Morphology of the Clutha River/Mata-Au between Roxburgh Dam and the Pacific Ocean

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Technical summary

This report assesses changes in the morphology of the Clutha River Mata-Au between the Pacific Ocean and the Roxburgh Dam using visual inspections, aerial and ground photography, and cross-section analysis. This assessment provides an update on changes in channel morphology that have occurred since the last assessment of trends was completed in 2008 (ORC, 2008). Also included is an investigation into recent (2016) changes in the size and shape of gravel bars in the river at the point of bifurcation near Balclutha, and potential influence on bank erosion in the vicinity. This report is designed to inform decisions relating to the management of the Clutha River/Mata-Au and its margins, including gravel extractions, floodwater conveyance, and asset management.

The analysis contained in this report shows that between the latest two surveys (2005 – 2014) in the Matau Branch of the Clutha River/Mata-Au there has been both aggradation and degradation with the largest amount of aggradation occurring closer to the mouth. The Koau branch showed only degradation[1] between the latest survey periods. Around Barnego and Balclutha the Clutha River/Mata-Au has experienced mostly aggradation or minor degradation between the latest surveys with only 3 of 11 cross-sections showing a decrease in mean bed level (MBL). The surveyed cross-sections between Barnego and Roxburgh Dam showed both aggradation and degradation with 25 cross-sections showing an increase in MBL and 10 cross-sections showing a decrease in MBL. The largest change in MBL occurred at Cross-section B13 near Beaumont which experienced an increase in MBL of about 0.9 m and cross-section C31 which experienced an increase in MBL of about 1 m. Minor bank erosion was observed at several cross-sections with larger erosion seen at cross-sections C17 and C20.

[1] The term ‘degradation’ in this case refers to the wearing down of the channel by the erosive action of water

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1. Introduction

This report identifies the changes that have occurred in the channel morphology of the Clutha River/Mata-Au between the Roxburgh Dam and the confluence with the Pacific Ocean between the latest two surveyed datasets. It provides an update to the 2008 ORC report, *Channel morphology and sedimentation in Lower Clutha River*, Dunedin, New Zealand, in which an assessment of bed level and bank erosion trends was documented. The recent changes in channel morphology are discussed within the context of longer term trends and analysis through historic aerial photography and cross-section analysis.

1.1. Catchment description

The Clutha River/Mata-Au catchment is the largest in New Zealand covering an area of some 21,000 km^2 (Figure 1). The Clutha River/Mata-Au itself commences at the outlet of Lake Wanaka, then flows through to Lake Dunstan where it joins with its largest tributary, the Kawarau River at Cromwell. The Clutha River/Mata-Au then makes its way to the East Coast and the Pacific Ocean near Balclutha via Clyde and Alexandra. There are several major tributary rivers and streams of the Clutha River/Mata-Au. These include: the Dart and Rees Rivers which flow into Lake Wakatipu; the Shotover River which flows into the Kawarau and eventually the Clutha River/Mata-Au; the Makarora River and Matukituki River which flow into Lake Wanaka; the Cardrona, Lindis, and Pomahaka Rivers which flow into the main stem of the Clutha River/Mata-Au (Figure 1).

Upper reaches

The upper reaches of the Clutha River/Mata-Au catchment contain a diverse range of topography and a wide variation in rainfall. In the far west, the country is mainly mountainous with peaks to nearly 3,000 m. To the south and east the catchment is characterised by lower mountain ranges which contribute flows to smaller river, such as the Cardrona and Lindis Rivers. The river passes through two man made dams in this reach, Clyde and Roxburgh.

Roxburgh Dam to Barnego

This section of the Clutha River/Mata-Au includes the mid and lower reaches of the river. In this reach the main tributary flows include the Pomahaka River, Waitahuna River, and the Teviot River. There are several large mid-channel islands in this reach including Manuka Island (survey cross section C17), Gull Island (C21), and Birch Island (C26).

Barnego to Pacific Ocean

This reach of the Clutha River/Mata-Au covers the lowest section between the confluence of the Pacific Ocean and the locale of Barnego. In this reach the Clutha River/Mata-Au bifurcates into two separate branches, the larger (by flow volume) and shorter (by distance) of the two is the Koau Branch (ORC 2016) which flows on the southern side of the Clutha Delta with the smaller (by volume) and more meandering Matau Branch on the northern side of the delta. The main tributaries in this reach include the Puerua River, the Waitepeka River, and the Kaitangata River.

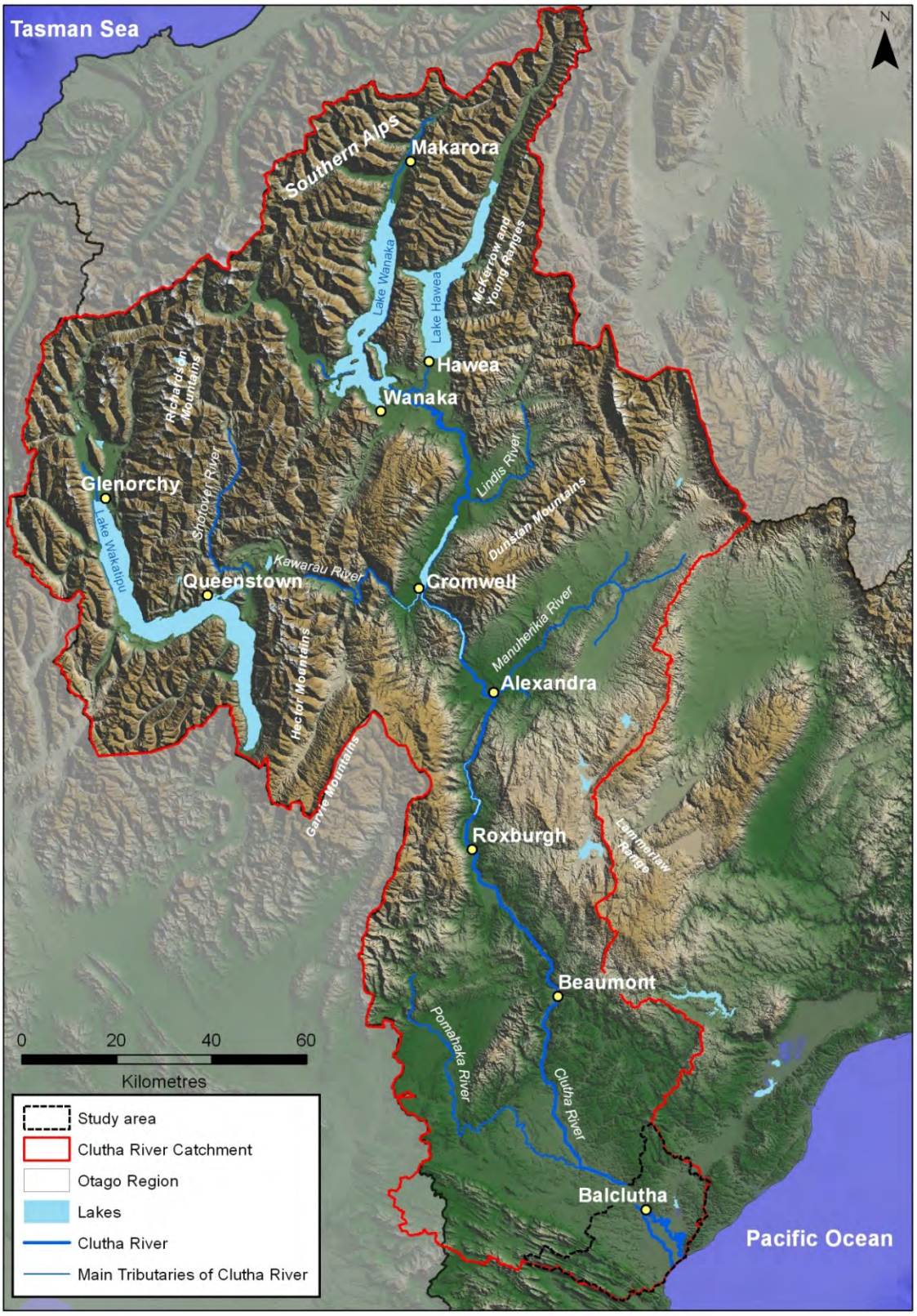


Figure 1. **Clutha River/Mata-Au showing the catchment outlined in yellow, with the Otago region showin in greyscale. Discussion of river morphology in this report covers the reach from Roxburgh to the coast.**

Geology

The geology of Clutha River/Mata-Au catchment is mostly metamorphic schists with glacial gravel deposits filling valleys and basins, and some Tertiary sedimentary rocks located in the larger basins such as the Manuherikia (Opus, 2000). The Clutha Delta is bisected by the Livingston Fault which separates the basement rocks of the Caples and Maitai Terranes of metamorphosed sandstones and siltstones (ORC 2016). The recent (Quaternary) geology of the Clutha Delta is coastal and river alluvium formed by interactions of the river and sea as well as changes in sea level (Irricon 1998; ORC 2016).

2. Background

Sediment sources

The main source of sediment into the Clutha River/Mata-Au comes from the Shotover River (60% into the upper Clutha River/Mata-Au at Cromwell) and Kawarau River (89% into the upper Clutha River/Mata-Au at Cromwell) catchments (NIWA, 2000). The Shotover River catchment is mostly located in the high topography area north of Queenstown between the Richardson Mountains and the Harris Range. The steep topography of the upper catchment coupled with the high erosion rates associated with uplift and weathering allows large amounts of sediment to enter the Shotover River and therefore become transported down the river system to end up in the Kawarau River and then into the Clutha River/Mata-Au.

Gold mining in the Clutha River/Mata-Au catchment also contributed sediment into the river system (ORC, 2008). Mining activities on the bed and banks of the Clutha Rive/Mata-Au and within the catchment such as sluicing and dredging add loose sediment into waterways which then become transported into the Clutha River/Mata-Au system (ORC, 2008). Sediment associated with mining activities that took place in the late 19th Century would have added a ‘slug’ of sediment into the Clutha River/Mata-Au; it is believed that this slug of sediment has since worked its way to the coast (NIWA, 2000).

The two dams located on the Clutha River/Mata-Au (Clyde and Roxburgh) have an effect on the amount of sediment moving down the Clutha River/Mata-Au. Larger sediment, especially bedload, becomes trapped behind the dams and therefore is not made available for the River to use downstream (NIWA, 2000). The presence of the Clyde and Roxburgh dams in the upper Clutha River/Mata-Au catchment creates a sediment starved environment which is likely to exacerbate the erosion of sand from Molyneux Bay (Contact Energy Ltd Resource Consent Hearing, 2002). The presence of the dams have also been identified as a factor that contributes to channel stability problems in the lower alluvial reaches due to factors such as reduced sediment input and an unnatural flow regime (NIWA, 2000). NIWA (2000) state that since the building of the Clyde and Roxburgh dams the potential yield of sand and gravel from the Clutha River/Mata-Au to the coast has reduced by 95% from 0.91 Mt/yr to 0.06 Mt/yr. This reduction in sediment supply may be a factor associated with the erosion of the coast line in areas of Molyneux Bay (ORC, 2014, 2016). Contact Energy operates a draw down programme to flush sediment from the two dams and transport the material downstream.

3. Results

3.1. Historic change

Appendix A shows the year of cross-section surveys and Appendix B shows the changes at the cross-sections between the first and latest survey period. The degree of change between the first and latest surveys varies as not all cross-sections were surveyed in each year, with some going back to 1940. Coverage varies cross-sections and surveyed years. In some cases such as cross-section C44 (below Roxburgh Dam) the channel bed has degraded by 6 m between 1948 and 2016[2] (Figure 87). Other cross-section such as C19 (Figure 60) have not changed significantly.

Changes in the river morphology over time can be attributed to several factors such as the presence of bedrock, sediment supply, frequency and magnitude of flood events, and human intervention such as gravel extraction, protection structures and dams. Figure 2 and Figure 3 show aerial photography of the Clutha River/Mata-Au between 1946, 2006, 1950 and 2013 highlighting changes in river morphology such as larger areas of gravel and more backwater areas.

Figure 2. **Comparison of aerial photography for the Koau Branch of the Clutha River/Mata-Au near Lawsons Road, aerial photography collected on 1946 (left) and 2006 (right).**

[2] Construction on Roxburgh Dam began in 1949

Figure 3. **Aerial photography comparison for the Clutha River/Mata-Au at Balclutha, aerial photography collected in 2013 (top) and 1950 (bottom).**

3.2. Mean bed level

Figure 4 shows the change in MBL at cross-sections on the Matau branch of the Clutha River/Mata-Au between 2014 and 2005 as well as between 2005 and 2000 (for some cross-sections)[3]. The magnitude of MBL change and the location of the cross-sections are shown in Figure 5. The highest rates of MBL change occurred at the downstream cross-sections with cross-section M223, M202, and M195 experiencing about 0.5 m aggradation between 2014 and 2005 (Figure 4). Degradation was experienced between cross-sections M154 and M94 between 2014 and 2005 as well as between 2005 and 2000 for cross-sections M147 and M99 (Figure 4). The upstream cross-sections on the Matau branch experienced both aggradation and degradation between 2014 and 2005 with cross-section M9 showing the highest rate of change at just under 0.2 m aggradation (Figure 4). Individual cross-sections in this reach are shown in Appendix C.

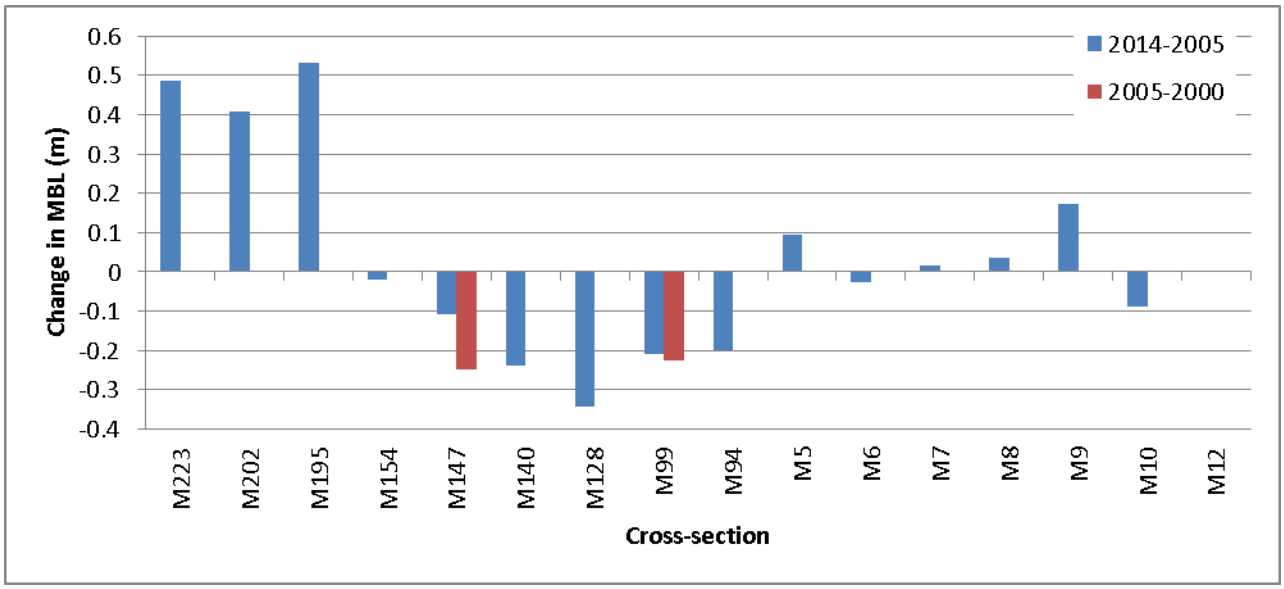


Figure 4. **Change in MBL at cross-sections on the Matau branch of the Clutha River/Mata-Au between 2014 and 2005 and 2005 and 2000. MBL could not be calculated at all cross-sections in each year due to differing coverage.**

Figure 6 shows the change in MBL for the Koau branch of the Clutha River/Mata-Au and the magnitude of MBL change and the location of the cross-sections are shown in Figure 5. All cross-sections on the Koau Branch experienced degradation between 2014 and 2005 and 2005 and 2000. The largest amount of degradation was observed at cross-section K11 at 0.36 m (Figure 6). Individual cross-sections in this reach are shown in Appendix C.

[3] Not all cross-sections were surveyed in each survey year. Table 1 (Appendix A) lists which year each cross-section was surveyed.

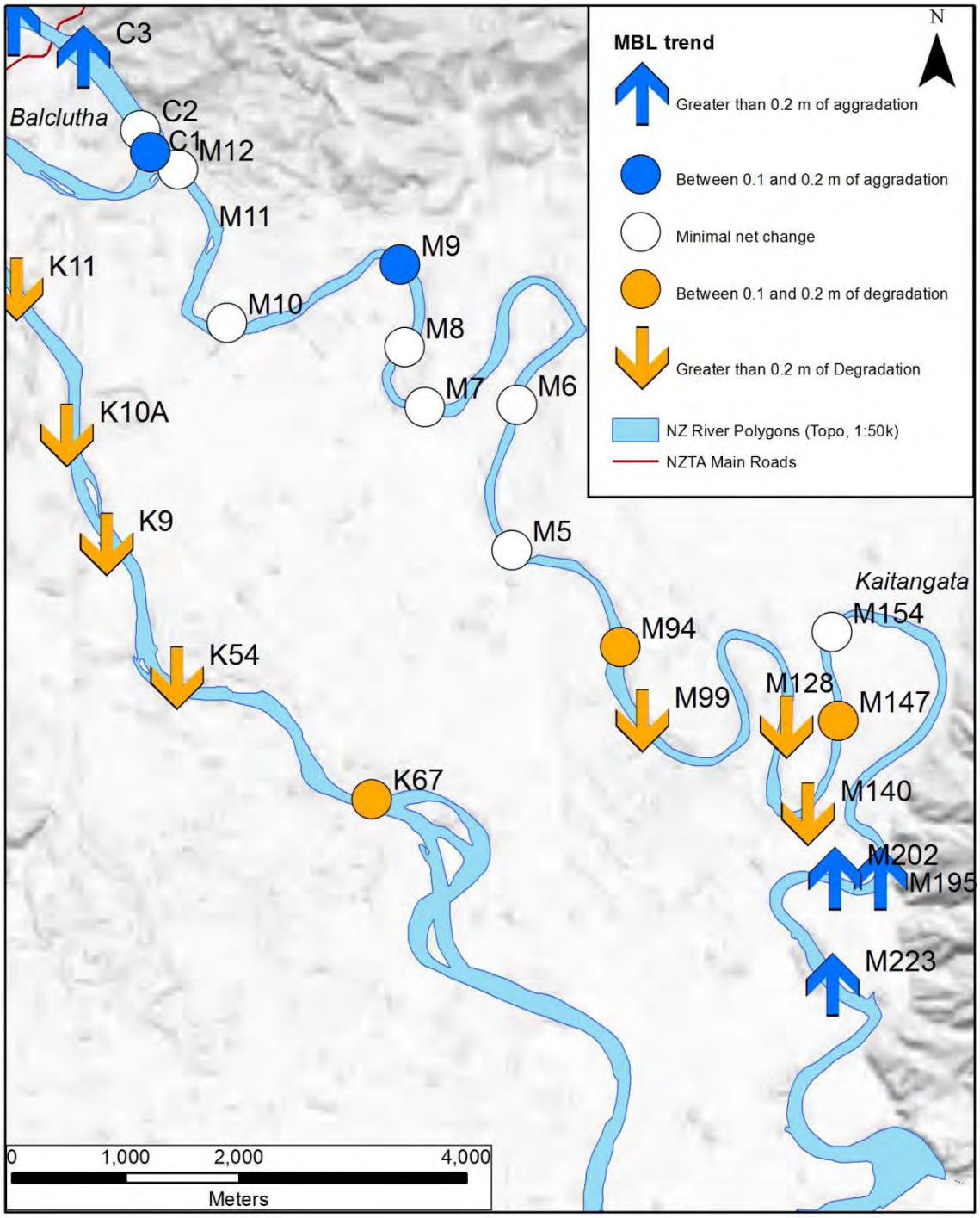


Figure 5. **The location of cross-section on the Clutha River/Mata-Au delta. The white, orange, and blue symbols show the magnitude of MBLchange at each cross-section between the two recent cross-section surveys (2014 – 2005).**

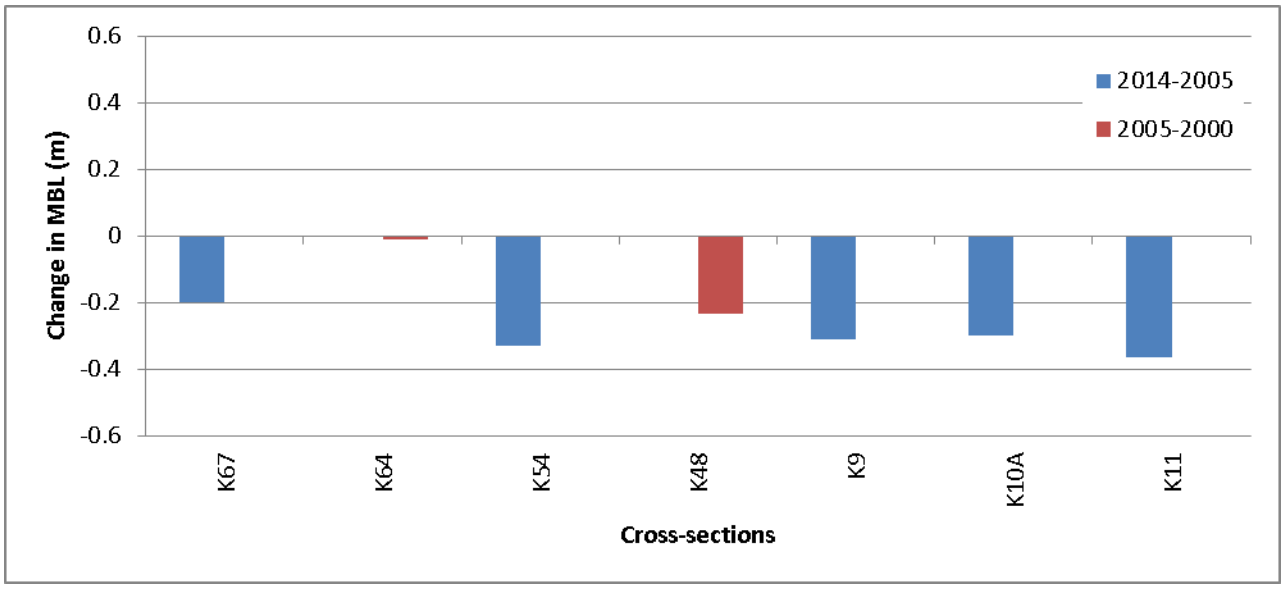


Figure 6. **Change in MBL at cross-sections on the Koau branch of the Clutha River/Mata-Au between 2014 and 2005 and 2005 amd 2000. MBL could not be calculated at all cross-sections in each year due to differing coverage.**

Figure 7 shows the change in MBL for the Clutha River/Mata-Au for the sections located near Barnego and Balclutha, the magnitude of MBL change and the location of the cross-sections are shown in Figure 5 and Figure 8. Most cross-sections near Barnego and Balclutha experienced aggradation or minor degradation between 2014 and 2005 with the exception of cross-section C8 which experienced 0.3 m degradation (Figure 7). Cross-section C13 experienced aggradation between 2002 and 2005 but degradation between 2014 and 2005 (Figure 7). Individual cross-sections in this reach are shown in Appendix C.

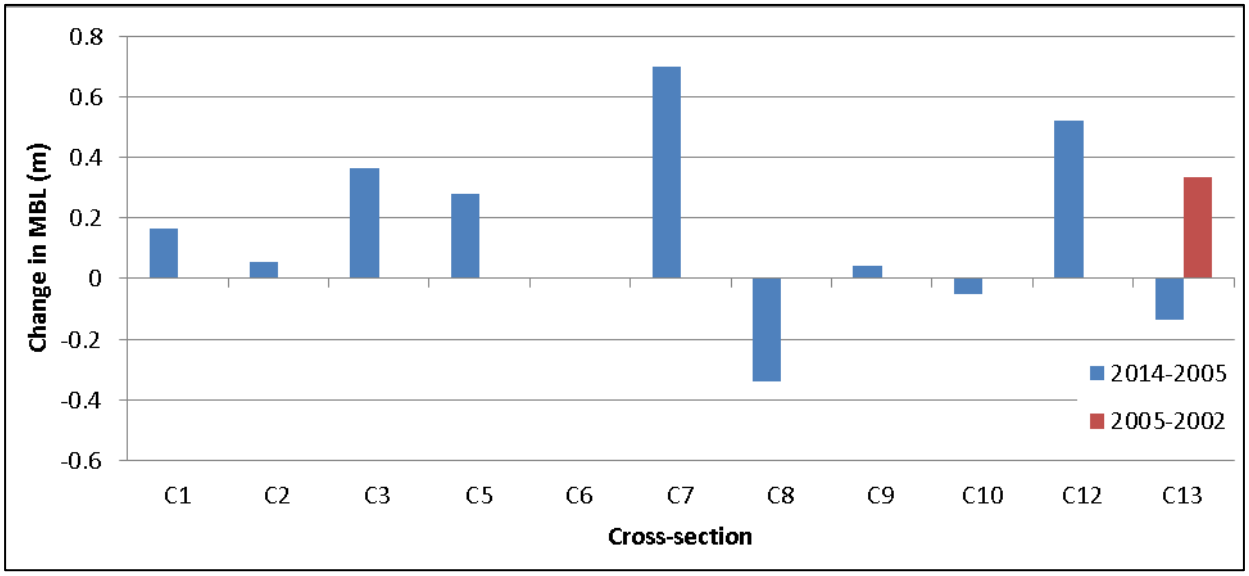


Figure 7. **Change in MBL at cross-sections on the Clutha River/Mata-Au around Barnego between 2014 and 2005. MBL could not be calculated at all cross-sections in each year due to differing coverage.**

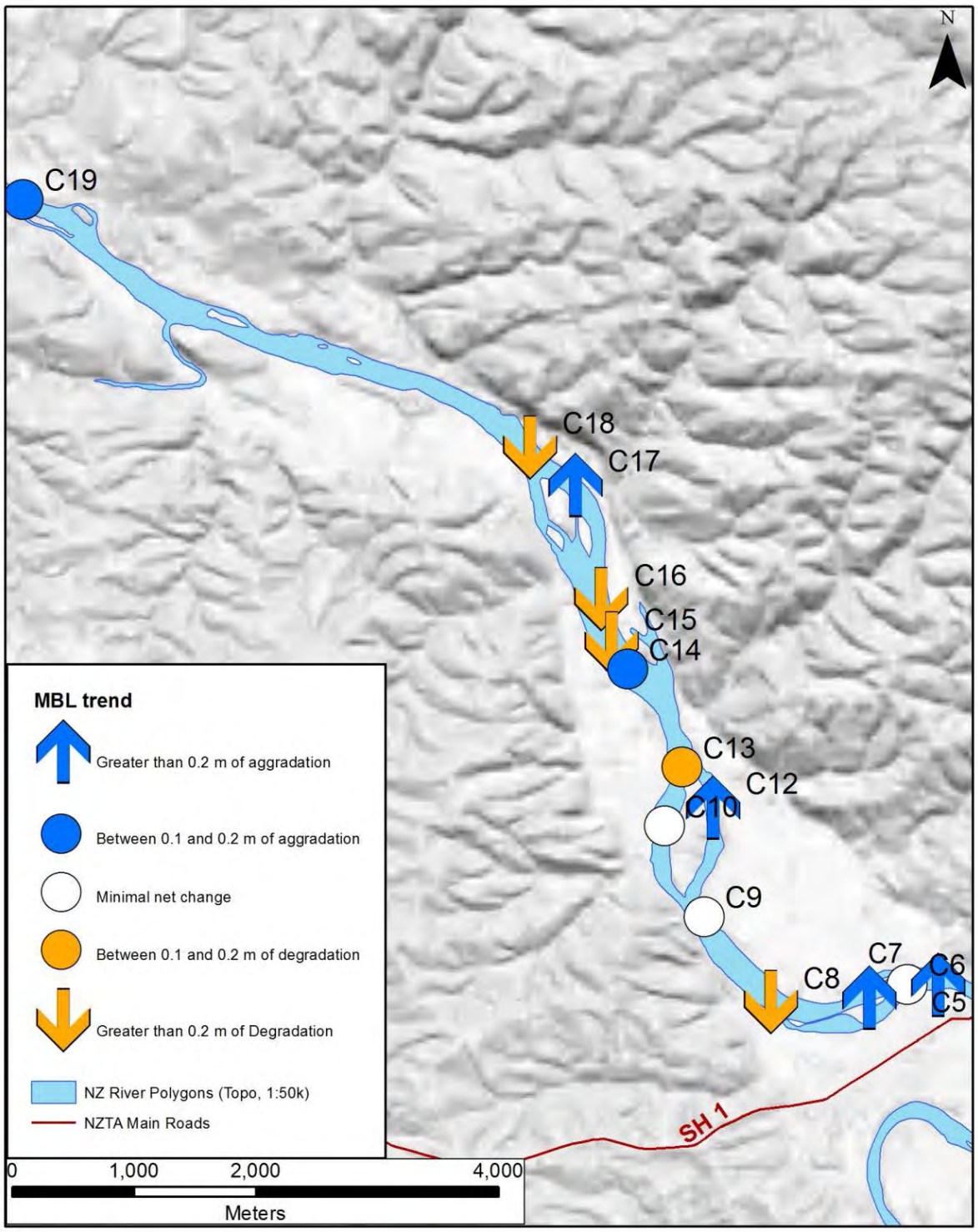


Figure 8. **The location of cross-section on the Clutha River/Mata-Au upstream of Balclutha. The white, orange, and blue symbols show the magnitude of MBLchange at each cross-section between the two recent cross-section surveys (2014 – 2005, 2016 - 2007).**

Figure 9 shows the change in MBL between 2016 and 2007 for the reach of the Clutha River/Mata-Au between Barnego and Roxburgh Dam, the magnitude of MBL change and the location of the cross-sections are shown in Figure 10 and Figure 11. The cross-sections in this reach experienced both aggradation and degradation with 24 cross-sections showing an increase in MBL and 10 cross-sections showing a decrease in MBL (Figure 8). The largest change in MBL occurred at cross-section B13 near Beaumont which experienced a change in MBL of about 0.9 m and cross-section C31 which experienced a change in MBL of about 1 m. Individual cross-sections in this reach are shown in Appendix C.

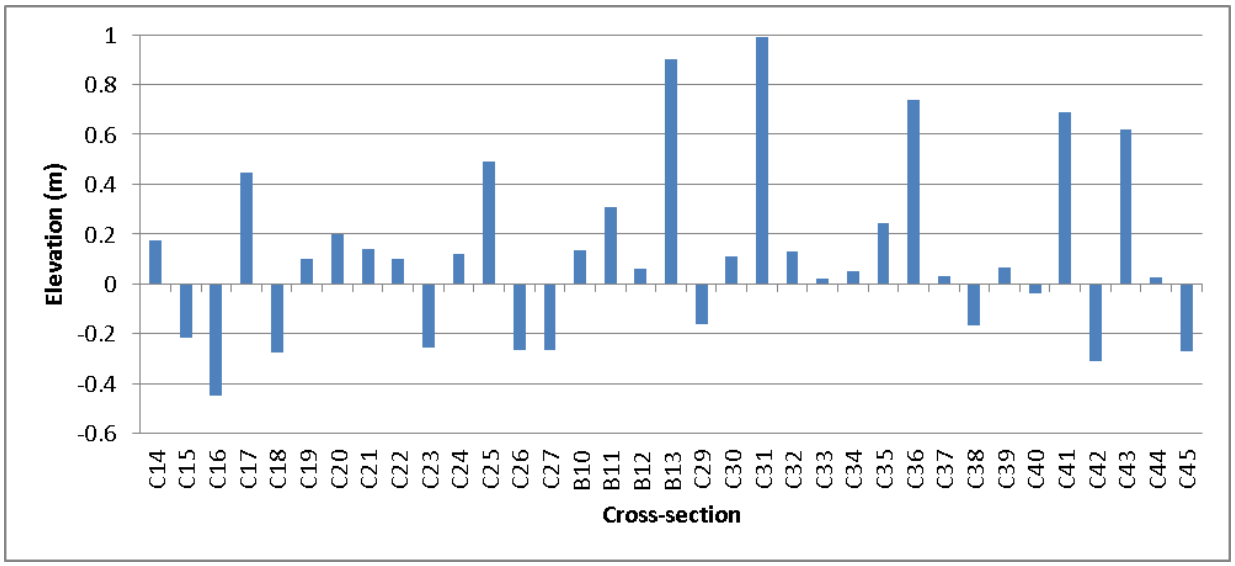


Figure 9. **Change in MBL at cross-sections on the Clutha River/Mata-Au for the reach between Barnego and Roxburgh Dam between the years 2016 and 2007.**

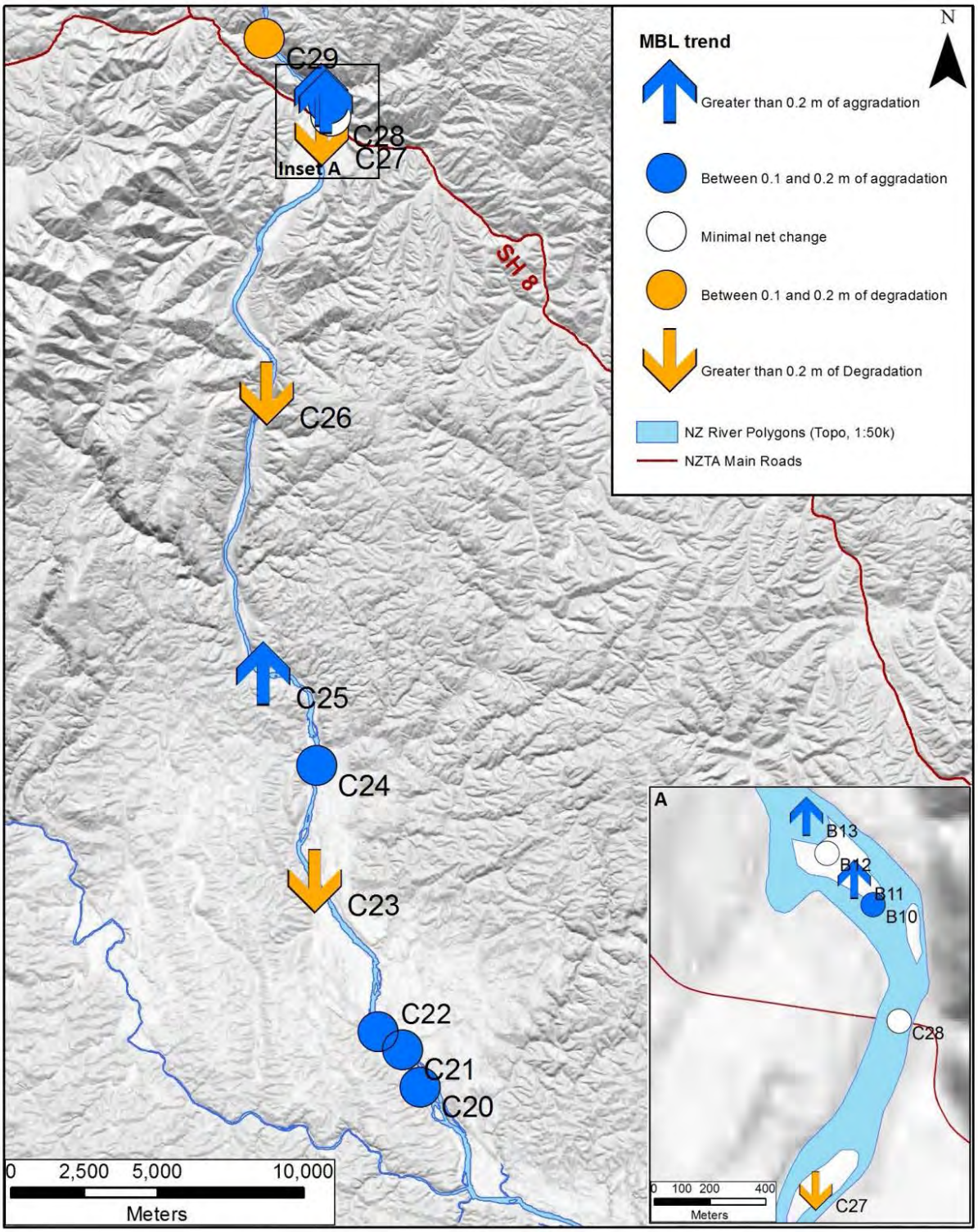


Figure 10. **The location of cross-section on the Clutha River/Mata-Au between Clydevale and Beaumont. The white, orange, and blue symbols show the magnitude of MBLchange at each cross-section between the two recent cross-section surveys (2016 – 2007).**

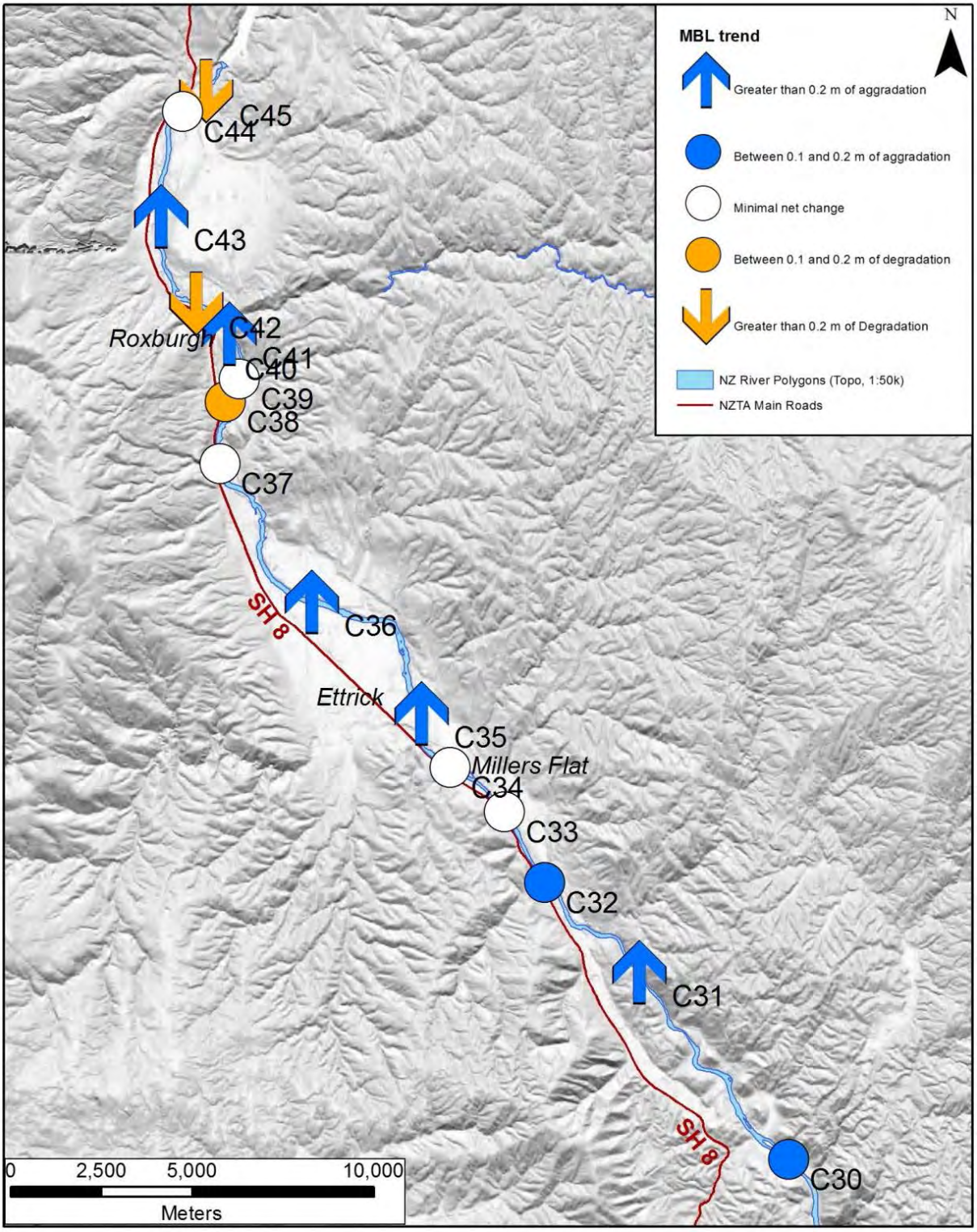


Figure 11. **The location of cross-section on the Clutha River/Mata-Au between Beaumont and Roxburgh Dam. The white, orange, and blue symbols show the magnitude of MBLchange at each cross-section between the two recent cross-section surveys (2014 – 2005).**

3.3. Longitudinal profile

Rivers generally increase in size (width/depth) as they flow in a downstream direction and receive additional flow from tributary waterways. This is the case for the Clutha River/Mata-Au. Longitudinal profiles change over time in response to several factors including: river flow, sediment size and location, flow resistance, velocity, width, depth, and slope (Leopold *et al*, 1964). The longitudinal profile of the Clutha River/Mata-Au will change over time in response to changes in the factors discussed above. The longitudinal profile of the Clutha River/Mata-Au displays a typical concave shape with steeper areas in the upper catchment and a shallower profile closer to the Pacific Ocean (Figure 9).

