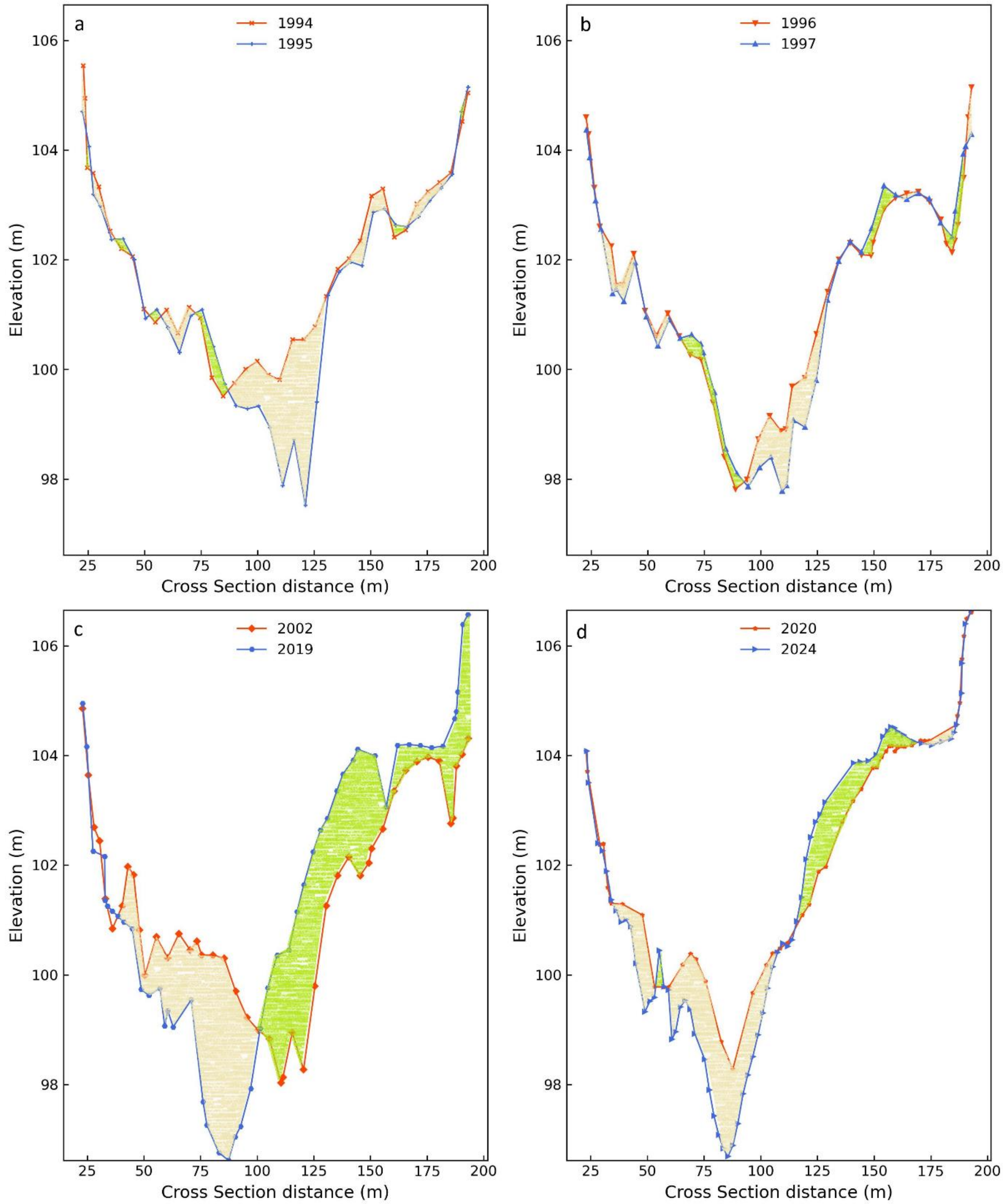


Figure 5-2: Changes in the bed at section C4. Brown areas indicate lowering of the bed, green indicates an increase in bed level.

5.1.2 Average bed level

For each cross-section survey, we can calculate the average level of the bed between the start and end points. Characteristically, average bed level falls in the downstream direction and is lower where a river channel narrows. The Balclutha average bed levels show a consistent pattern over the years, being high around sections C5–C6, falling by around a metre at section C4, then rising again moving downstream by around 1.5 m, to be highest where the river splits into the Matau and Koau Branches (Figure 5-3). The changes in average bed level upstream of the split show no clear trend on this graph with variations roughly within a 0.6 m range over the last 30 years. From the split downstream, the range in bed level variation increases, reaching around 0.8 m in the Matau branch (at section M11). At the split the bed levels dip, typically remaining lower into the Koau Branch in most years and rising downstream into the Matau Branch in all surveyed years. The average bed level of the most downstream section on the Matau Branch (M11) is higher than more upstream Balclutha sections.

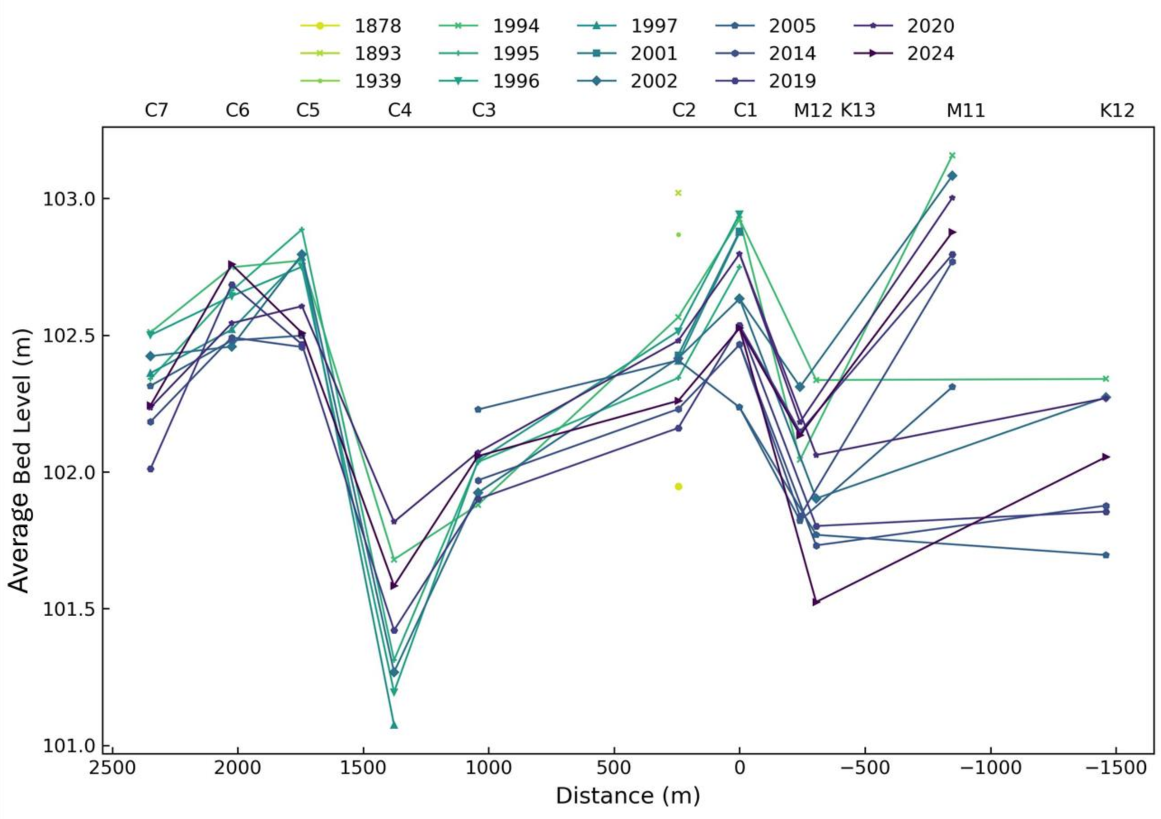


Figure 5-3: Historical changes in the average bed level of the Clutha River near Balclutha township. The horizontal axis shows river distances measured from cross-section C1, with positive distances representing upstream cross-sections and negative distances downstream. Cross-section names are indicated at the top of the graph.

To better assess changes in bed level at each cross-section, average bed level values were plotted against survey years (Figure 5-4). A straight line was fitted to the data points to identify any trends. The closeness of fit of data to the line is indicated by an R^2 number at top right of each graph. $R^2 = 1$ means a perfect trend whereas $R^2 = 0$ would mean no trend at all. All sections except C3, C4, C6, and M12 indicate a falling trend in average bed level over the past 30 years. Sections C5 and C7, in particular, have higher R^2 values confirming significant river bed lowering over time. At C5 and C7 the average bed level has fallen by 0.35 m from the 1990s to the present day. Section K13 shows lowering over time (R^2= 0.43) with 0.8 metre decrease in averaged bed level.

At section C2, the first surveys (from 1878) show noticeable bed raising occurred before 1900. Conditions have since changed with land use and construction of the Roxburgh Dam. To identify trends following these changes by excluding the pre-1900 data, the section exhibits a clear lowering trend in average bed level (green line in Figure 5-4). A similar pattern is observed in cross-sections K12 and M11 when outlying data points are excluded.

Sections M12, C3 and C6 do not display any significant trend in average bed level and appear to have remained relatively stable over the analysed period. C4 shows a weak rising trend.

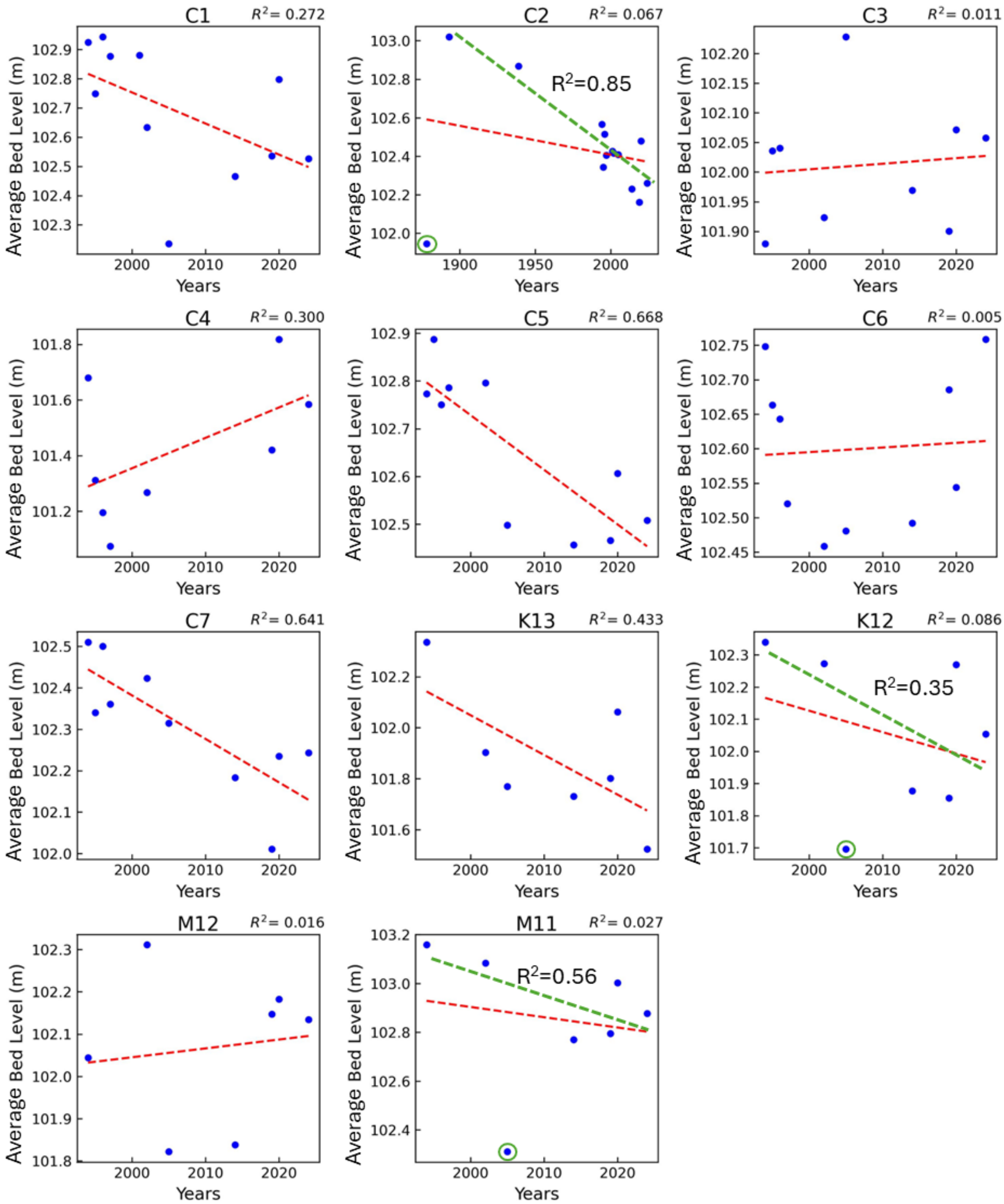


Figure 5-4: Changes in the average bed level over the years at each cross-section. The red lines indicate a straight-line trend for the cross-section survey years. The R^2 values in the top right corner of each sub plot indicate the goodness of fit for all data. The green lines and associated R^2 values indicate a straight-line trend after removing outliers. For cross-section C2, when the first survey in 1878 is ignored, a strong trend of lowering in average bed level is observed. For cross-sections K12 and M11, the 2005 survey is ignored for the green line (part of the mid-river section was missing in the 2005 survey). Note that the axis scales differ on some plots.

Further analysis was conducted by averaging the average bed level changes for each recent decade and comparing these values with a 1990s baseline average bed level (Figure 5-5). Following the period with very high flows from 1994 to 1999, bed levels generally fell below 1990 levels until the 2010s (blue and orange lines) then rose again in the 2020s (yellow line.). Except at C6, C4, C3 and M12, averaged levels are still below the 1990 levels. Section C4 has risen 0.4 m above the 1990 average bed level.

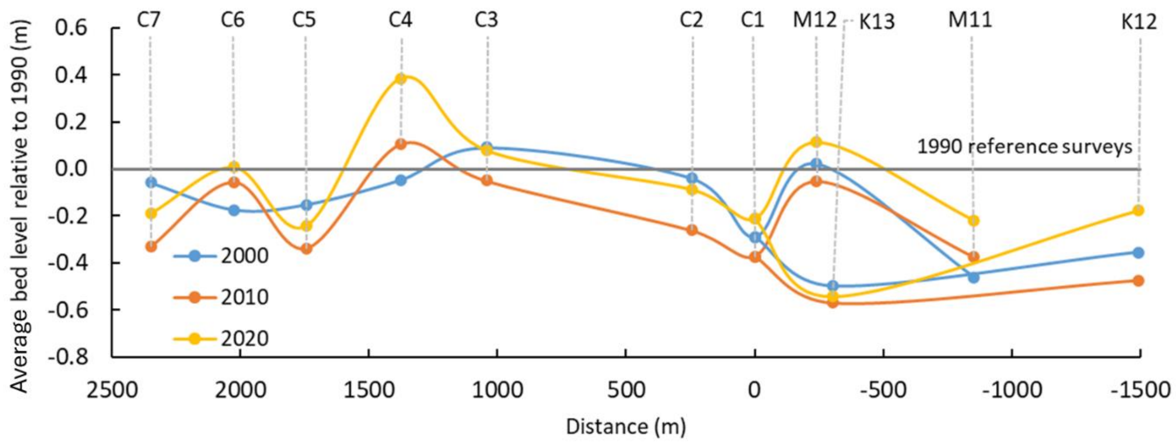


Figure 5-5: Average bed level change relative to 1990 in the Clutha River near Balclutha, with surveys grouped and averaged by decade. The "1990" reference line represents combined surveys from 1990–1999, the "2000" line includes surveys from 2000–2009, the "2010" line covers surveys from 2010–2019, and the "2020" line represents surveys from 2020 onward. The horizontal axis shows river distances measured from cross-section C1 with positive distances representing upstream cross-sections and negative distances downstream. Cross-section names are indicated at the top of the graph.

5.1.3 Minimum bed level

Changes in minimum bed levels are shown in Figure 5-6 with a separate line for each surveyed year. From cross-section C6 to C4, the minimum bed level decreases in the downstream direction, reaching a low point around cross-sections C3 and C4. Beyond this point, the minimum bed level rises again in the downstream direction to cross-section C1. From C1, the minimum bed level falls moving down the Koau Branch (sections K13 and K12). For the studied cross-sections, except for a high C1 level in 1994, the minimum bed level downstream in the Matau Branch is higher than at the upstream sections. The higher Matau Branch bed was also evident in the average bed level analysis (Section 5.1.1).

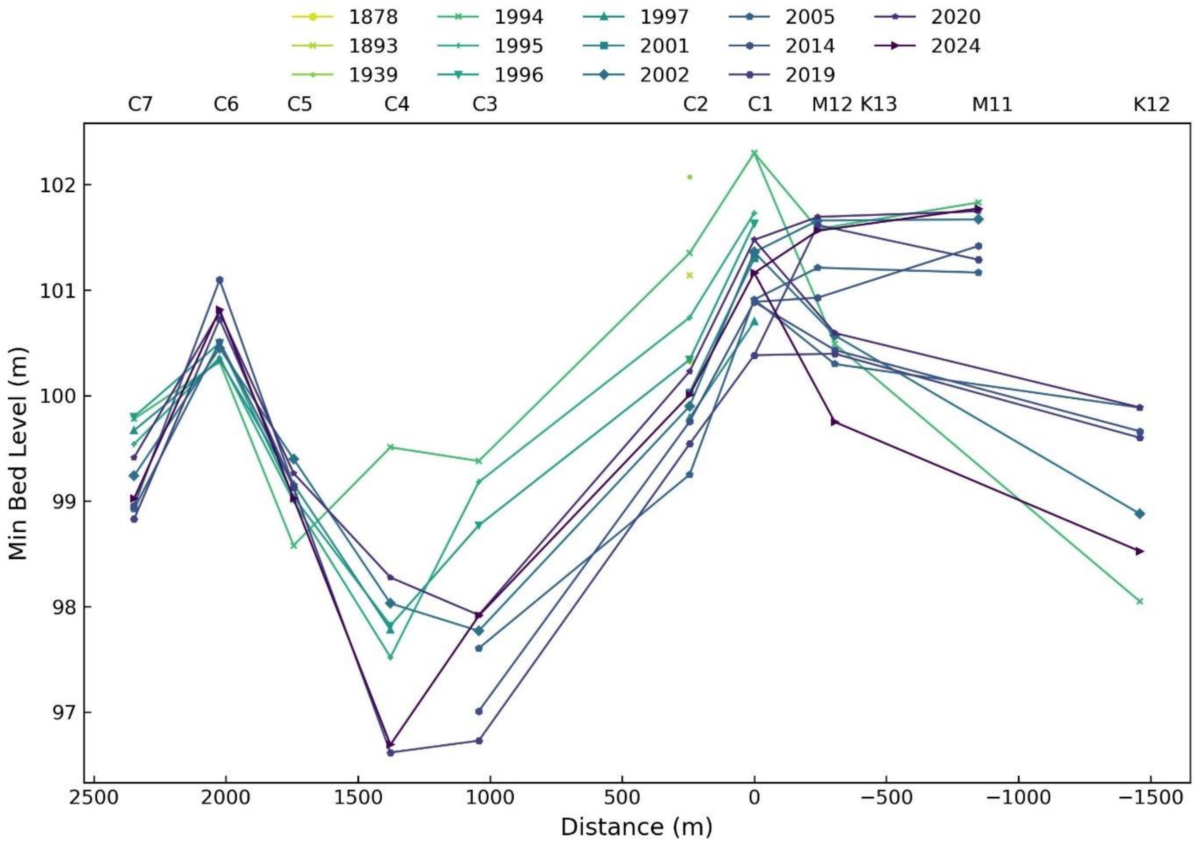


Figure 5-6: Historical changes in the minimum bed level of the Clutha near Balclutha. The horizontal axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross-sections and negative distances downstream. Cross-section names are indicated at the top of the graph.

Straight-line trend analysis for minimum bed levels is shown in Figure 5-7. While cross-section C6 exhibited no clear trend in **average** bed level over time (Figure 5-4), the deepest point used to be on the right side of the channel but is now in the centre (shown in Appendix A). The **minimum** bed level shows a long-term rise in the deepest part of the river (Figure 5-7). These changes may be a result of historical, upstream river training works. Cross-section C3 similarly showed no discernible trend in average bed level, but the minimum bed level indicated sustained bed lowering in the deepest portion of the channel, highlighting localised changes not captured by average bed level analysis. Cross-section C7 displayed a consistent lowering trend in minimum bed level that mirrored the overall changes observed in the average bed level. The bed level changes at C7 are more uniform across the entire cross-section, affecting both the average and minimum bed levels in a similar manner. Cross-section K13, on the Koau Branch, exhibited a similar pattern, with both the minimum and average bed levels indicating recent deepening.

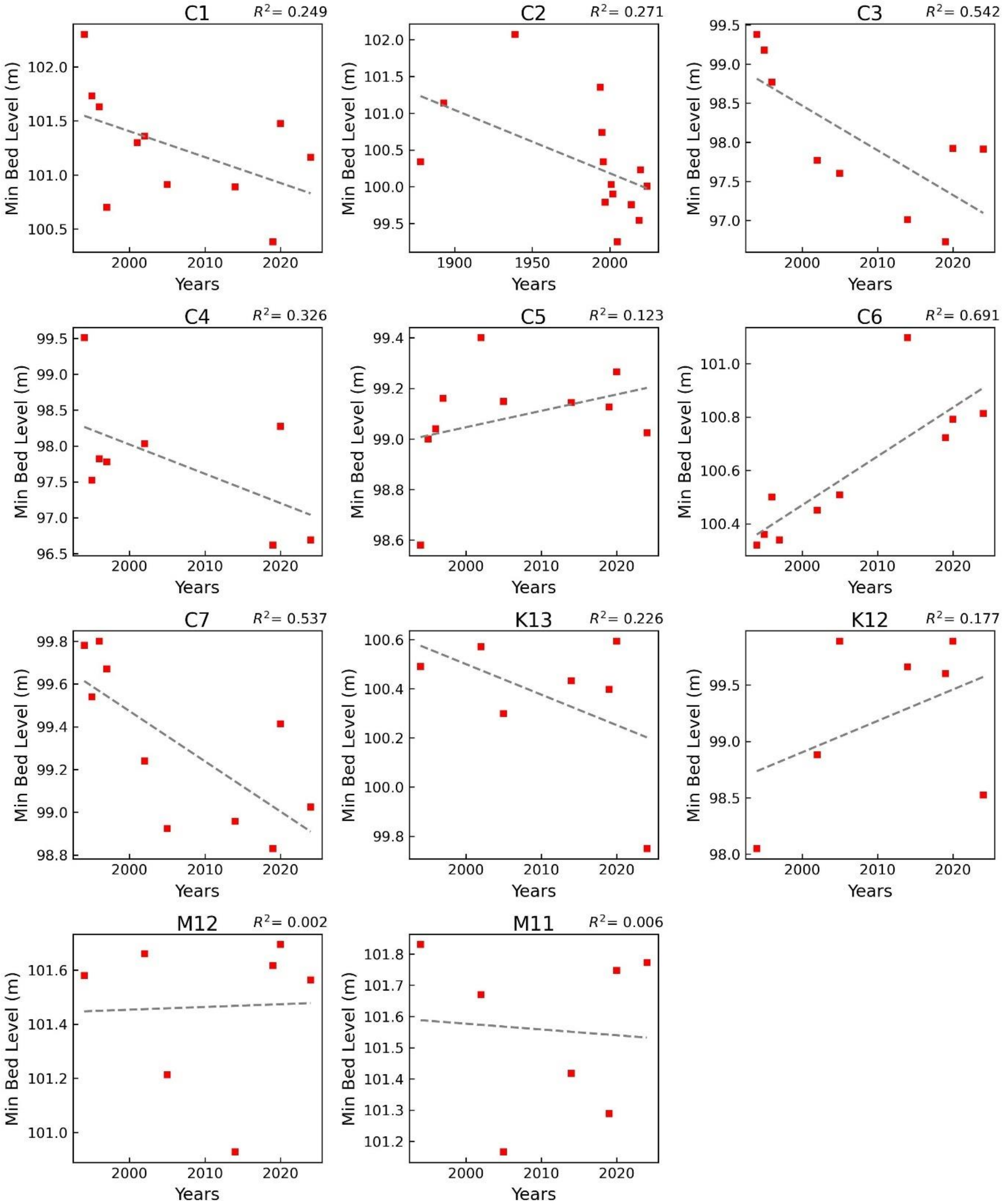


Figure 5-7: Changes in the minimum bed level over the years at each cross-section. The dashed lines indicate the straight-line trend for the changes observed. The R^2 values for the regression lines are displayed in the top-right corner of each subplot. Note that the axis scales differ on some plots.