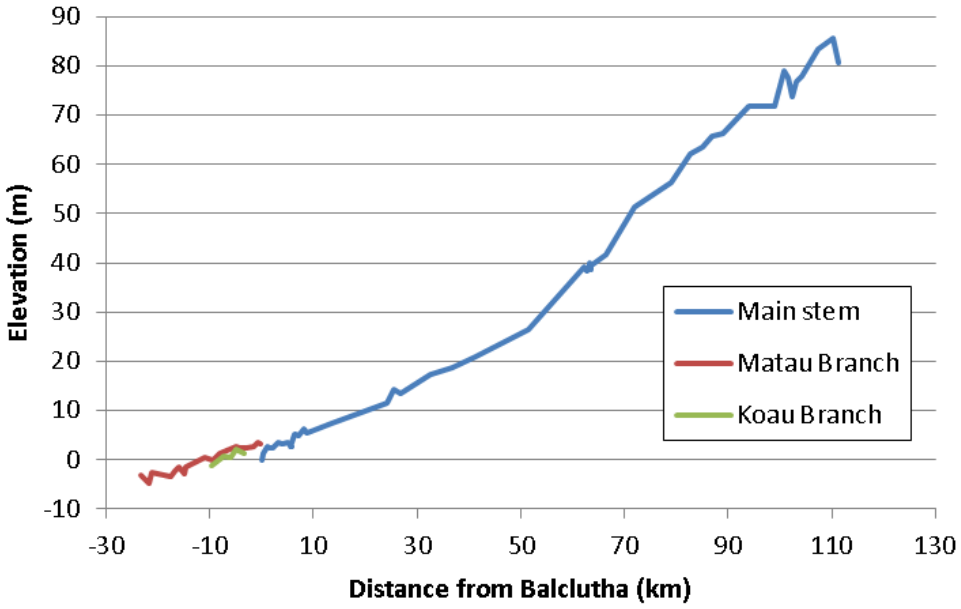


Figure 12. **Longitudinal profile (showing the MBL) of the Clutha River/Mata-Au from the latest survey data (2014, 2016).**

3.4. Hydrology and flood hazard

Changes in the morphology of the Clutha River/Mata-Au are in part driven by the hydrological characteristics of the river including the magnitude and frequency of flood flows. Since November 1999 there have not been any floods in the Clutha River/Mata-Au exceeding 2,000 m^3. The Clutha River/Mata-Au has experienced large flood events in the past with the September 1878 flood being the largest since records began (ORC, 2016). The November 1999 flood event is the largest in recent history at the Roxburgh recorder (Figure 10), and is the third largest at the Balclutha recorder (Figure 11)[4]. The September 1878 flood caused the Manuherikia River to back up the valley due to the damming effect of the Clutha River/Mata-Au. This had the effect of creating a sediment deposition area and Gilkison (1930) reported that after the flood, the Manuherikia River valley was covered with several feet of silt.

[4] A more comprehensive report on the flood hazard of the Clutha River/Mata-Au delta can be found in ORC (2016).

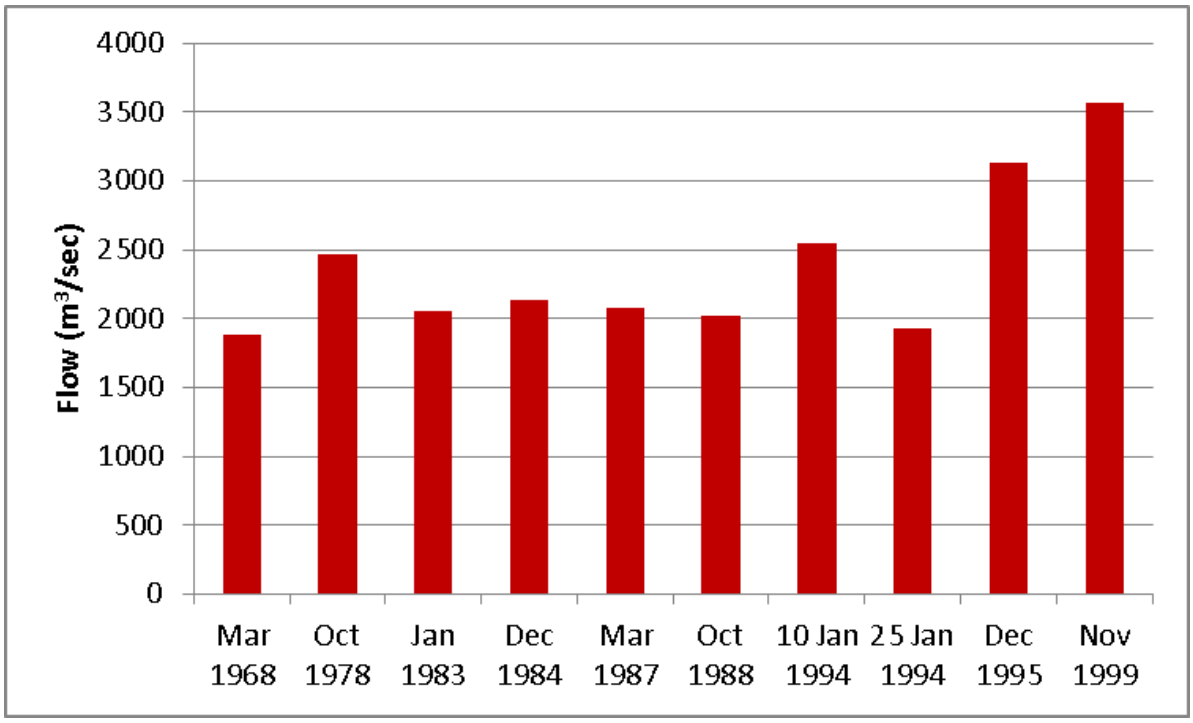


Figure 13. **Ten highest flows in the Clutha River/Mata-Au at the Roxburgh Dam recorder since records began in 1965.**

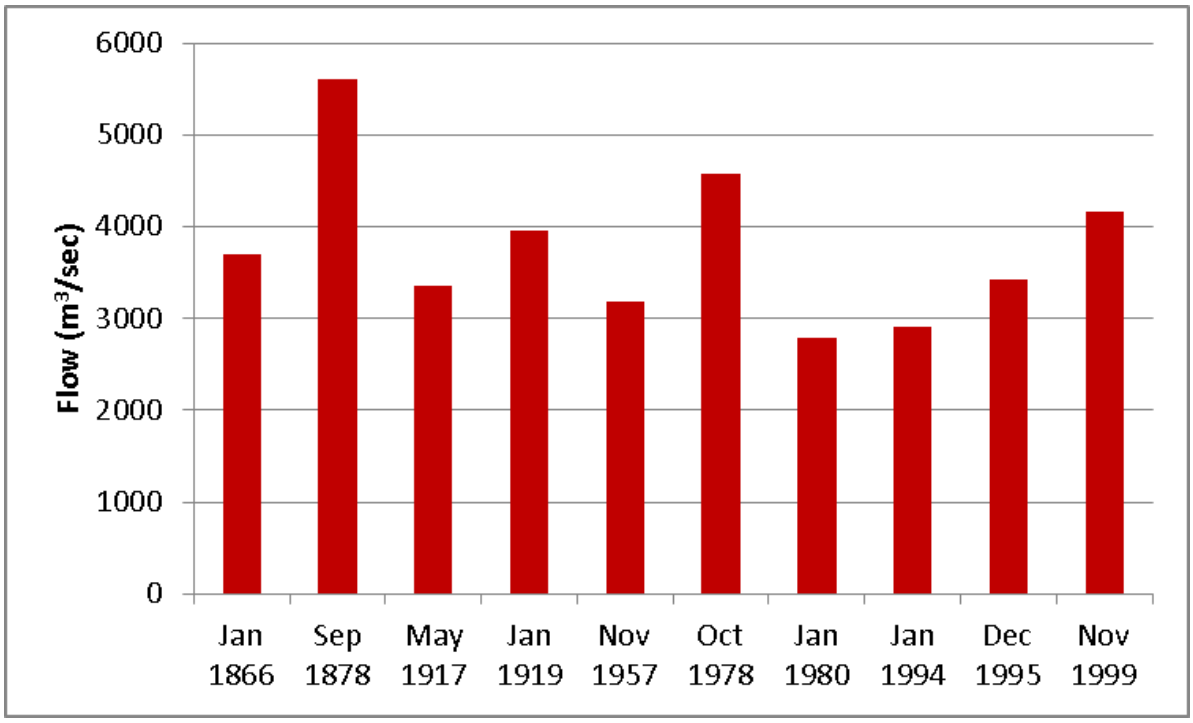


Figure 14. **Ten highest flows (estimated or recorded at Balclutha) in the Clutha River Mata-Au at since 1863.**

3.5. Bank erosion

Bank erosion is considered to be the erosion of the margins of the active channel fairway and not the erosion of the low flow channels. Minor bank erosion was observed at several cross-sections between the latest survey periods with larger areas of erosion observed at cross-sections C17 and C20 (Figure 170, Figure 176). As the coverage of survey data across the cross-sections varies a direct comparison of the banks and any erosion cannot be made for every cross-section. Bank erosion also occurs in areas outside of the cross-section coverage and has been observed in previous reports (Figure 12) (ORC, 2008, ORC 2013).

Figure 15. **Evidence of erosion on the true right bank upstream of Gull Island/cross section C21 (April 2002).**

3.6. Gravel beach migration at Clutha bifurcation, Balclutha

Two gravel bars in the Clutha River/Mata-Au adjacent to Balclutha have caused concern to some landholders due to their apparent growth and migration downstream into the zone where the river bifurcates into the Koau and Matau branches. The bifurcation site was visited by ORC natural hazards staff members during August 2016 and gravel beaches with vegetation and birds beneath the road bridge were noted. These had been features for some time and although they were higher in some parts at present, the corresponding parts of the river channel had deepened during the same time period.

Concerns were also raised about erosion of the true right bank of the Koau branch just south of Balclutha, near the end of Glasgow Street. Understanding was that the island of gravel in the centre of the river had built up in the recent past and was now pushing current hard into the true right bank, causing rapid erosion (Figure 16).

The site was visited on October 21st 2016. Significant erosion has occurred along this bank and at the time of visiting, during spring high flows in the Clutha, the bank had been actively eroding into the river at a rate of ~2 metres over the past few weeks, according to local observers.

Aerial photos from 1950, 2006, 2013 and 2016 were compared in ArcGIS and Google Earth historic imagery to show movement of the gravel bars (Figure 17). The gravel point in the middle of the bifurcation of the Koau and Matau branches was ~80 m further north in 2006 than in 2016. The mid-channel gravel islands that cross sections C3 and C2 cross have migrated south over this time period. The comparison photos in Figure 17 indicate the highest areas of the islands have moved about 20-40 m downstream over the last 3 years. See Figure 3 for comparison with historic (1950) imagery of the area.

Figure 16. **Left: Aerial view of Koau branch immediately south of Balclutha, looking upstream. Right: Eroding bank highlighted in left image, 21 October 2016. This is also the approximate location of cross section K12.**

Figure 17. **Google Earth images showing changes in gravel bars visible during summer low-flow. Cross section locations shown.**

Cross section C1 backs up the aerial imagery by showing major redistribution of gravel in the region of the mid channel/bifurcation point (Figure 18). C2 shows the growth of the gravel bar seen in the aerial photographs, as the high-point at its centre migrates downstream. NB the MBL of this section has remained relatively constant, as the channel to the left of this bar has incised (see Figure 19). Cross section K12 shows erosion of the true right bank by about 30 m between 2002 and 2014 and a further ~10 m by 2016 as shown by a partial cross section collected by a gravel extraction consent holder (Figure 19). The 2005 cross section does not extend far enough up the bank to further constrain timing. Section K13 also shows erosion and steepening of the true right bank.

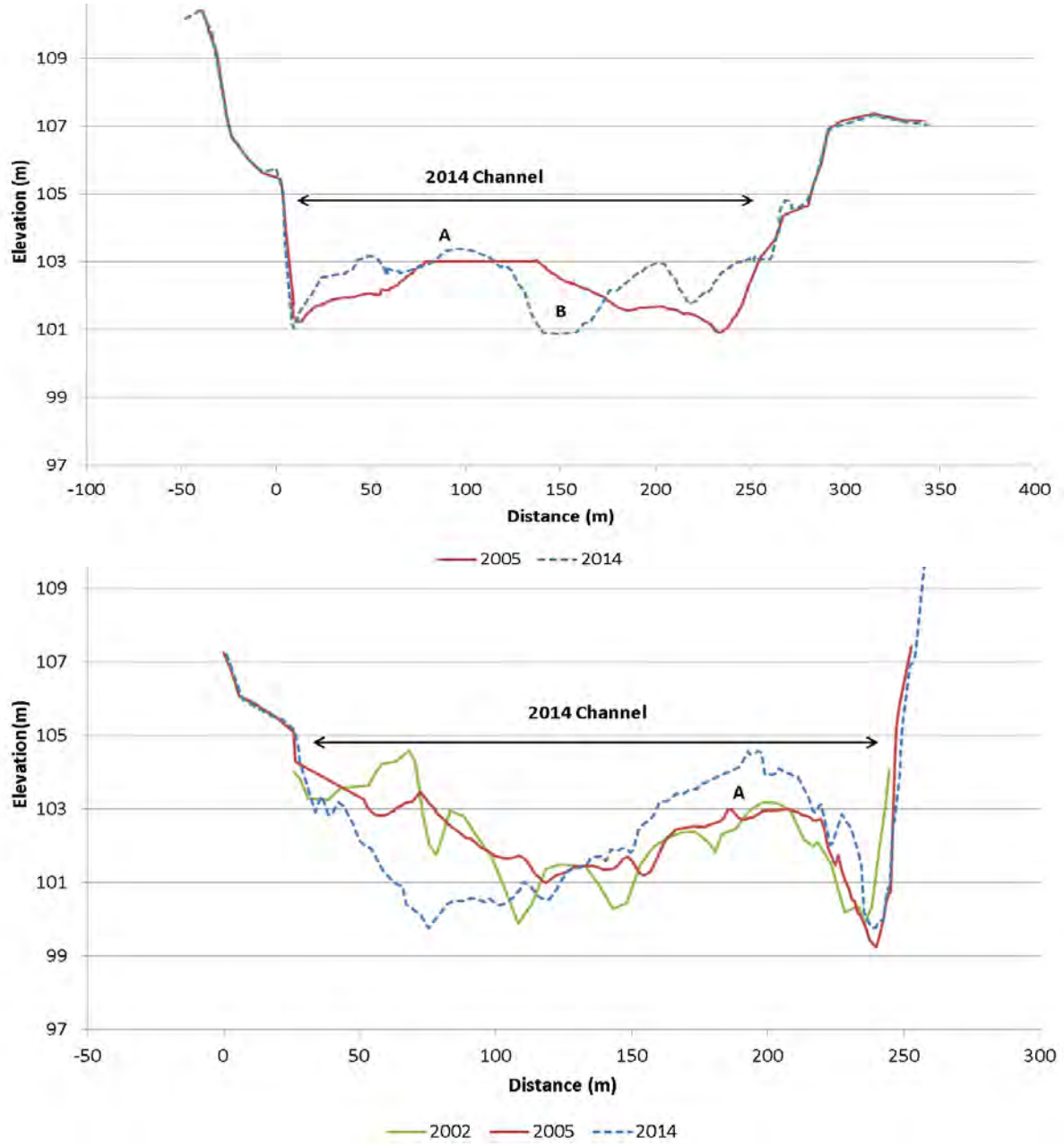
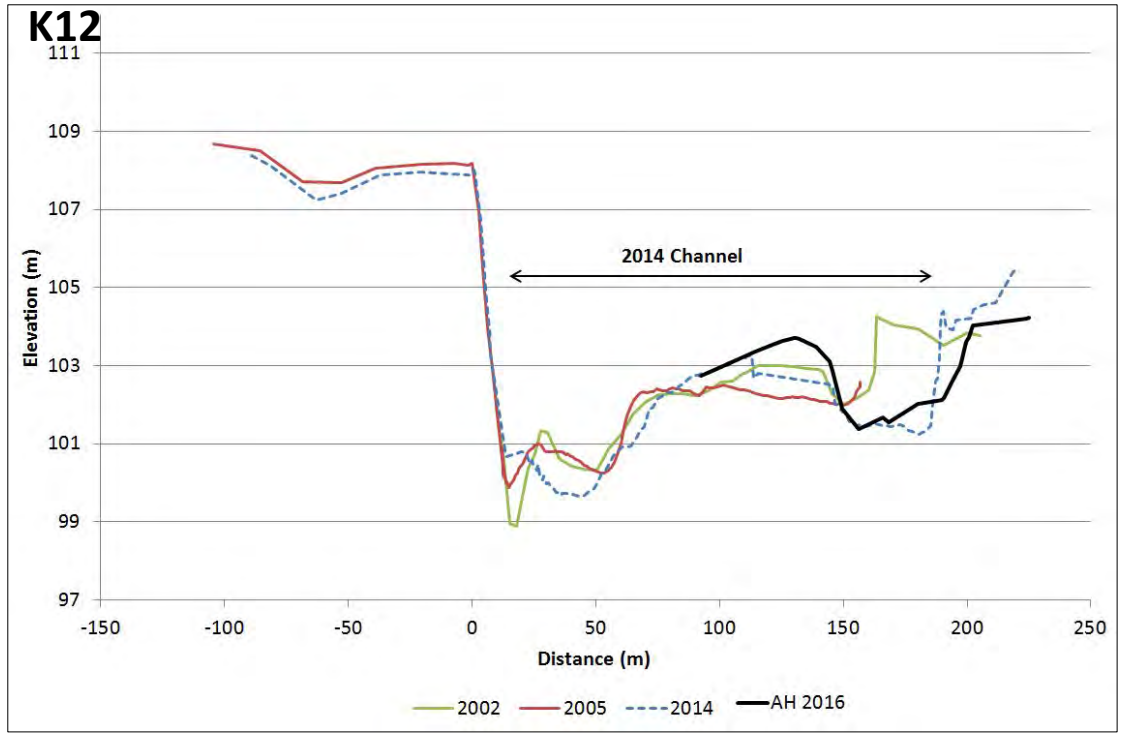


Figure 18. Changes in channel profile of cross sections C1 and C2.



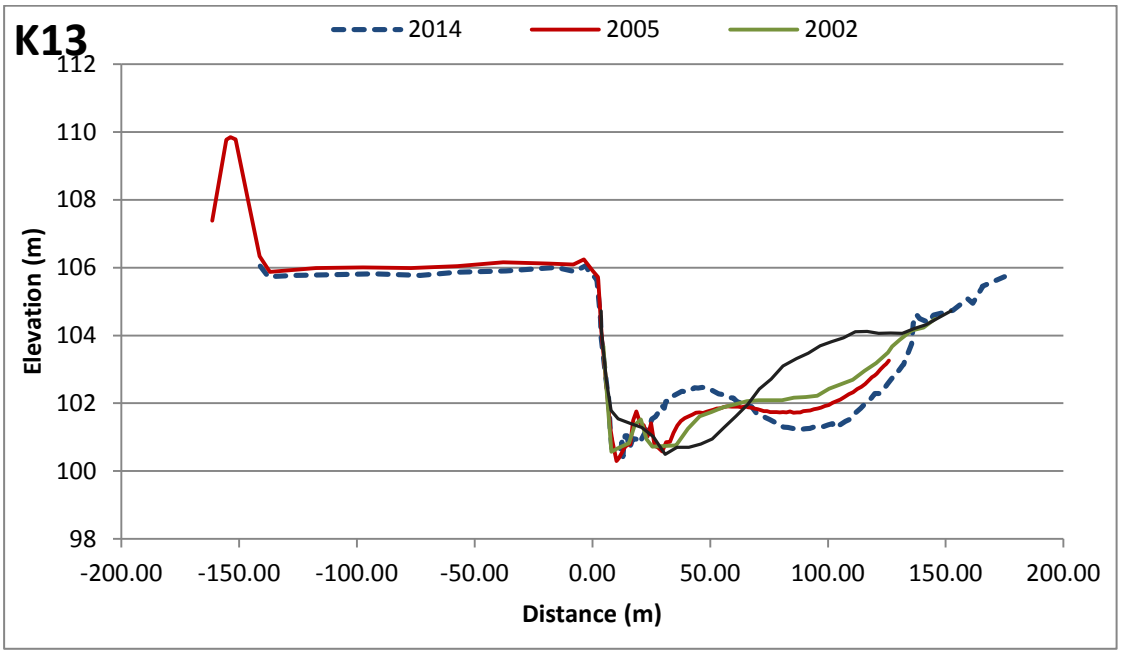


Figure 19. **Changes in channel profile of cross sections K12 and K13 (looking downstream), including 2016 data collected by gravel extraction consent holder that partially covers cross section K12.**

The partial cross-section K12 (Figure 19) collected in 2016 by the gravel extraction consent holder indicates there has been a build-up of the mid-channel bar and erosion of the bank, but whether the erosion can be attributed more to overall gravel stripping or gravel build-up and displacement of the channel is not clear without a complete cross section and data from up- and down-stream of the site. A full re-survey of this and surrounding cross sections is recommended before any further gravel extraction is consented in the area, given the fact

that is still unclear whether extraction has helped stop bank erosion or exacerbated it in recent years, and the overall trend of recent bed degradation in the Koau branch.

In summary, erosion has clearly occurred along the true right bank of the Koau branch, just to the south of Balclutha. The Matau branch appears relatively stable (from cross section data) despite localised bank slumping investigated during the August site visit. The point at the bifurcation of the Clutha/Mata-Au has eroded back by ~80 m in 10 years and two large mid-channel gravel bars that sit beneath the railway bridge have also migrated a few tens of metres in the past few years. The lower gravel bar and any association with erosion or changes in flood flows in the upper Koau branch should be monitored.

3.7. Gravel extraction

Gravel extraction has historically taken place in the Clutha River/Mata-Au between Roxburgh Dam and the river mouths (Figures 20, 21, and 22) with extraction currently occurring on the Koau Branch of the Clutha River/Mata-Au at Balclutha and downstream of the Clydevale Bridge. Between 1996 and 2016 362,000 m^3 of gravel was removed from the Clutha River/Mata-Au between the Clyde Dam and the confluence of the Pacific Ocean (based on ORC gravel returns). The total consented volume of gravel allowed to be extracted over this period was 2,237,000 m^3. Majority of gravel extraction consents issued for the Clutha River/Mata-Au between Roxburgh Dam and the confluence of the Pacific Ocean are located below Beaumont with only 11 of 120 being located above Beaumont (Figures 21 and 22).

Figure 20. **Gravel extraction on the Koau Branch of the Clutha River/Mata-Au, looking upstream to the bifurcation, photographs taken 1994.**

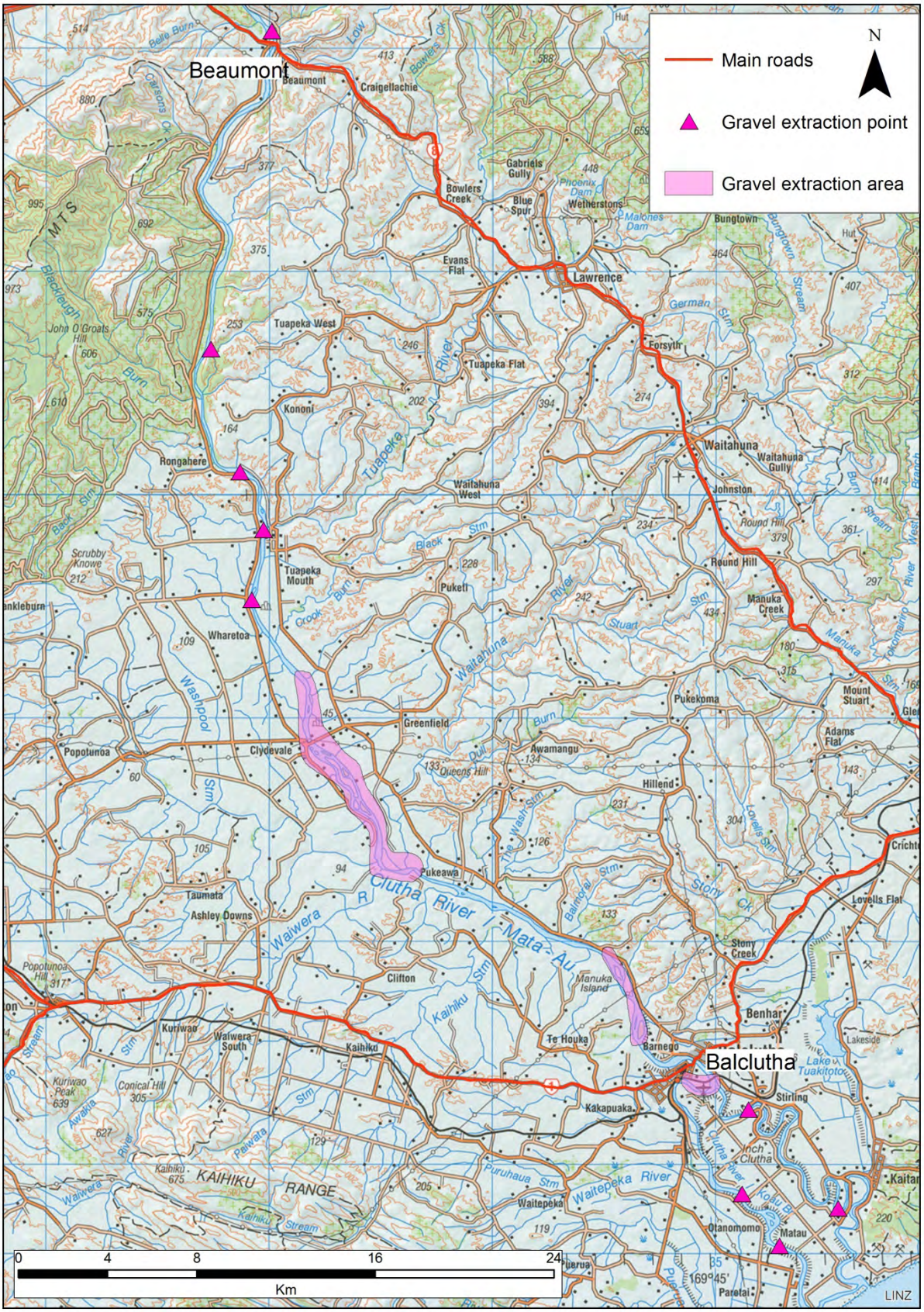


Figure 21. **Historic and current gravel extraction locations on the Clutha River/Mata-Au between the river mouth and Beaumont.**

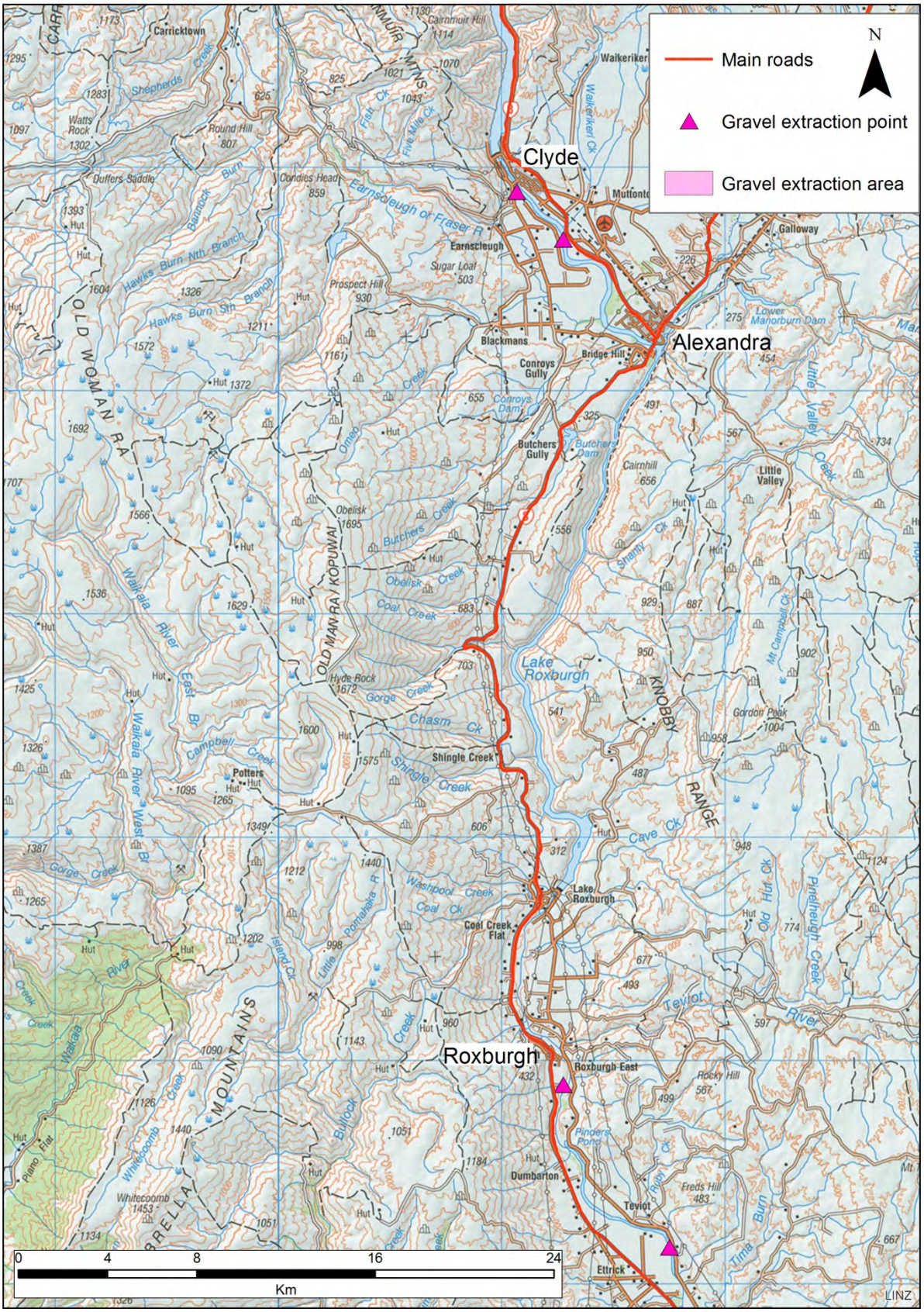


Figure 22. **Historic and current gravel extraction locations on the Clutha River/Mata-Au between Ettrick and Clyde.**

4. Conclusion

The results of this report show that the Clutha River/Mata-Au between Roxburgh Dam and the confluence with the Pacific Ocean is a dynamic system with changes constantly occurring. The survey results show that in the Matau Branch the river has both aggraded and degraded with the largest aggradation occurring closer to the mouth. The Koau branch showed only degradation between the latest survey periods (2005 – 2014). Around Barnego the Clutha River/Mata-Au has experienced mostly aggradation or minor degradation between the latest surveys with only 3 of 11 cross-sections showing a decrease in MBL. The surveyed cross-sections between Barnego and Roxburgh Dam showed both aggradation and degradation 25 cross-sections showing an increase in MBL and 10 cross-sections showing a decrease in MBL. The largest change in MBL occurred at Cross-section B13 near Beaumont which experienced a change in MBL of about 0.9 m and cross-section C31 which experienced a change in MBL of about 1 m. Minor bank erosion was observed at several cross-sections with larger erosion seen at cross-sections C17 and C20.

Appendix A: Clutha River/Mata-Au survey dates

Table 1. Surveyed cross-sections for the Clutha River/Mata-Au, a blank space indicates that a survey was not completed in that year

XSID	2016	2014	2007	2005	2003	2002	2001	2000	1997	1996 JUL	1996	1995	1994	1993	1983	1982	1961	1960	1958	1948	1947	1940
K2014		X																				
K91		X																				
K84																						
K67		X		X				X										X			X	
K64				X				X										X			X	
K54		X		X				X									X				X	
K48				X				X													X	
K9		X		X		X		X	X		X	X										
K10				X		X			X		X	X	X									
K10A		X		X							X	X		X								
K11		X		X		X			X		X	X	X									
K12		X		X		X			X		X	X	X									
K13		X		X		X	X		X		X		X									
M223		X		X				X													X	
M202		X		X				X													X	
M195		X		X				X													X	
M171								X												X		

XSID	2016	2014	2007	2005	2003	2002	2001	2000	1997	1996 JUL	1996	1995	1994	1993	1983	1982	1961	1960	1958	1948	1947	1940
M154		X		X				X													X	
M147		X		X				X													X	
M140		X		X				X													X	
M128		X		X				X													X	
M99		X		X				X													X	
M94		X		X				X													X	
M5		X		X		X		X	X		X	X									X	
M6		X		X		X			X		X	X									X	
M7		X		X		X			X		X	X									X	
M8		X		X		X			X		X	X							X		X	
M9		X		X		X			X		X	X							X		X	
M10		X		X		X			X		X	X	X									
M11		X		X		X			X		X	X	X									
M12		X		X		X	X		X		X	X	X									
C1		X		X		X	X		X	X	X	X	X									
C2		X		X		X	X		X	X		X	X									
C3		X		X		X			X	X		X	X									
C4						X			X	X		X	X									
C5		X		X		X			X	X		X	X									

XSID	2016	2014	2007	2005	2003	2002	2001	2000	1997	1996 JUL	1996	1995	1994	1993	1983	1982	1961	1960	1958	1948	1947	1940
C6		X		X		X			X	X		X	X									
C7		X		X		X			X	X		X	X									
C7A									X	X		X	X									
C8		X		X		X			X	X		X	X									
C9		X		X		X			X	X		X	X									
C10		X		X		X			X	X		X	X									
C11		X		X		X			X	X		X	X									
C12		X		X		X			X	X		X	X									
C13		X		X		X			X	X		X	X									
C14	X		X			X			X	X		X	X									
C15	X		X			X			X	X		X	X									
C16	X		X			X			X	X		X	X									
C17	X		X			X			X	X		X	X									
C18	X		X			X			X	X		X	X									
C19	X		X			X			X	X		X	X									
C20	X		X			X			X		X		X									
C21	X		X			X			X		X		X									
C22	X		X			X			X	X		X	X							X		
C23	X		X			X			X		X		X									

XSID	2016	2014	2007	2005	2003	2002	2001	2000	1997	1996 JUL	1996	1995	1994	1993	1983	1982	1961	1960	1958	1948	1947	1940
C24	X		X			X			X		X		X									
C25	X		X												X							
C26	X		X													X						
C27	X		X																			
C28	X		X													X				X		
B10	X		X		X						X											
B11	X		X		X						X											
B12	X		X		X						X											
B13	X		X		X						X											
C29	X		X													X						
C30	X		X													X						
C31	X		X													X						
C32	X		X													X						
C33	X		X													X				X		X
C34	X		X													X						
C35	X		X													X						
C36	X		X													X						
C37	X		X																			
C38	X		X													X						

XSID	2016	2014	2007	2005	2003	2002	2001	2000	1997	1996 JUL	1996	1995	1994	1993	1983	1982	1961	1960	1958	1948	1947	1940
C39	X		X																			
C40	X		X													X						
C41	X		X																	X		
C42	X		X													X						
C43	X		X													X						
C43A																X				X		
C44	X		X													X				X		
C45	X		X													X						

Appendix B: Clutha River/Mata-Au cross-sections historic change[5]

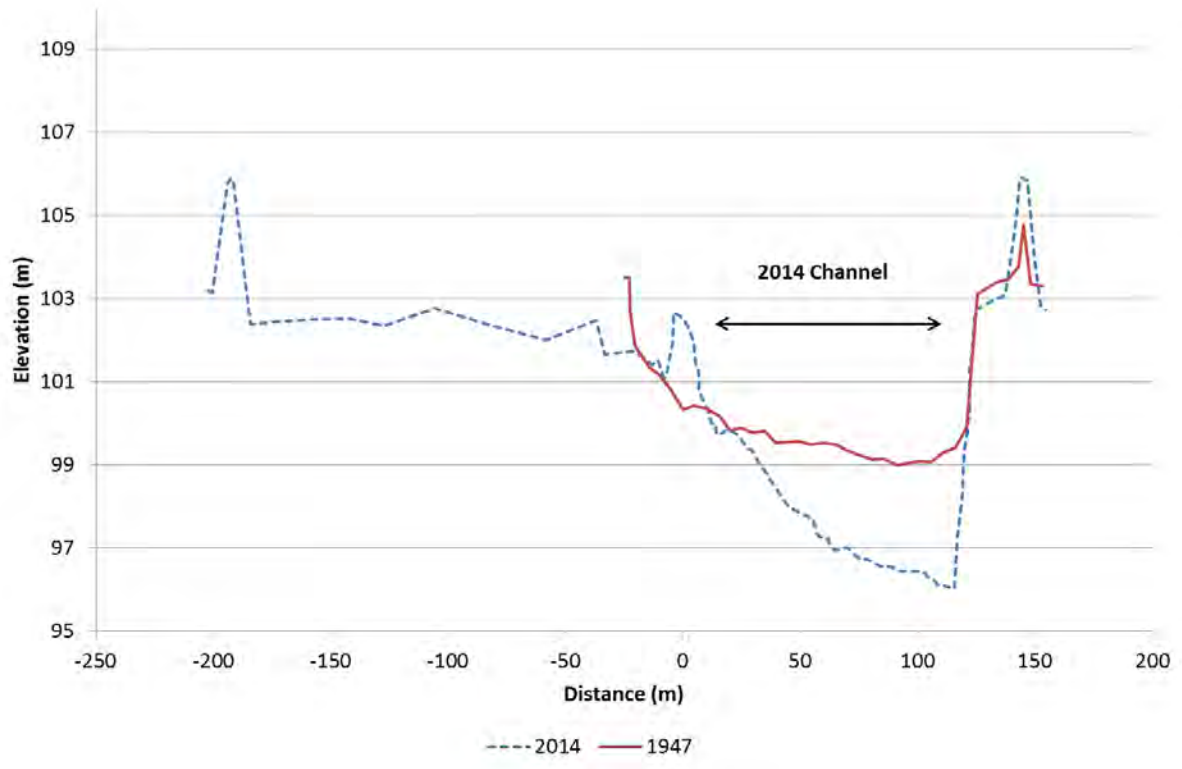


Figure 23. **Clutha River/Mata-Au cross-sections K67, looking downstream**

[5] Not every cross-section is shown here as the horizontal and vertical alignment on some cross-sections does not appear consistent with the latest survey.