5.1.4 Average height above average bed level

The area above average bed level, divided by the width of the cross-section, gives an average height of the part of the river bed lying above the average bed level. This value signifies how much the bed level varies across a section. This value is plotted against downstream distance in Figure 5-8 for each surveyed year. Overall, there is a slight trend of decreasing bed level variation across a cross-section, moving in the downstream direction towards the split into the Koau and Matau branches.

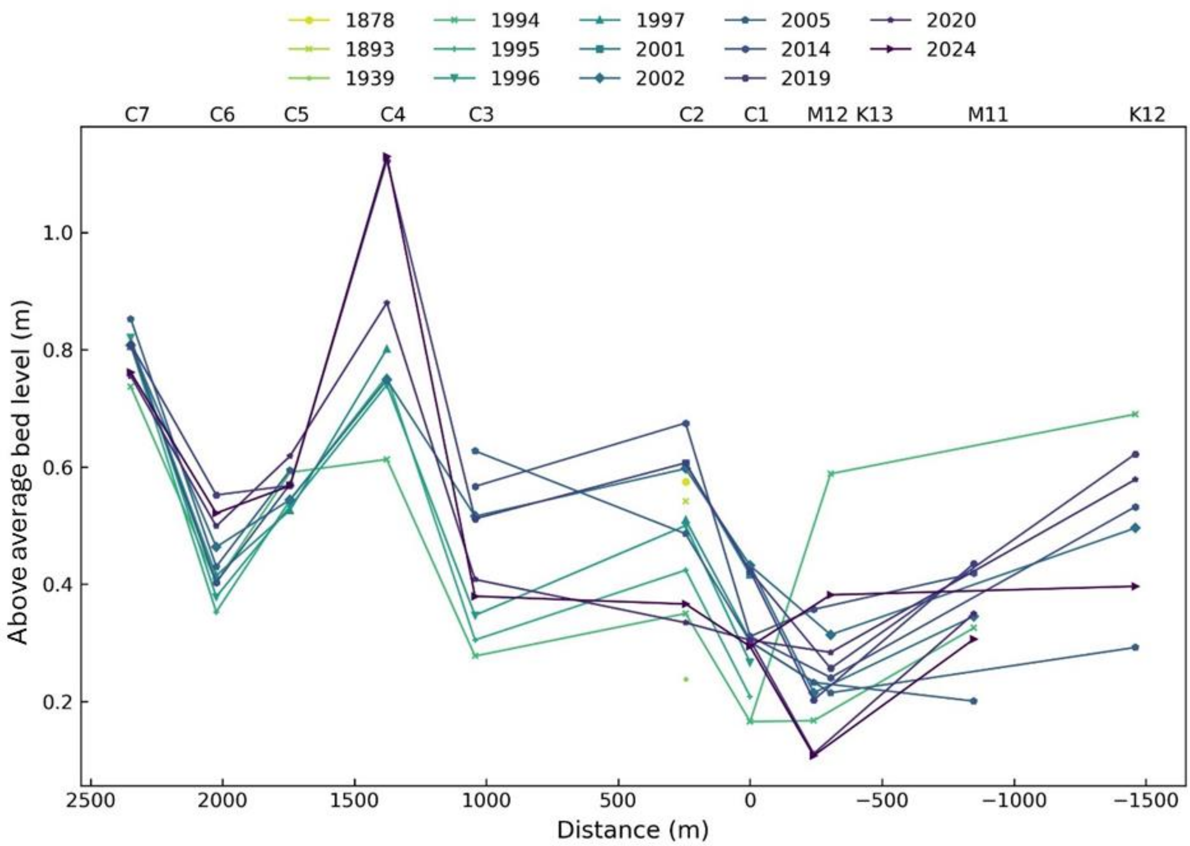


Figure 5-8: Historical changes in the height above bed level values of the Clutha River near Balclutha. The horizontal axis shows river distances measured relative to cross-section C1 with positive distances representing upstream cross-sections and negative distances downstream. Cross-section names are indicated at the top of the graph.

Considering Figure 5-9, the average height above average bed level values show a clear increasing trend with time at cross-sections C4 and C6, indicating an increase in the exposed (visible) area of the river bed during low-flow conditions. Variation has increased significantly at section C4. This suggests the development or expansion of bars or deepening of low flow channels in these sections over time. In contrast, the height above average bed level values at the other cross-sections did not exhibit any clear trends, implying minimal to no long-term changes in the bed forms.

There is no cross-section located on a large gravel bar that exists between cross-sections C2 and C3 (located next to Kaitangata Highway and downstream of Ipswich Street). Therefore, it is not possible to quantify changes in the height of this significant bar from the cross-section data.

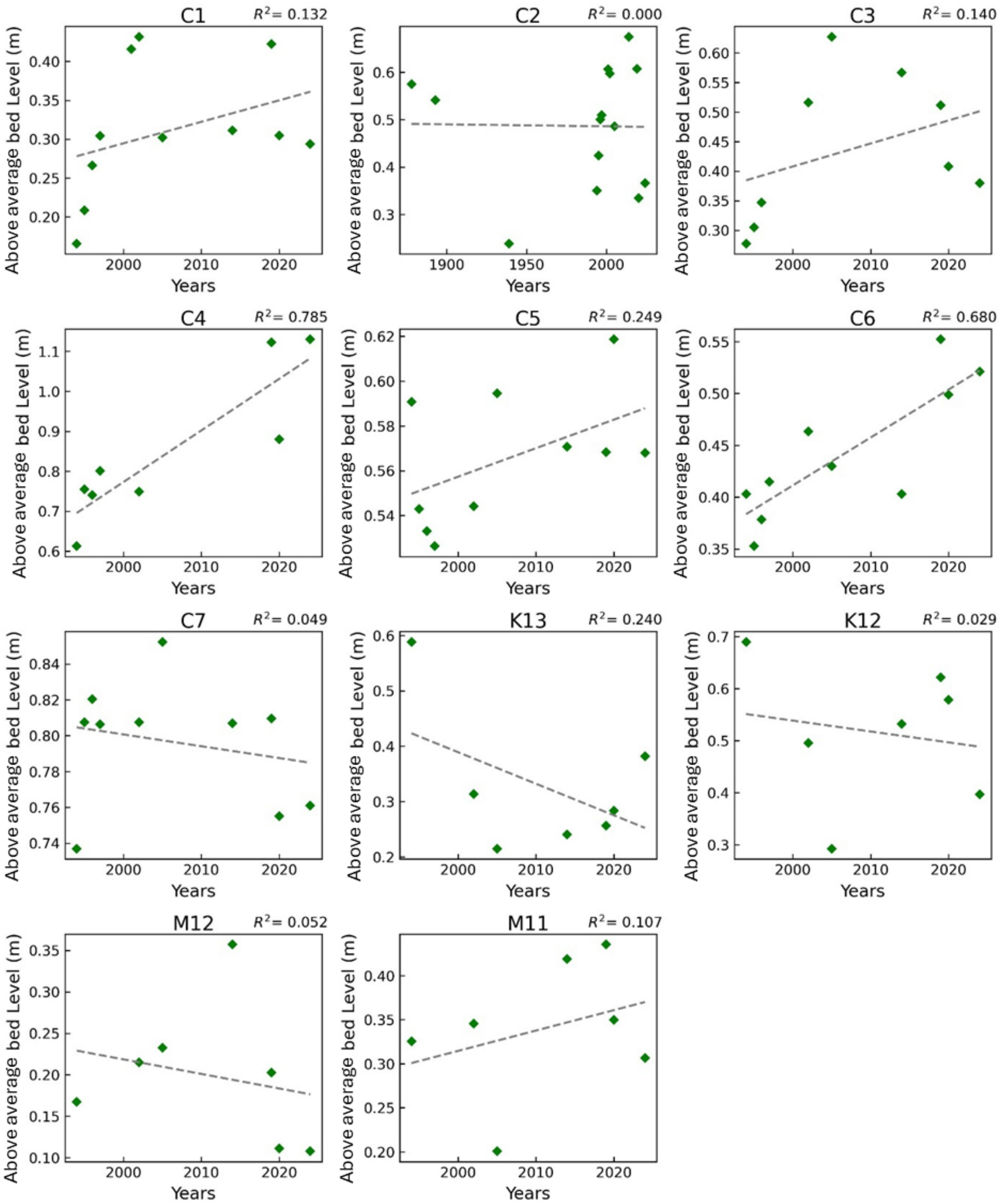


Figure 5-9: Changes in the average height above average bed level over the years at each cross-section. The dashed lines indicate the straight-line trend for the changes observed. The R^2 values for the regression lines are displayed in the top-right corner of each subplot. Note that the axis scales differ on some plots.

5.2 Changes across individual cross-sections

Looking at the overlaid sections in Appendix A and plots in Figures 5-2 to 5-6, we see the following net changes moving from downstream to upstream:

- **Cross-sections K12 and M11:** No clear trend of raising or lowering is evident over recent time based on the recorded survey data.
- **Cross-section M12:** In the 1990s the section was relatively flat. The channel then deepened on the right side and raised on the left side of the centreline. By 2019 the channel had risen on the right side and by 2024 was again relatively flat. NIWA gauging comments indicate 10,000 cubic metres of gravel extraction occurred on the right bank and 8,500 cubic metres from the left bank of the downstream channel split over the period 17-Feb-2002 to 13-Mar-2002.
- **Cross-section K13:** In the 1990s the section was high on the right bank of the main channel, but this bar was gone by 2002. The data then indicate low variation in bar height until 2020 when the channel deepens left of the main channel centreline and rises on the right bank of the main channel.
- **Cross-section C1:** Over the last 10 years, a noticeable shift in the gravel bar located in the middle of the cross-section is observed where the river splits into the two branches. The middle bar has migrated further to the right, resulting in increased flow and bank erosion along the left bank.
- **Cross-section C2:** Being near the railway bridge, this cross-section has the longest survey record, dating back to 1878. Between the first recorded survey in 1878 and the second in 1893, the river bed rose up to 2 metres across the cross-section. By 1939, raising of up to 1.5 m occurred towards the right bank, while lowering of up to 2 m was observed on the left bank. Between 1939 and the present day, slow lowering has dominated across the entire channel width.
- **Cross-section C3:** Between 1994 and 2024, this cross-section experienced periods of shifting in the middle bar and channel, along with phases of channel deepening (1994–2019) followed by significant raising (2019–2024). The middle bar rose approximately 2.3 m from 1994 to 2005, reaching its maximum recorded height. However, from 2005 to 2024 gradual lowering of the middle bar occurred, with about 1.1 m of bar height lost.
- **Cross-section C4:** This section showed gradual scouring along the left bank and deeper parts of the channel, while raising was observed along the right bank. Between 1994 and 2024 the deeper section of the channel experienced scouring of up to 3 m, whereas up to 2.1 m of sediment accumulation occurred along the right bank.
- **Cross-section C5:** A gradual lowering trend was observed from 1994 to 2024, accompanied by localised sediment accumulation along a small section of the right bank between 185 to 220 m cross-section distance.
- **Cross-section C6:** Different patterns of change were observed across this cross-section. Both the left and right banks experienced bed raising, whereas the mid-channel deepened. From 1994 the middle section of the cross-section (between 100 m and 200 m) rose up to 1.5 m by 2024. The right bank (between 200 m and 250 m) rose up to 3 m, while the left bank (between 0 m and 80 m) experienced 1.1 m of rise. Overall, average bed level fell until 2002 then rose back to the 1994 level by 2024.

- **Cross-section C7:** Bed lowering was observed at the left bank between 1994 and 2024. The deeper section of the channel experienced lowering from 1994 to 2019, followed by bed raising between 2019 and 2024.