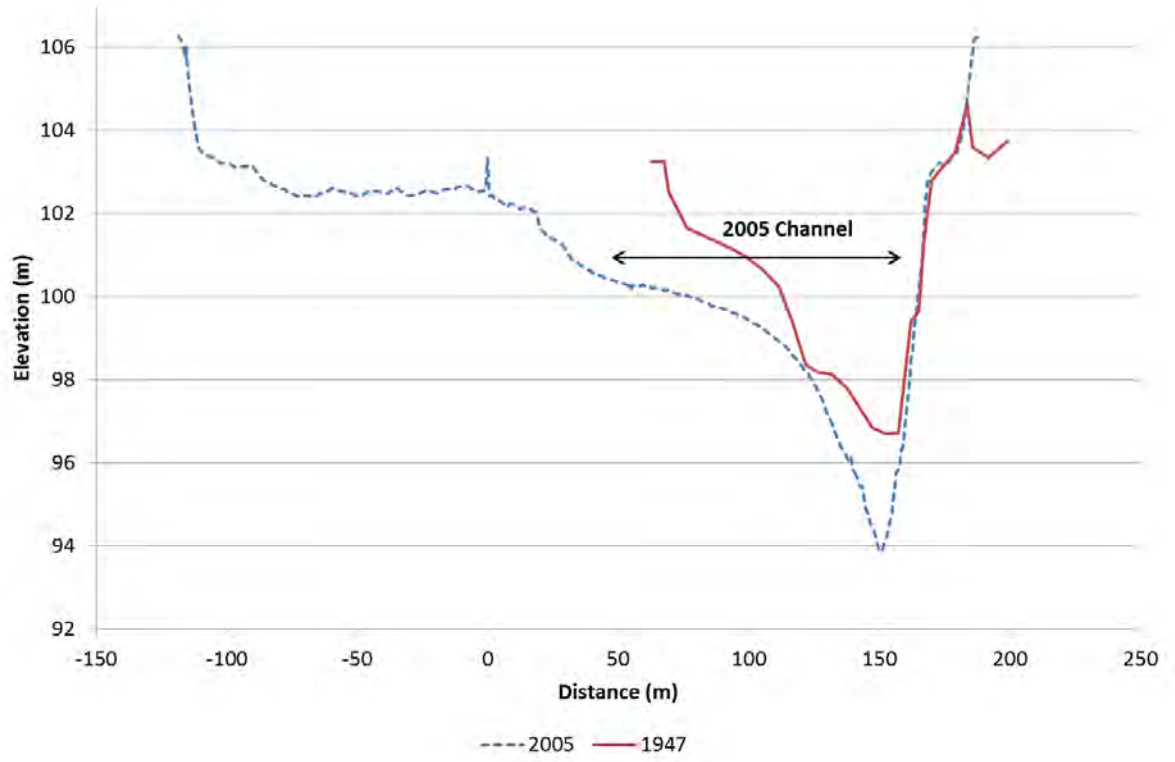


Figure 24. Clutha River/Mata-Au cross-section K64, looking downstream

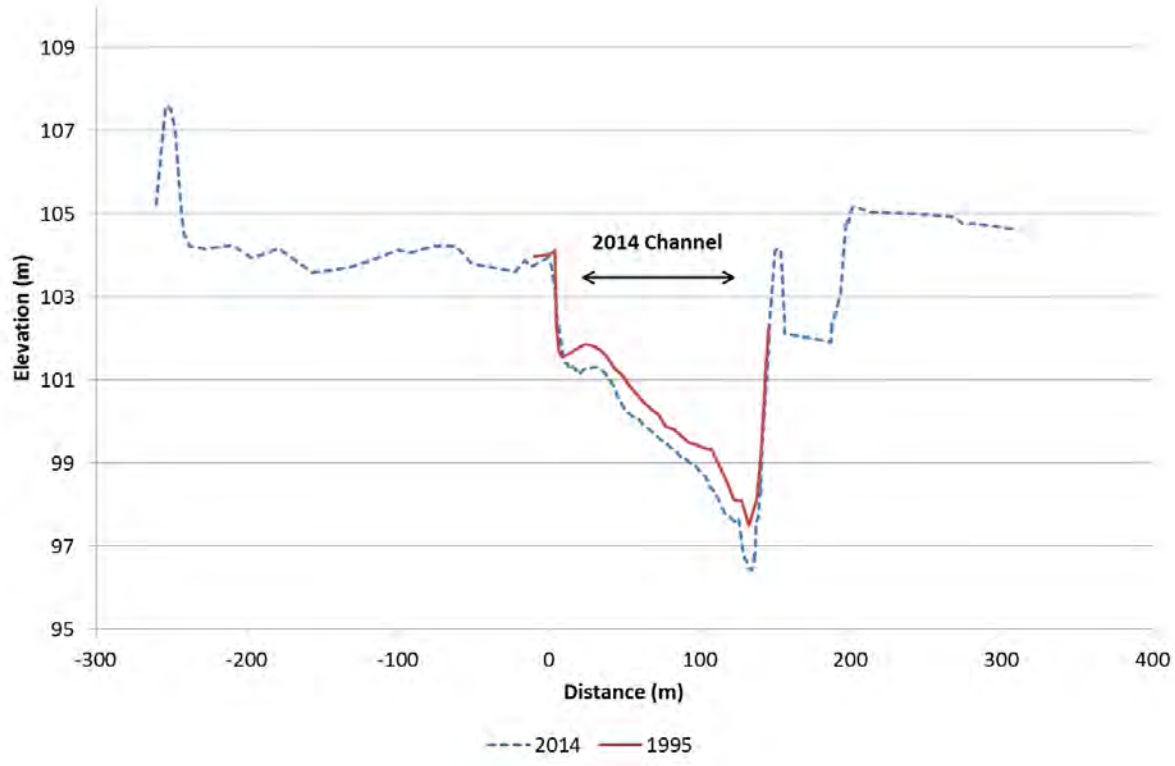


Figure 25. Clutha River/Mata-Au cross-section K9, looking downstream

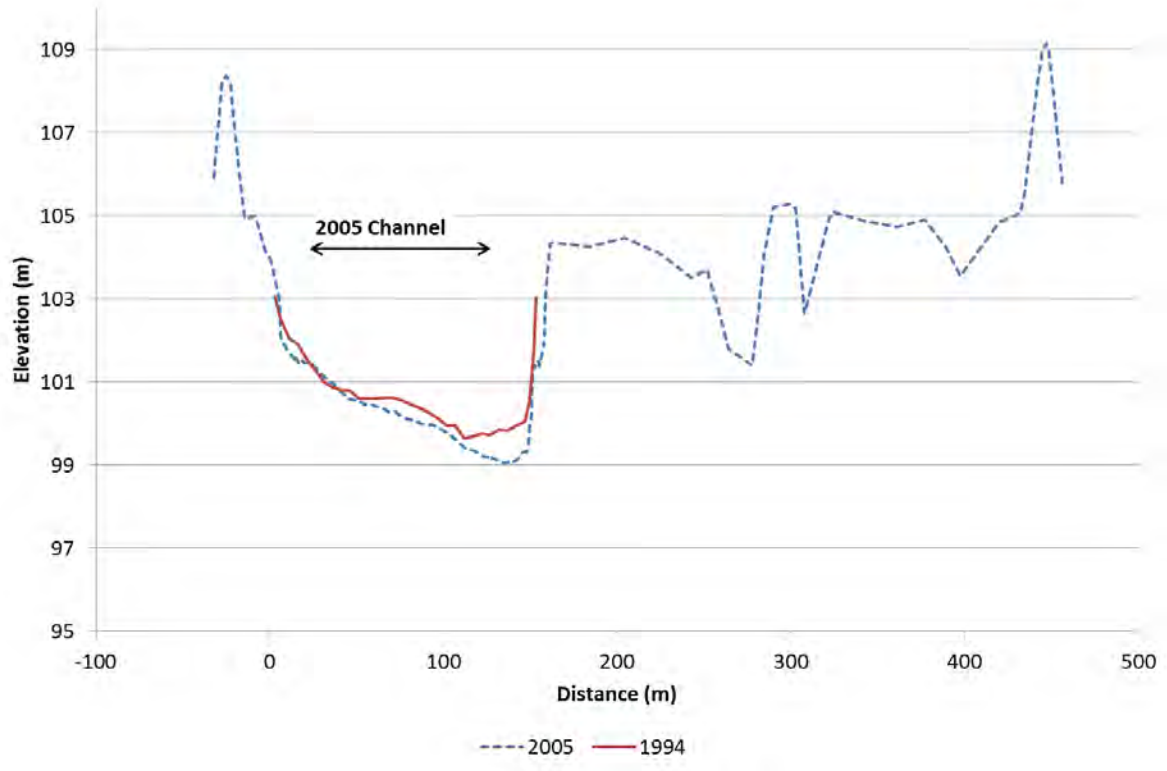


Figure 26. **Clutha River/Mata-Au cross-section K10, looking downstream**

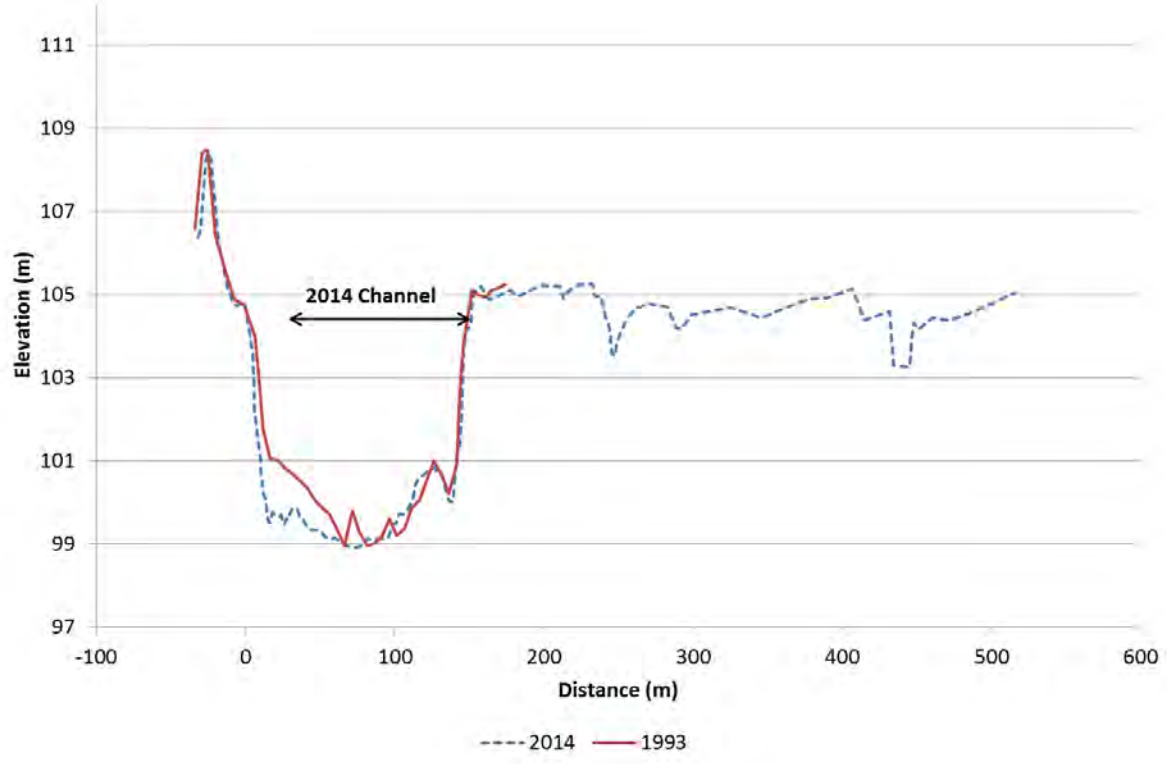


Figure 27. **Clutha River/Mata-Au cross-section K10A, looking downstream**

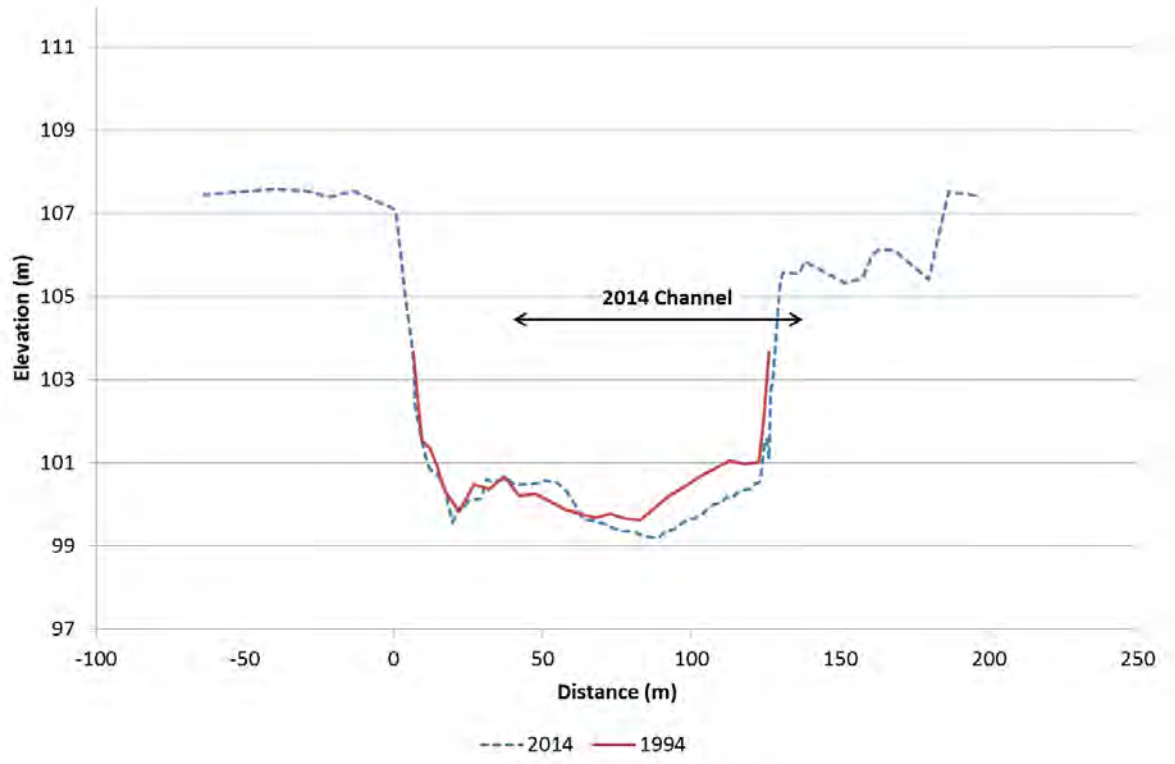


Figure 28. **Clutha River/Mata-Au cross-section K11, looking downstream**

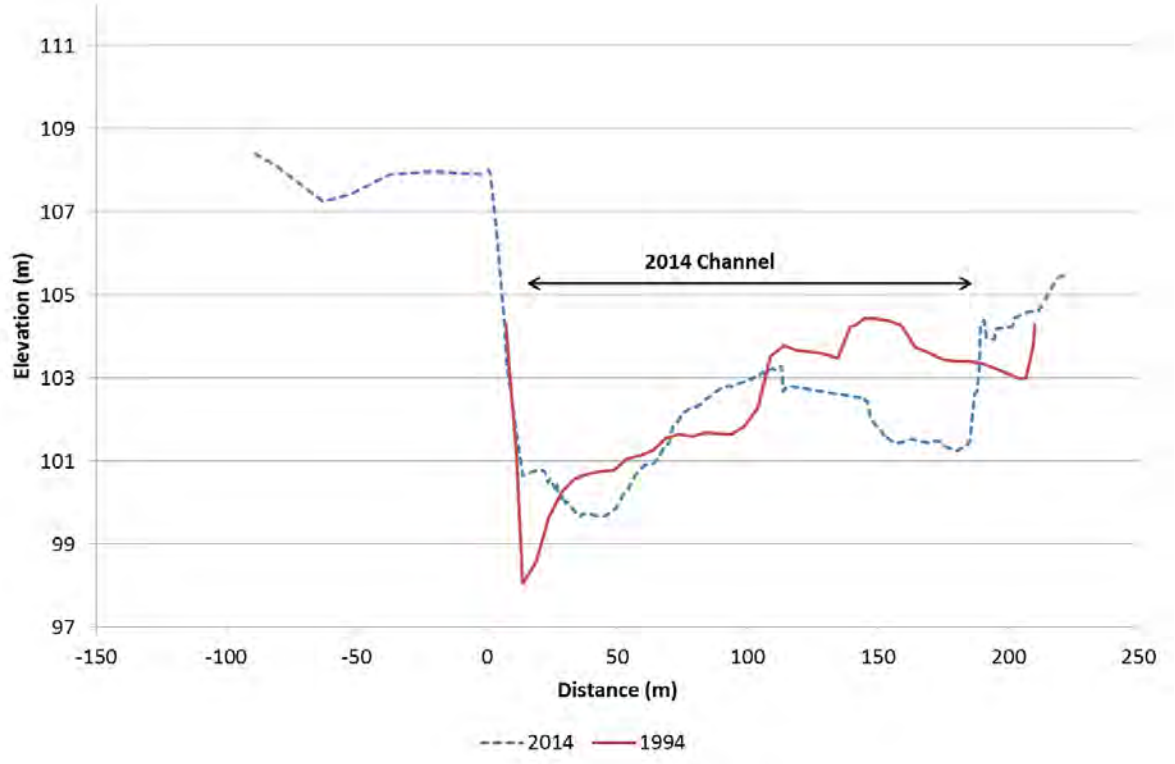


Figure 29. **Clutha River/Mata-Au cross-section K12, looking downstream**

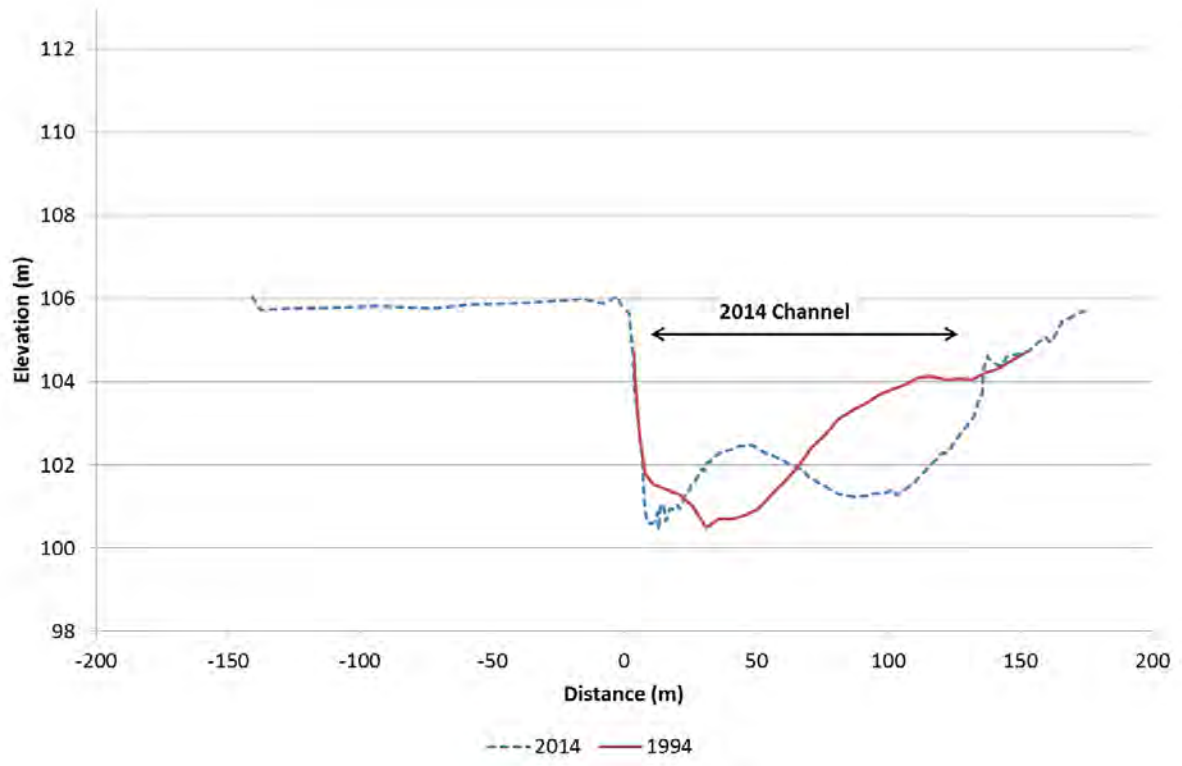


Figure 30. **Clutha River/Mata-Au cross-section K13, looking downstream**

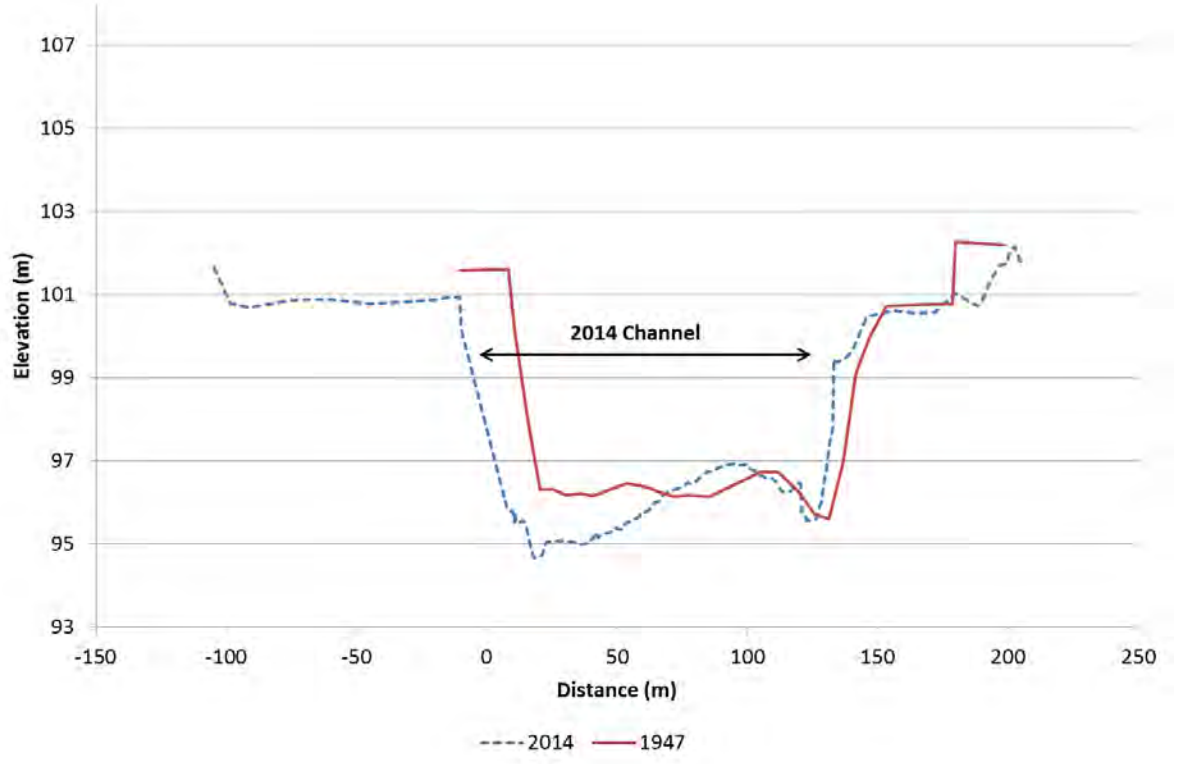


Figure 31. **Clutha River/Mata-Au cross-section M223, looking downstream**

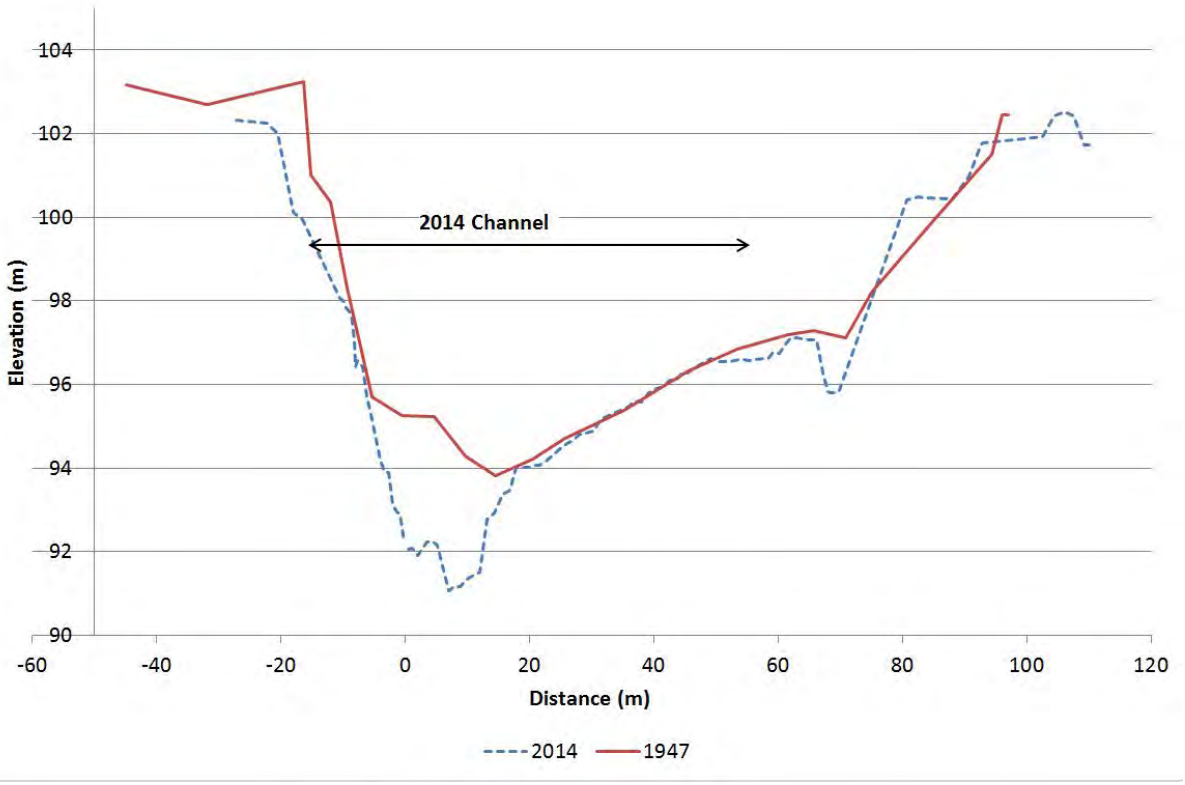


Figure 32. **Clutha River/Mata-Au cross-section M202, looking downstream.**

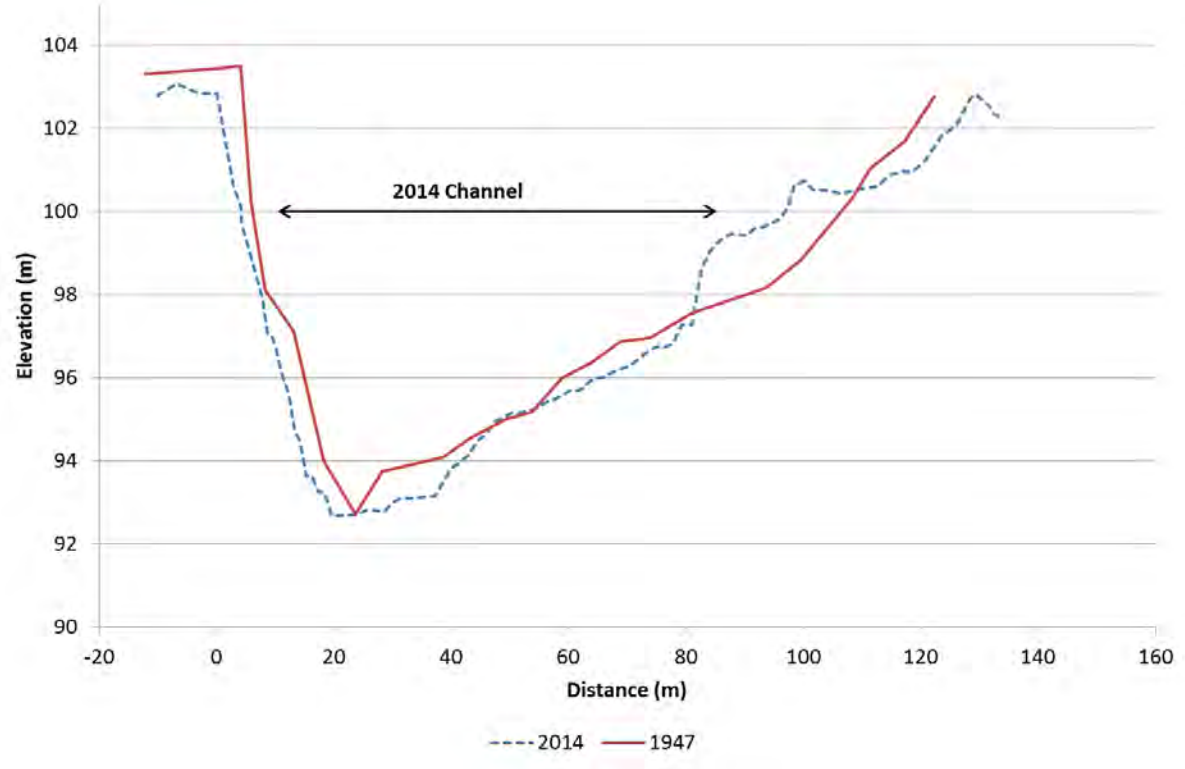


Figure 33. **Clutha River/Mata-Au cross-section M195, looking downstream**

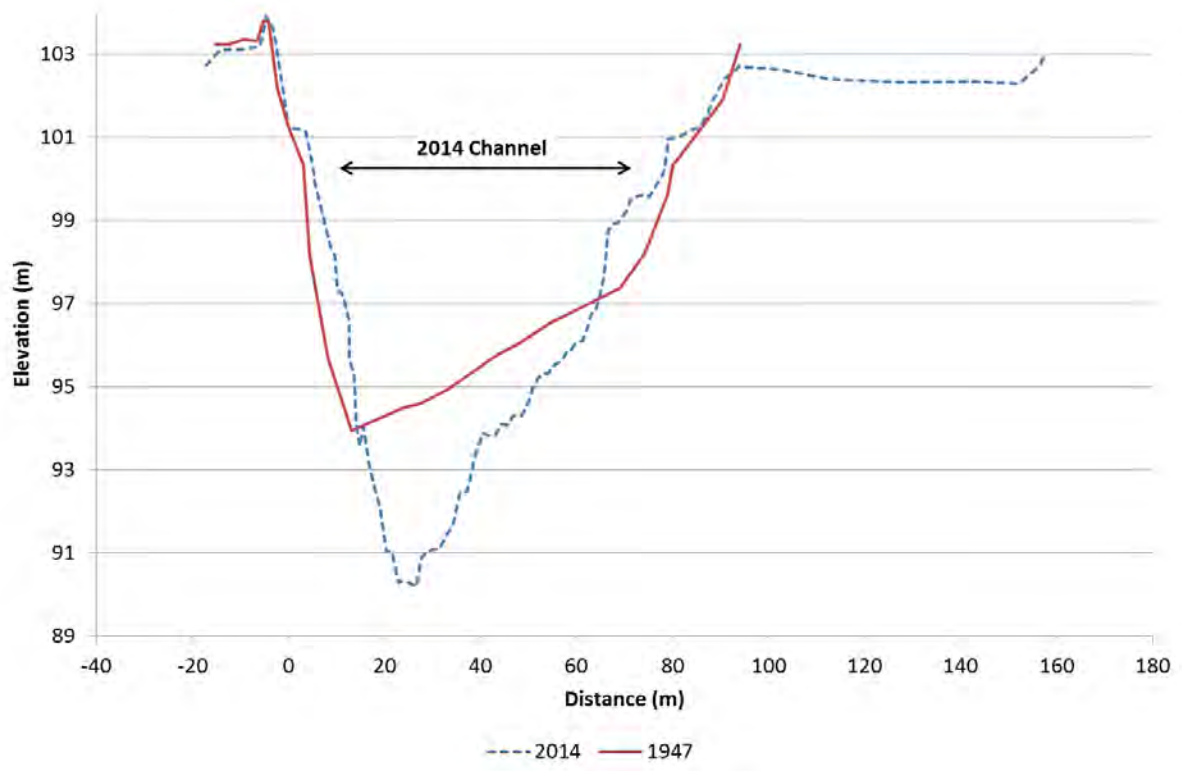


Figure 34. **Clutha River/Mata-Au cross-section M154, looking downstream**

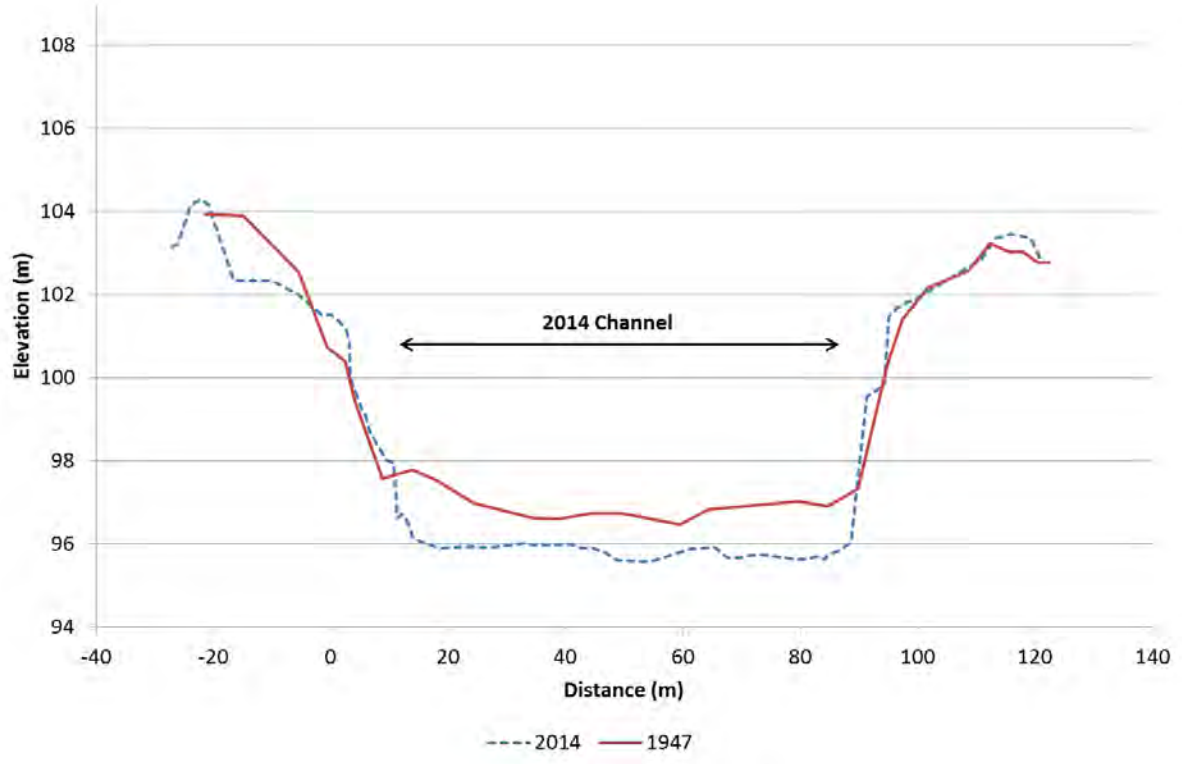


Figure 35. **Clutha River/Mata-Au cross-section M147, looking downstream**

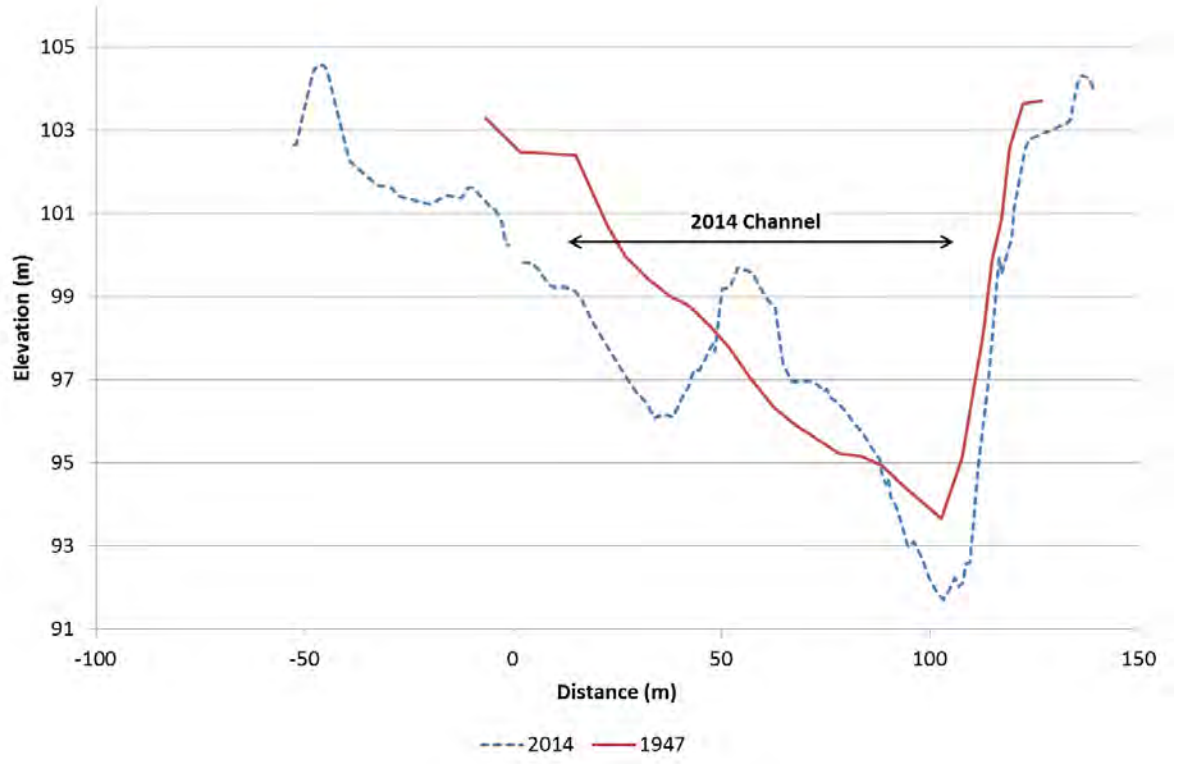


Figure 36. **Clutha River/Mata-Au cross-section M140 looking downstream**

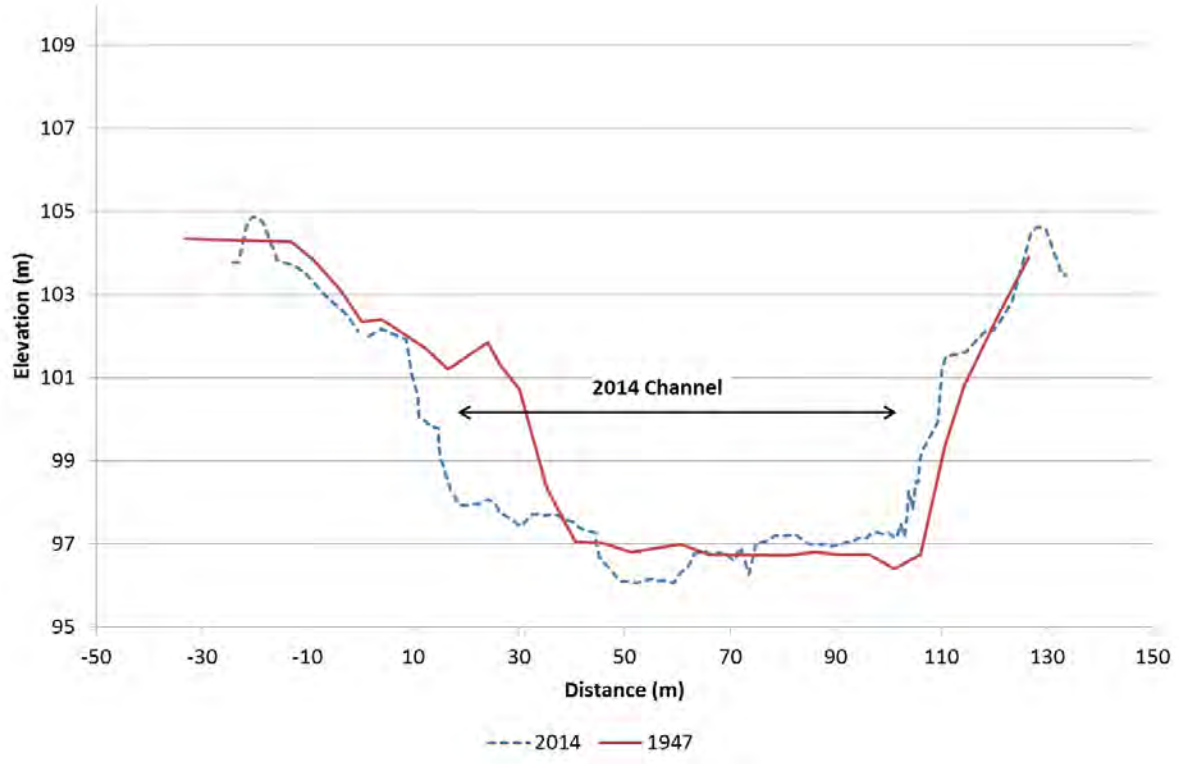


Figure 37. **Clutha River/Mata-Au cross-section M128, looking downstream**

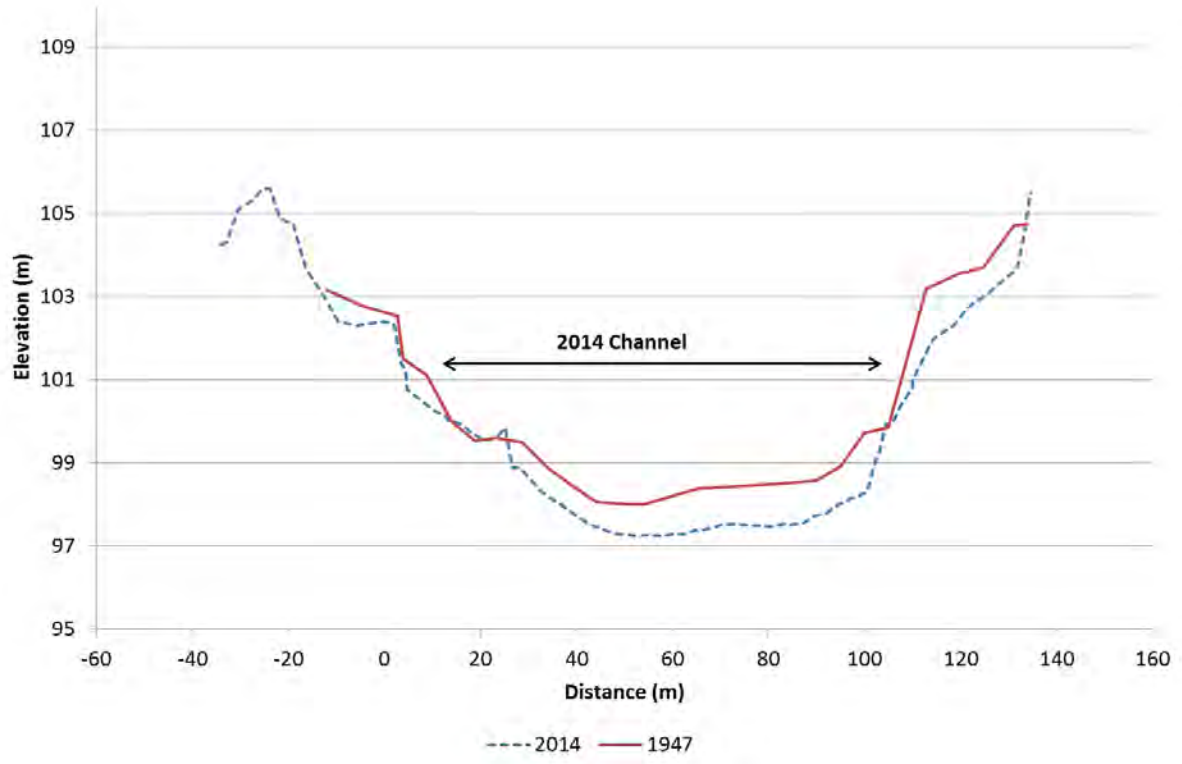