5.3 Satellite imagery

Overhead images can reveal positions and sizes of channels and bars in a river. Examples are shown in Figure 5-10 and Figure 5-11. Seven selected images, captured between 2016 and 2025, are presented in Appendix B. Interpretation of bar size and shape is not straightforward, as river flow was not the same when the images were captured.

A noticeable change occurred between 2016 and 2025 with the movement of the gravel bar on the right bank, just before the Clutha River splits into the Matau and Koau branches. In the 2016 imagery, this bar intersects the railway bridge and extends across both C1 and C2 cross-sections. The bar shape evolves, and by 2025, has disappeared. From 2020 a new bar develops on the opposite bank, and by 2025 it has fully formed at the tip of Inch Clutha (Figure 5-11).

The location of the mid-river bar between cross-sections C2 and C3 has remained relatively stable over the years.

The long, thin, right-bank bar extending from C4 to C5 is stable over the years and becomes progressively more vegetated until by 2025 it resembles a river berm.

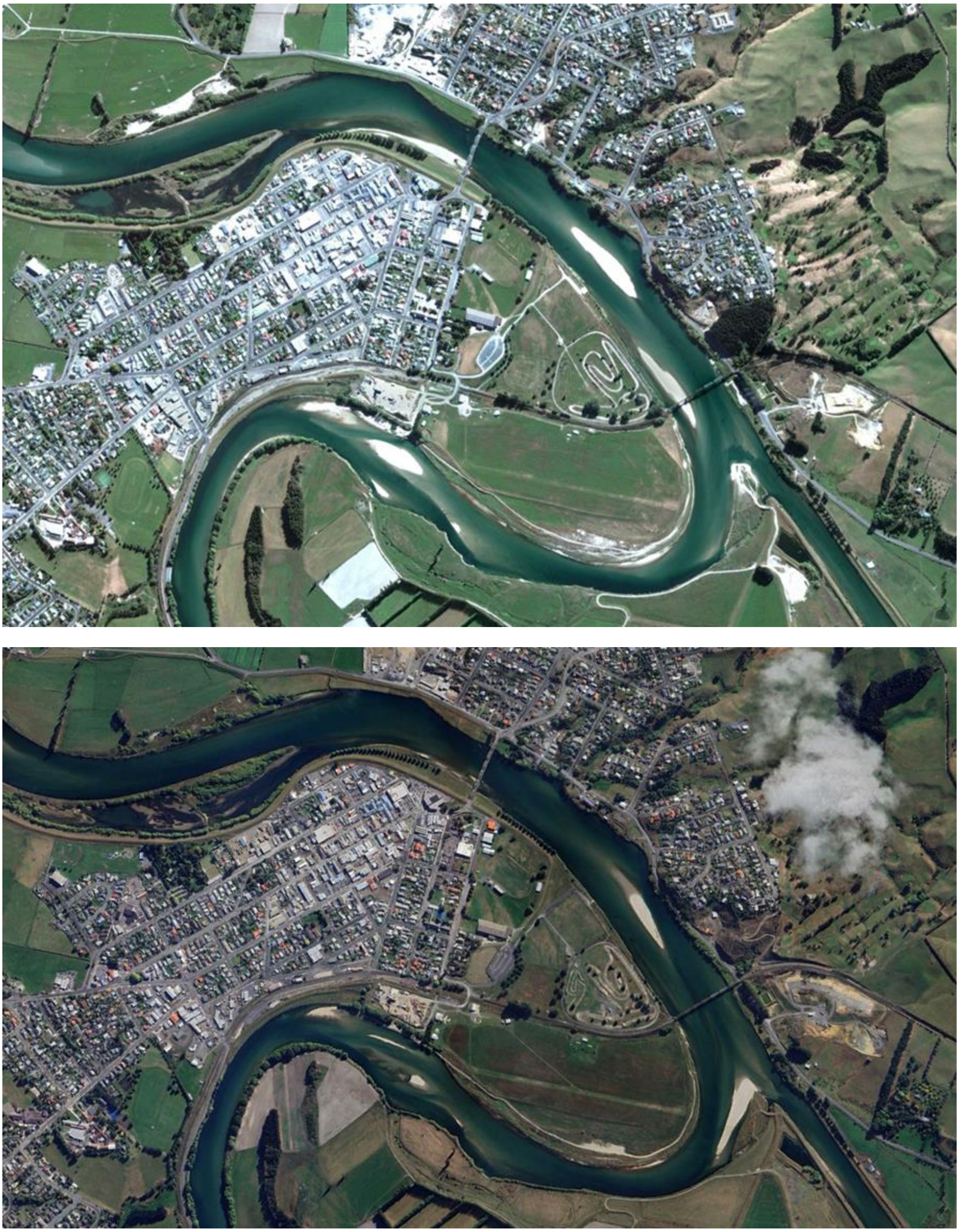


Figure 5-10: Imagery of the Clutha River at Balclutha in March 2013 (top) and March 2024 (below). The bars between the two bridges have moved downstream.

Figure 5-11: Satellite imagery of the Clutha River at Balclutha on two dates: January 10, 2016 (left) and January 27, 2025 (right). Imagery from Sentinel-2 satellite data. Red lines indicate the cross-section locations. The flow monitoring site is shown with a magenta dot.

5.4 Flow data analysis

A NIWA flow recorder has operated at Balclutha since 1952. The measurement cross-section was located near river cross-section C3 until 2007 when it was moved upstream of the previous location.

5.4.1 Minimum bed level

Up until 2010, the maximum water depth was recorded at the time of a NIWA measurement. Subtracting the maximum water depth from the water surface level gives the minimum bed level at the time of the measurement. The minimum bed levels from measurement data are shown in orange on Figure 5-12. After 2007, NIWA changed to jet boat measurements, made 180 to 250 metres upstream of the previous cableway. Recording of maximum water depth was subsequently discontinued. A few maximum bed depths made at the new location are shown in bright red on Figure 5-12 . Also shown are the ORC cross-section survey minimum bed levels at section C3 (from Figure 5-7). An abrupt rise in minimum bed level occurred during the 1957 November flood. From the 1970s to the present the minimum bed level at section C3 has been getting lower.

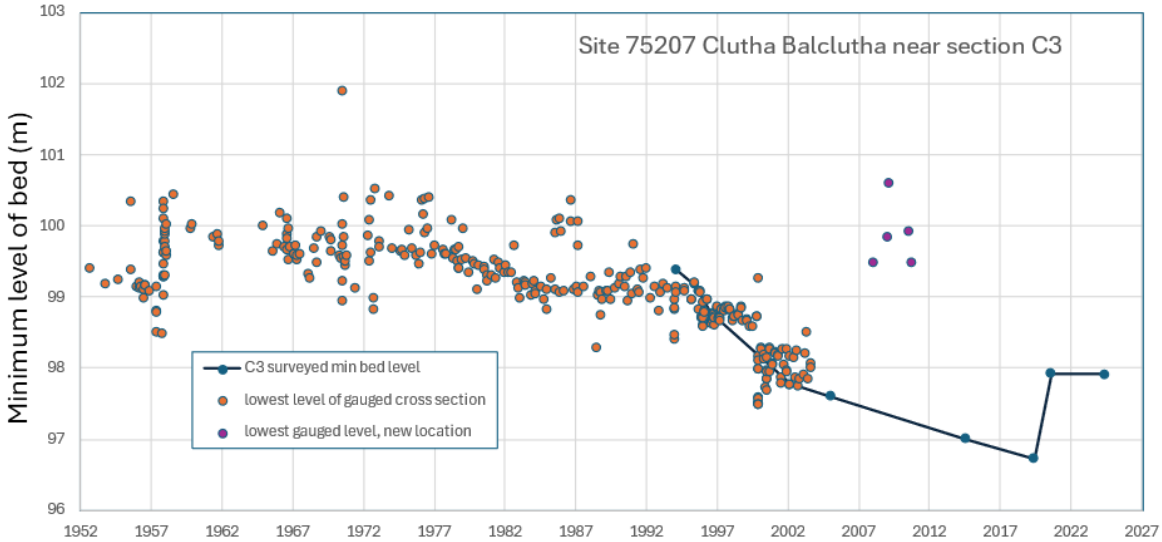


Figure 5-12: Minimum bed level at times of NIWA flow measurements near section C3. NIWA measurements after 2007 (bright red dots) apply 180 to 250 m upstream of the previous cableway location.

5.4.2 Water level for a given flow

Figure 5-13 shows the differences between measured water levels and what the water level would have been if there had been no changes in the river bed since 1952. Figure 5-14 shows differences in water levels compared to what they would have been with the December 1978 river bed. While individual measurements are made at different flows, and it is not meaningful to interpret every little change in these graphs, the graphs reveal the overall, long-term trends.

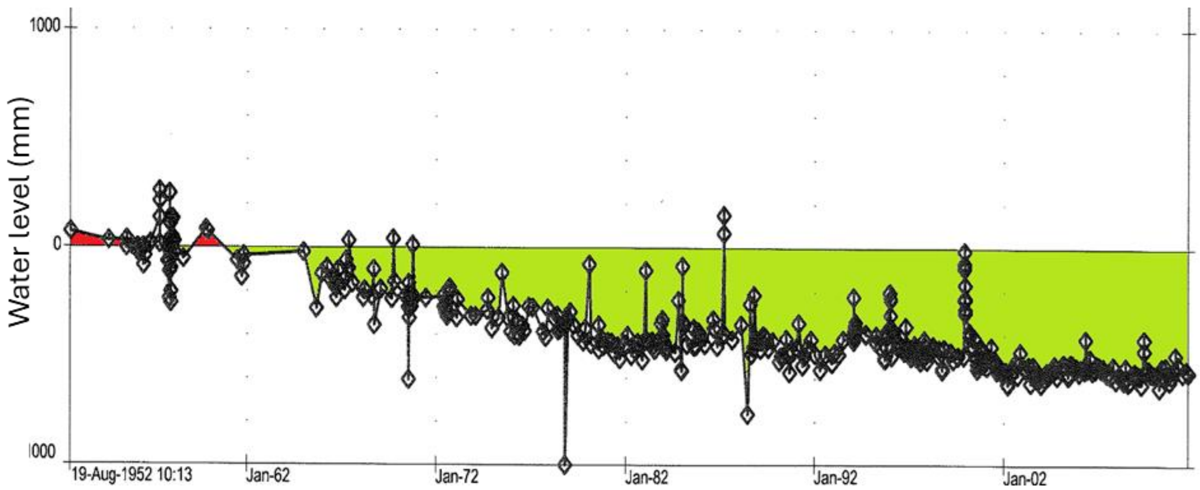


Figure 5-13: Water level for a given flow compared with preservation of 1952 bed levels. Red areas have a higher water level and green areas are lower than what they would have been in 1952.

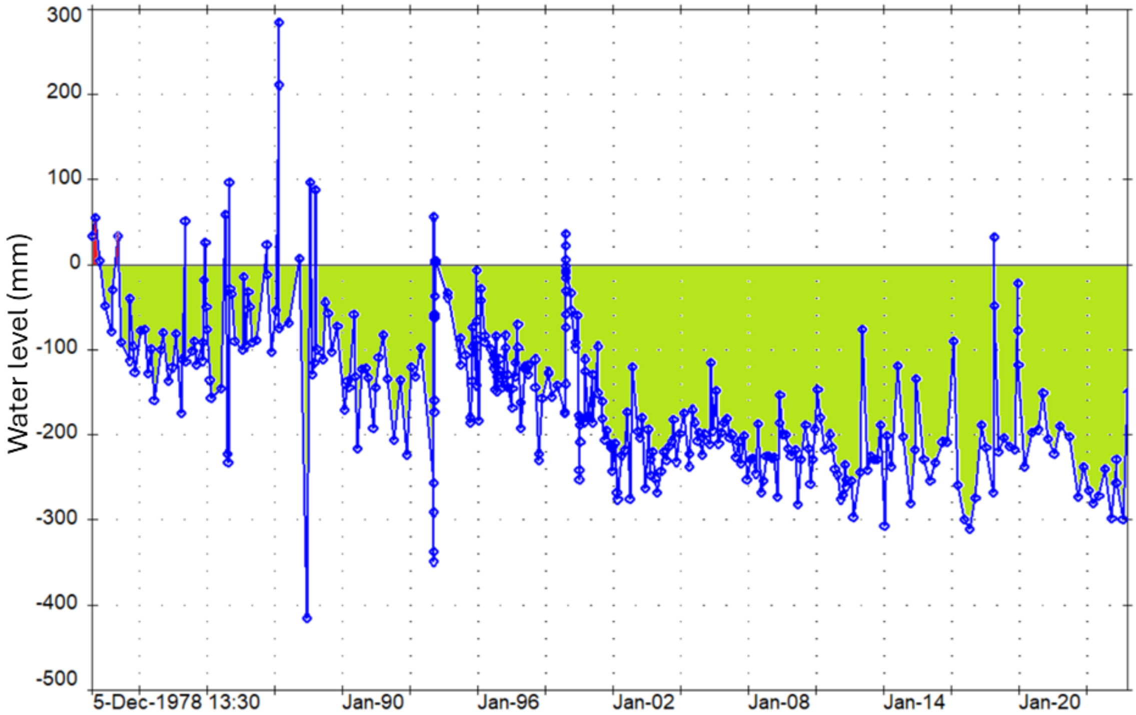


Figure 5-14: Water level for a given flow compared with preservation of 1978 bed levels. Red areas have a higher water level and green areas are lower than what they would have been in 1978.