Figure 38. **Clutha River/Mata-Au cross-section M99, looking downstream**

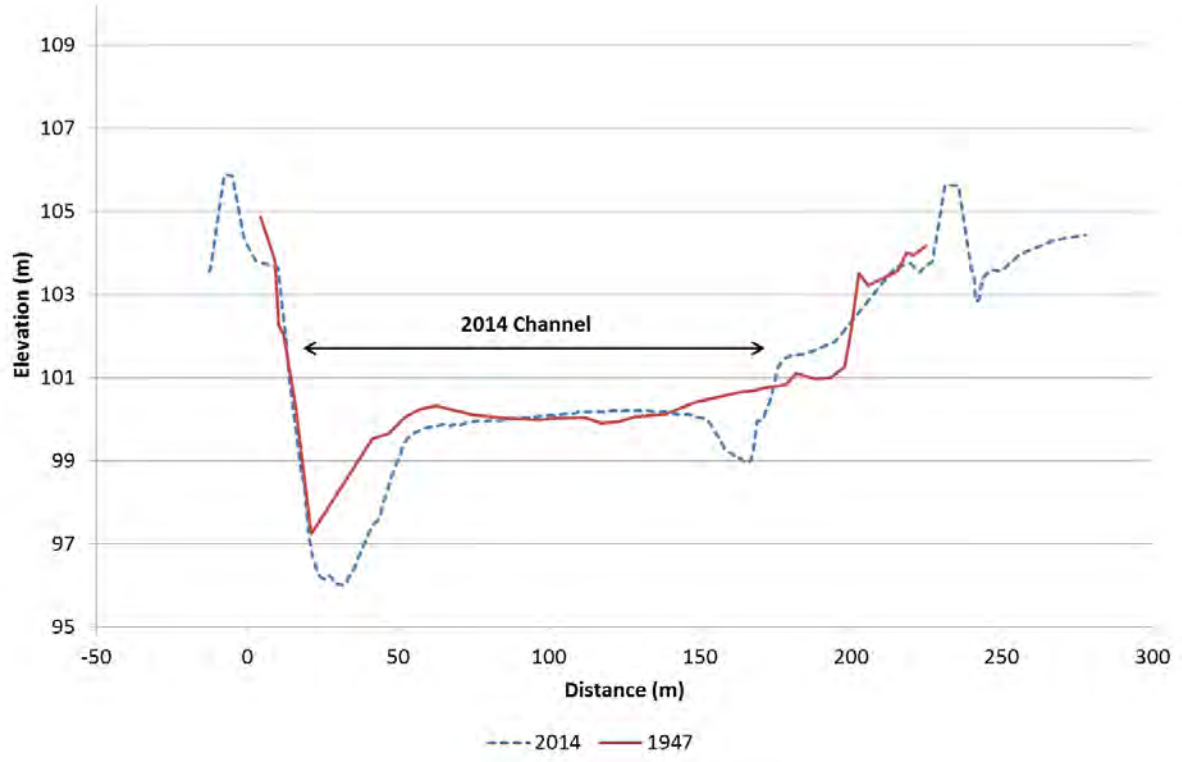


Figure 39. **Clutha River/Mata-Au cross-section M94, looking downstream**

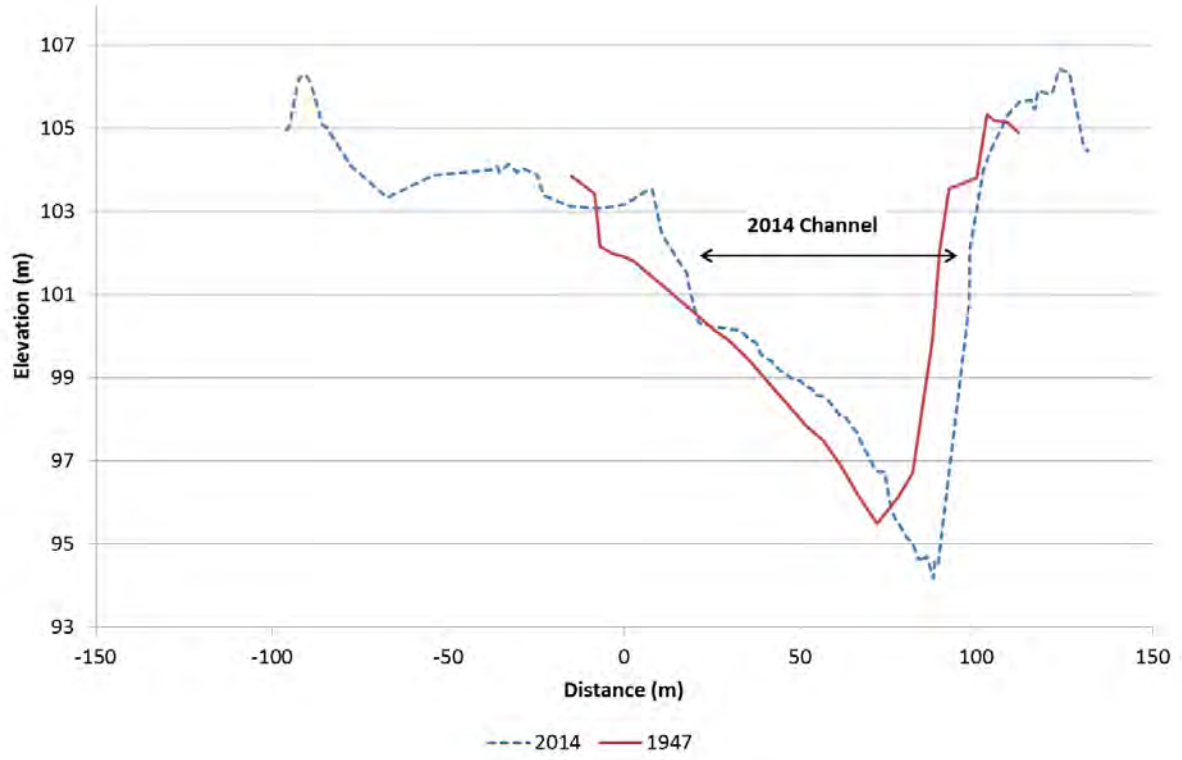


Figure 40. **Clutha River/Mata-Au cross-section M5, looking downstream**

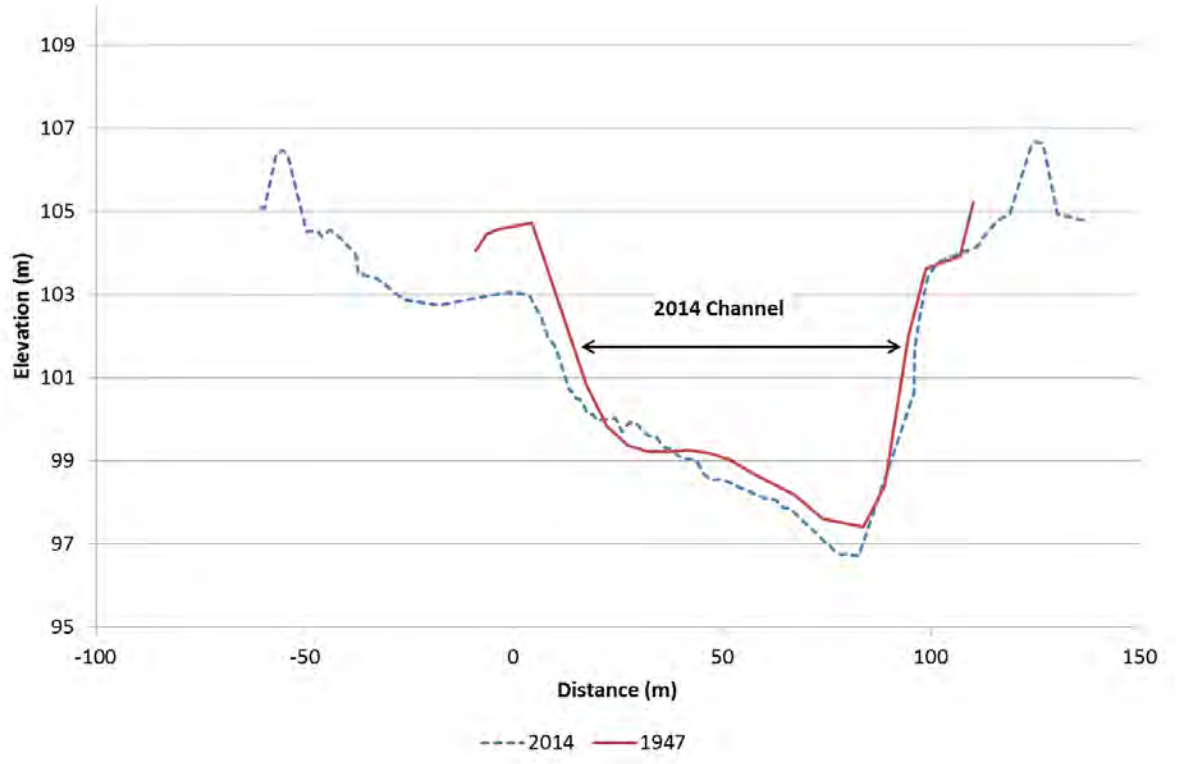


Figure 41. **Clutha River/Mata-Au cross-section M6, looking downstream**

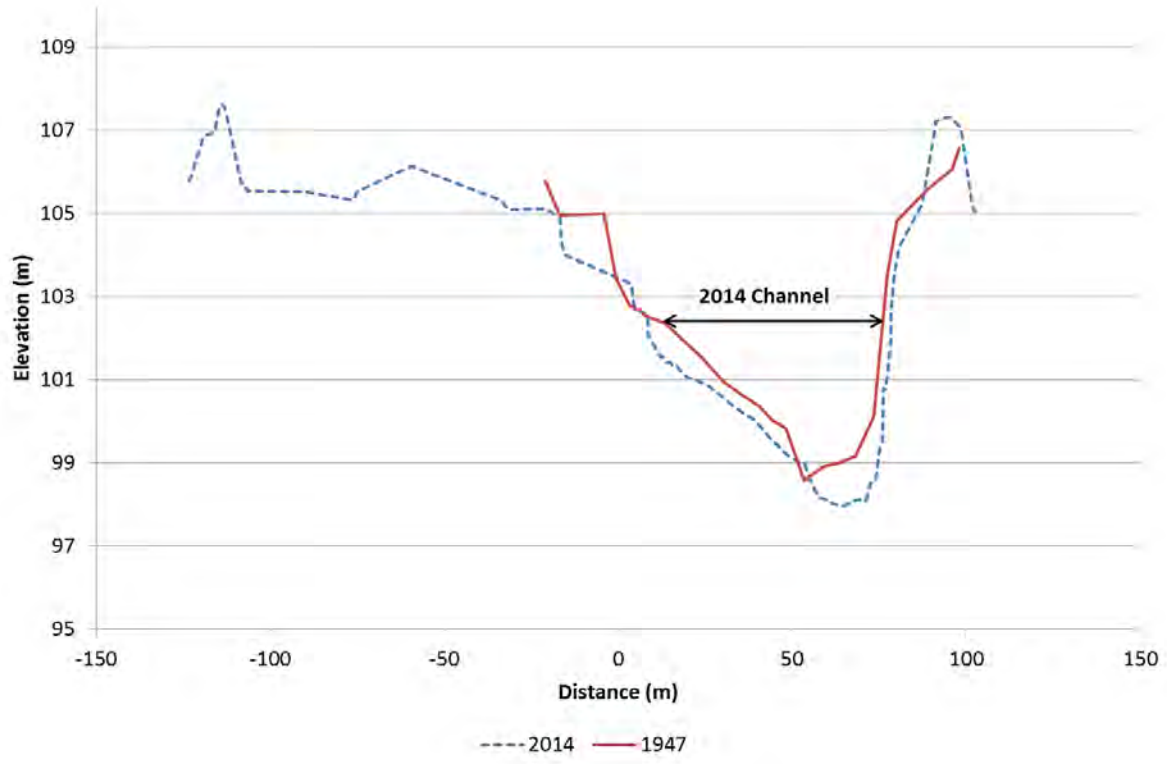


Figure 42. **Clutha River/Mata-Au cross-section M7, looking downstream**

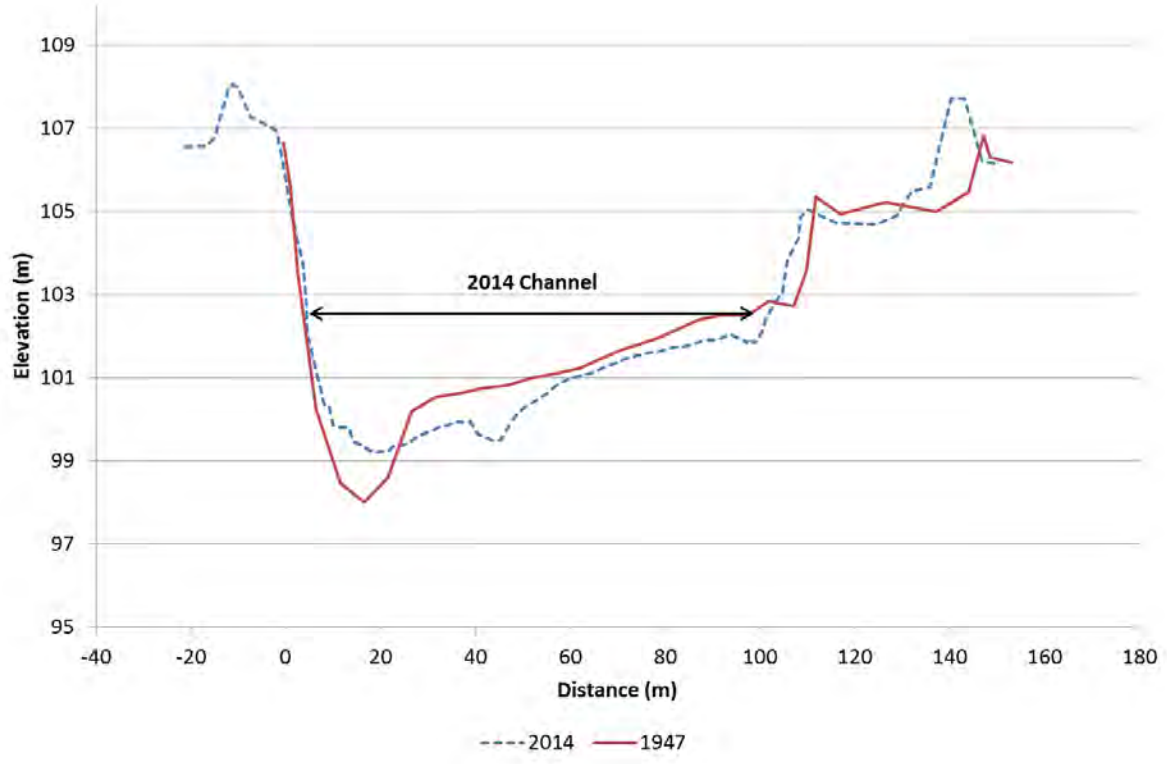


Figure 43. **Clutha River/Mata-Au cross-section M8, looking downstream**

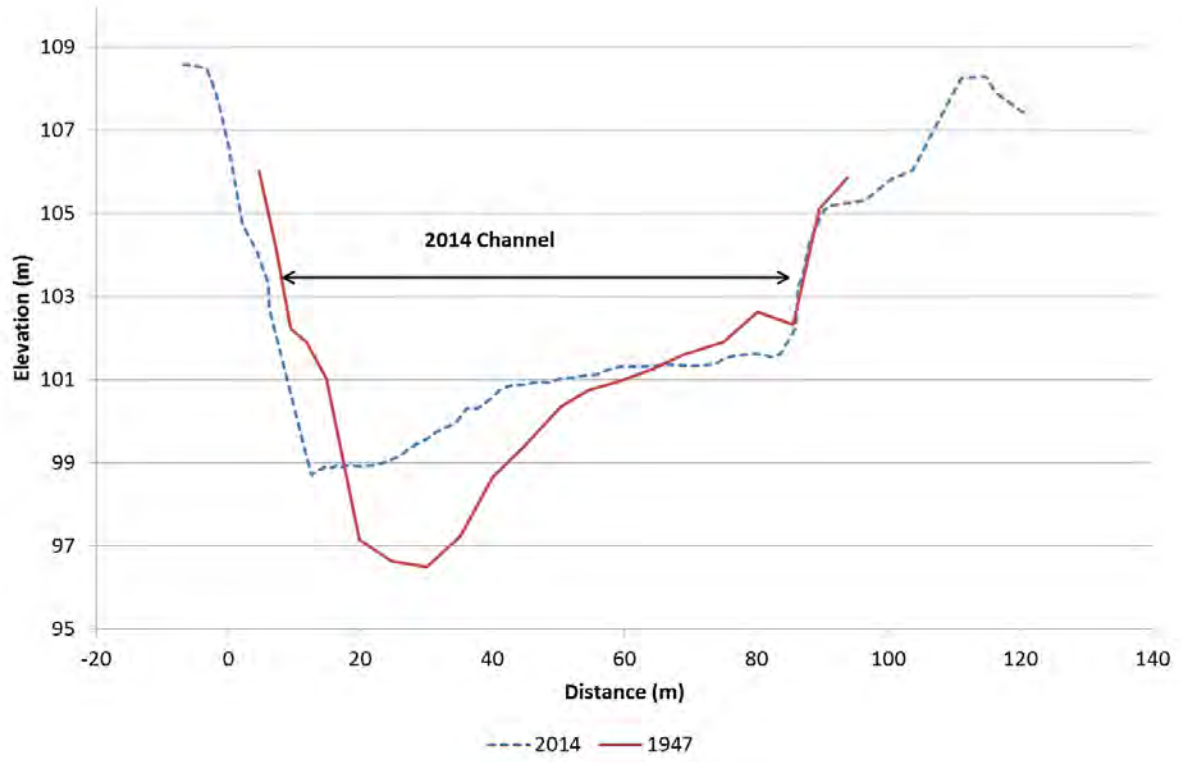


Figure 44. **Clutha River/Mata-Au cross-section M9, looking downstream**

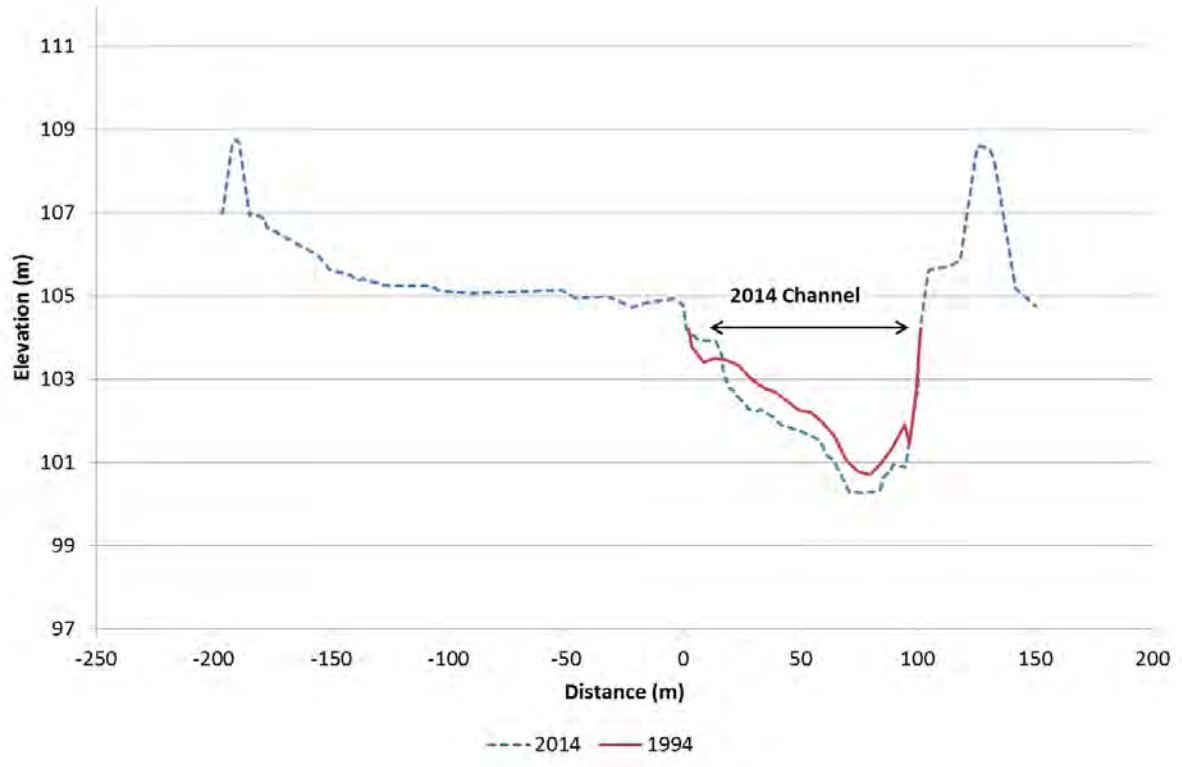


Figure 45. **Clutha River/Mata-Au cross-section M10, looking downstream**

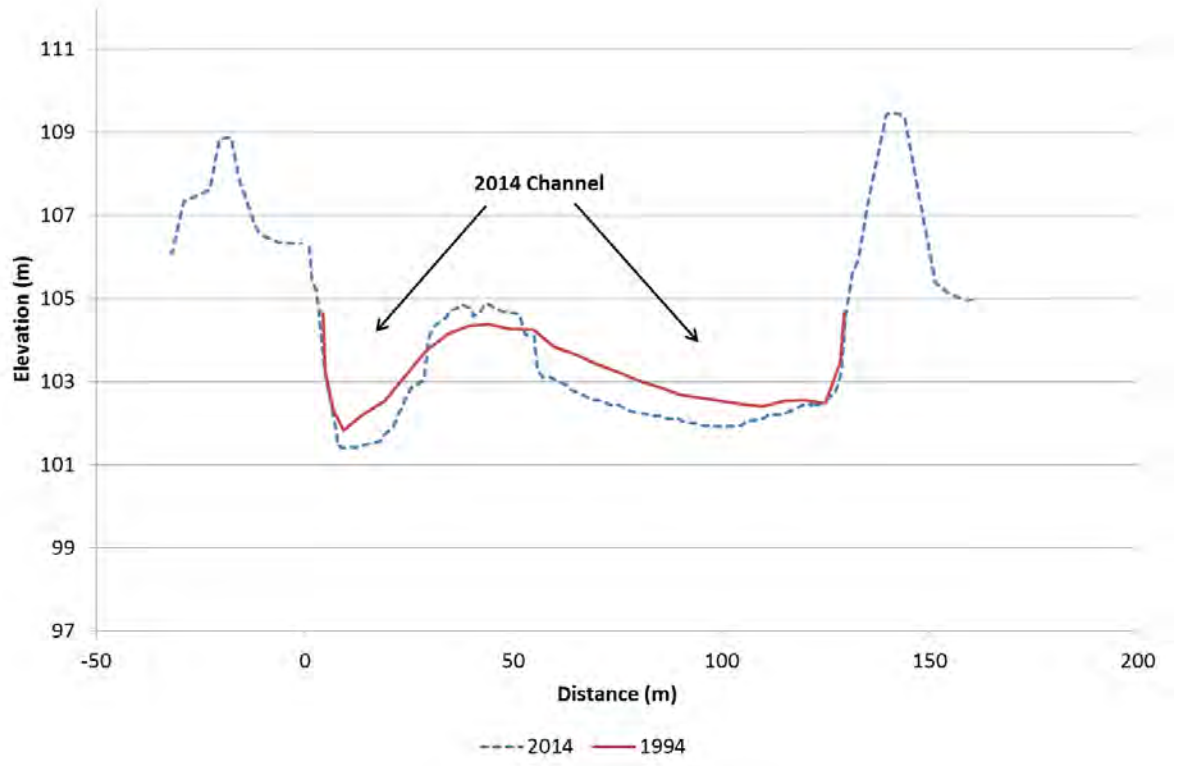


Figure 46. **Clutha River/Mata-Au cross-section M11, looking downstream**

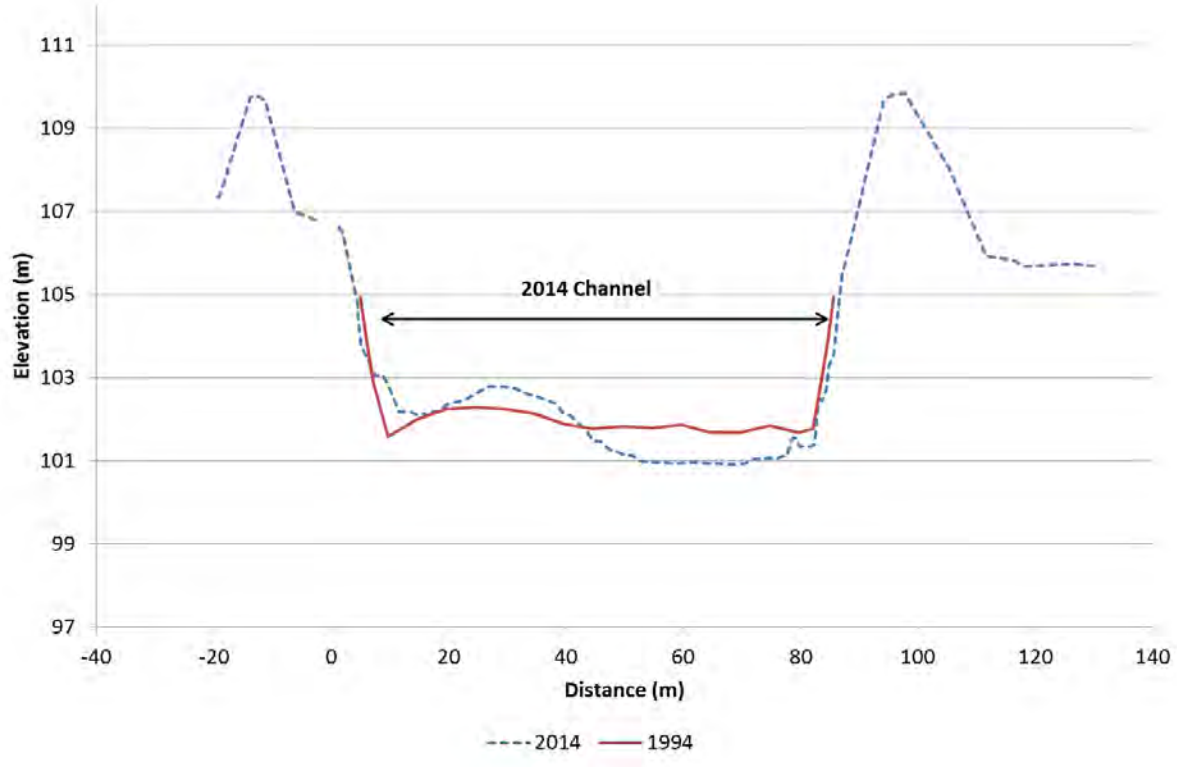


Figure 47. **Clutha River/Mata-Au cross-section M12, looking downstream**

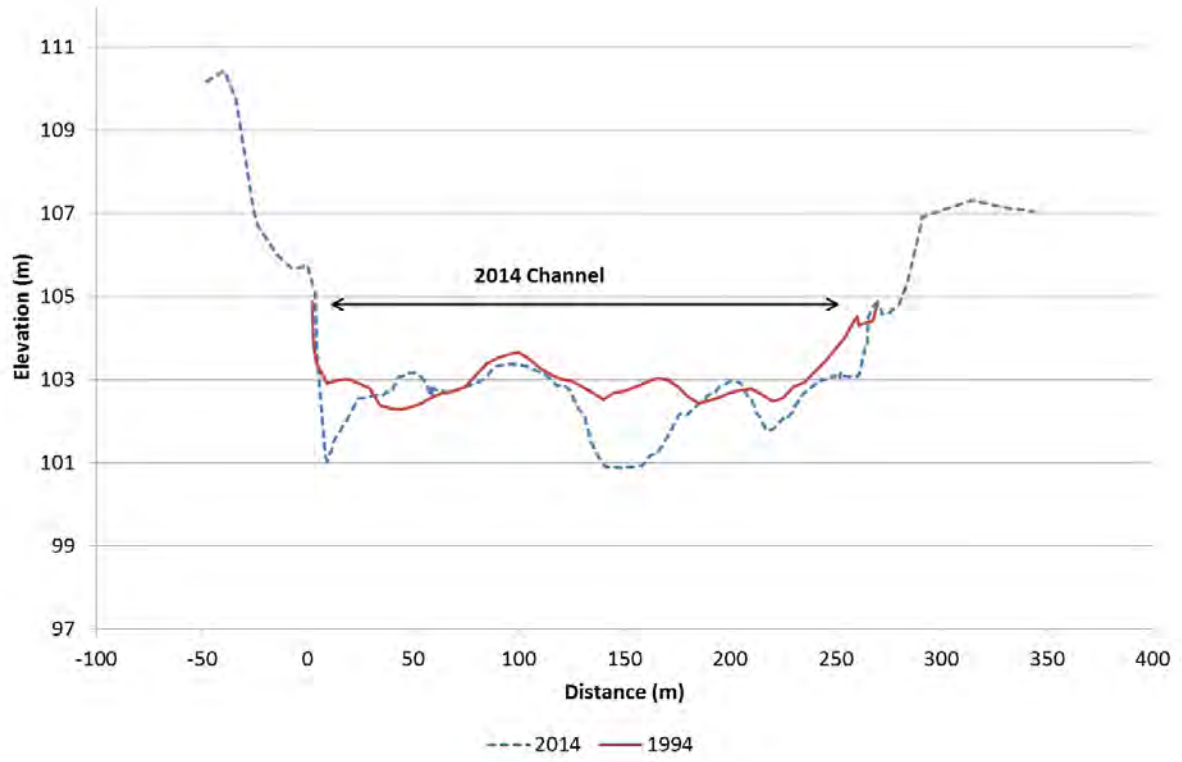


Figure 48. **Clutha River/Mata-Au cross-section C1, looking downstream**

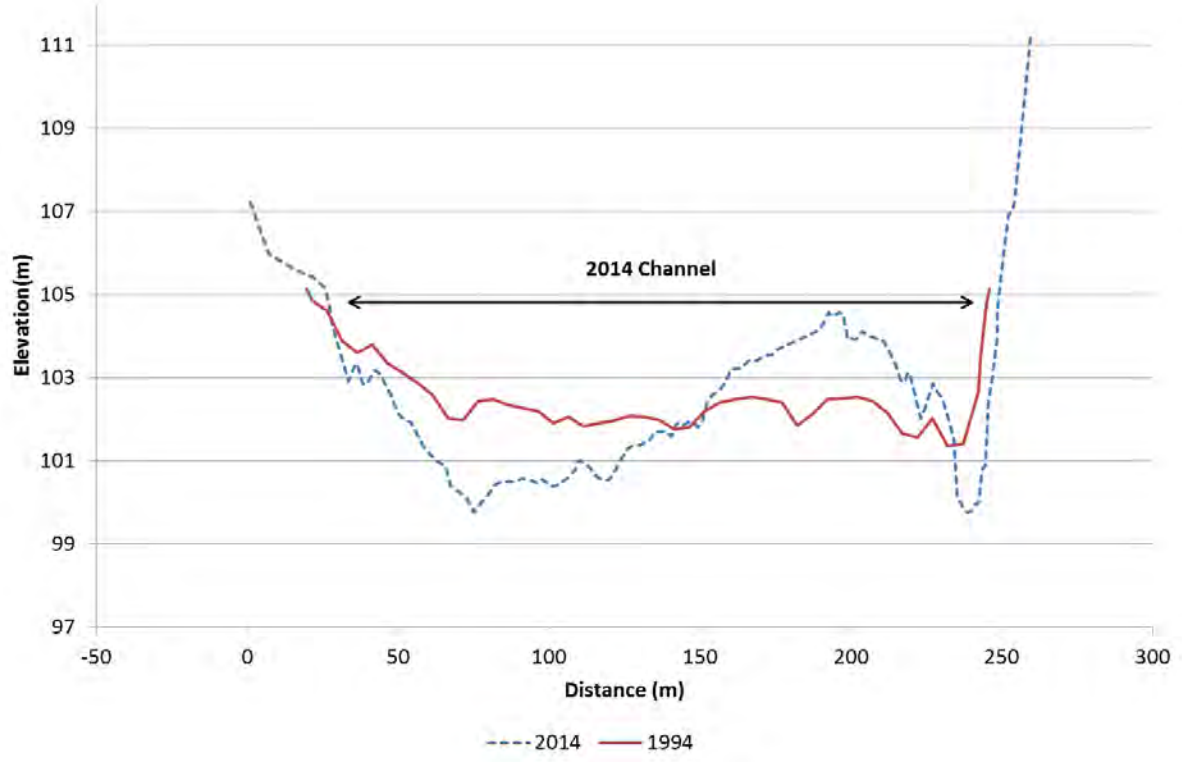


Figure 49. **Clutha River/Mata-Au cross-section C2, looking downstream**

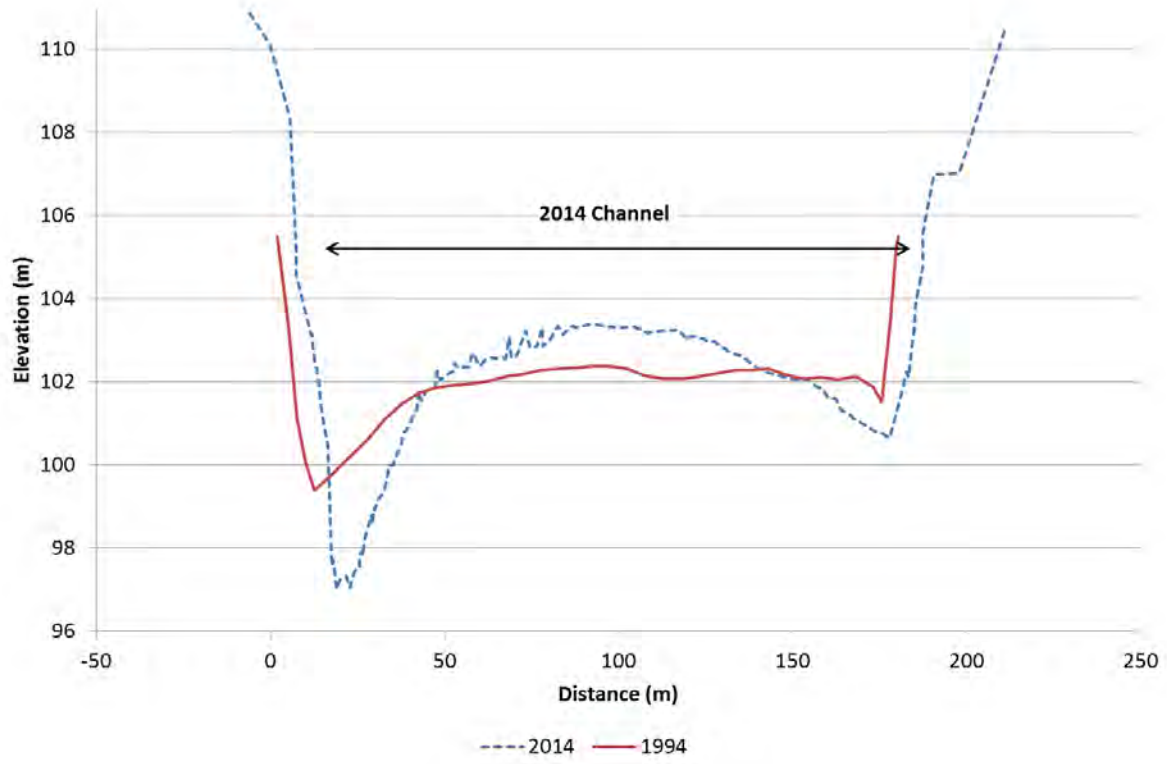


Figure 50. **Clutha River/Mata-Au cross-section C3, looking downstream**

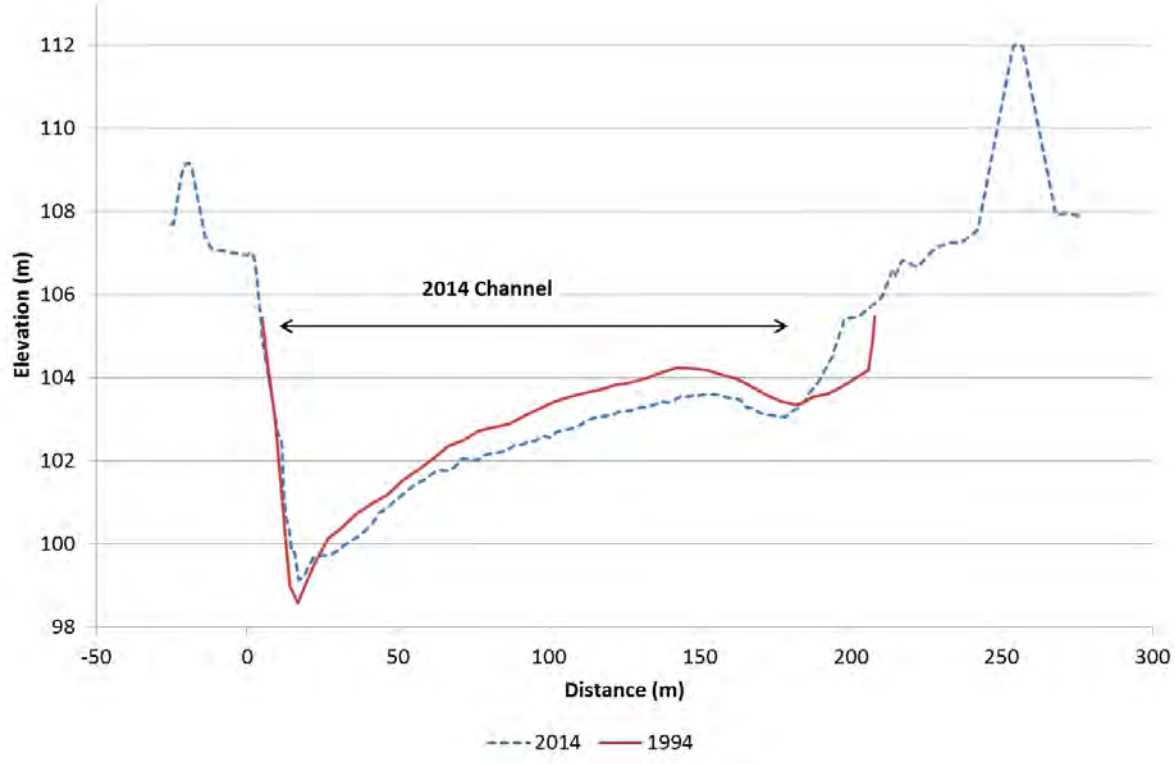


Figure 51. **Clutha River/Mata-Au cross-section C5, looking downstream**

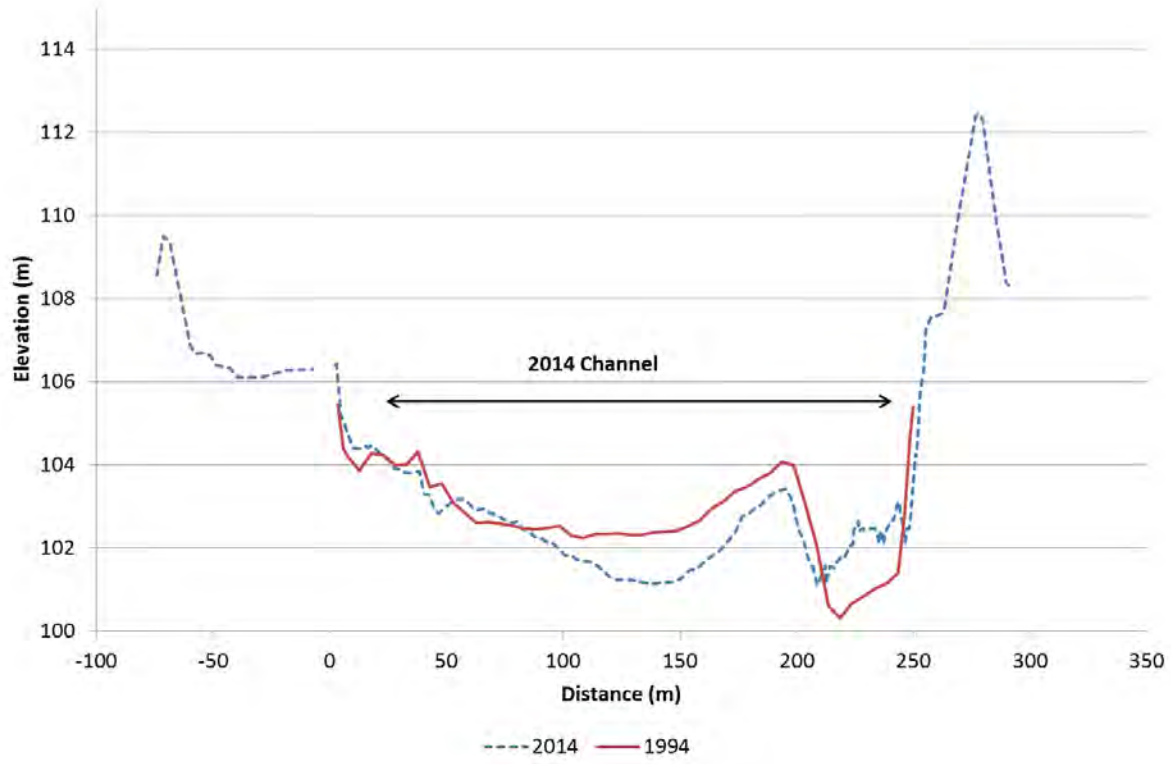


Figure 52. Clutha River/Mata-Au cross-section C6, looking downstream

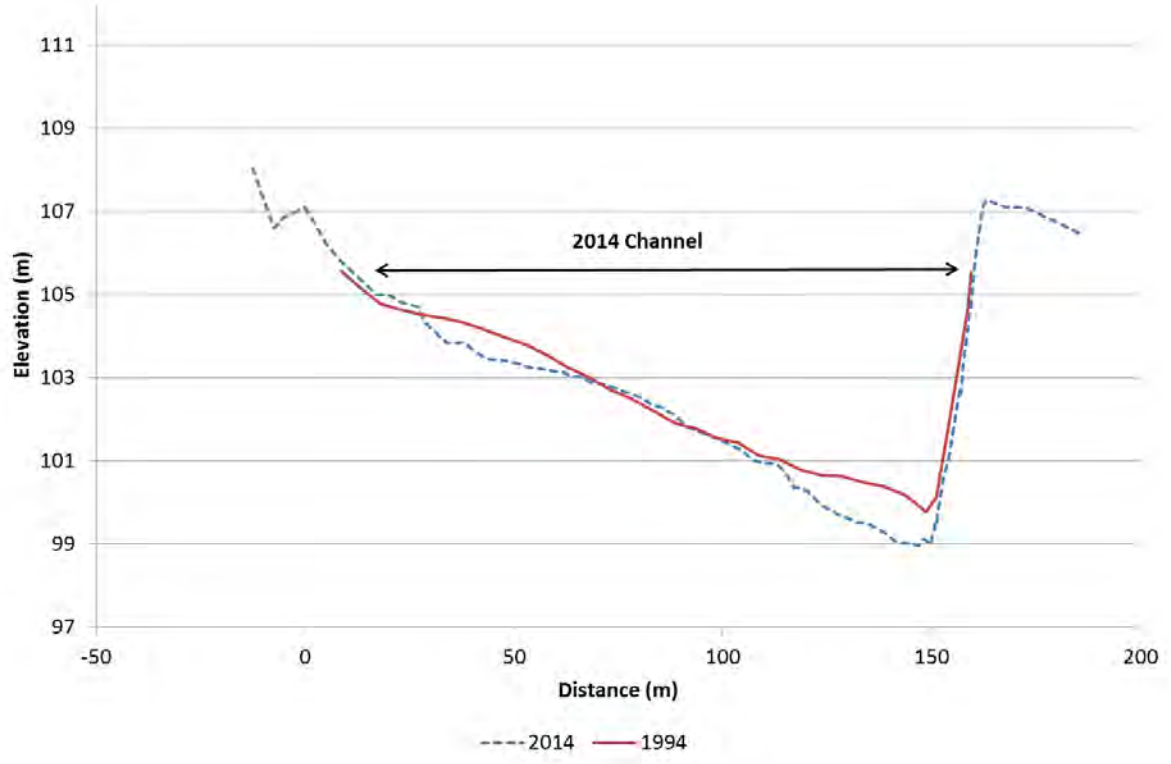


Figure 53. Clutha River/Mata-Au cross-section C7, looking downstream

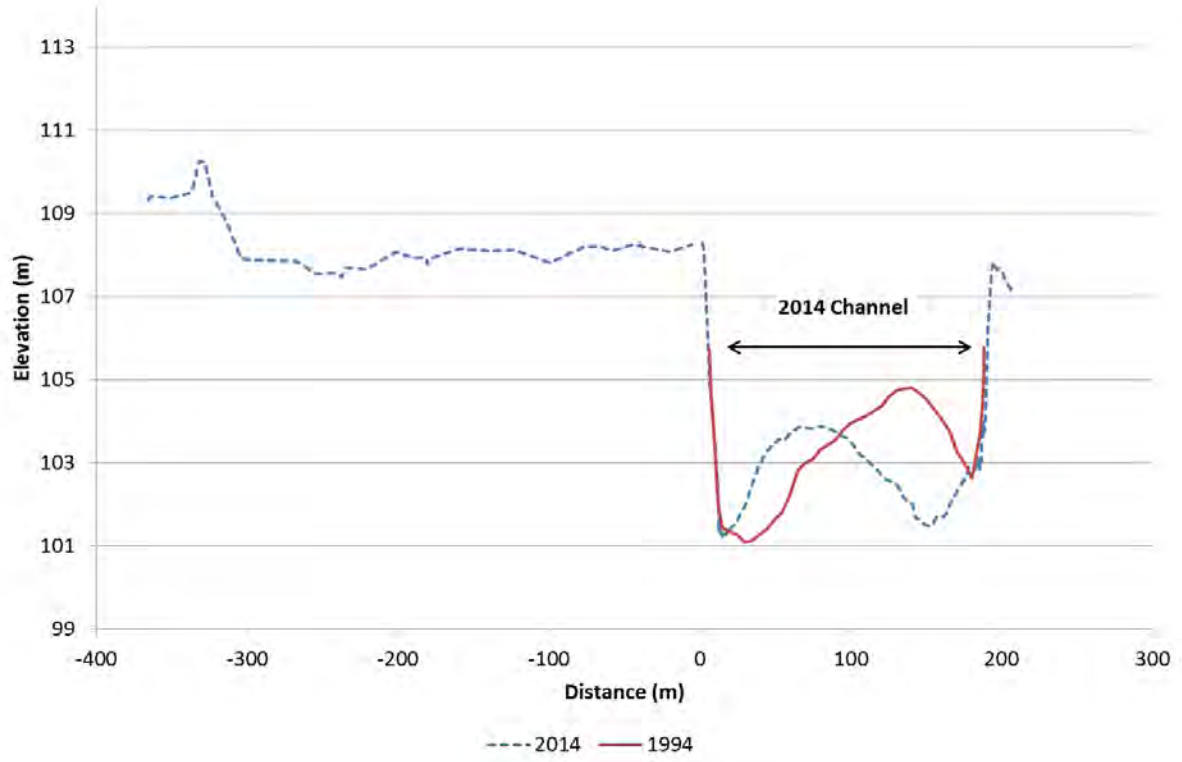


Figure 54. **Clutha River/Mata-Au cross-section C8, looking downstream**

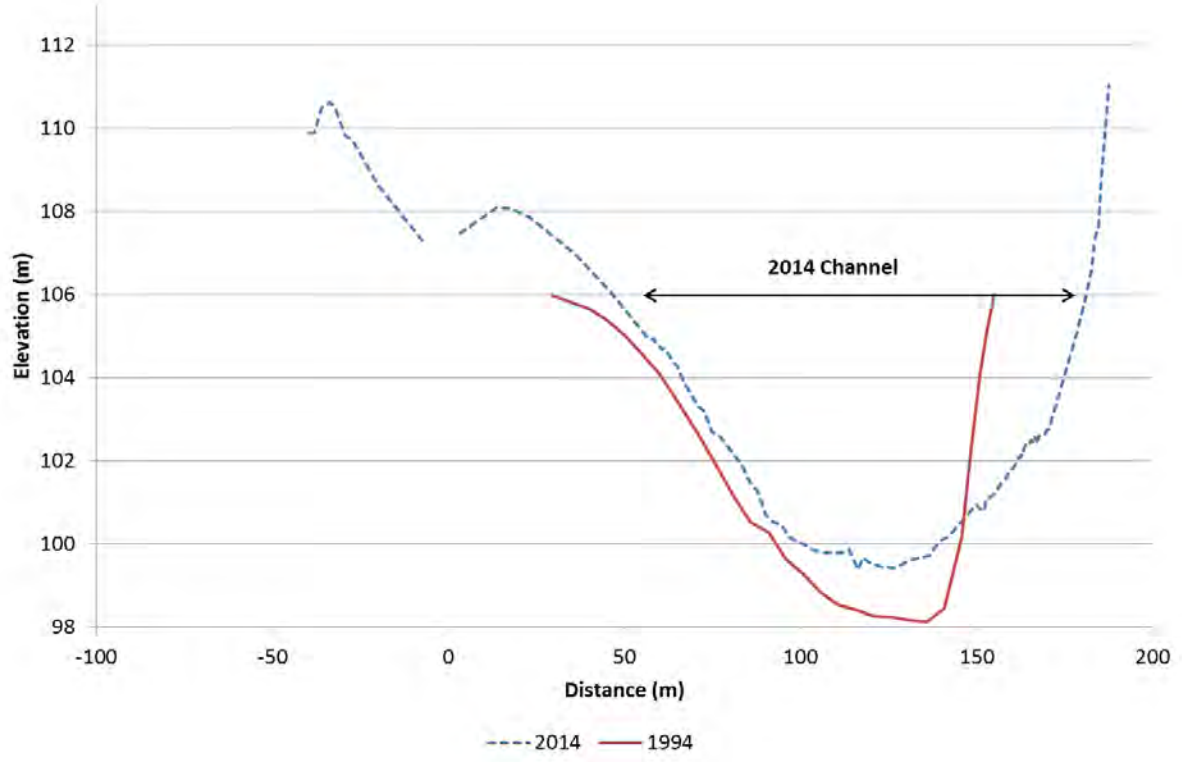


Figure 55. **Clutha River/Mata-Au cross-section C9, looking downstream**

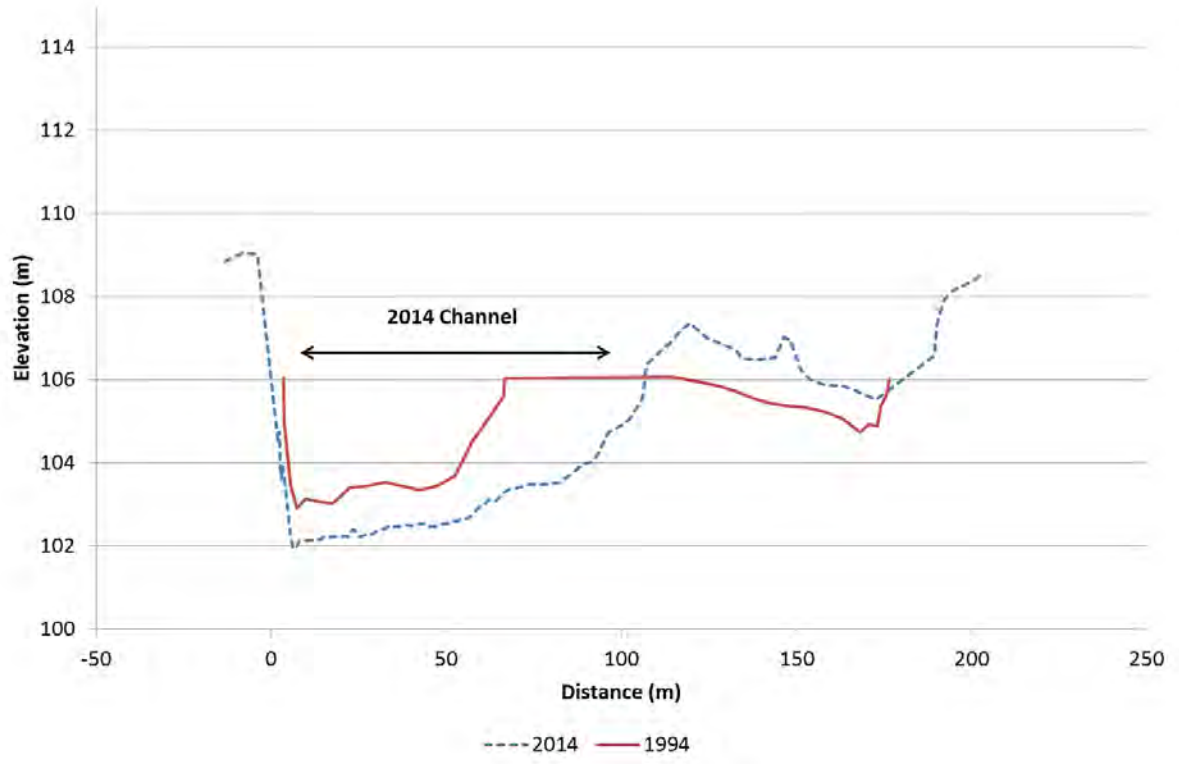


Figure 56. **Clutha River/Mata-Au cross-section C10, looking downstream**

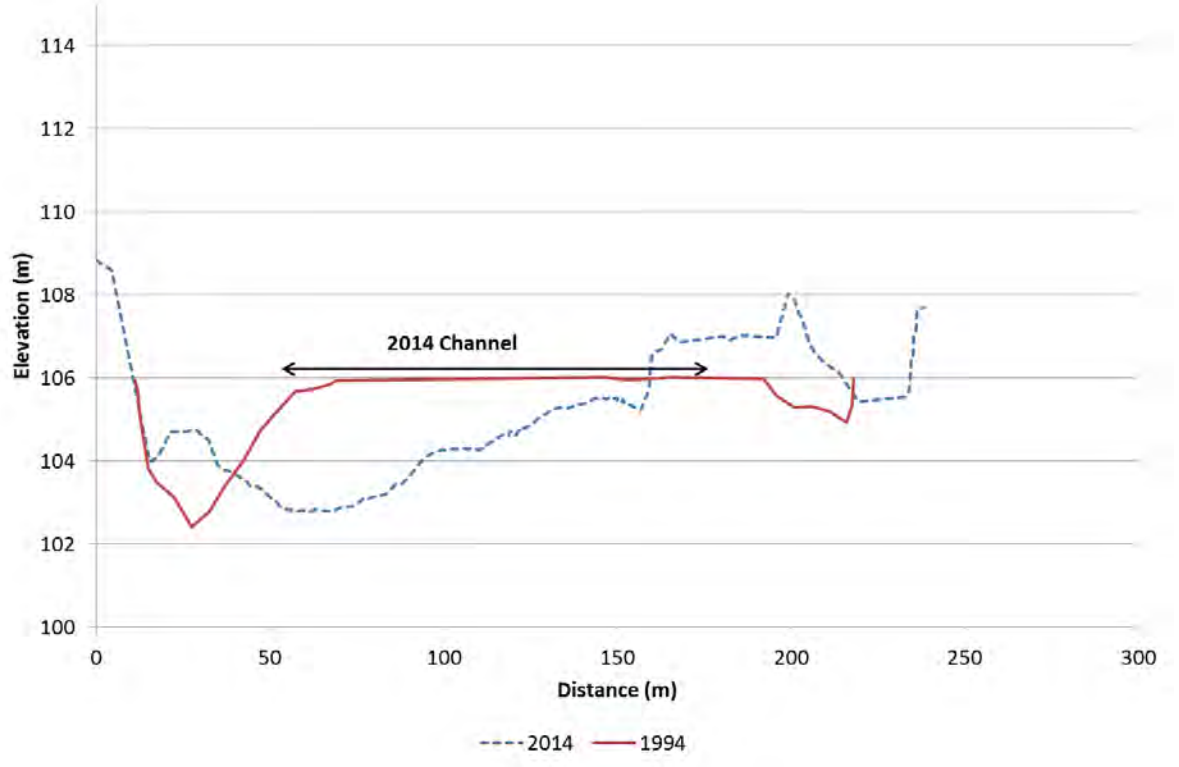


Figure 57. **Clutha River/Mata-Au cross-section C11, looking downstream**

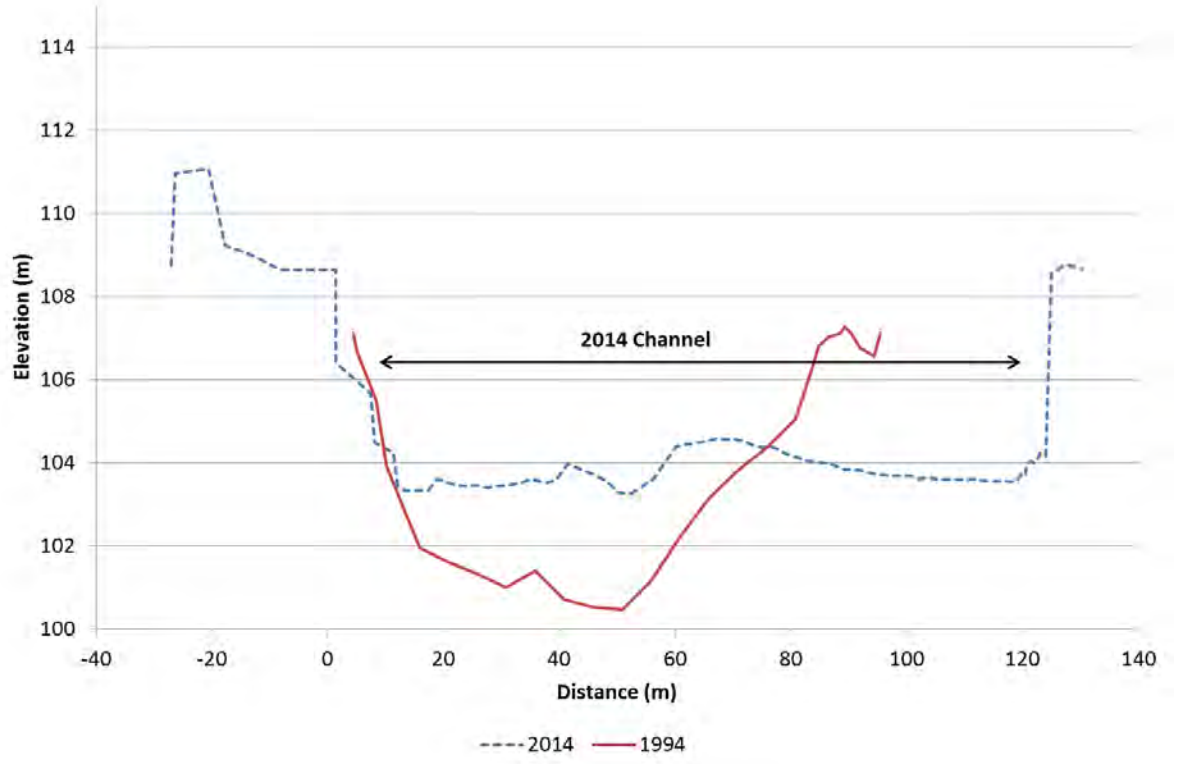


Figure 58. **Clutha River/Mata-Au cross-section C12, looking downstream**

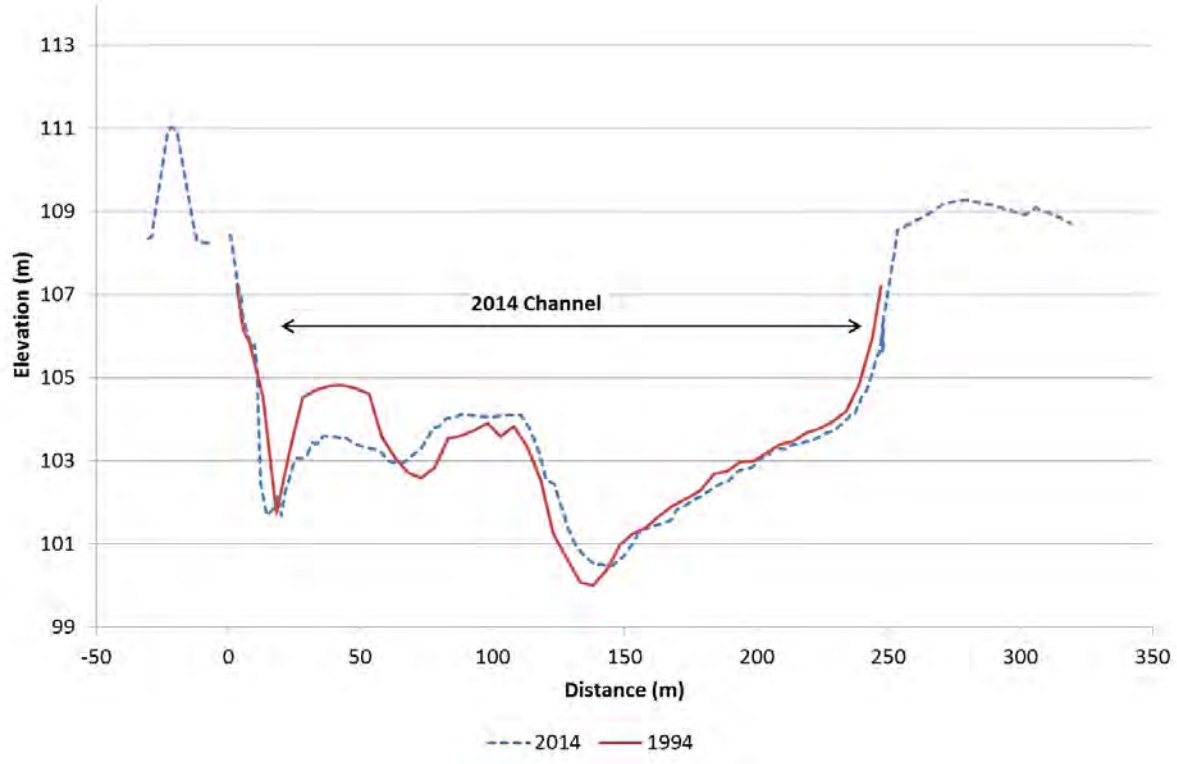


Figure 59. **Clutha River/Mata-Au cross-section C13, looking downstream**

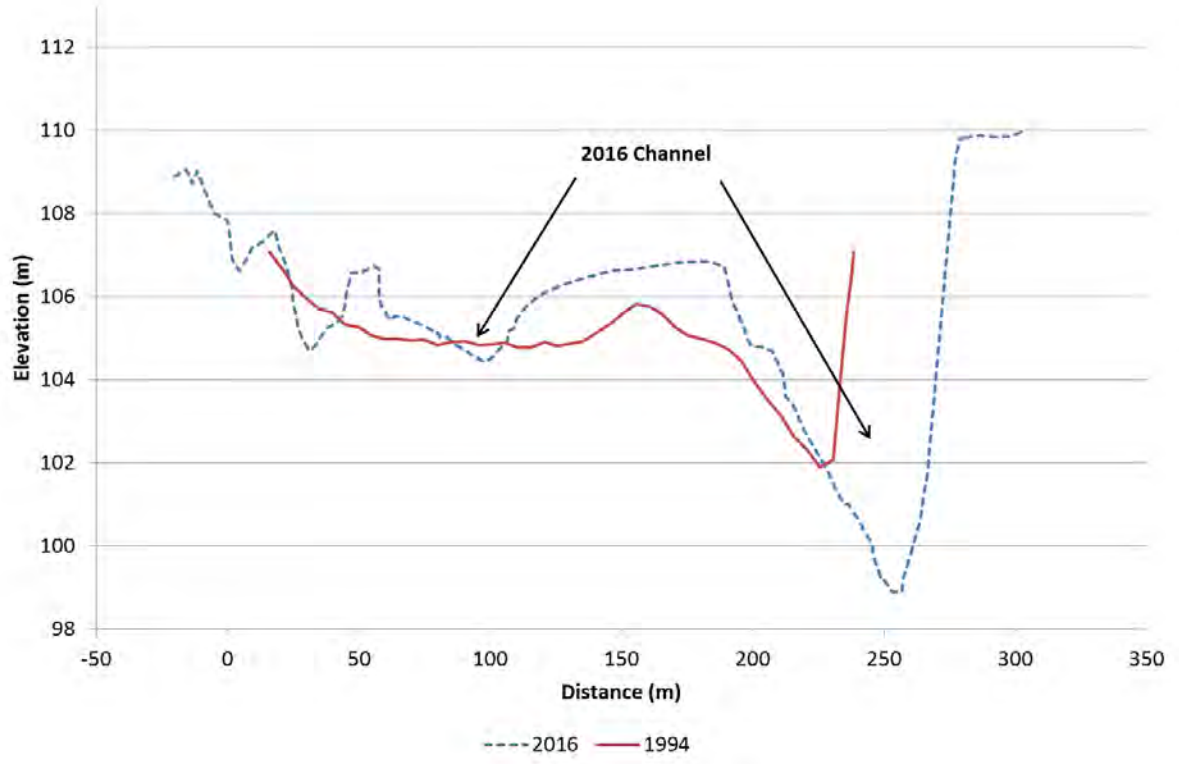


Figure 60. **Clutha River/Mata-Au cross-section C14, looking downstream**

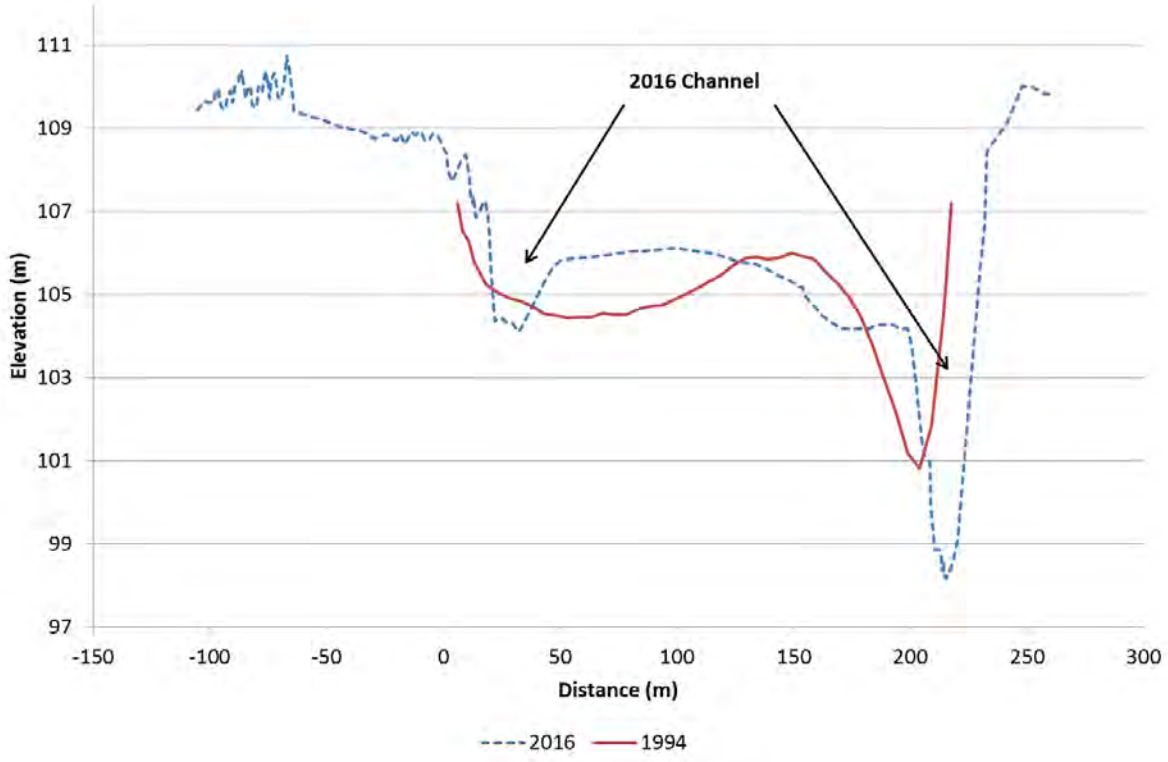


Figure 61. **Clutha River/Mata-Au cross-section C15, looking downstream**

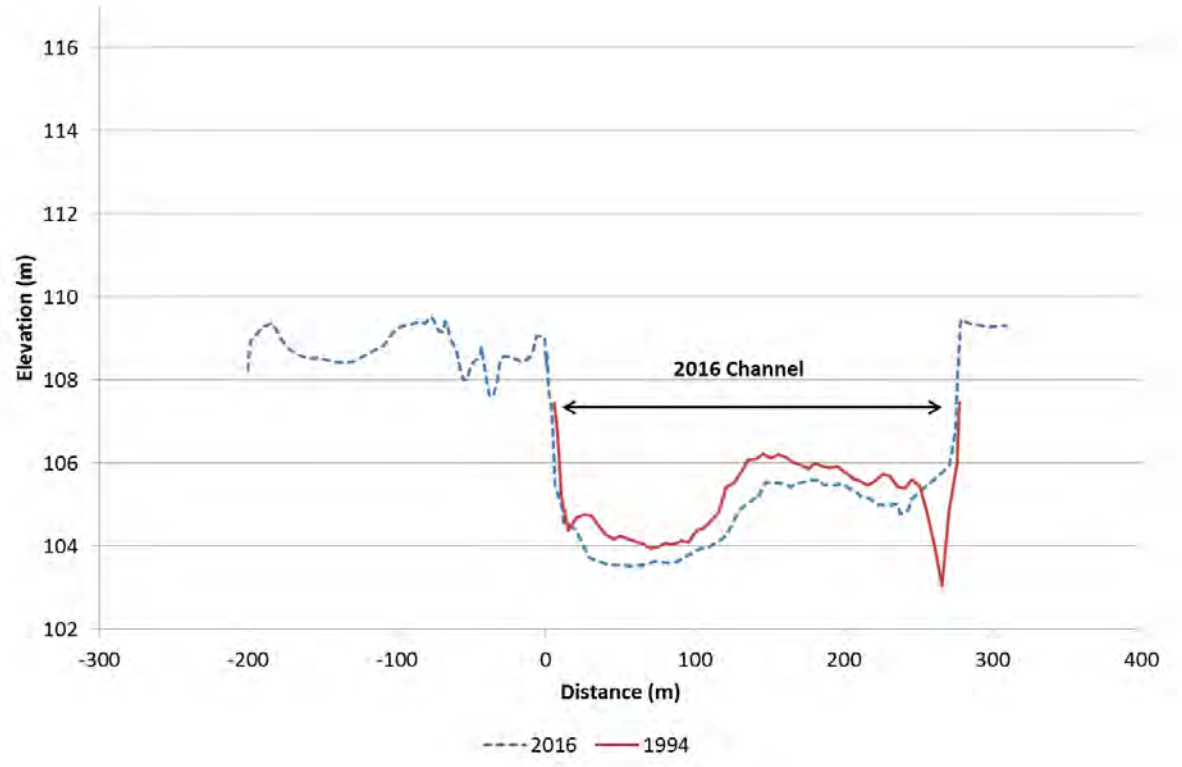


Figure 62. **Clutha River/Mata-Au cross-section C16, looking downstream**

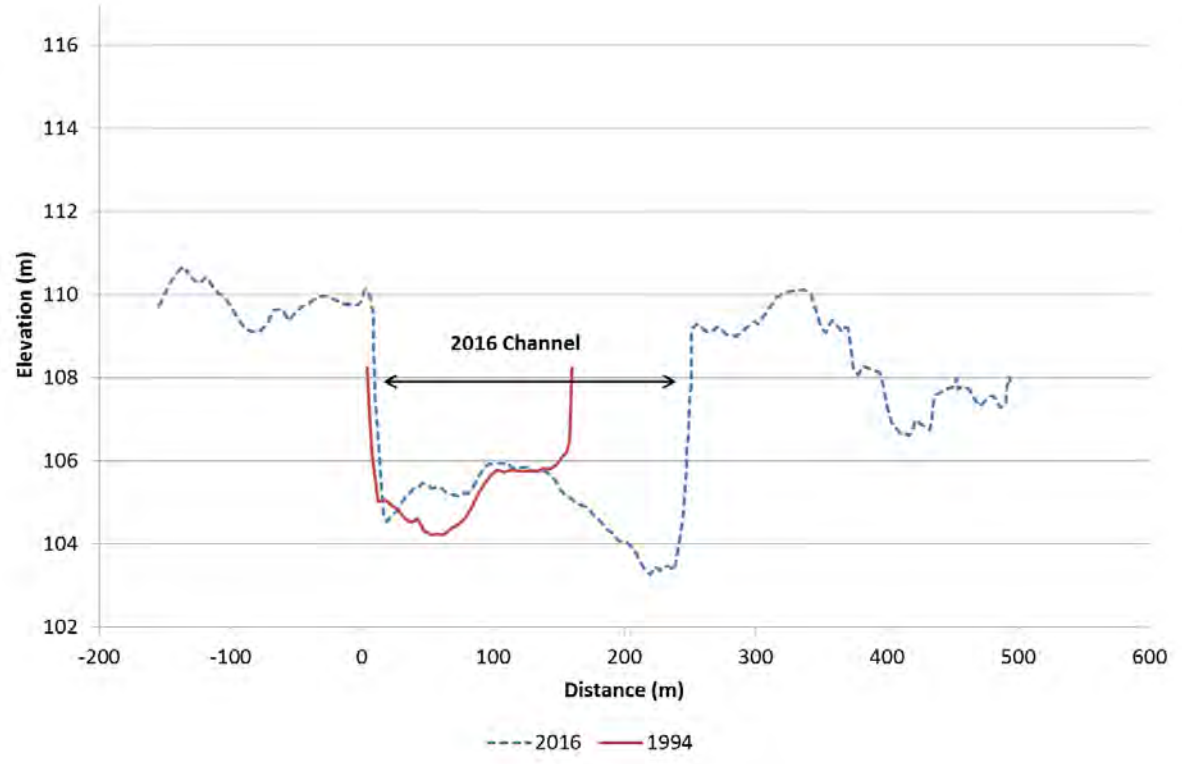


Figure 63. **Clutha River/Mata-Au cross-section C17, looking downstream**

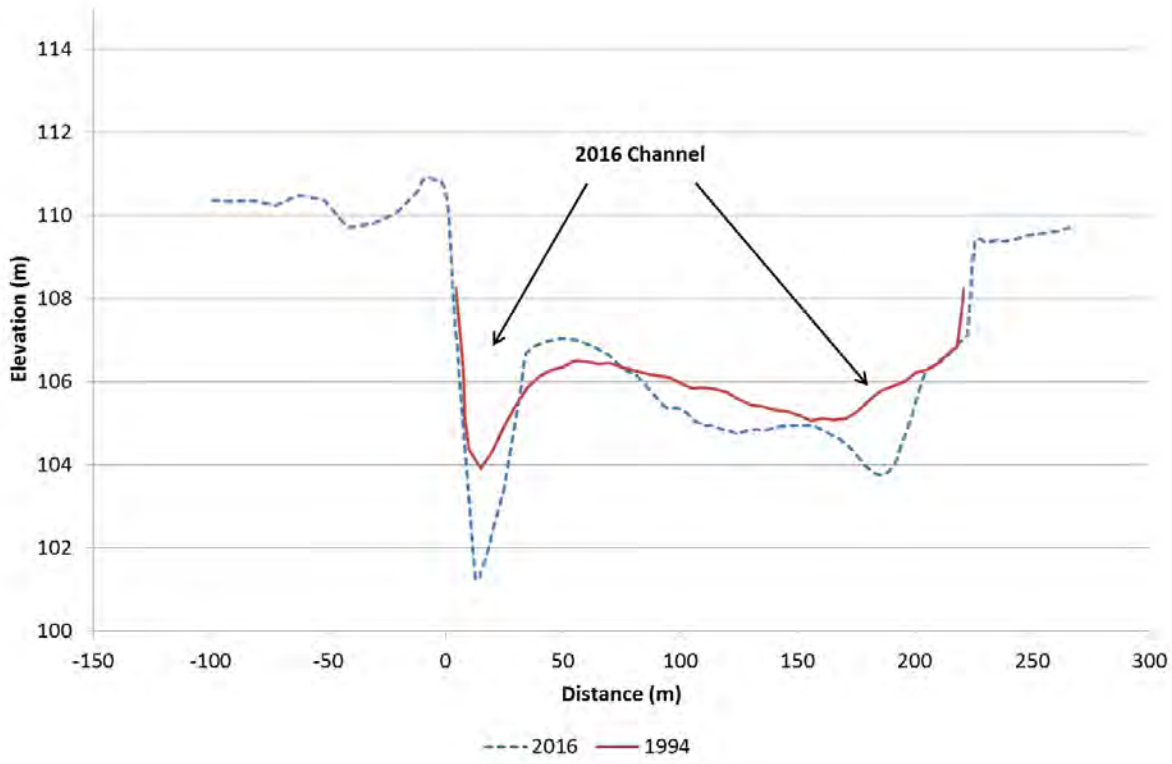


Figure 64. **Clutha River/Mata-Au cross-section C18, looking downstream**

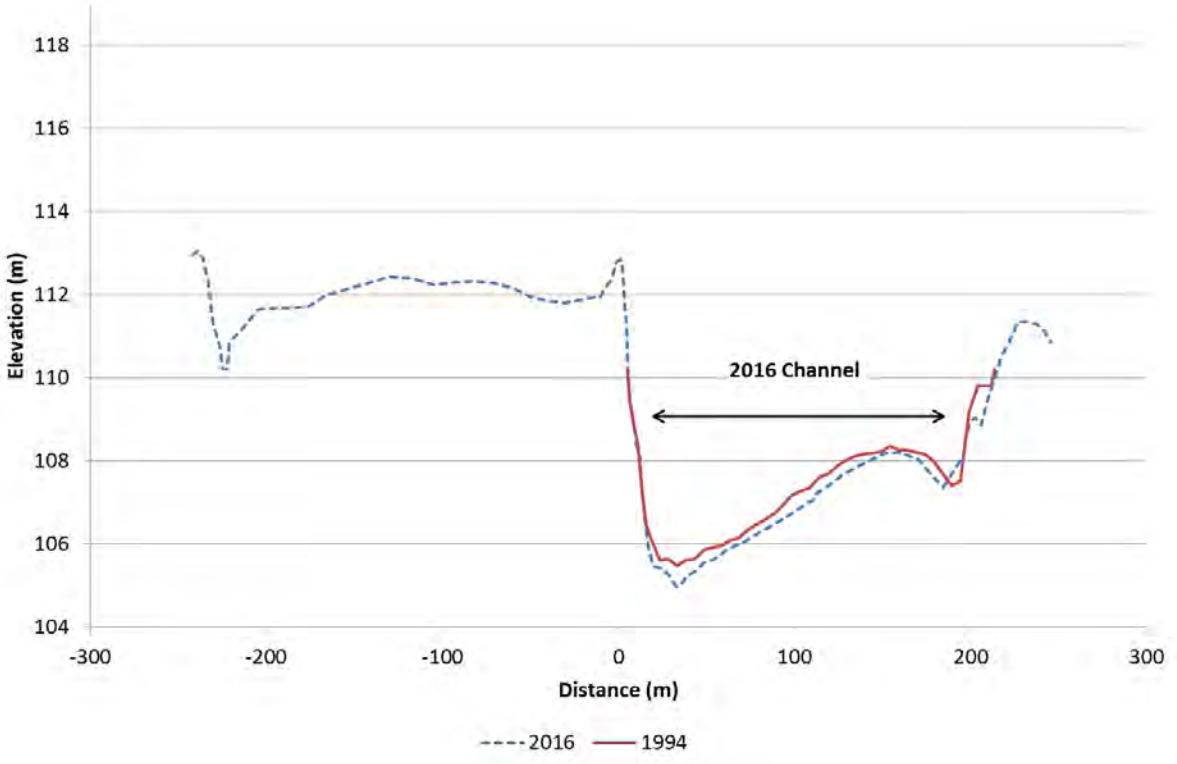


Figure 65. **Clutha River/Mata-Au cross-section C19, looking downstream**

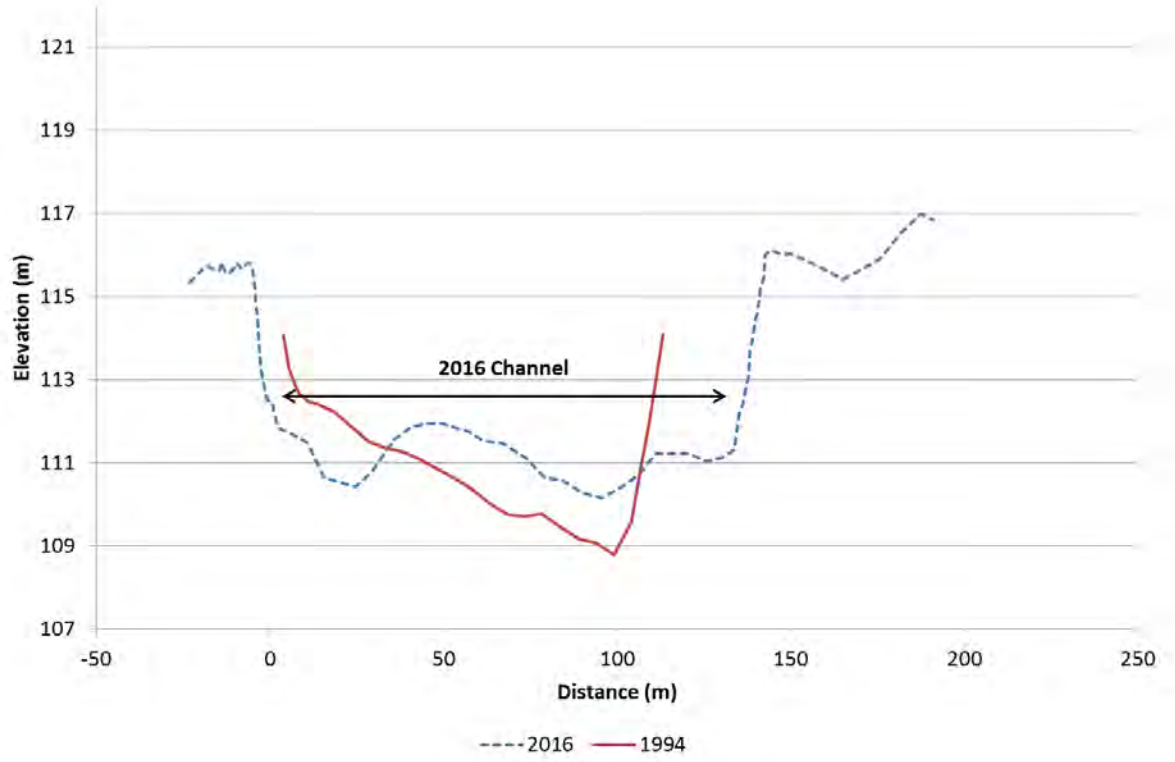


Figure 66. **Clutha River/Mata-Au cross-section C20, looking downstream**

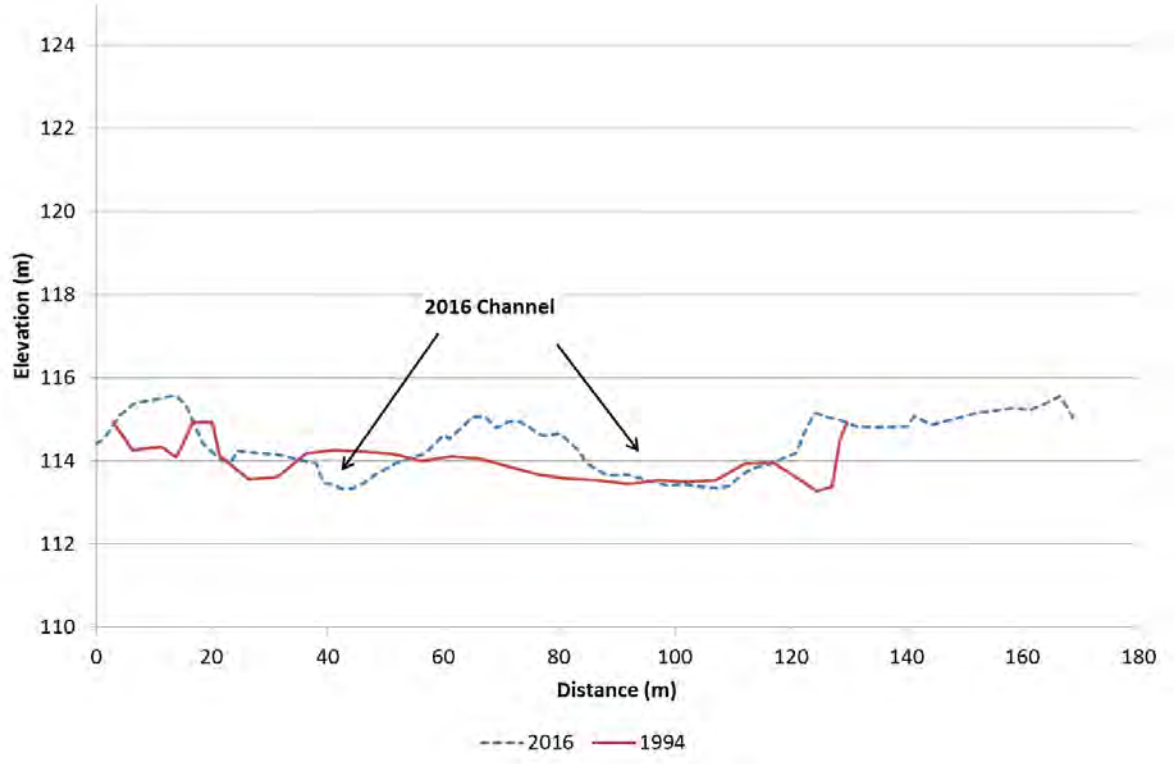


Figure 67. **Clutha River/Mata-Au cross-section C21, looking downstream**