According to these plots, water levels fell gradually from 1952 to be about half a metre lower by 1982. From 1983 to mid-2000 the levels oscillated with no net trend, then dropped approx. 0.2 m to reach another fairly stable state for the most recent 20-year period.

Further information on water level trends at all measured flows can be found by comparing water level -vs- flow curves from measurements made at different times. In Figure 5-15, flow measurements are compared for three decades: 1952–1961, 1990–1999 and 2015–2024. Flows as low as 38.3 cubic metres per second occurred in the early record as the Roxburgh Dam was filling in 1956. The lowest flow measured by NIWA was 50.3 cubic metres per second. In the middle decade there were several high floods (between 1994 and 1999). Figure 5-15 shows that, in the 1990s, flows up to 3000 cubic metres per second occurred at a lower water level than in the 1950s. In the most recent decade flows up to around 1500 cubic metres per second occurred at a lower water level than in the 1990s. This indicates channel deepening or reducing flow resistance since the 1950s. For very high flood flows[3] the trend line for flood level increased relative to the 1990's but, up to 3000 cubic metres per second, remains lower than in the 1950s.

[3] The two highest gaugings in 2015–2024 were made upstream of the NIWA rating site and adjusted by ORC to allow for the 2.5 km interdistance.

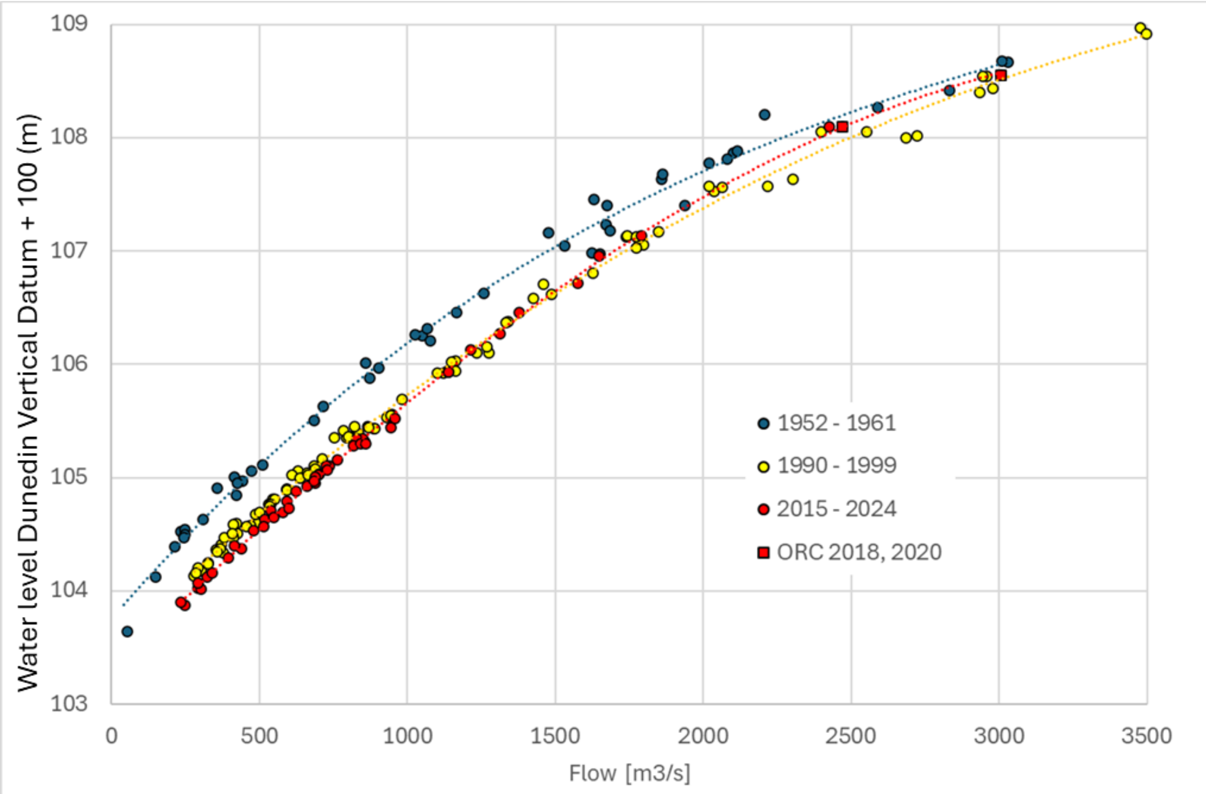


Figure 5-15: Comparing water level for a given flow data from gauging measurements over the years. Curves show three decades: 1952–1961, 1990–1999 and 2015–2024. Vertical axis is Dunedin Vertical Datum 1958 + 100 m.

6 Discussion

6.1 Determine whether there is a significant trend in river bed levels

Cross-sections C1, C2, C5, C7, M11 and K12 show a clear lowering trend from the 1990s to the present. In particular, average bed levels at C5 and C7 have fallen by around 0.35 m. Sections C3 and C6 do not display any significant trend in average bed level and appear relatively stable over the analysed period. C4 shows a weak rising trend.

6.2 Assess changes in gravel bars or islands

The average height-above-average-bed-level analysis indicates the vertical range in bed levels at measured cross-sections. Changes in average height-above-average-bed-level can indicate development or decay of channel bars. Over the surveyed years 1994 to 2024, there is a trend of increasing bed level variation at C4 and C6 but no noteworthy trend at other sections. Moving in the downstream direction, there is a slight general trend of decreasing bed level variation across the cross-sections, which would suggest lower or flatter bars moving downstream past Balclutha.

Satellite imagery reveals a noticeable change between 2016 and 2025 with the movement of a gravel bar on the right bank, just before the Clutha River splits into the Matau and Koau branches. In the 2016 imagery, this bar intersects the railway bridge and extends across both C1 and C2 cross-sections. The bar shape evolves, and by 2025, has disappeared. From 2020 a new bar develops on the opposite bank, and by 2025 it has fully formed at the tip of Inch Clutha. No net effect is evident in the C1 and C2 area above average bed level plots. There is no cross-section located on a large gravel bar between cross-sections C2 and C3 (located next to Kaitangata Highway and downstream of Ipswich Street). Considering different flow rates at times of the satellite imagery, this bar appears stable over the 2016 to 2025 period.

6.3 Identify factors driving changes observed

In general, observed changes correspond to the expected long-term, river response following a severe reduction in sediment input (i.e., Roxburgh Dam construction). Bed levels and water levels have initially fallen, and the rate of lowering appears to have tailed off with time. Recent reports that gravel bars are more evident at Balclutha may be due to the bar movement noted above and the fact that a stable bar can become more visible and appear to be higher if the river level falls alongside the bar. There has been a clear change in shape at section C6. The deepest point used to be in the channel on the right side but is now in the centre. Historic aerial imagery (Figure 6-1 below) shows that between 1946 and 1995, mid-channel river training works narrowed and re-directed the channel upstream of C6. These works are likely to be the explanation for the channel movement at C6. There were also river training works to re-narrow the entrance to the Matau branch in the early 1970s[4].

[4] Retrolens.co.nz: air photos of 27/2/1968 and 28/2/1975

Figure 6-1: Aerial photographs from 1946 (left) and in 1995 (right). Blue line indicates the mid-channel river training works upstream of cross-section C6.

6.4 Evaluate whether observed river bed level changes are sufficient to reduce flood capacity

The NIWA water level data show comparative water levels near C3 fell gradually from 1952 to be about half a metre lower by 1982. From 1983 to mid-2000 the levels varied with no net trend, then dropped approx. 0.2 m to reach another fairly stable state for the most recent 20-year period. In the 1990s, flows up to 3000 cubic metres per second occurred at a lower water level than in the 1950s. In the most recent decade flows up to around 1600 cubic metres per second occurred at a lower water level than in the 1990s.

Because the river is not steep, changes in flood levels at the NIWA gauging location are indicative of general changes in Clutha River levels alongside Balclutha, and we can presume that flood capacity at Balclutha has not reduced. While the levels of floods of a given size have not increased, the frequency of floods is expected to increase in the future due to climate change. Also, local changes in cross-sections can re-direct currents against a bank, possibly causing localised overtopping.

There is evidence that temporary bed lowering may occur during a rising flood with the bed refilling as the flood falls. Assuming this effect does not change, historic behaviour does not indicate a reduction of flood capacity in the Balclutha reach.

7 Summary and conclusions

7.1 Purpose

The Otago Regional Council commissioned NIWA to analyse and report on historical changes in Balclutha river bed levels to help understand any significant trends and to guide river management strategies into the future.

7.2 What was done

Data from river bed cross-section surveys, flow measurements and satellite imagery were studied. The data were overlayed and plotted to provide a clear visual representation of changes over time. Historical changes were quantified by calculating average bed levels, minimum bed levels and changes in the higher parts of each cross-section, representing gravel bars. Flow records were studied to determine whether the water level for a given flow has changed over time. Satellite imagery was studied to detect changes in the extent of gravel bars.

7.3 Important findings

The cross-section data suggest that there was an increase in the bed level at the railway bridge in the late 1800s. Little is known about bed levels in the early 1900s, and a general long-term trend of lowering of the river bed occurred from the 1950s to about 2002, with less trend evident since 2002. This behaviour is consistent with the river adjusting to a reduction in sediment load following the 1954 commissioning of the Roxburgh hydro dam which traps sediment from upstream.

Average bed level of ten of the eleven studied cross-sections is stable or lowering. Section C4 (at the State Highway Bridge) shows a weak rising trend in average bed level. Minimum bed levels are stable or falling at each cross-sections except C6 (North end of Elizabeth Street) where the surveyed low point is rising with time due to previous river training works. Cross-sections C4 and C6 show a trend of growth of the relative height of bars. This could be due to deepening of low flow channels beside the bars. Flow measurements at Balclutha, since 1952, show channel capacity is increasing for floods up to around 1600 cubic metres per second.

Reports that gravel bars are now more evident at Balclutha may be due to the fact that a stable bar will become more visible and appear to be higher if the river level falls alongside the bar.

7.4 Cautions

The following factors could affect these conclusions:

- Bed lowering during a rising flood and re-filling on a falling flood may mask the true cross-section during a flood peak. The amount of flood scour and its effect on channel flood capacity is unknown.
- The effect of any gravel mining on cross-section evolution has not been quantified.

7.5 Recommendations

- A field inspection may be able to shed light on the possibility that bars appear to be higher because the low flow channels beside the bars are deepening.

- Ongoing monitoring and, in particular, flow measurements during future high floods, is strongly recommended. This would help quantify the degree of bed scour induced by floods, which will improve understanding of the river behaviour.

8 Acknowledgements

Survey data and funding for these analyses were provided by the Otago Regional Council.