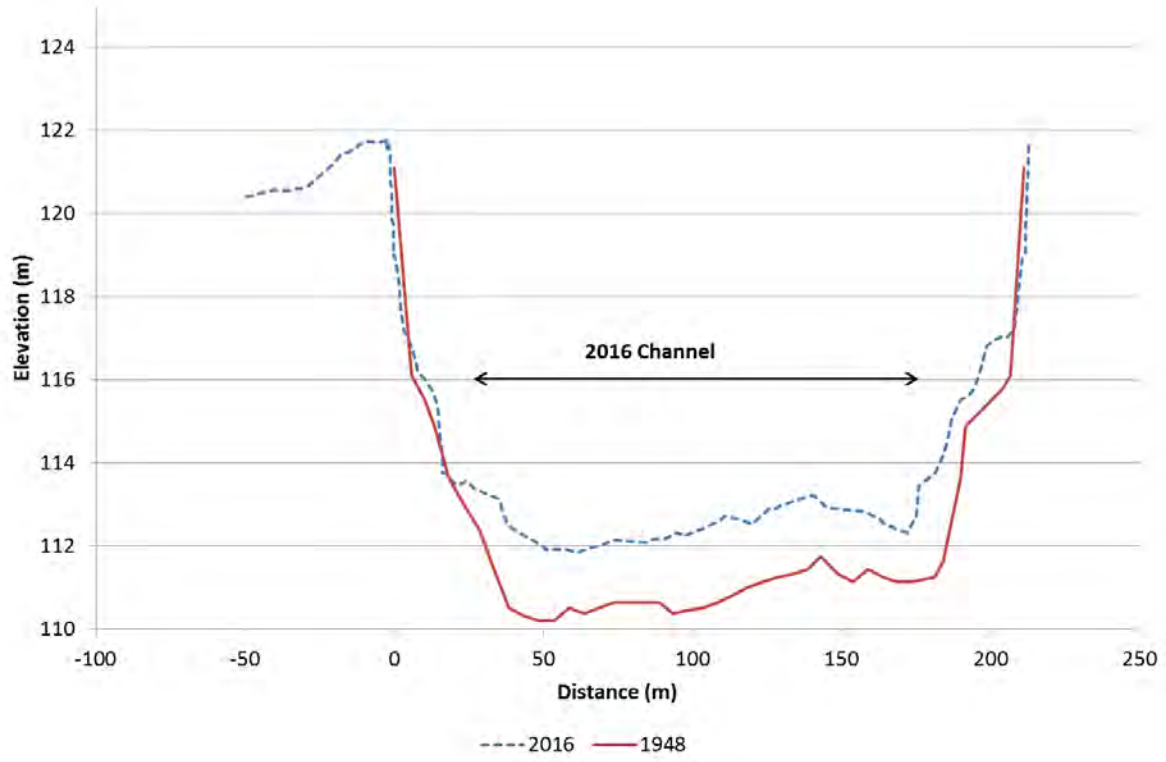


Figure 68. **Clutha River/Mata-Au cross-section C22, looking downstream**

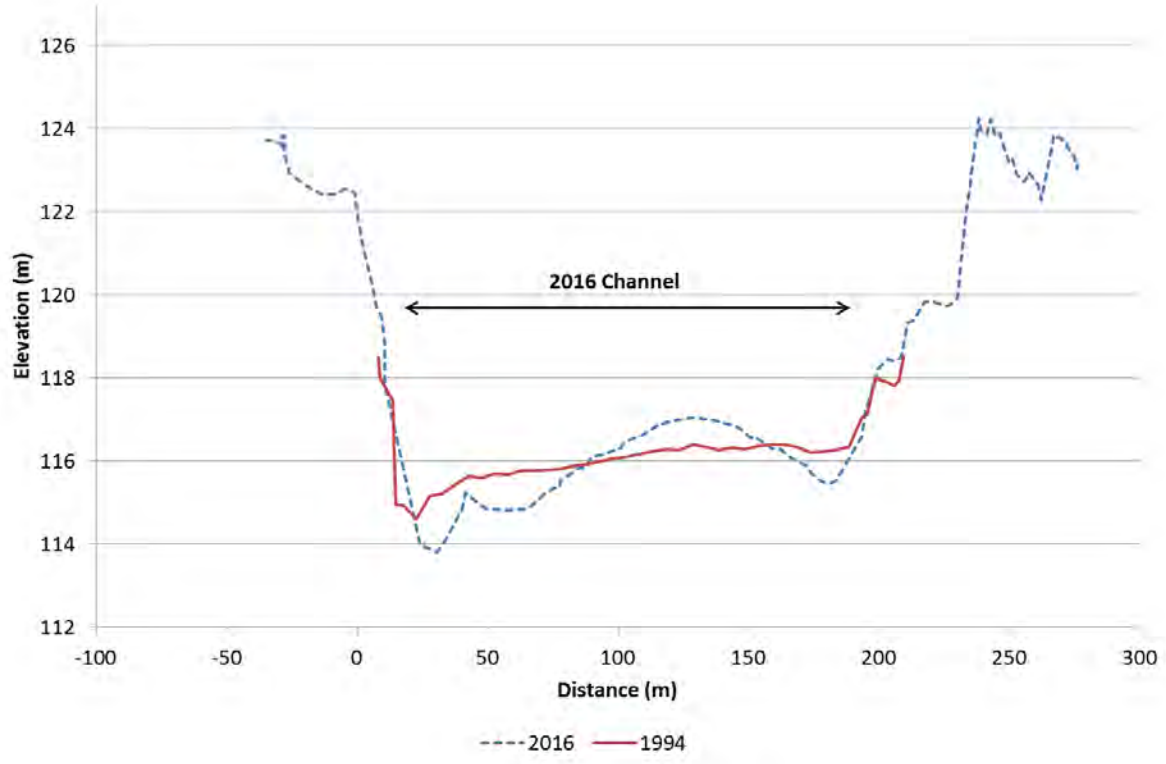


Figure 69. **Clutha River/Mata-Au cross-section C23, looking downstream**

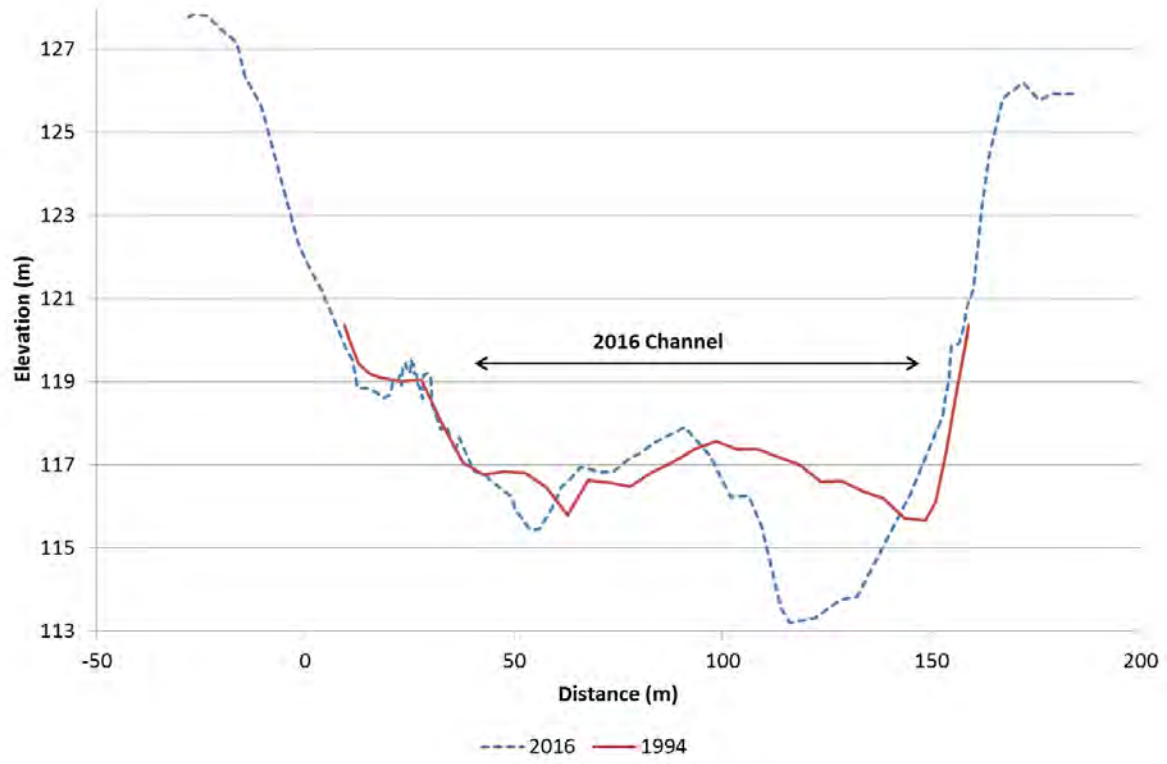


Figure 70. **Clutha River/Mata-Au cross-section C24, looking downstream**

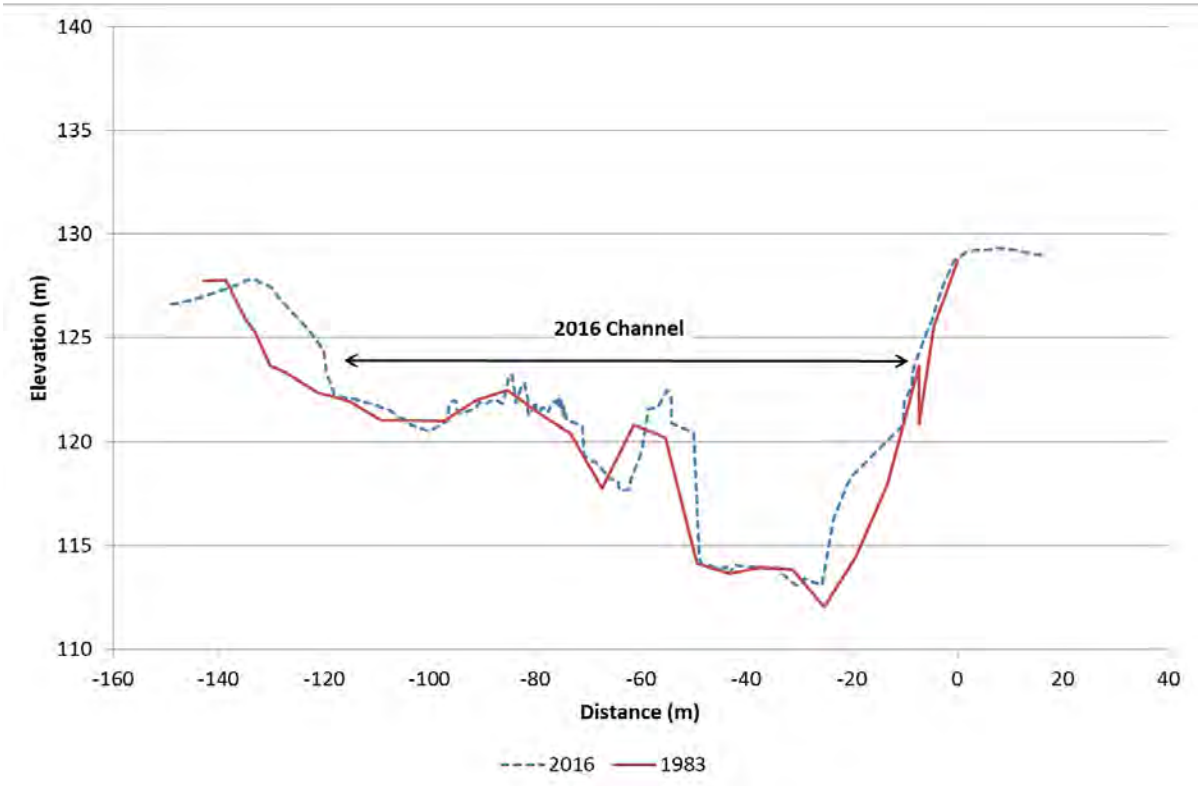


Figure 71. **Clutha River/Mata-Au cross-section C25, looking downstream**

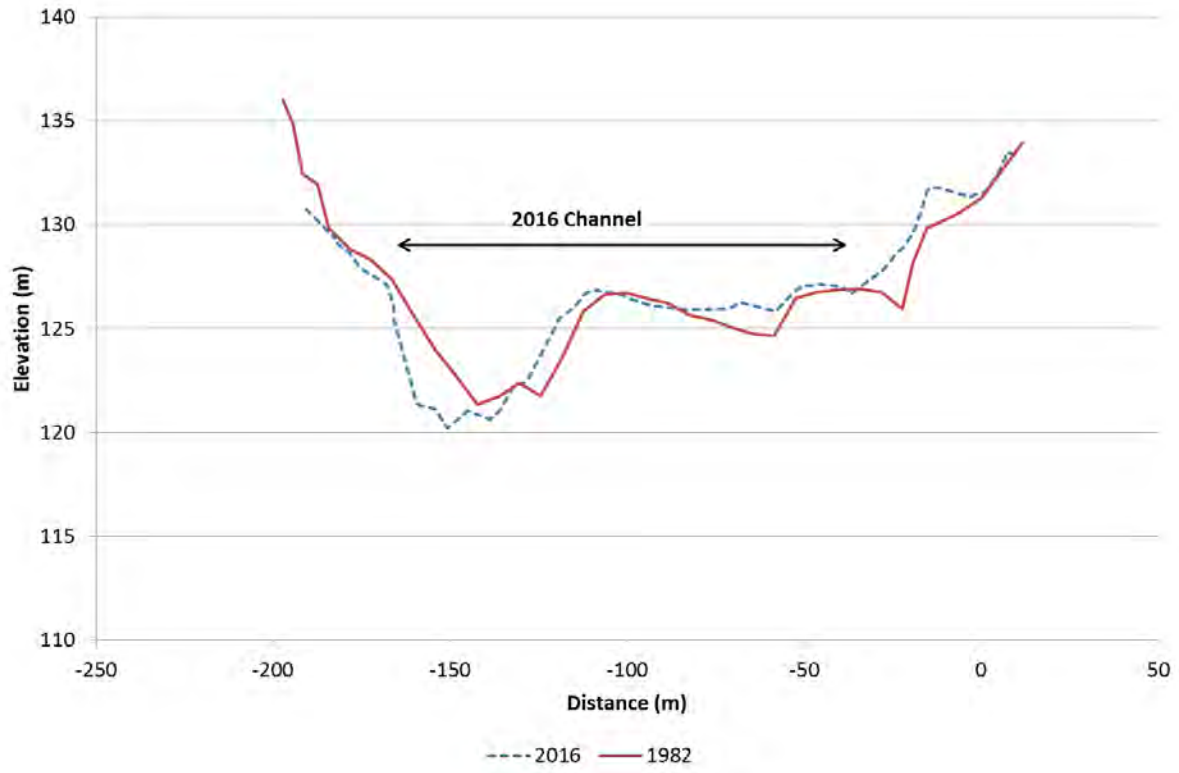


Figure 72. **Clutha River/Mata-Au cross-section C26, looking downstream**

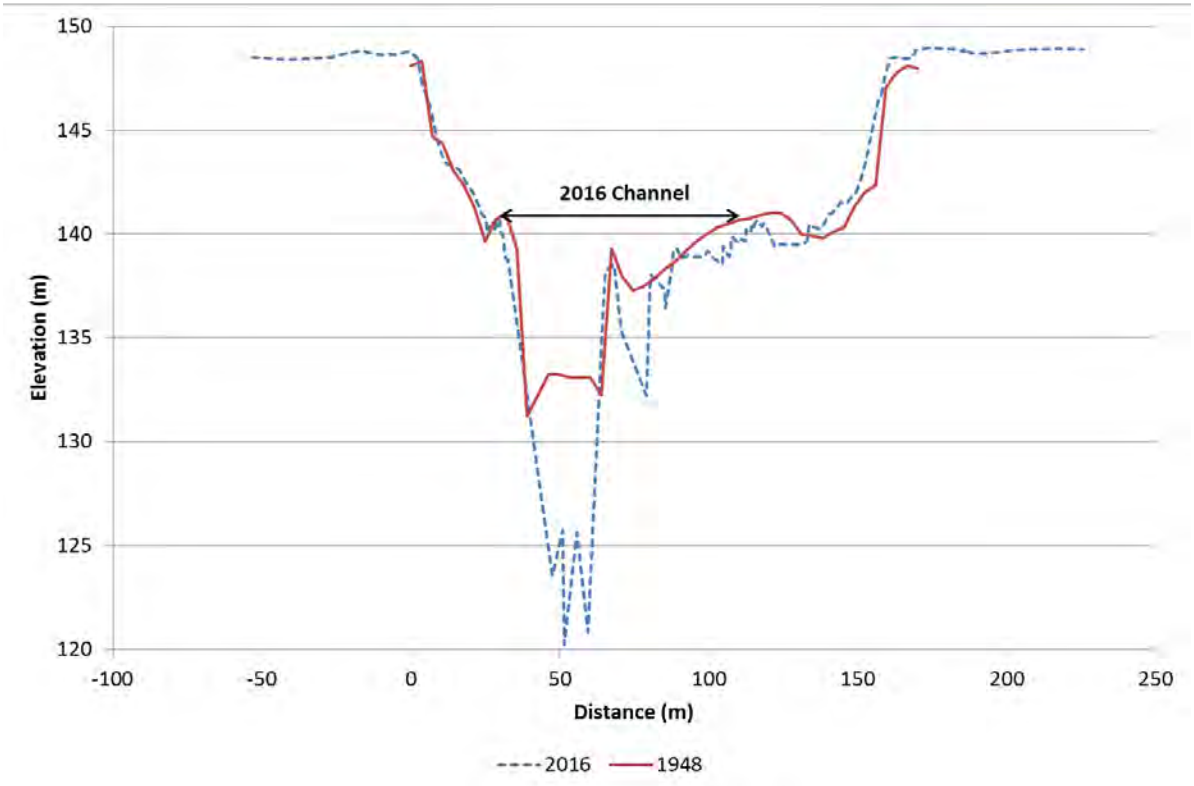


Figure 73. **Clutha River/Mata-Au cross-section C28, looking downstream**

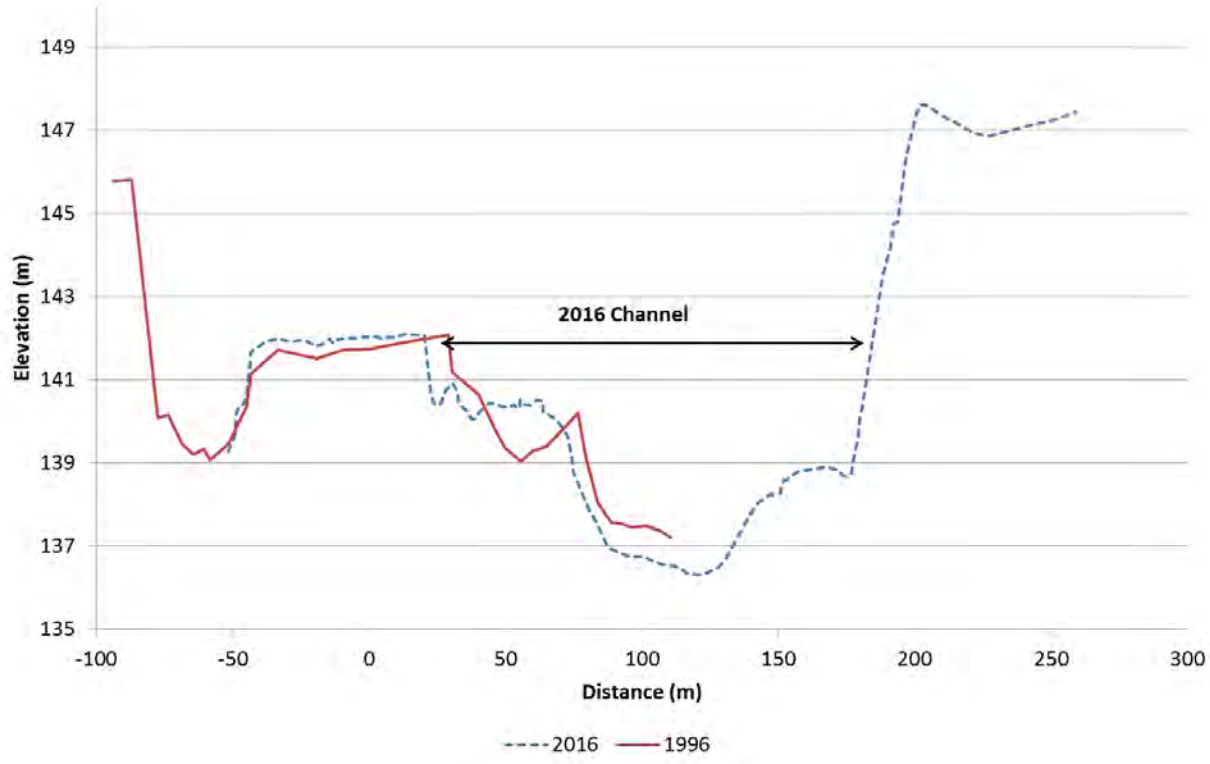


Figure 74. **Clutha River/Mata-Au cross-section B10, looking downstream**

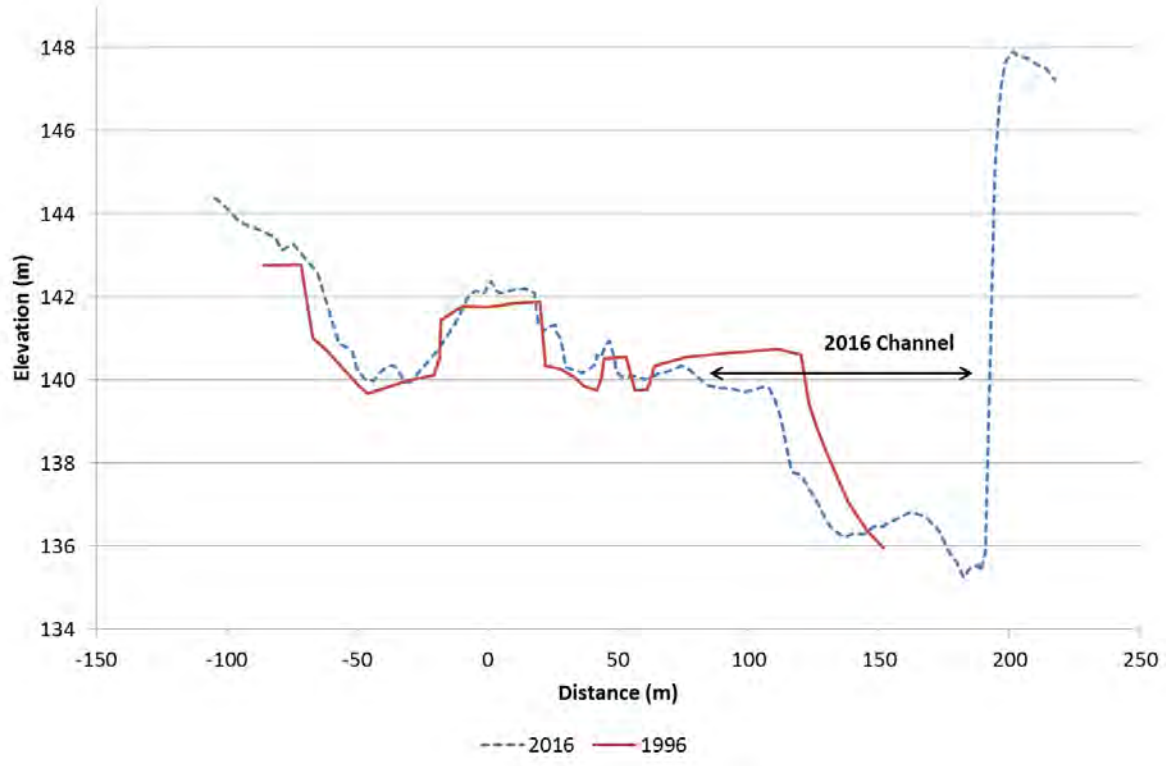


Figure 75. **Clutha River/Mata-Au cross-section B11, looking downstream**

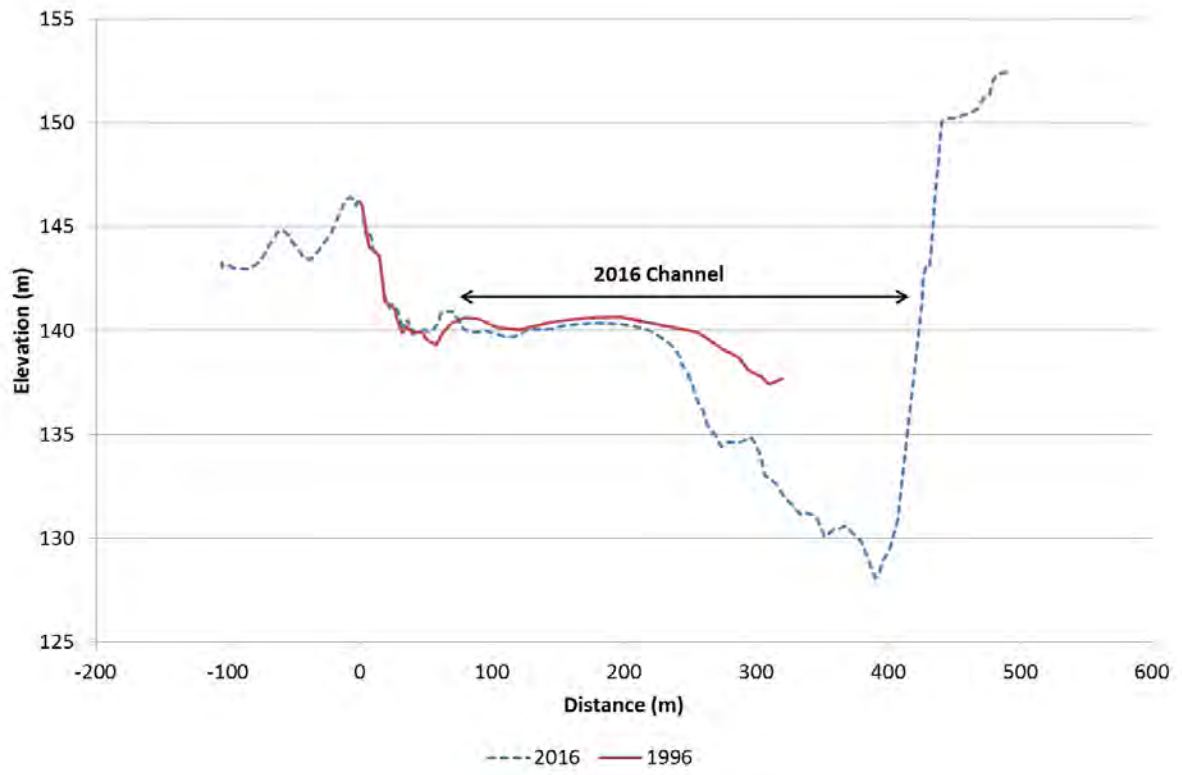


Figure 76. Clutha River/Mata-Au cross-section B12, looking downstream

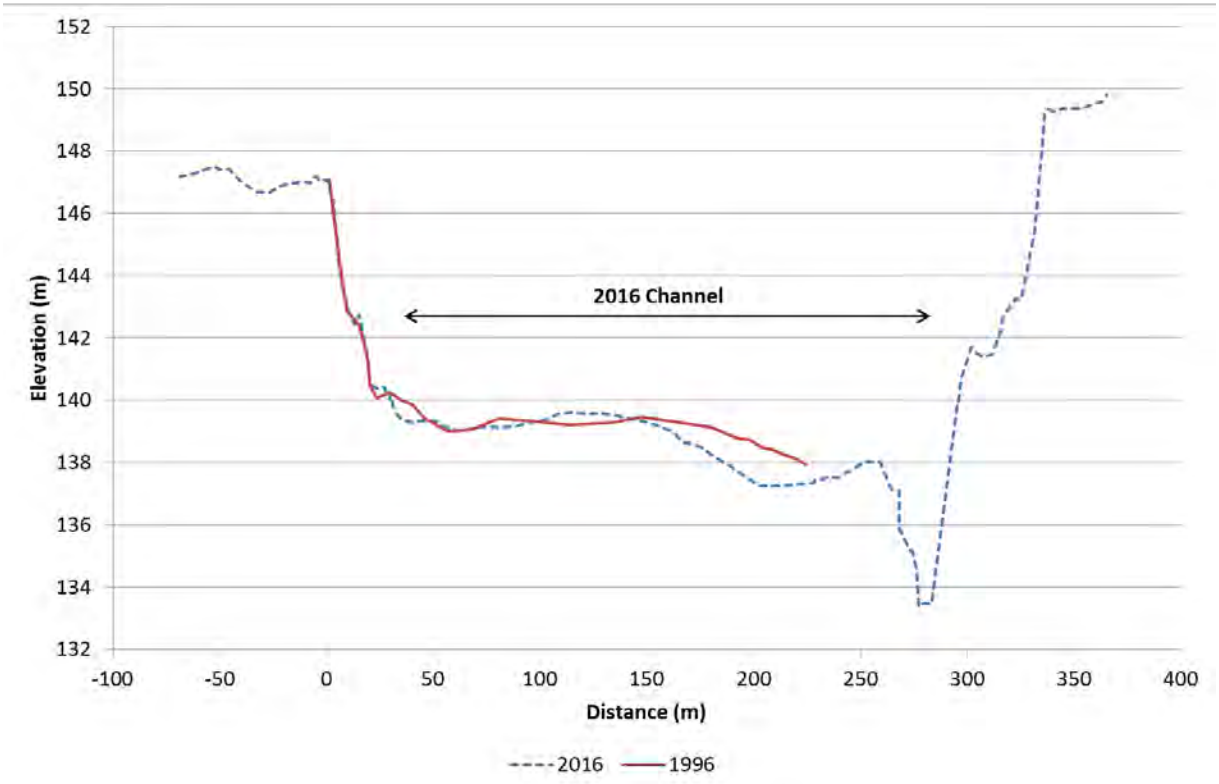


Figure 77. Clutha River/Mata-Au cross-section B13, looking downstream

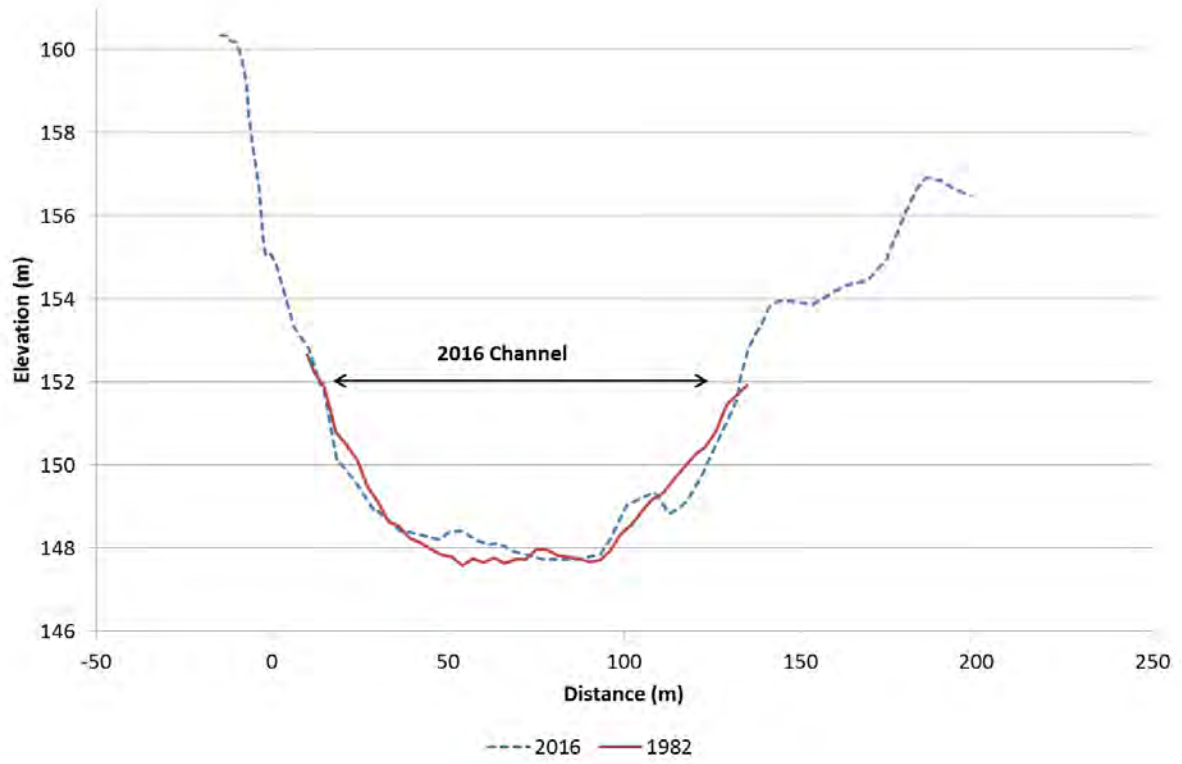


Figure 78. **Clutha River/Mata-Au cross-section C30, looking downstream**

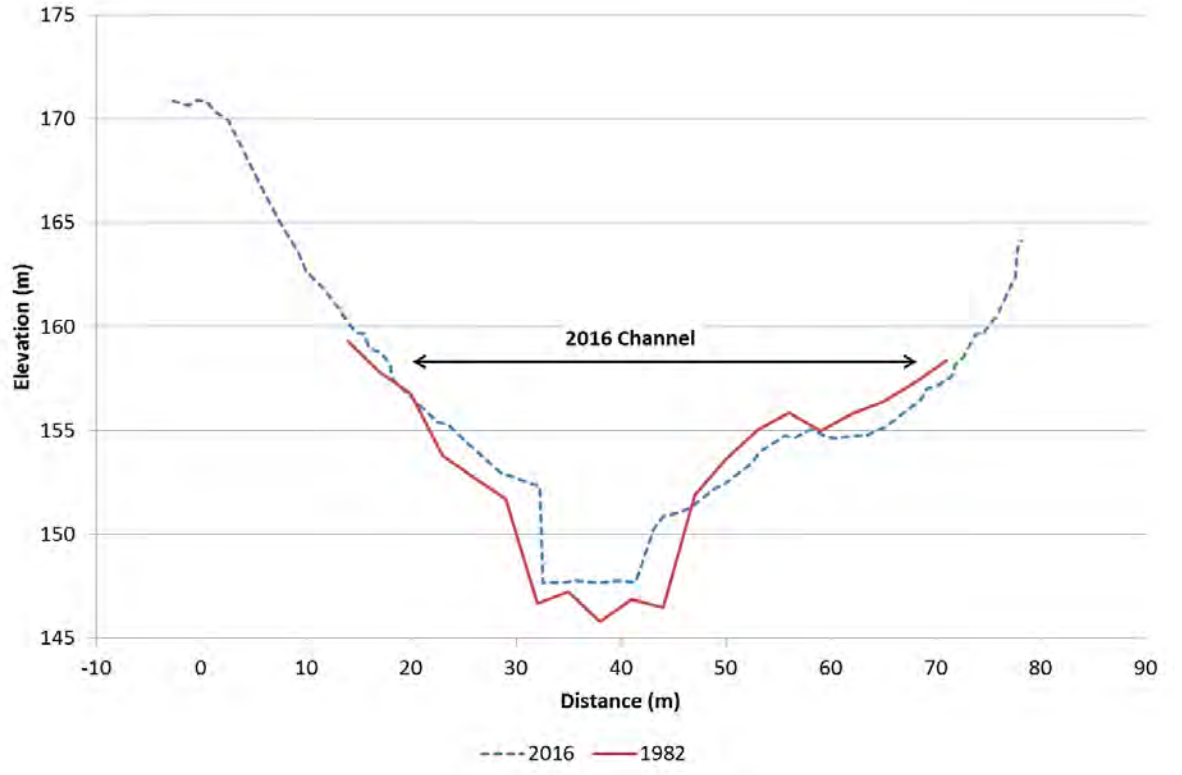


Figure 79. **Clutha River/Mata-Au cross-section C31, looking downstream**

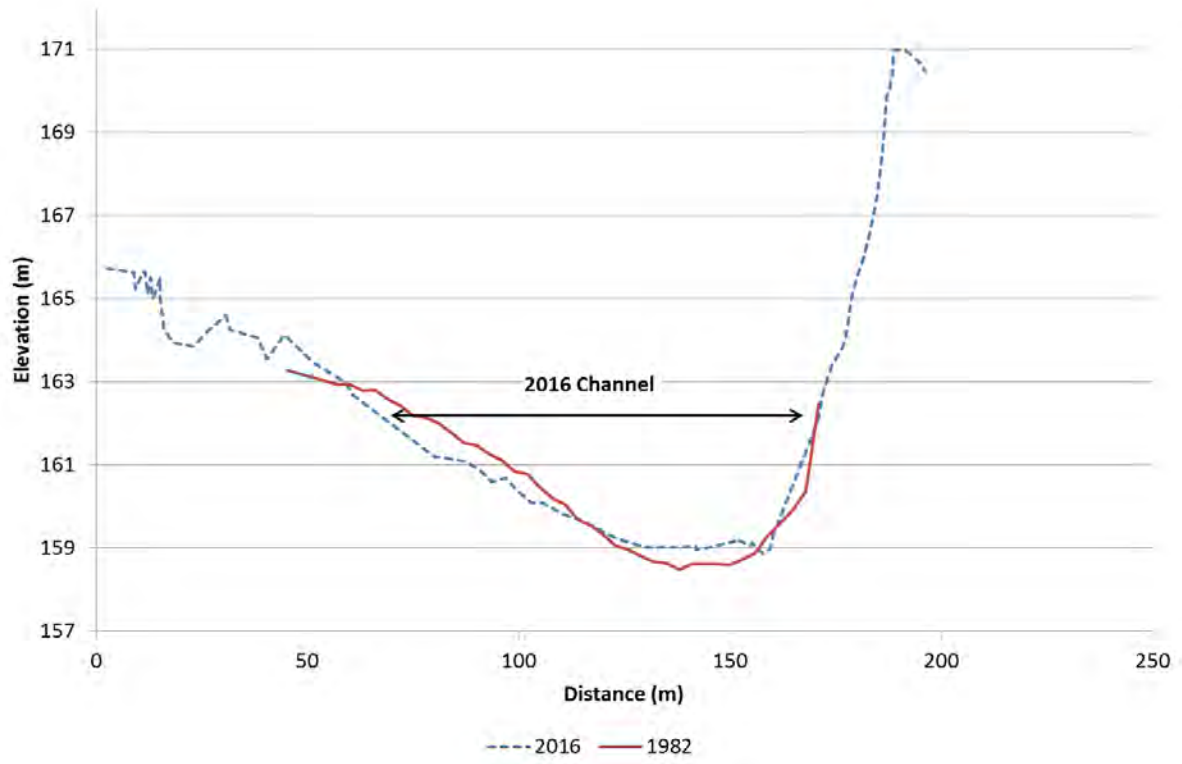


Figure 80. **Clutha River/Mata-Au cross-section C32, looking downstream**

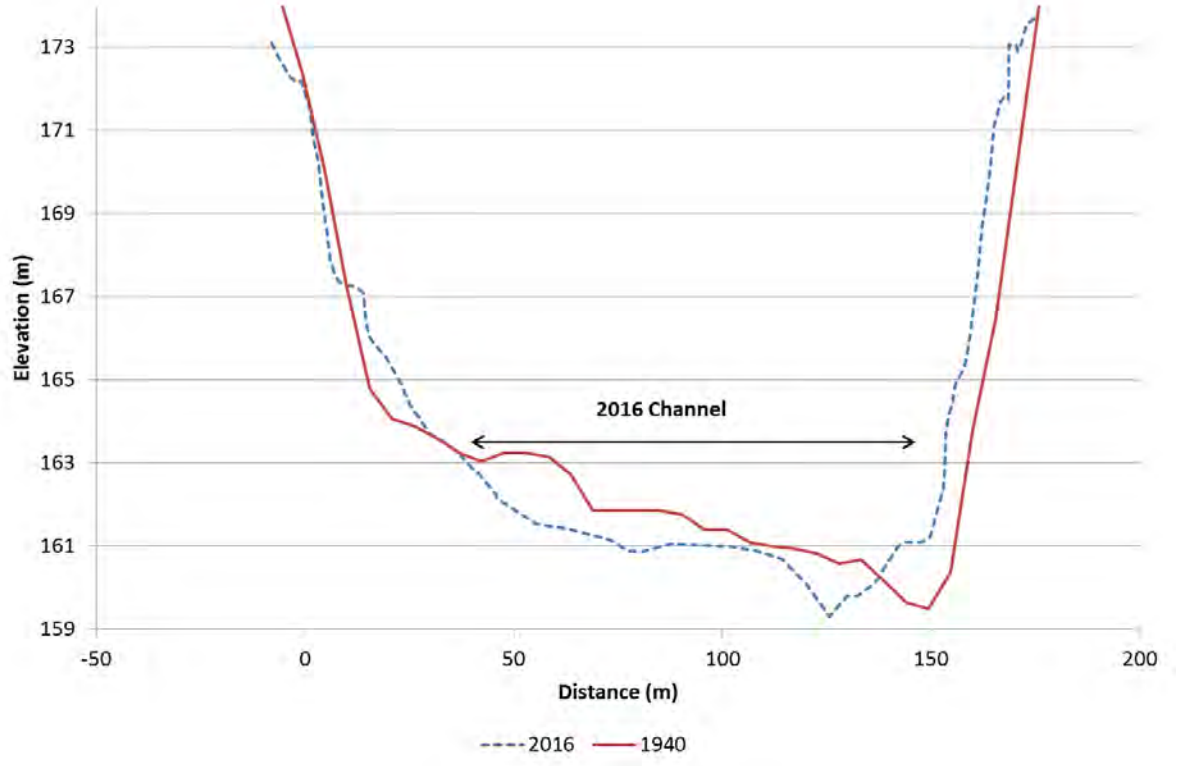


Figure 81. **Clutha River/Mata-Au cross-section C33, looking downstream**

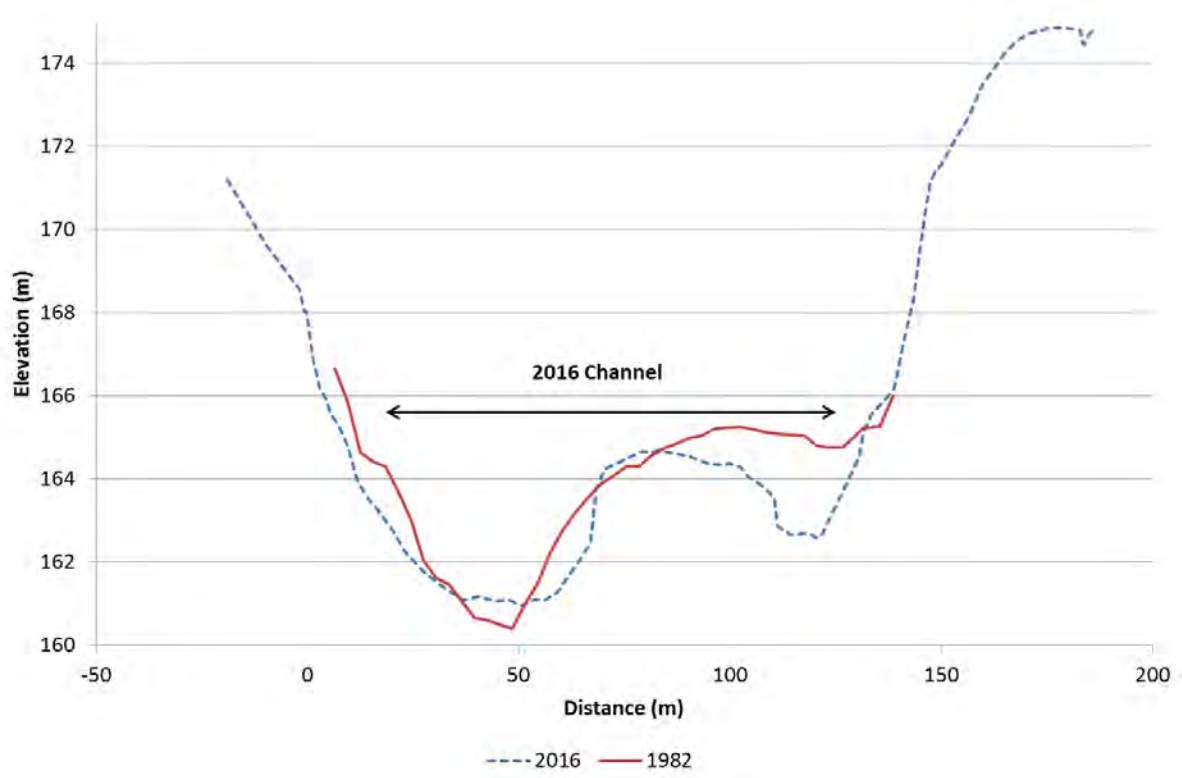


Figure 82. **Clutha River/Mata-Au cross-section C34, looking downstream**

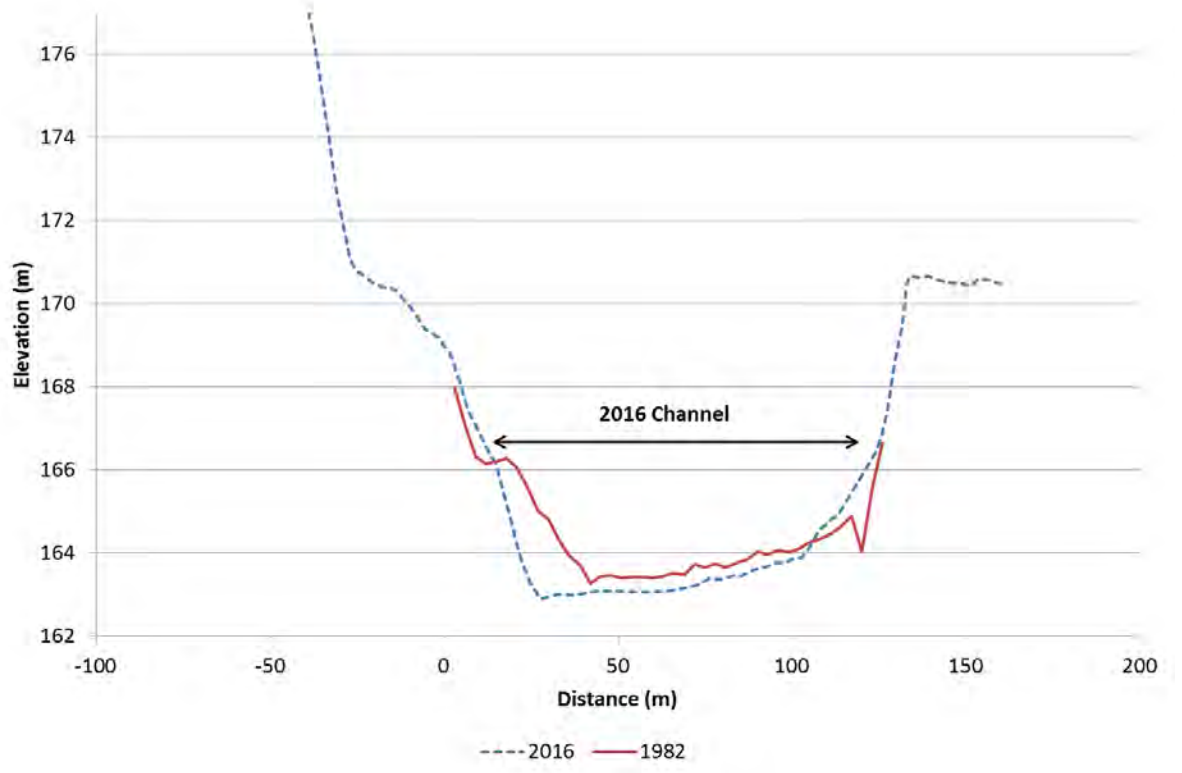


Figure 83. **Clutha River/Mata-Au cross-section C35, looking downstream**

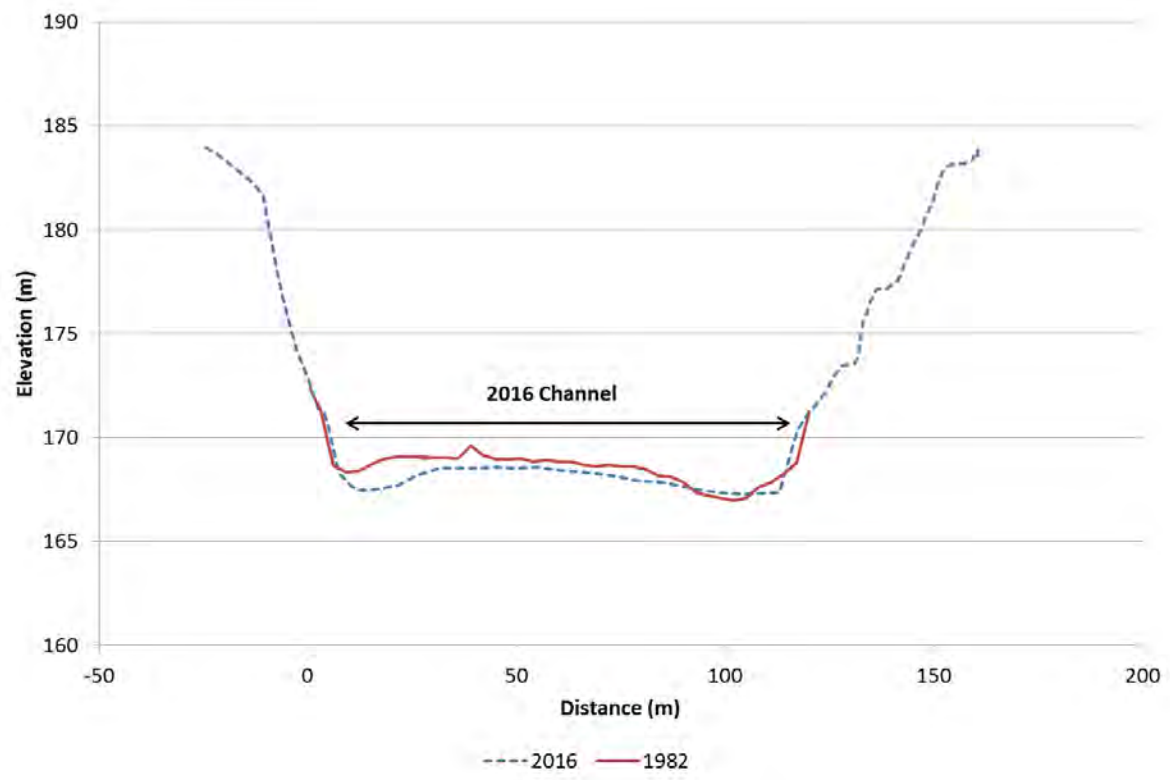


Figure 84. **Clutha River/Mata-Au cross-section C36, looking downstream**

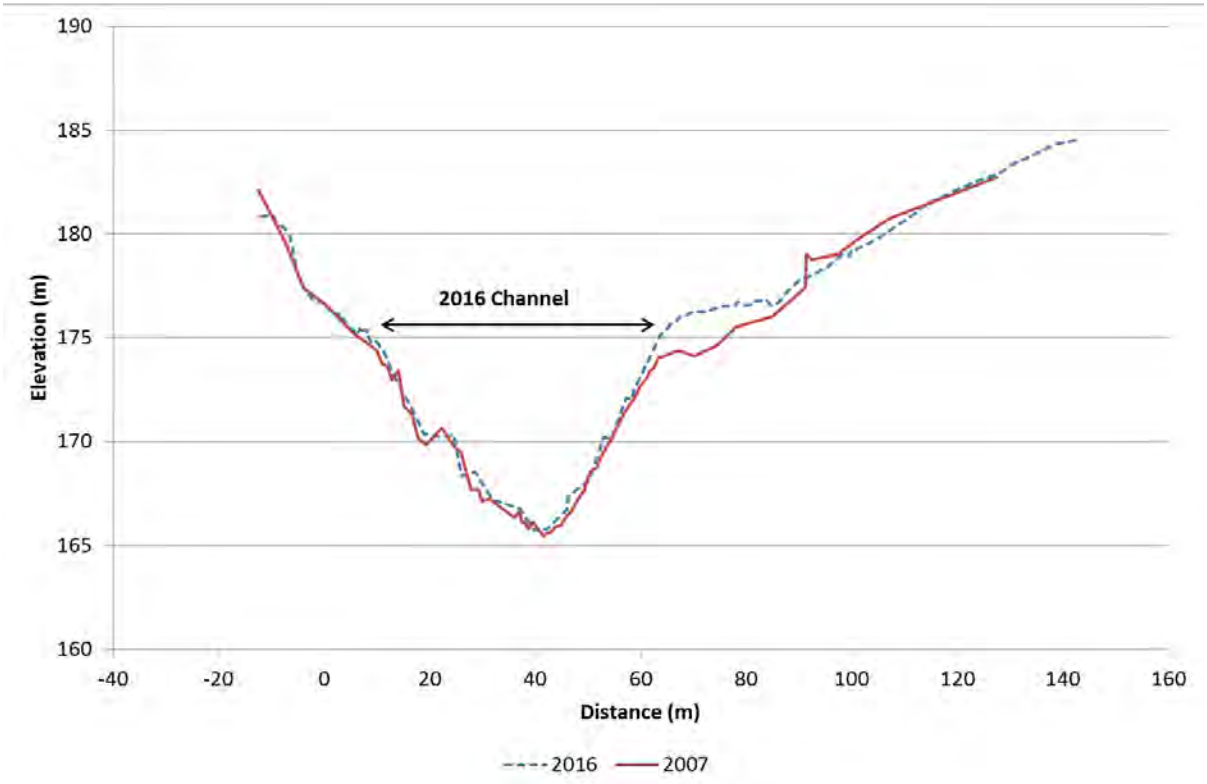


Figure 85. **Clutha River/Mata-Au cross-section C37, looking downstream**

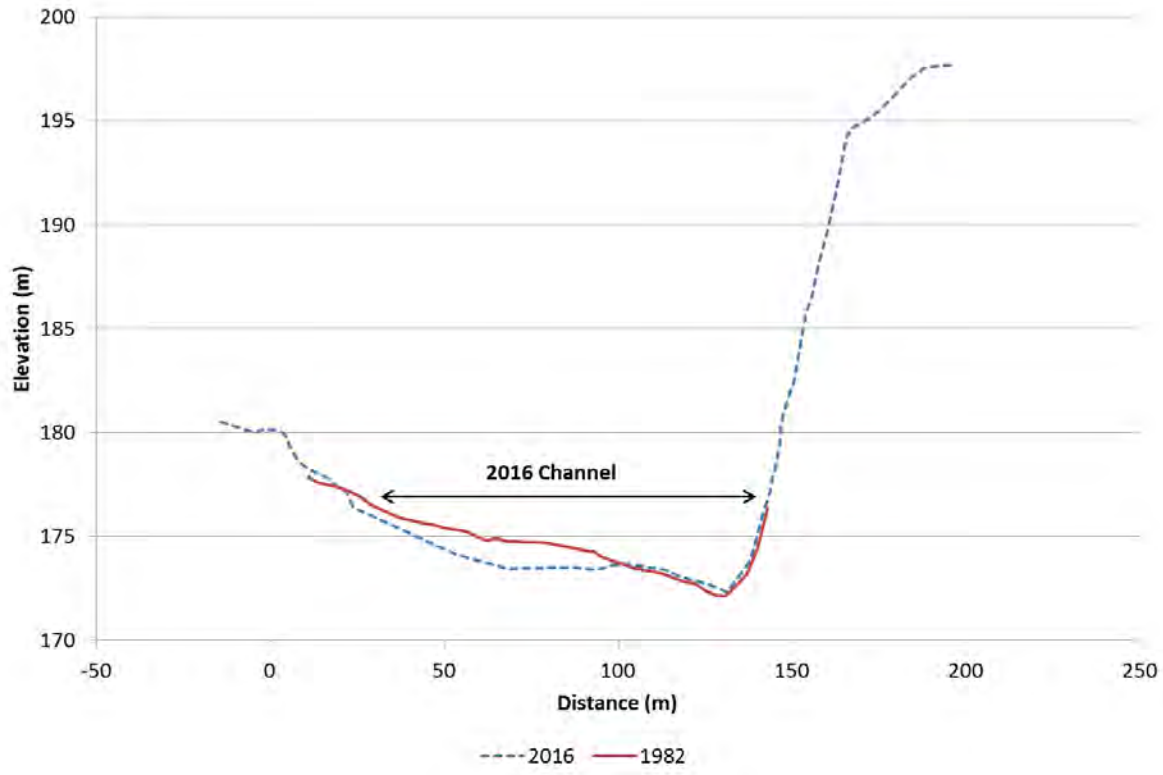


Figure 86. **Clutha River/Mata-Au cross-section C38, looking downstream**

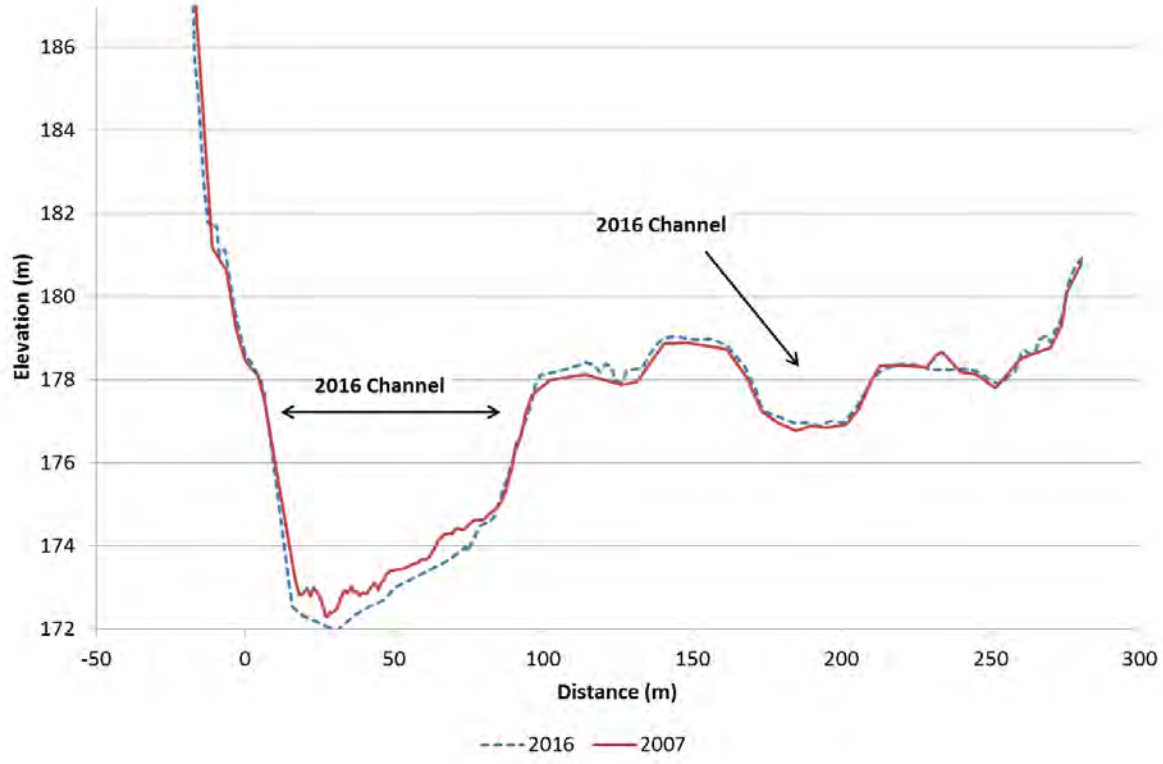


Figure 87. **Clutha River/Mata-Au cross-section C39, looking downstream**

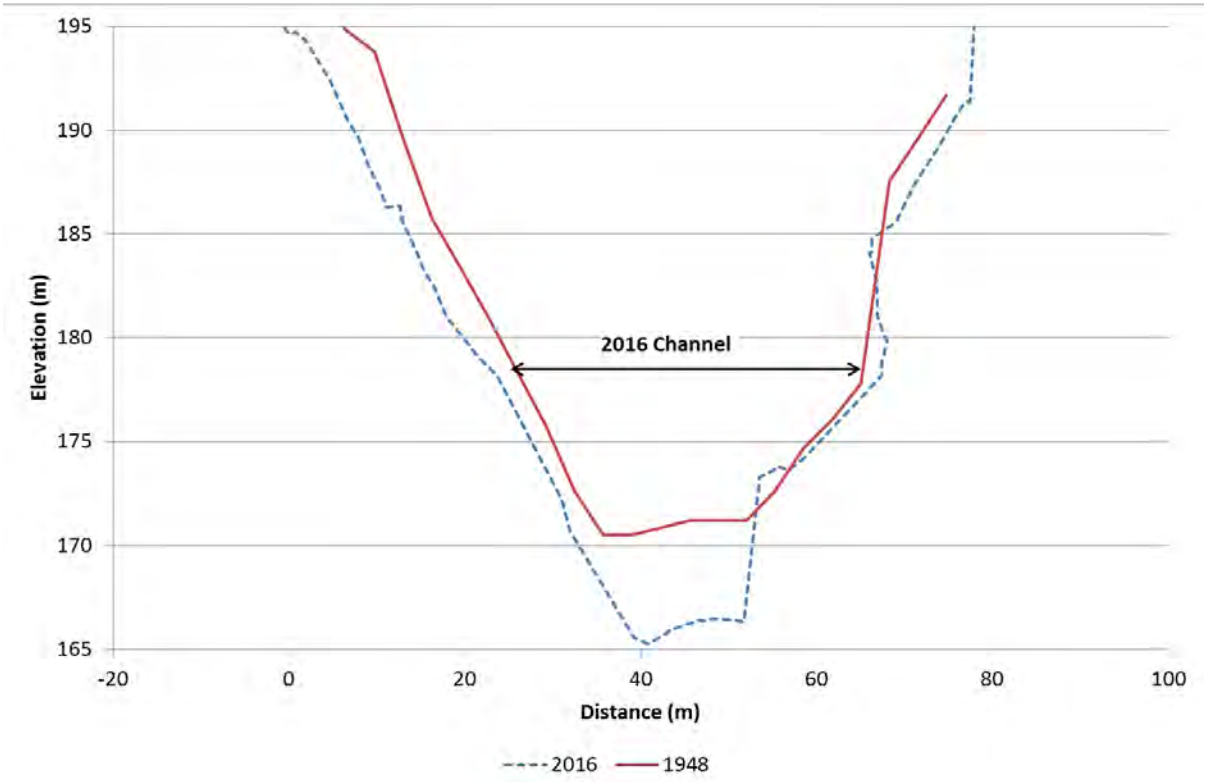


Figure 88. **Clutha River/Mata-Au cross-section C41, looking downstream**

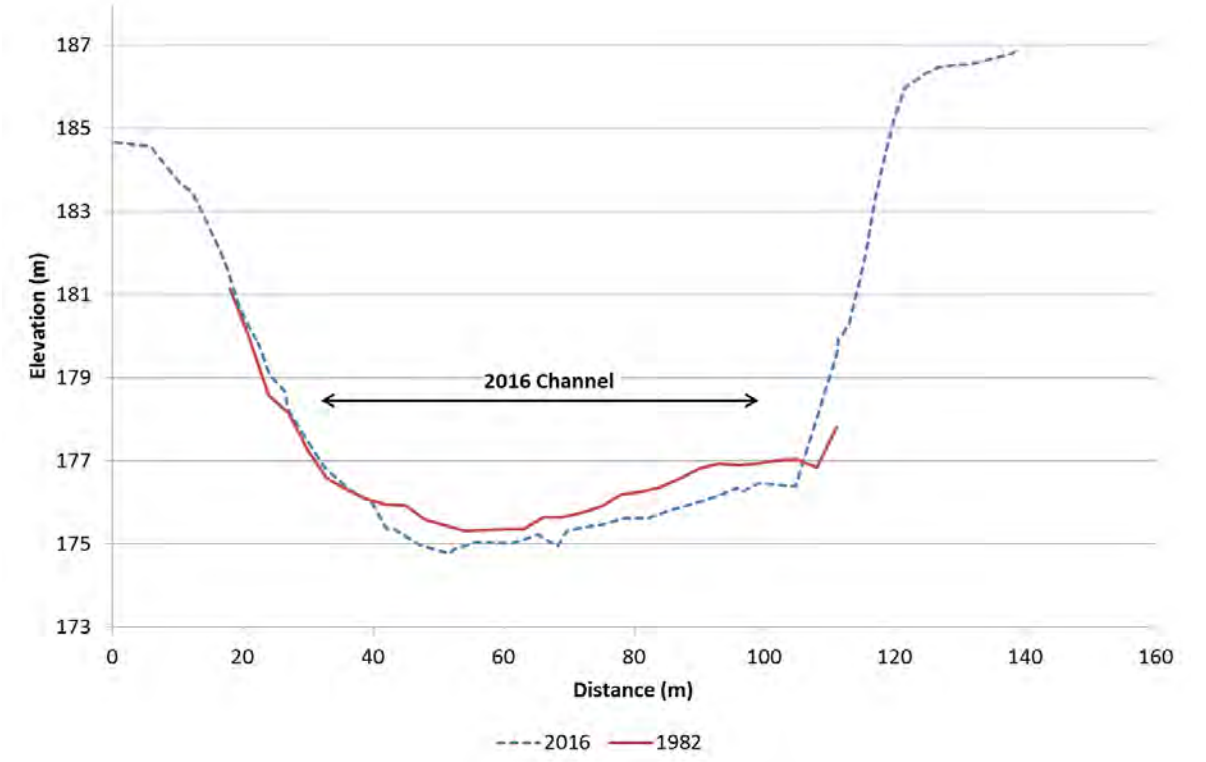


Figure 89. **Clutha River/Mata-Au cross-section C42, looking downstream**

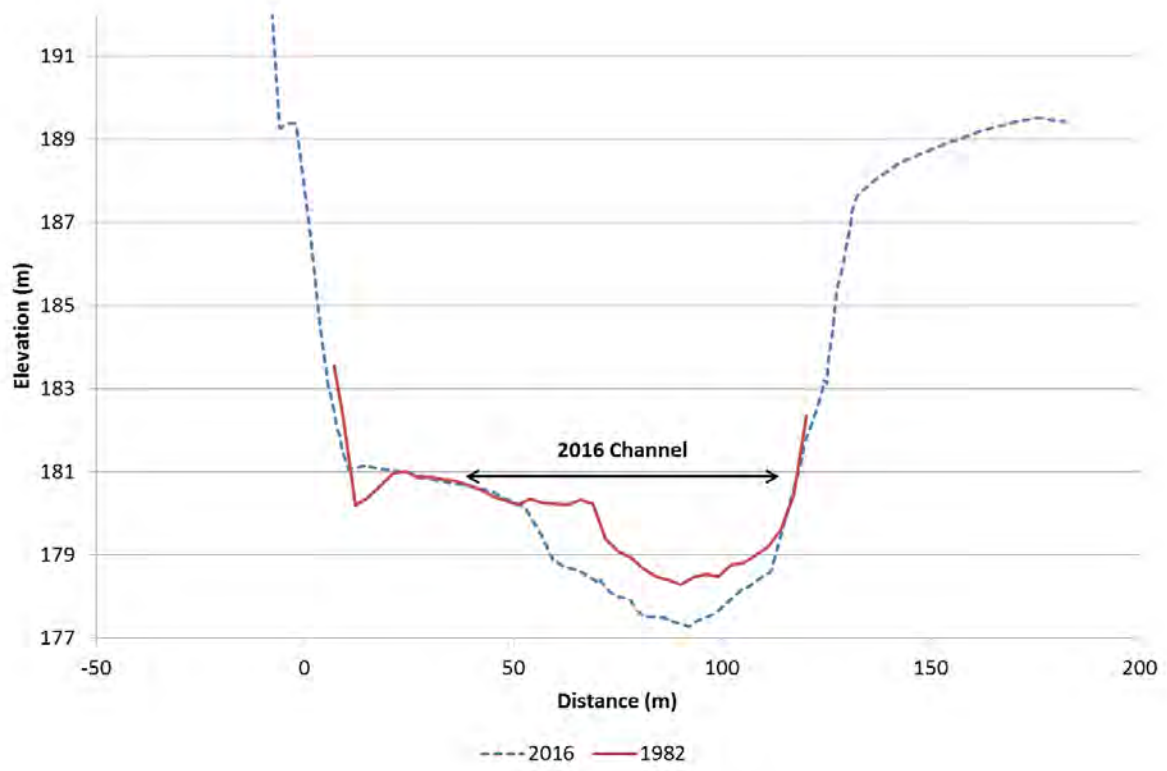


Figure 90. **Clutha River/Mata-Au cross-section C43, looking downstream**

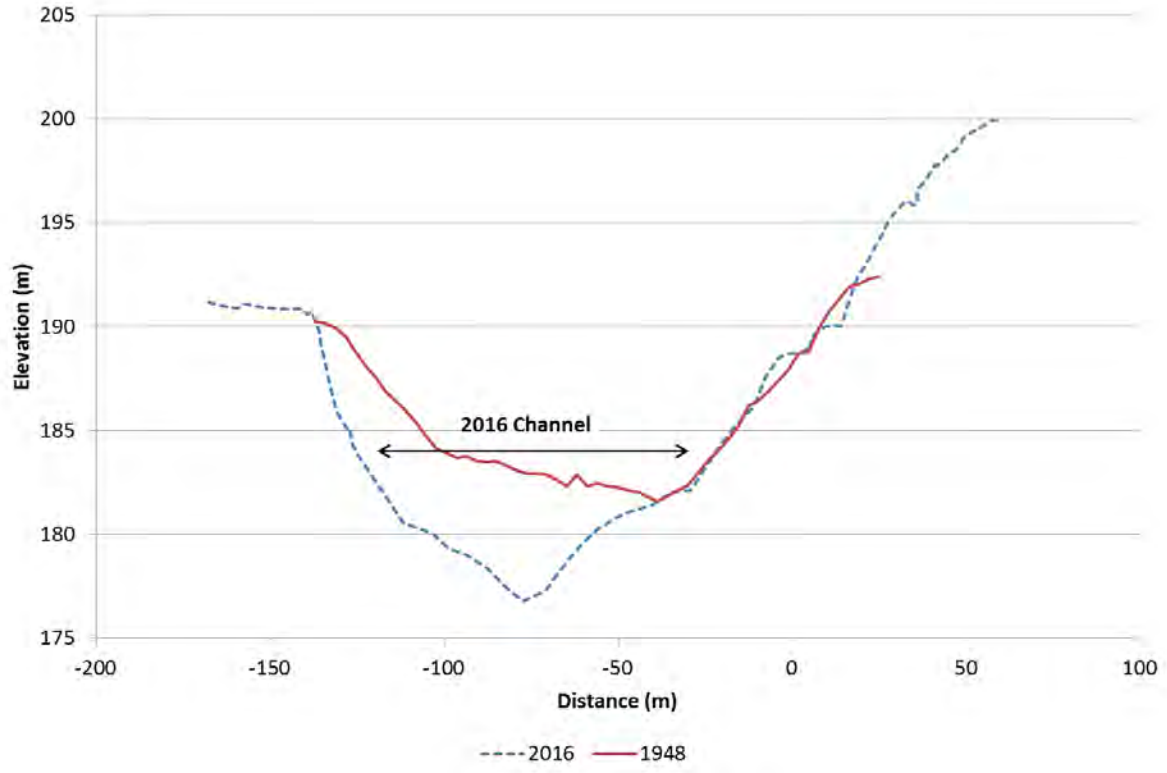


Figure 91. **Clutha River/Mata-Au cross-section C44, looking downstream**

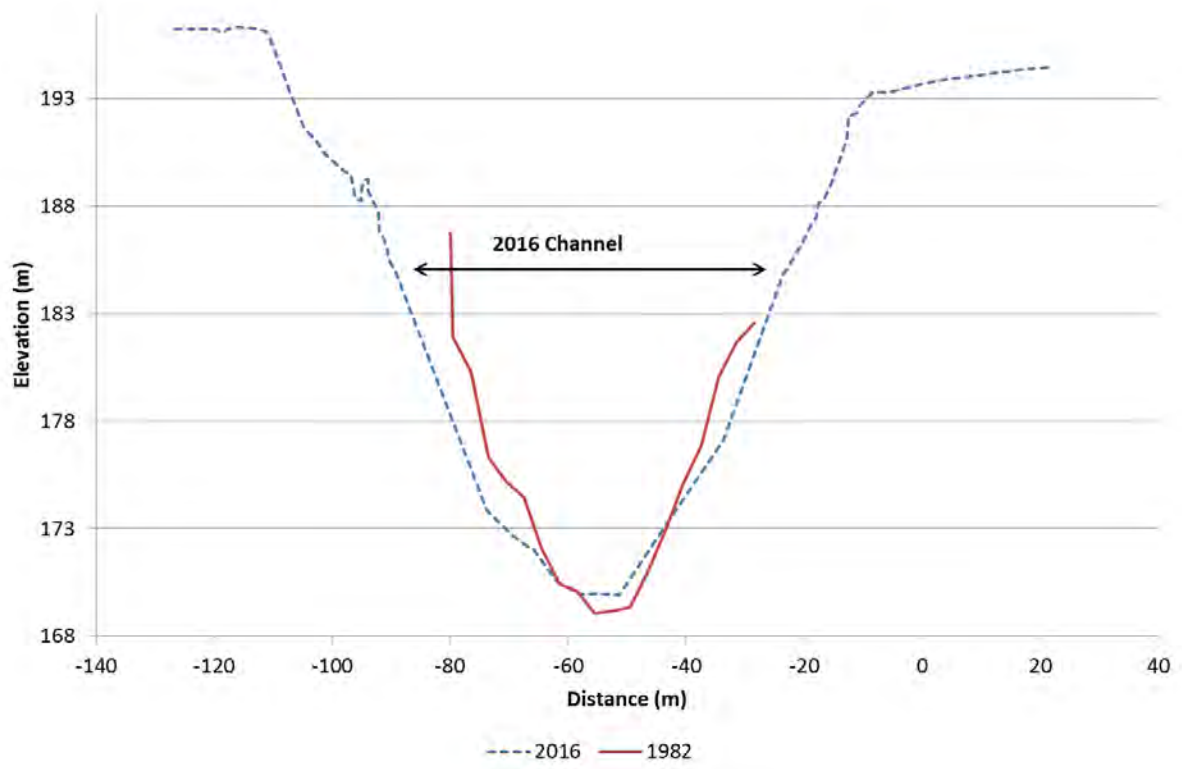


Figure 92. Clutha River/Mata-Au cross-section C45, looking downstream

Appendix C: Summaries – Clutha River/Mata-Au cross-sections

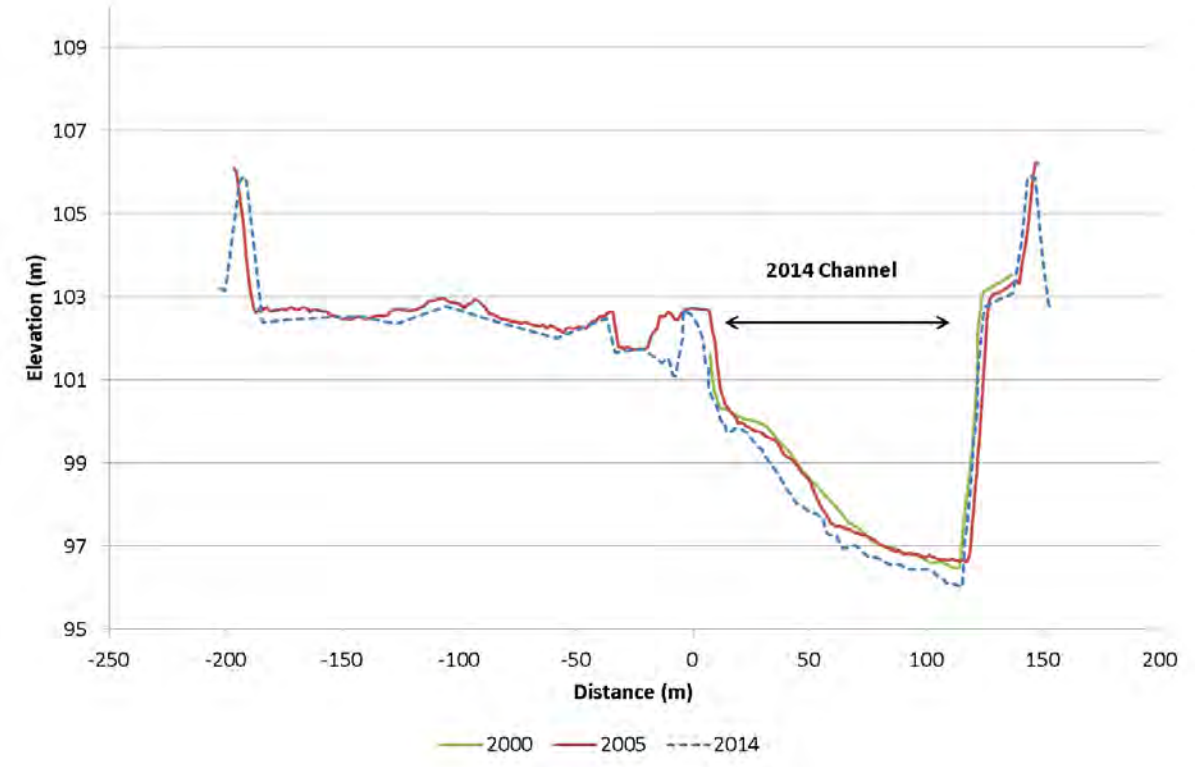


Figure 93. **Clutha River/Mata-Au cross-section K67, looking downstream**

Figure 94. **Clutha River/Mata-Au cross-section K67, looking downstream**

Cross-section K67 is located 6.8 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the Pacific Ocean. Between 2005 and 2014 the main channel has deepened with some erosion and topography change on the true left floodplain.