9 References

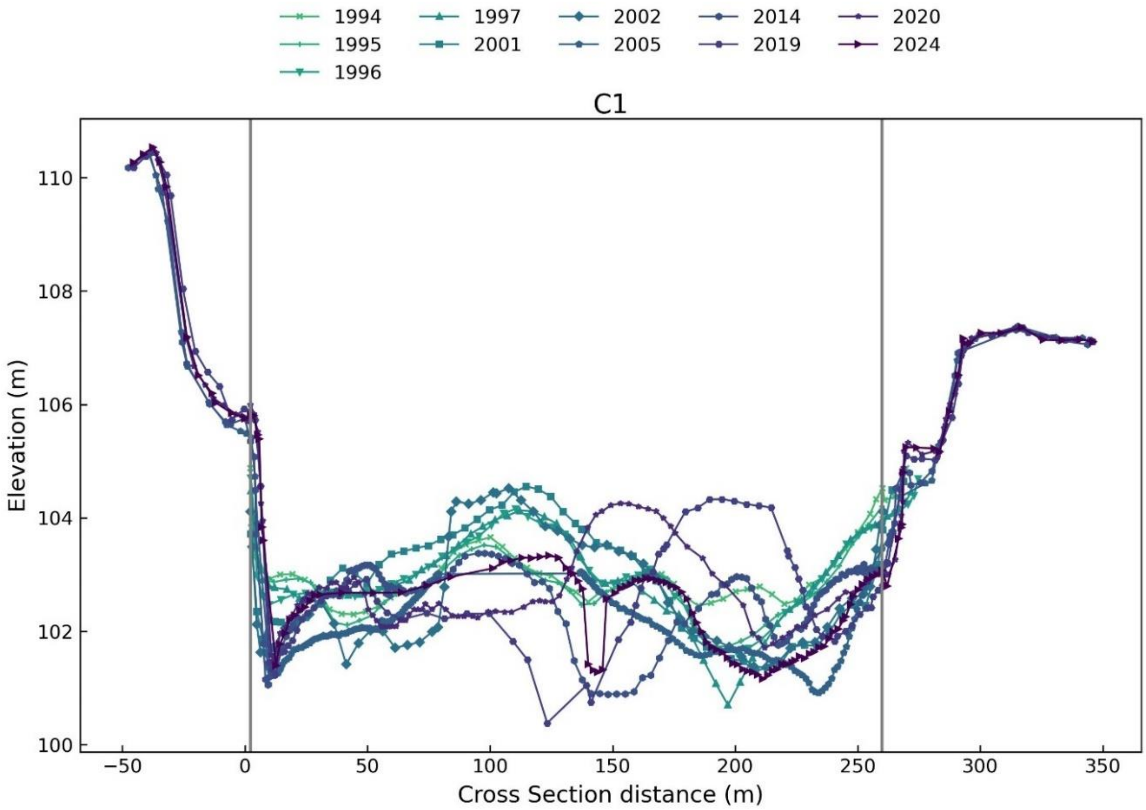
Grant, G. E., Fassnacht, H., McClure, E. M., & Klingeman, P. C. (2003) Downstream effects of the Pelton-Round Butte hydroelectric project on bedload transport, channel morphology, and channel-bed texture, lower Deschutes River, Oregon. Water Science and Application, 7, 175-176.

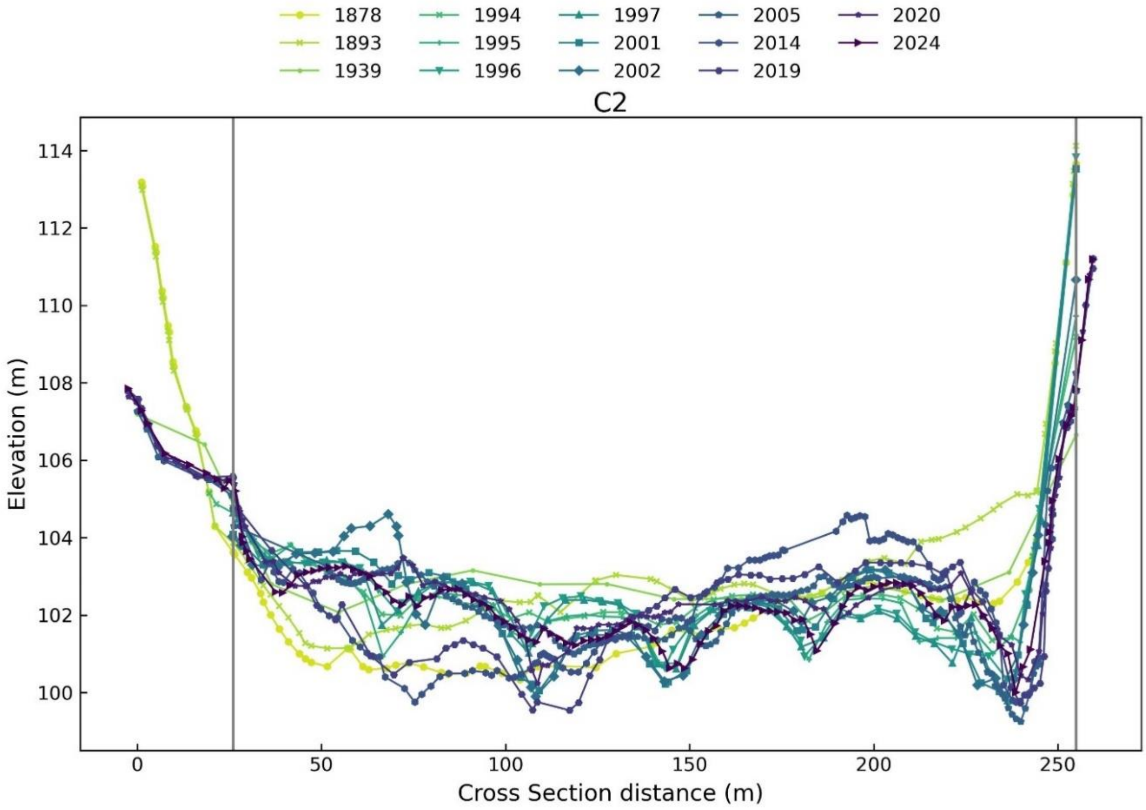
Hicks DM, Walsh JM and Duncan MJ. (2000) Clutha River Sediment Budget. NIWA Client Report CHC00/45.

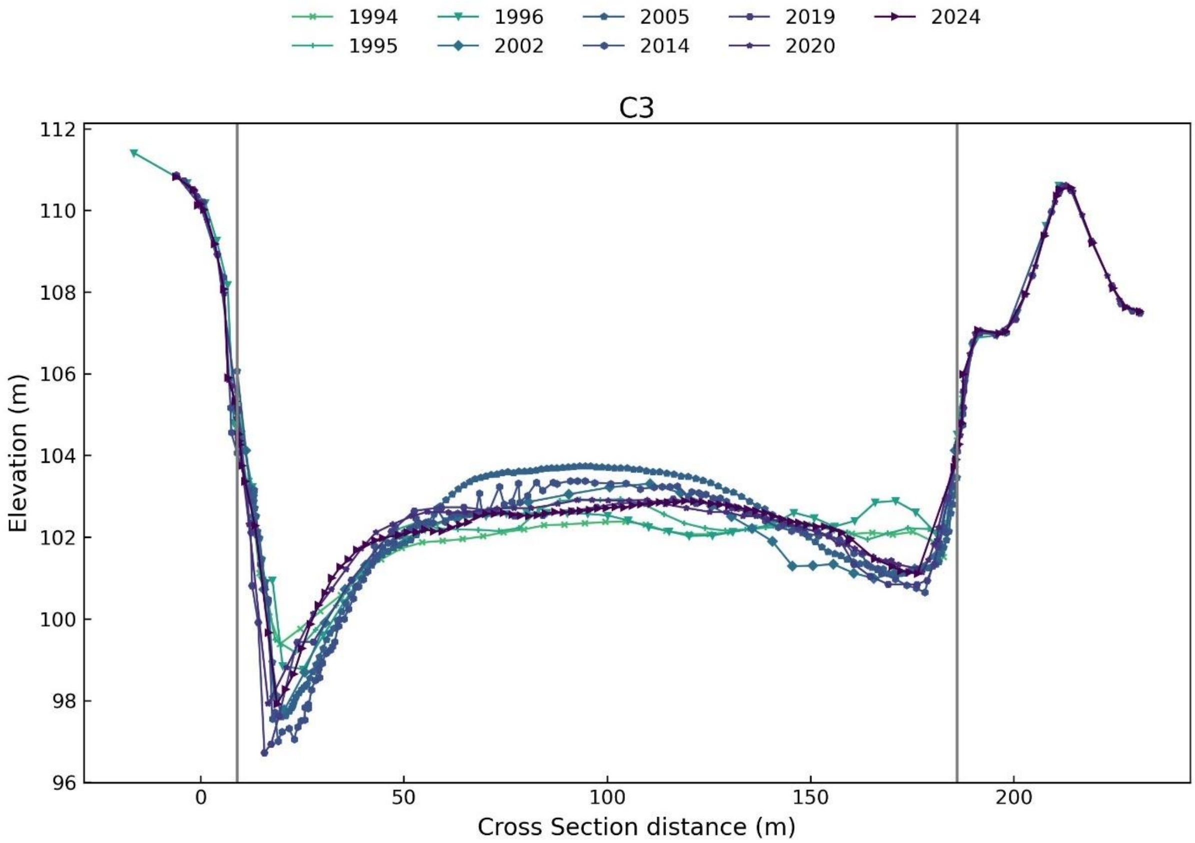
Otago Regional Council (2008) Channel morphology and sedimentation in the Lower Clutha River. ISBN: 1-877265-59-4

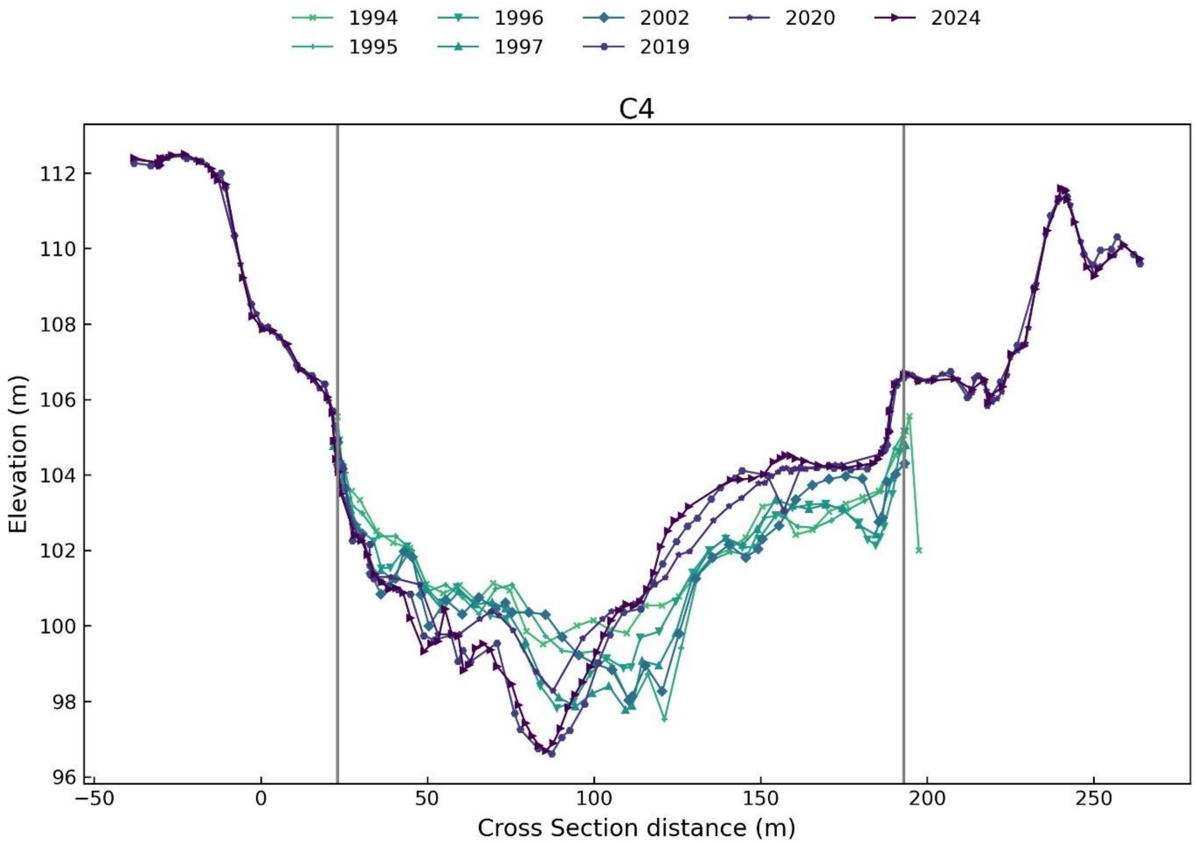
Appendix A Cross-section profiles for surveyed years

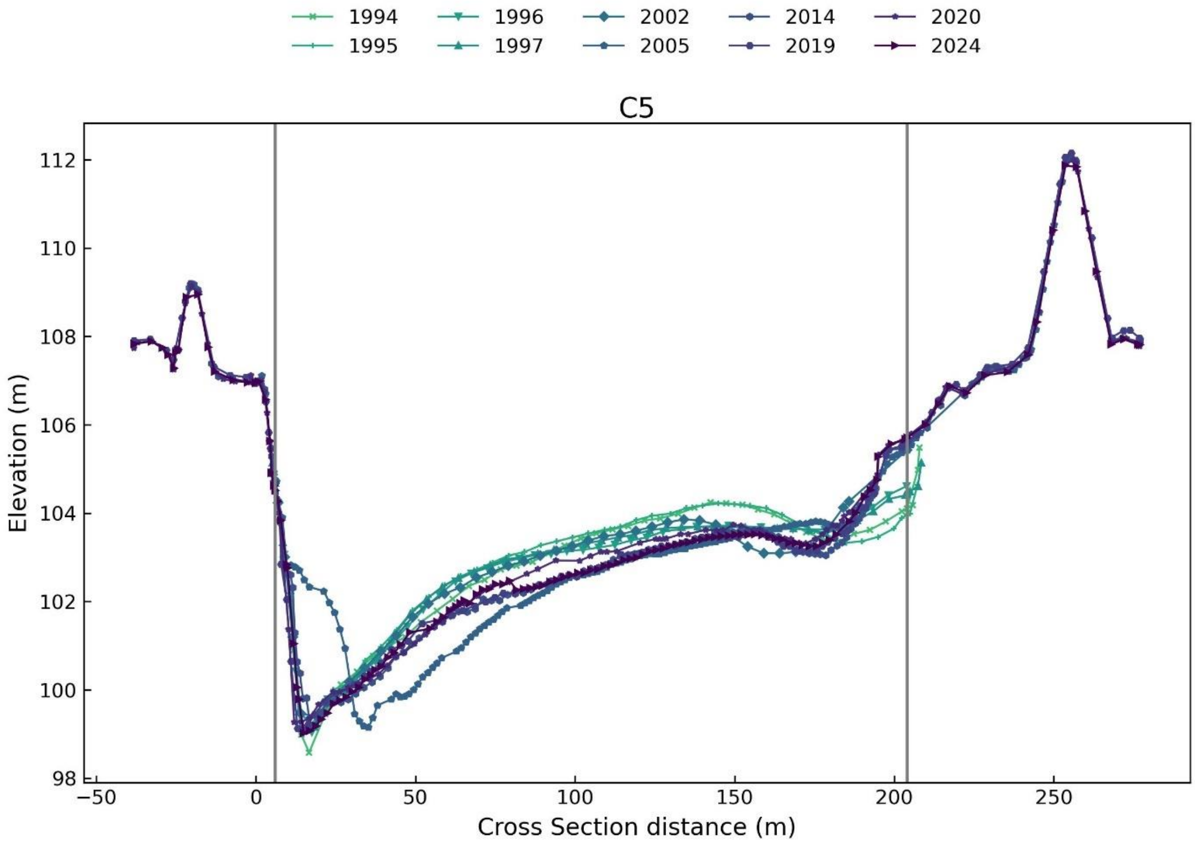
All cross-sections are viewed looking downstream.

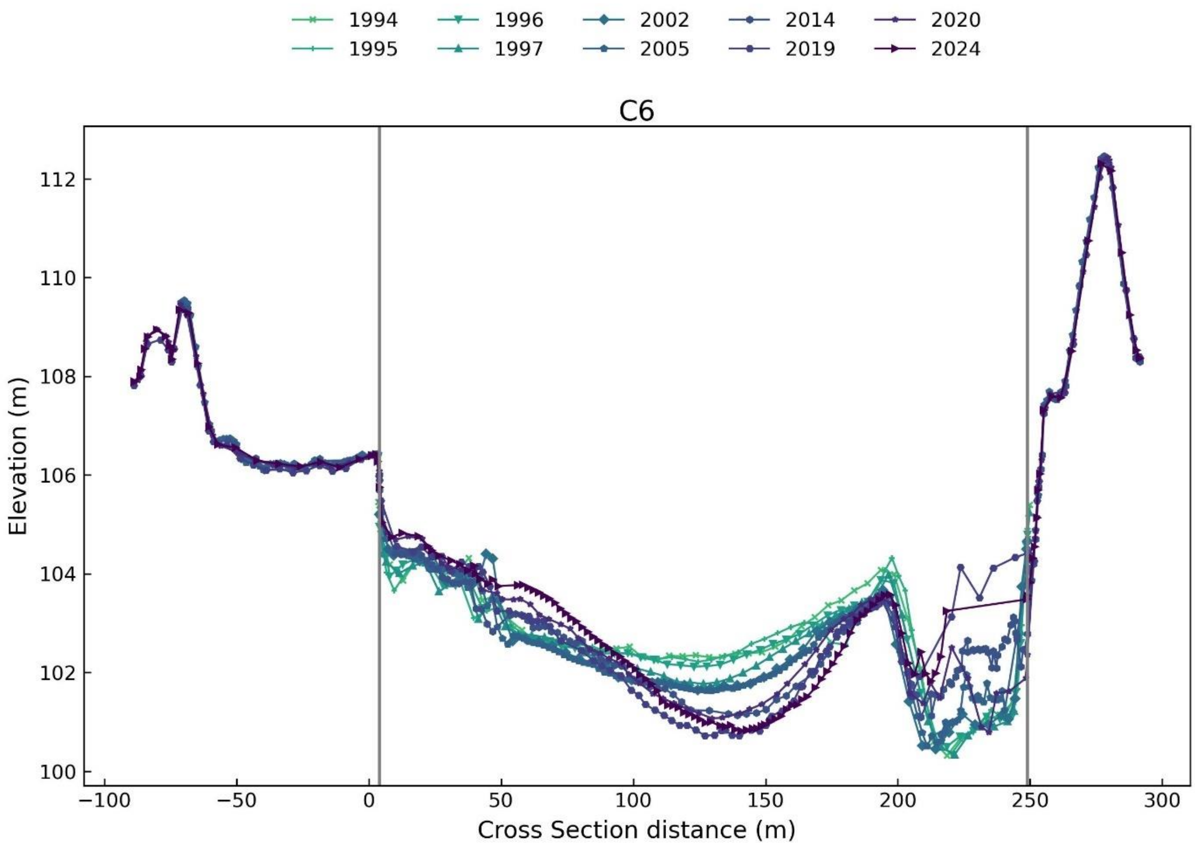


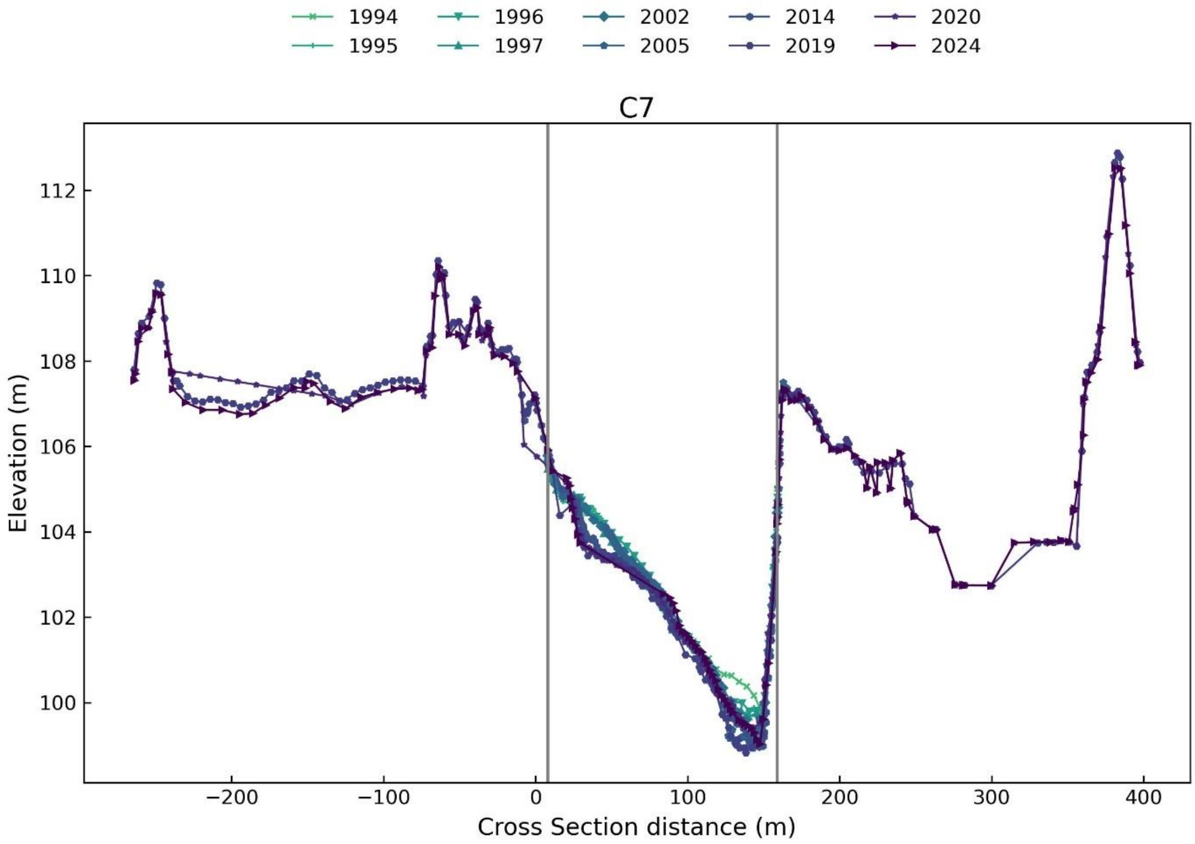


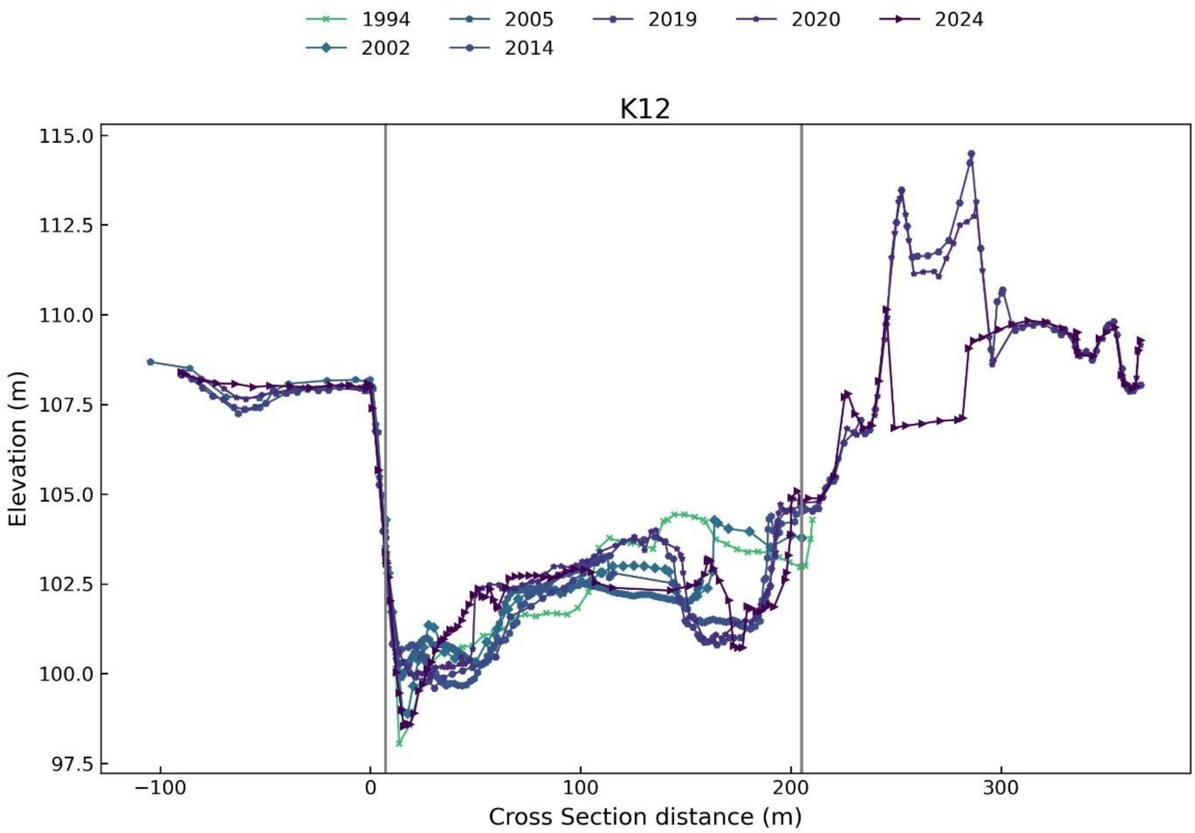

1994
1996
2005
2019
2024
1995
2002
2014
2020
C3
Elevation (m)
Cross Section distance (m)

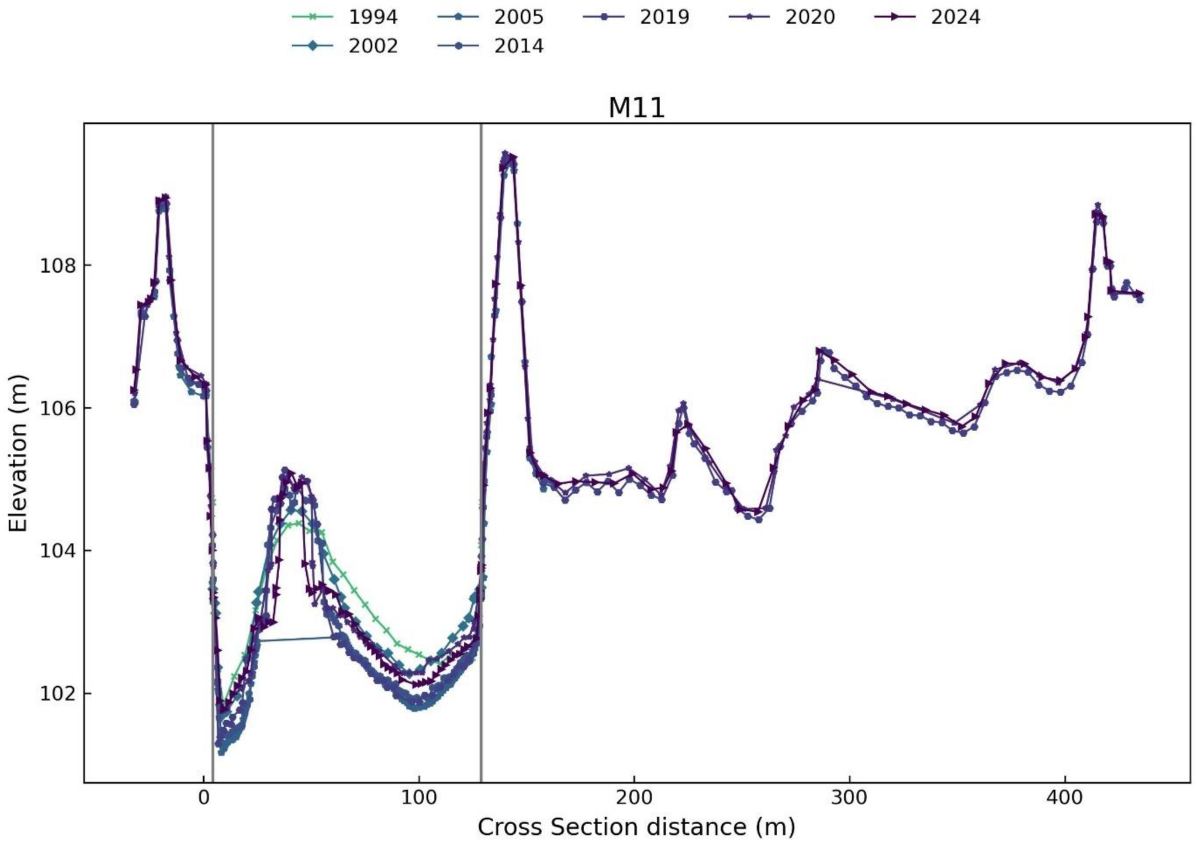

1994
1996
2002
2020
2024
1995
1997
2019
C4
Elevation (m)
Cross Section distance (m)

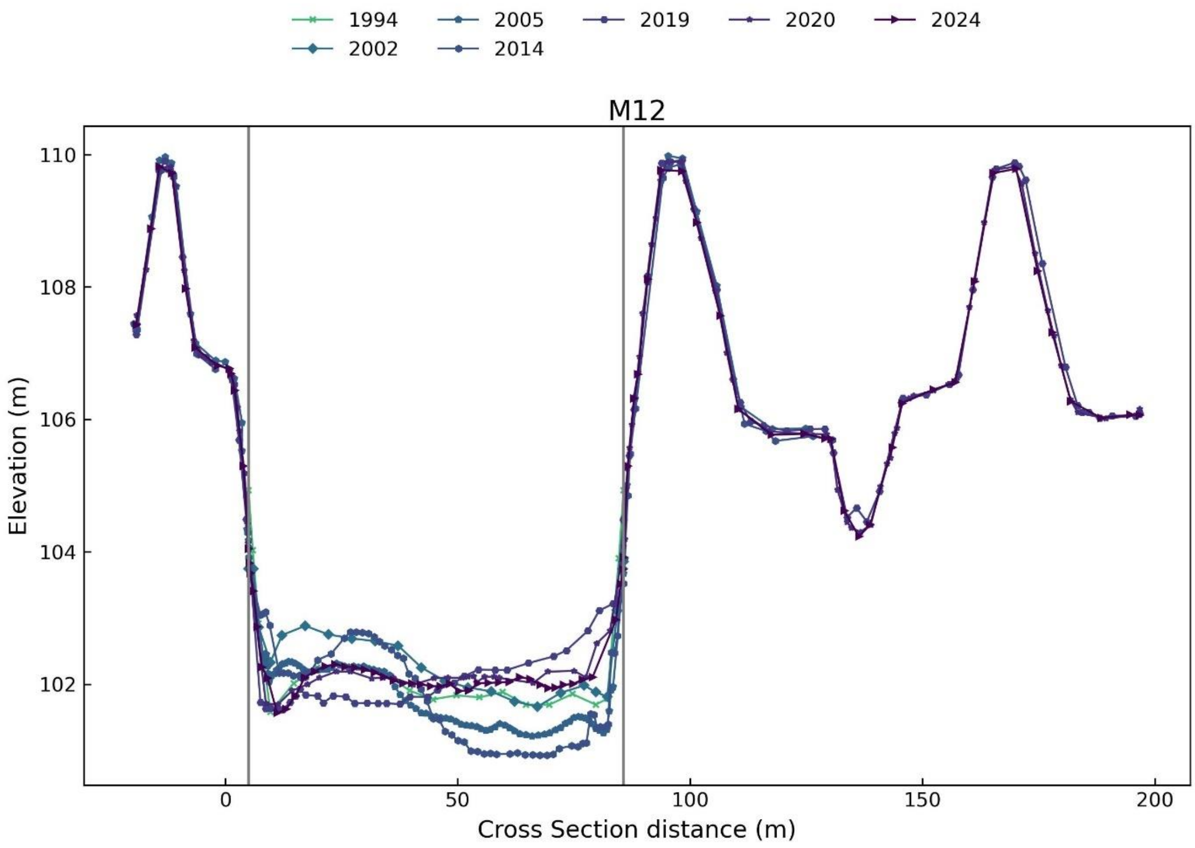

1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C5
Elevation (m)
Cross Section distance (m)


1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C6
Elevation (m)
Cross Section distance (m)


1994
1995
1996
1997
2002
2005
2014
2019
2020
2024
C7
Elevation (m)
Cross Section distance (m)


1994
2002
2005
2014
2019
2020
2024
K12
Elevation (m)
Cross Section distance (m)


1994
2005
2019
2020
2024
2002
2014
M11
Elevation (m)
Cross Section distance (m)


1994
2005
2019
2020
2024
2002
2014
M12
Elevation (m)
Cross Section distance (m)

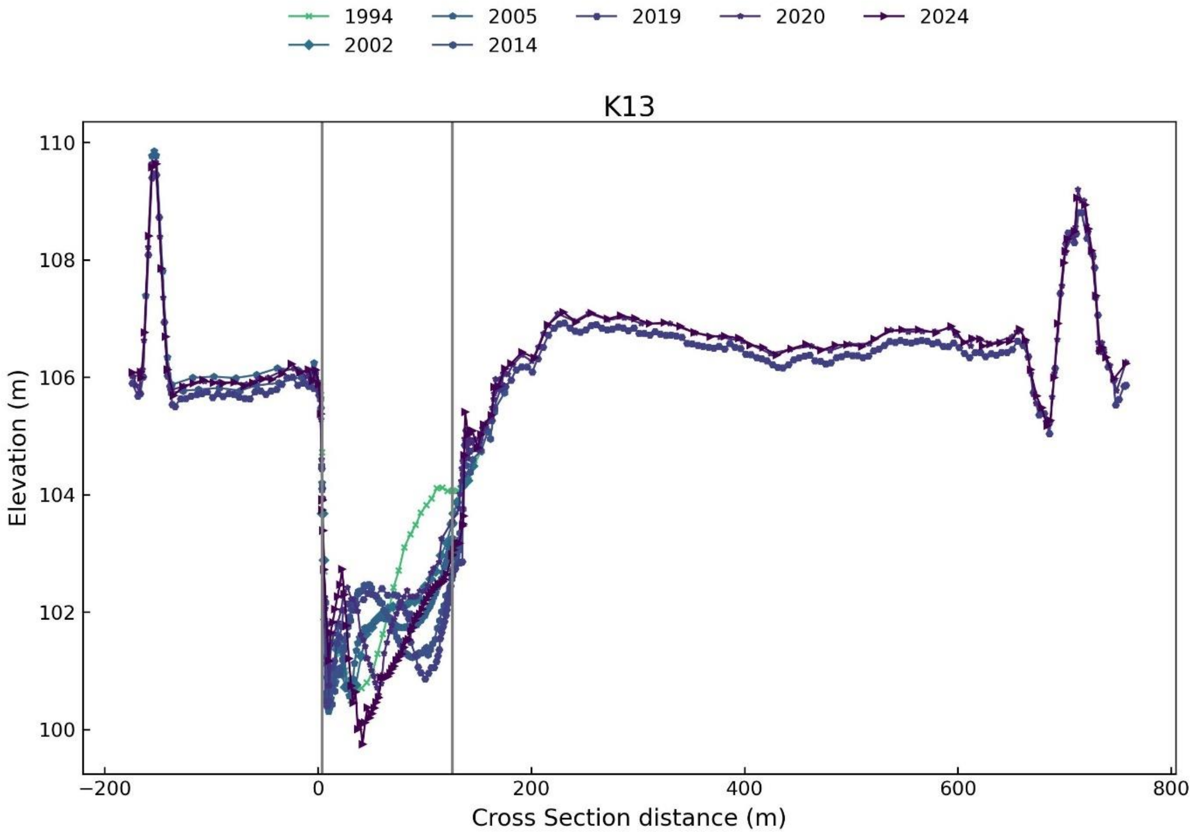


Figure A-1: Cross-sectional profiles of C2 to C7, M11, M12, K12, and K13 for all surveyed years.

Appendix B Satellite images of the Clutha River at Balclutha between 2016 and 2025


12-Jan-2018
Mean daily flow = 274 m3/s
N
0 0.2 0.4 0.8
Km


23-Apr-2020
Mean daily flow = 440 m3/s
N
0
0.2
0.4
0.8
Km


22-Mar-2022
Mean daily flow = 267 m3/s
N
0 0.2 0.4 0.8
Km


27-Feb-2023
Mean daily flow = 371 m³/s
N
0
0.2
0.4
0.8
Km


1-Mar-2024
Mean daily flow = 424 m3/s
N
0 0.2 0.4 0.8
Km

Figure B-1: Satellite imagery of the Clutha River at Balclutha for seven years between 2016 and 2025. The exact date of the satellite capture and average daily flow values are inserted in bottom left of each image. Red lines indicate cross-section locations.