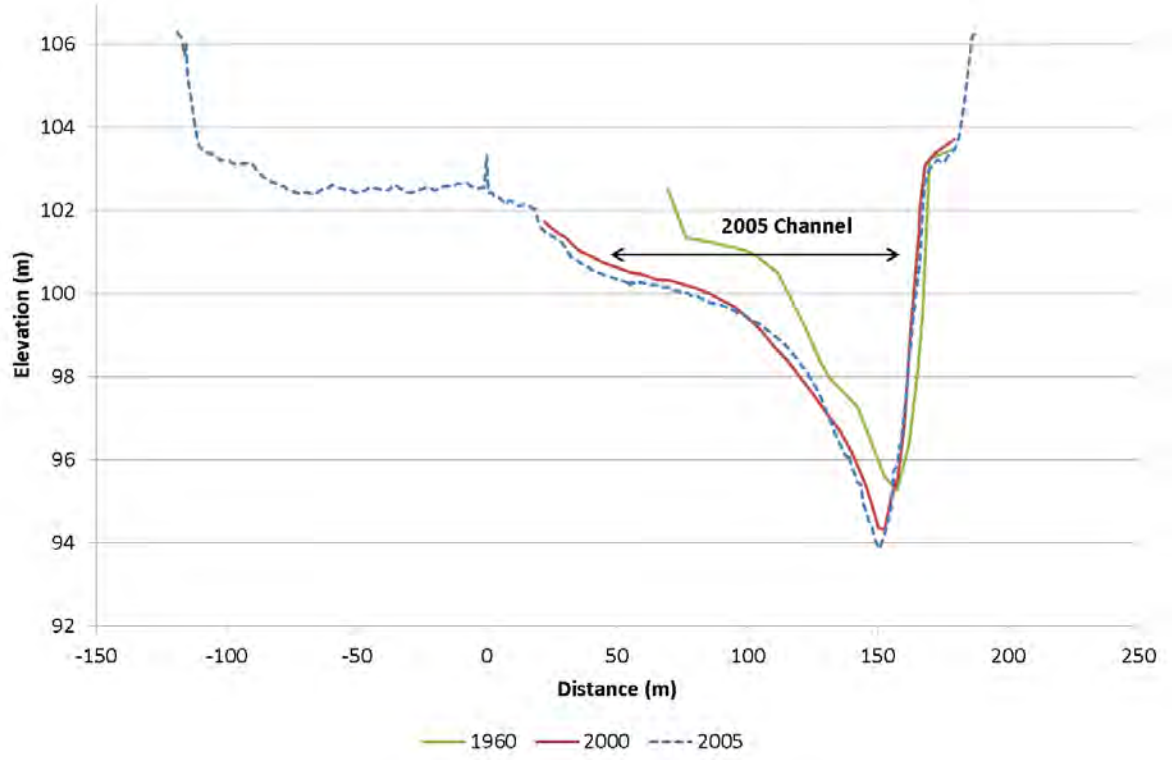


Figure 95. Clutha River/Mata-Au cross-section K64, looking downstream

Cross-section K64 is located 7.1 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the Pacific Ocean. Limited change occurred between the two latest surveys of 2000 and 2005, the thalweg has decreased and there has been aggradation of the true left of the main channel.

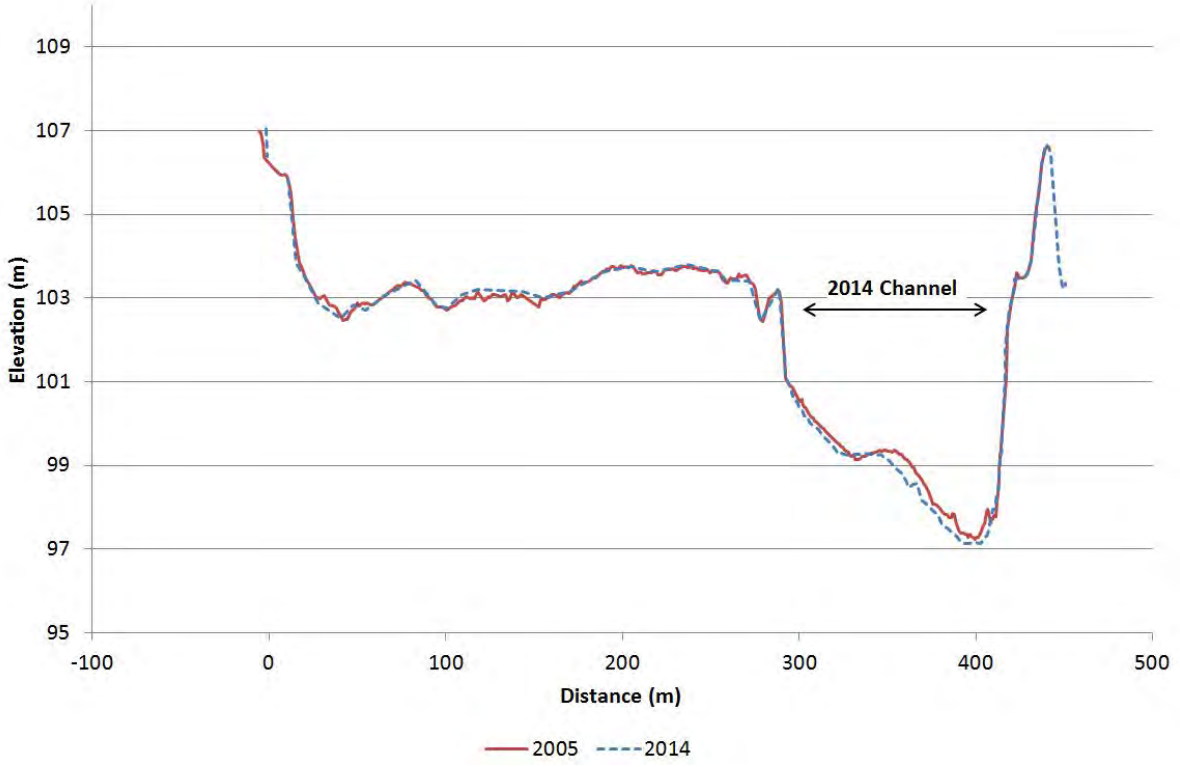


Figure 96. **Clutha River/Mata-Au cross-section K54, looking downstream**

Figure 97. **Clutha River/Mata-Au cross-section K54 looking from true right to true left bank**

Cross-section K54 is located 9 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the Pacific Ocean. Between 2014 and 2005 the main channel has degraded slightly.

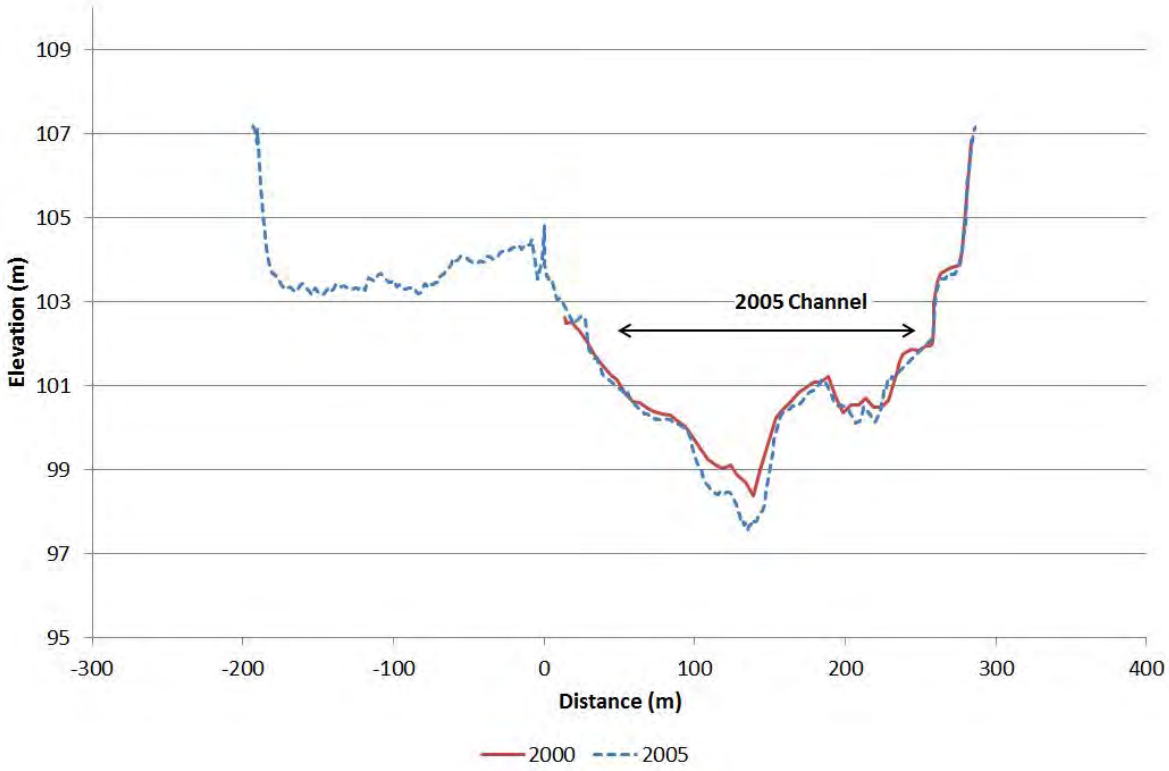


Figure 98. Clutha River/Mata-Au cross-section K48, looking downstream

Cross-section K48 is located 9.3 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the Pacific Ocean. The main channel experienced degradation with the thalweg lowering by about 1 m between 2000 and 2005.

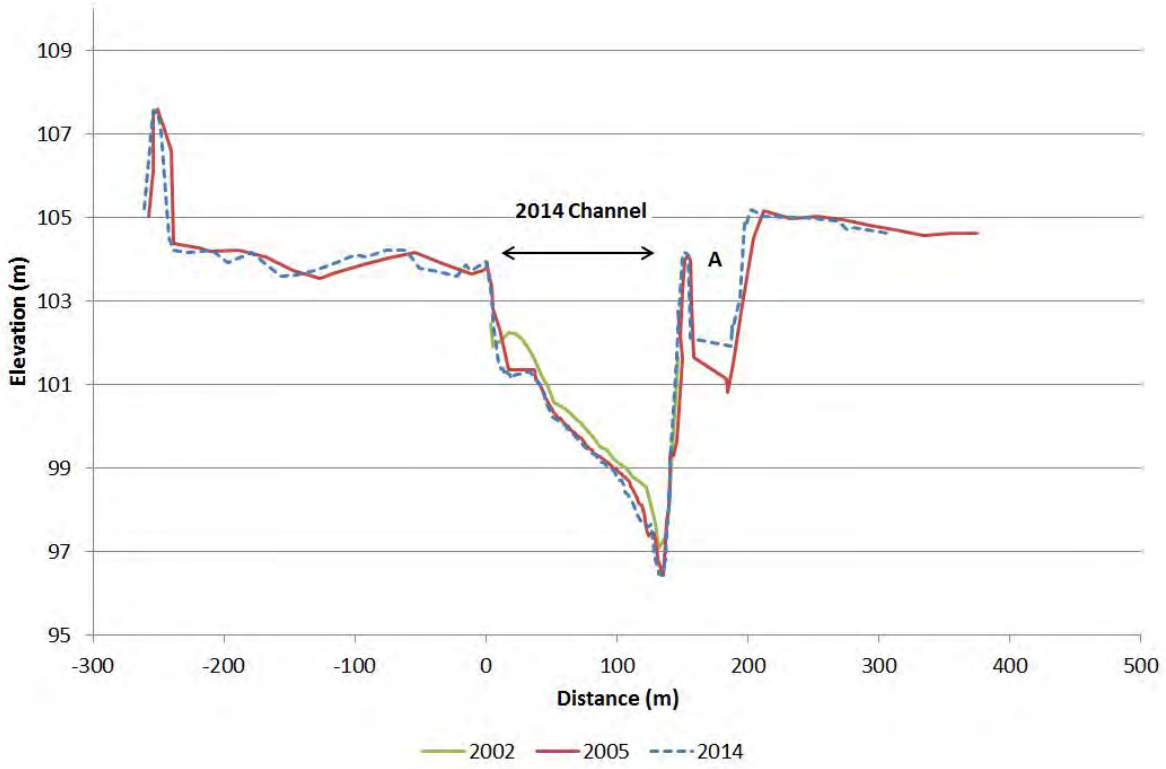


Figure 99. **Clutha River/Mata-Au cross-section K9, looking downstream**

Figure 100. **Clutha River/Mata-Au cross-section K9 looking from true right to true left bank**

Cross-section K9 is located 10.5 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the Pacific Ocean. The backwater (point labelled A) aggraded between 2005 and 2014. The main channel remained similar between 2002 and 2005 with some degradation occurring through the main channel.

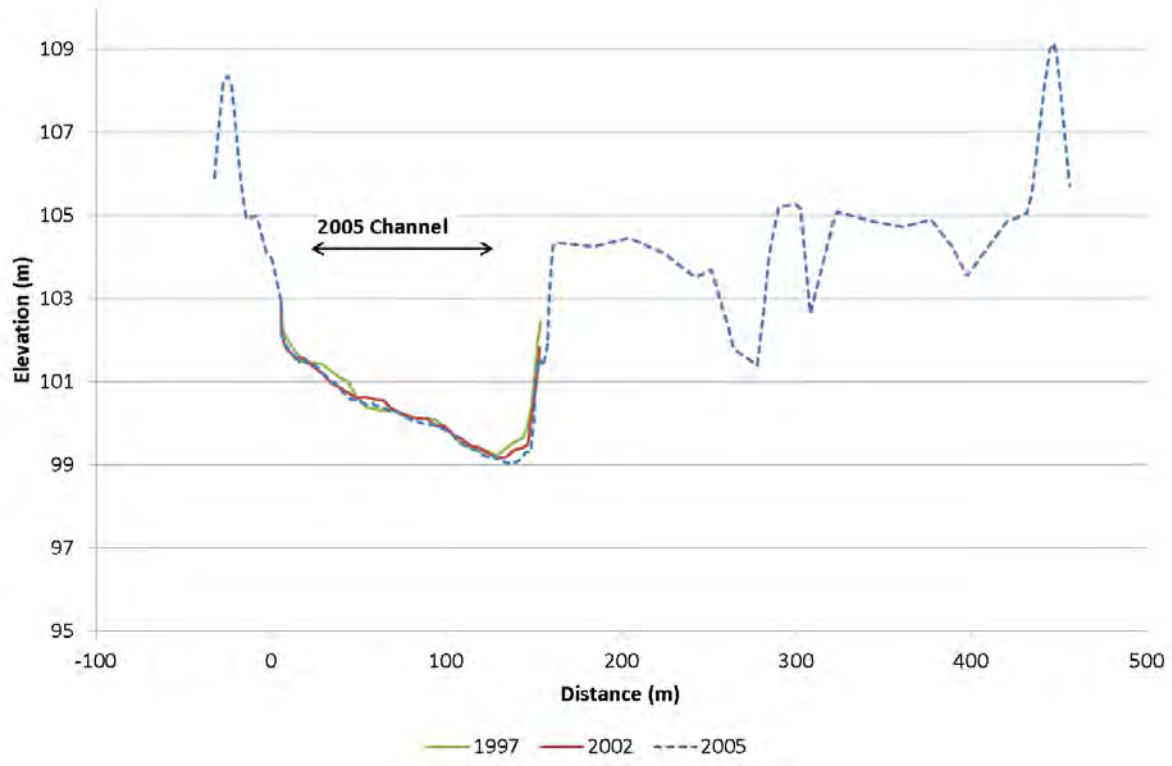


Figure 101. Clutha River/Mata-Au cross-section K10, looking downstream

Cross-section K10 is located 11.2 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the Pacific Ocean. Between 2002 and 2005 the channel bed has remained similar. The 2002 survey did not extend sufficiently up the banks to allow a comparison to be made.

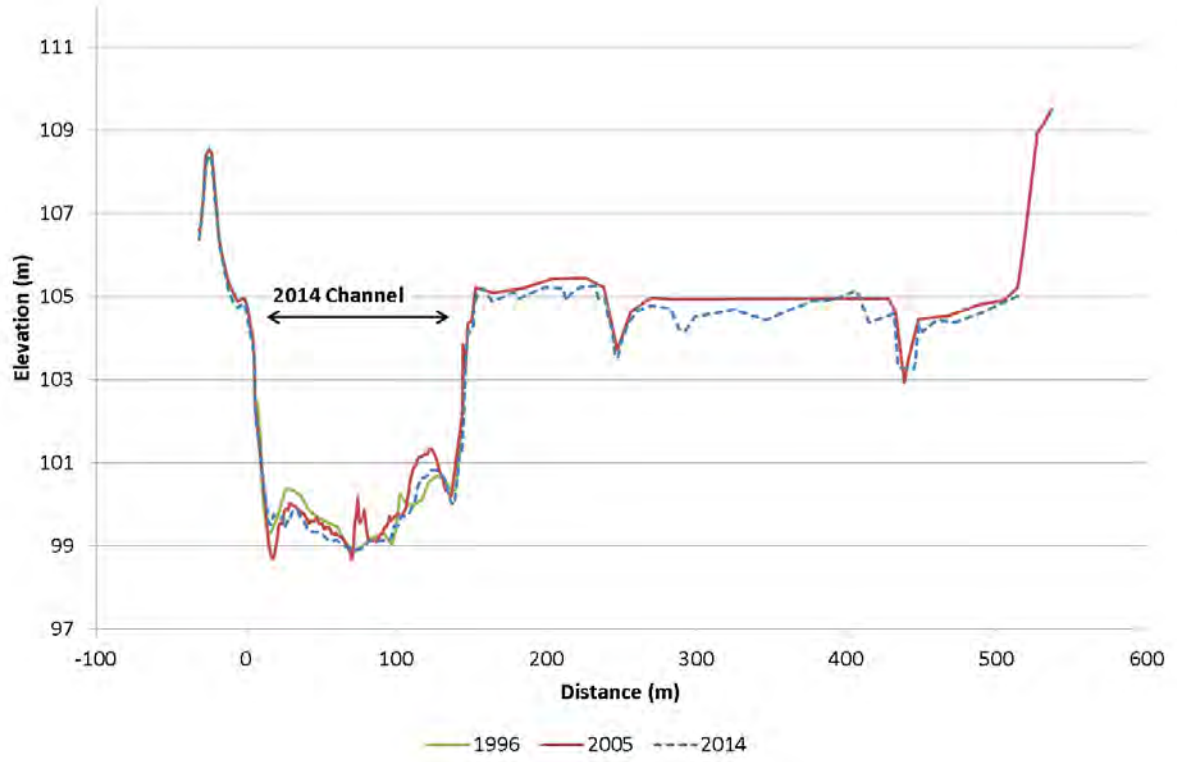


Figure 102. Clutha River/Mata-Au cross-section K10A, looking downstream

Figure 103. Clutha River/Mata-Au cross-section K10A, looking downstream

Cross-section K10A is located 11.5 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the Pacific Ocean. Between 2005 and 2014 the main channel has both aggraded and degraded with the thalweg staying at a similar position. The true right floodplain has degraded between 2005 and 2014.

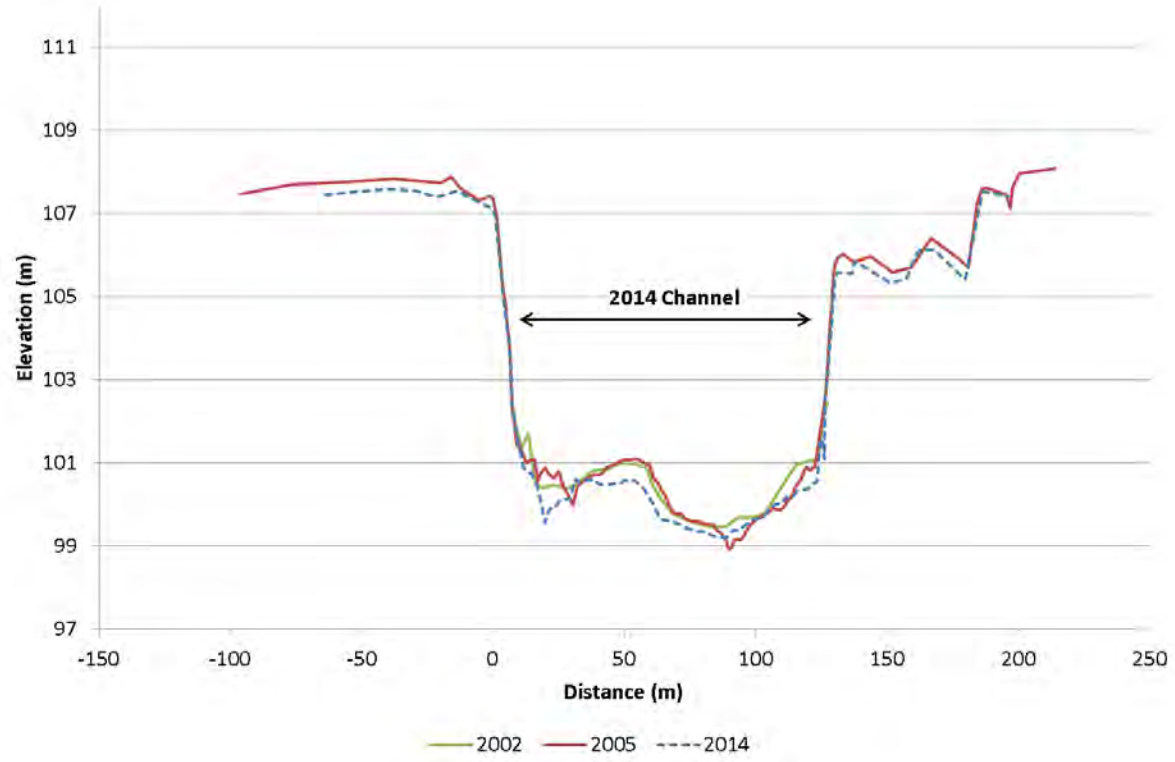


Figure 104. Clutha River/Mata-Au cross-section K11, looking downstream

Figure 105. Clutha River/Mata-Au cross-section K11, looking downstream

Cross-section K11 is located 12.9 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au and the Pacific Ocean. Between 2005 and 2014, the main channel experienced mostly degradation with a small increase in the thalweg level. The true left and right floodplains also degraded between 2005 and 2014.

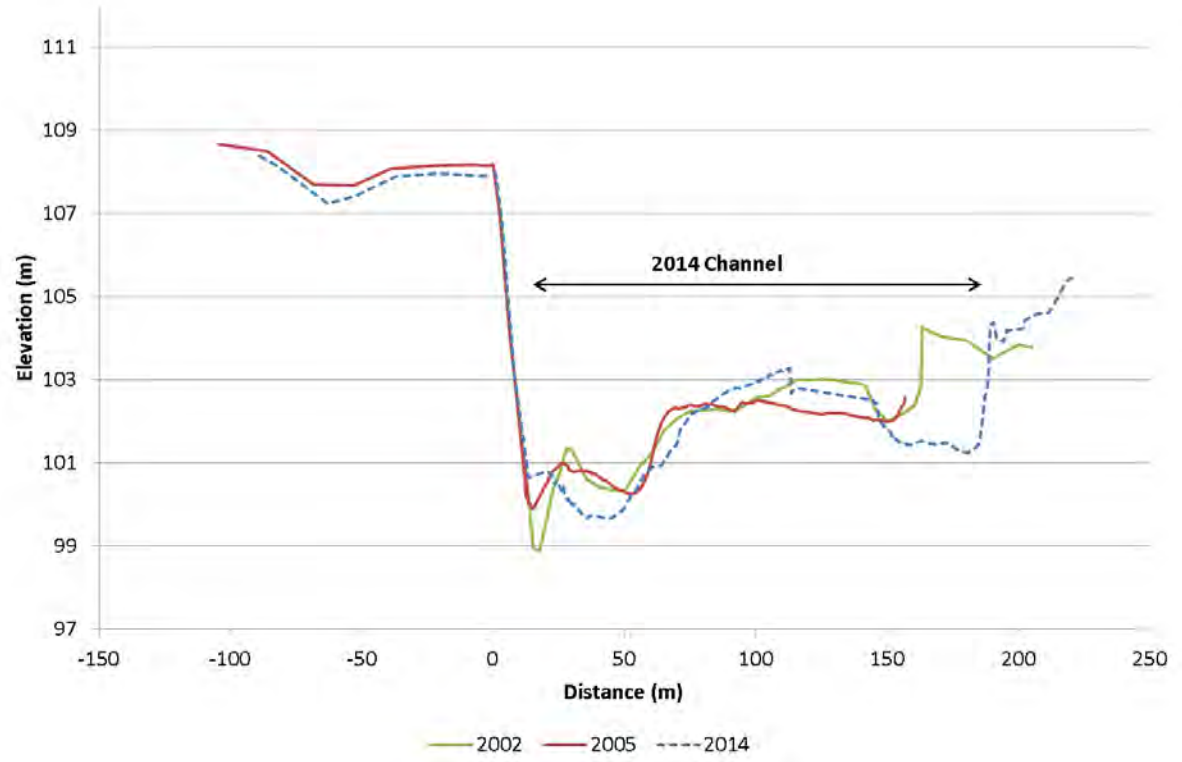


Figure 106. Clutha River/Mata-Au cross-section K12, looking downstream

Figure 107. Clutha River/Mata-Au cross-section K12, looking downstream

Cross-section K12 is located 14.9 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the Pacific Ocean. Between 2005 and 2014 the main channel has experienced both aggradation and degradation on the true left bank, the centre of the channel has aggraded. The true right bank of the main channel appears to have eroded, however the 2005 survey did not extend far enough on the right bank to confirm this.

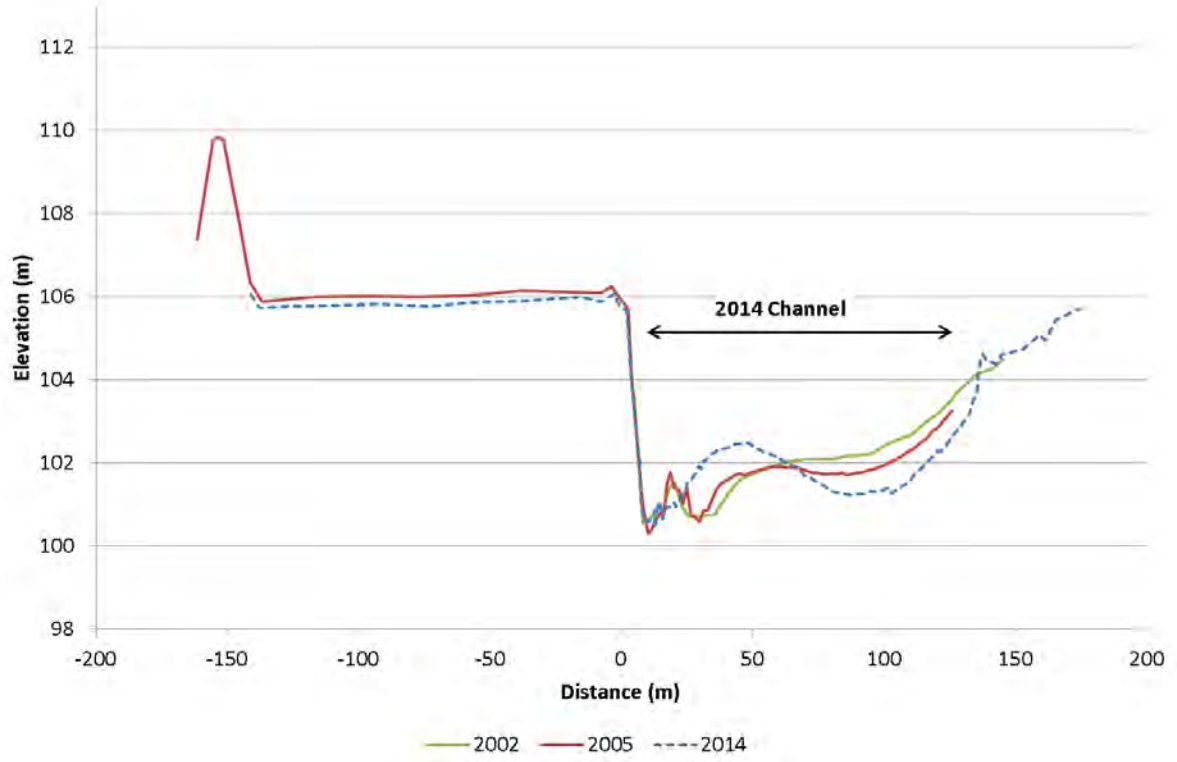


Figure 108. Clutha River/Mata-Au cross-section K13, looking downstream

Figure 109. Clutha River/Mata-Au cross-section K13, looking downstream

Cross-section K13 is located 16 km upstream of the confluence of the Koau branch of the Clutha River/Mata-Au with the confluence of the Pacific Ocean. The true left of the main channel has remained similar between 2005 and 2014, the centre of the main channel has aggraded with degradation and bank erosion occurring on the true right of the main channel.

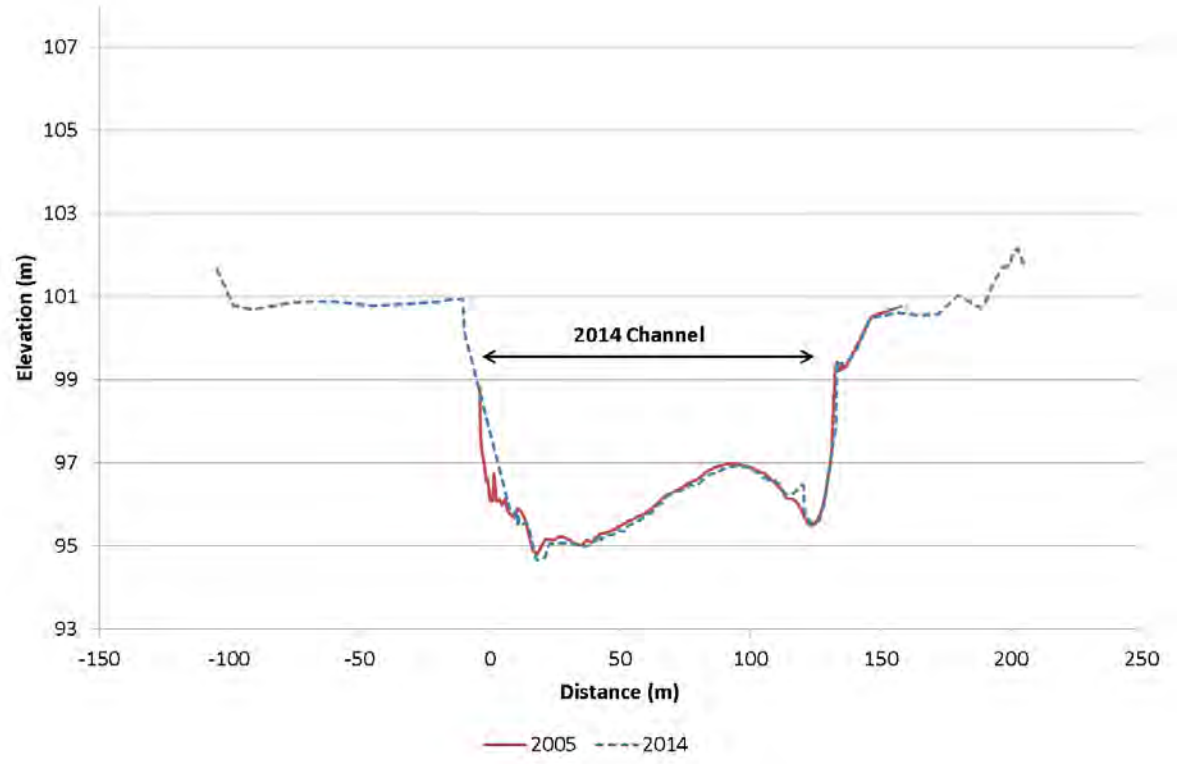


Figure 110. Clutha River/Mata-Au cross-section M223, looking downstream

Figure 111. Clutha River/Mata-Au cross-section M223, looking downstream

Cross-section M223 is located 3.3 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. The main channel has remained in a similar position between 2005 and 2014 with aggradation occurring on the true left bank.

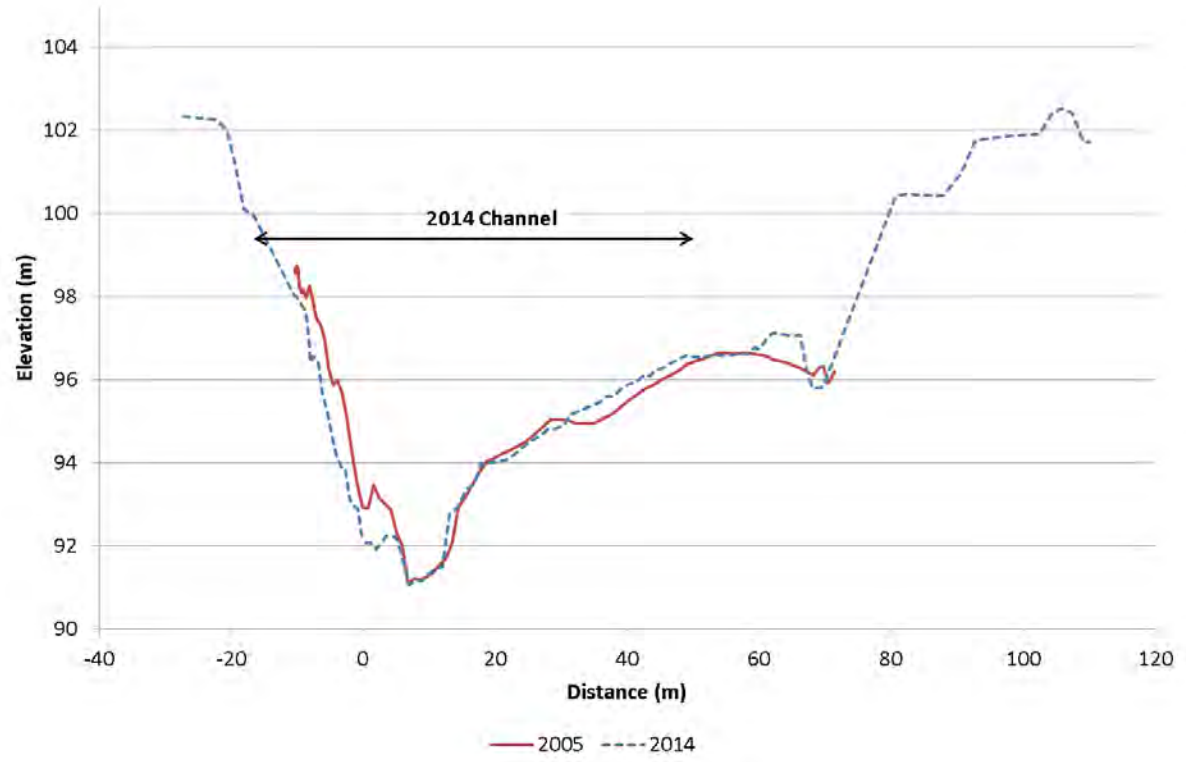


Figure 112. Clutha River/Mata-Au cross-section M202, looking downstream

Figure 113. Clutha River/Mata-Au cross-section M202, looking upstream

Cross-section M202 is located 4.9 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. Between 2005 and 2014 there has been erosion of the true left bank and aggradation of the true right side of the main channel. The 2005 survey did not extend sufficiently far enough on the true right bank to allow a comparisons to be made.

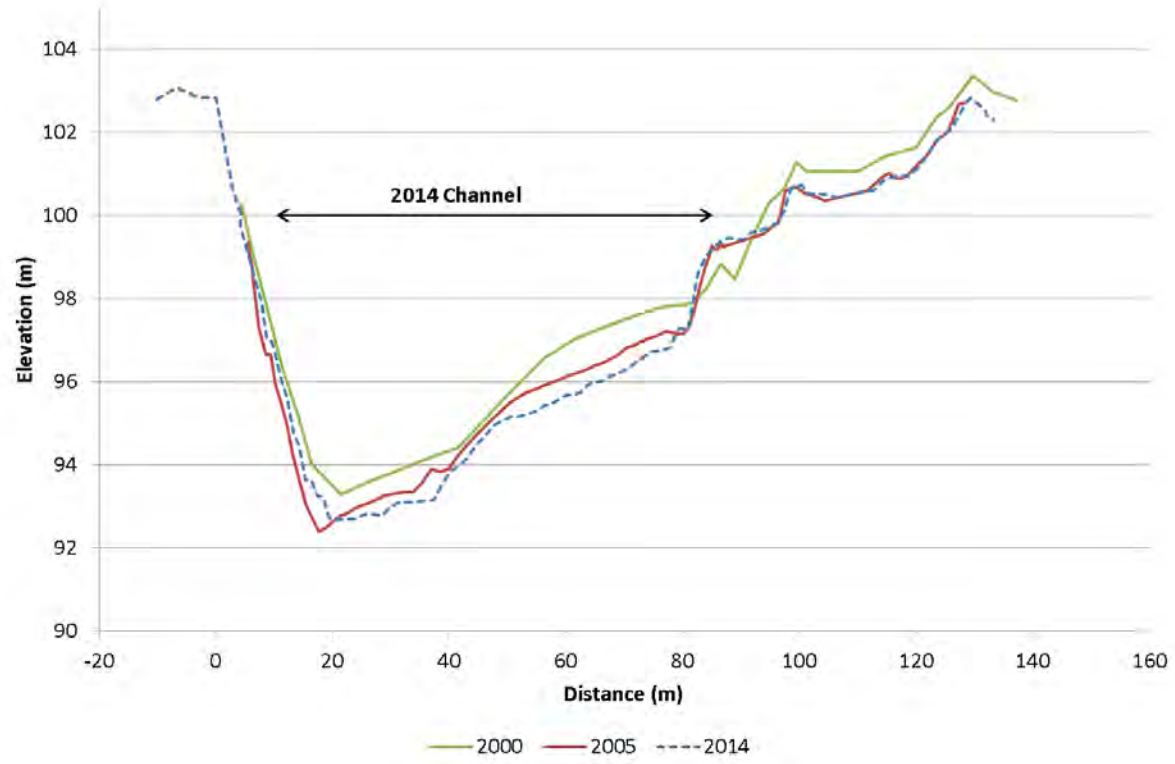


Figure 114. Clutha River/Mata-Au cross-section M195, looking downstream

Figure 115. Clutha River/Mata-Au cross-section M195, looking from true left to right bank

Cross-section M195 is located 5.3 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. The channel has degraded between 2005 and 2014 with some aggradation occurring on the true left bank.

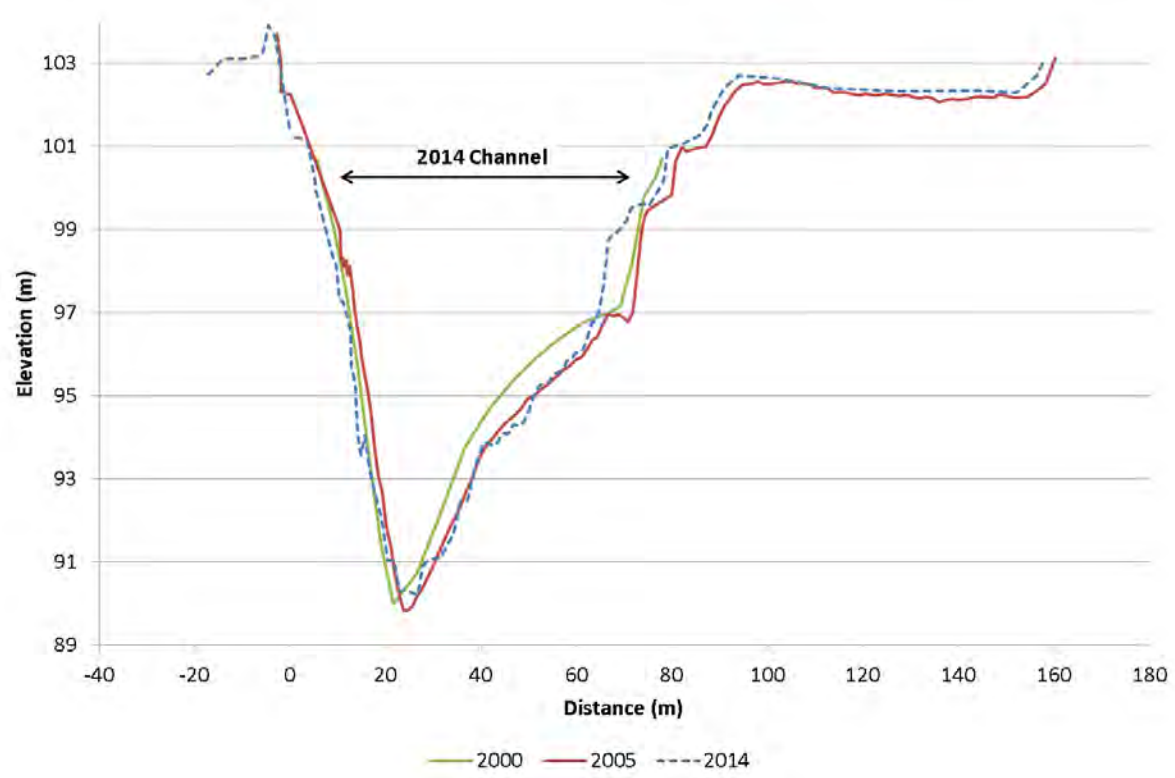


Figure 116. Clutha River/Mata-Au cross-section M154, looking downstream

Figure 117. Clutha River/Mata-Au cross-section M154, looking from true left to right bank

Cross-section M154 is located 9 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean and 150 m upstream of the Riverside Road bridge. The true left bank has eroded between 2005 and 2014 with a small increase in the thalweg level. The true right bank has aggraded and there is minor change in the true right floodplain between 2005 and 2014.

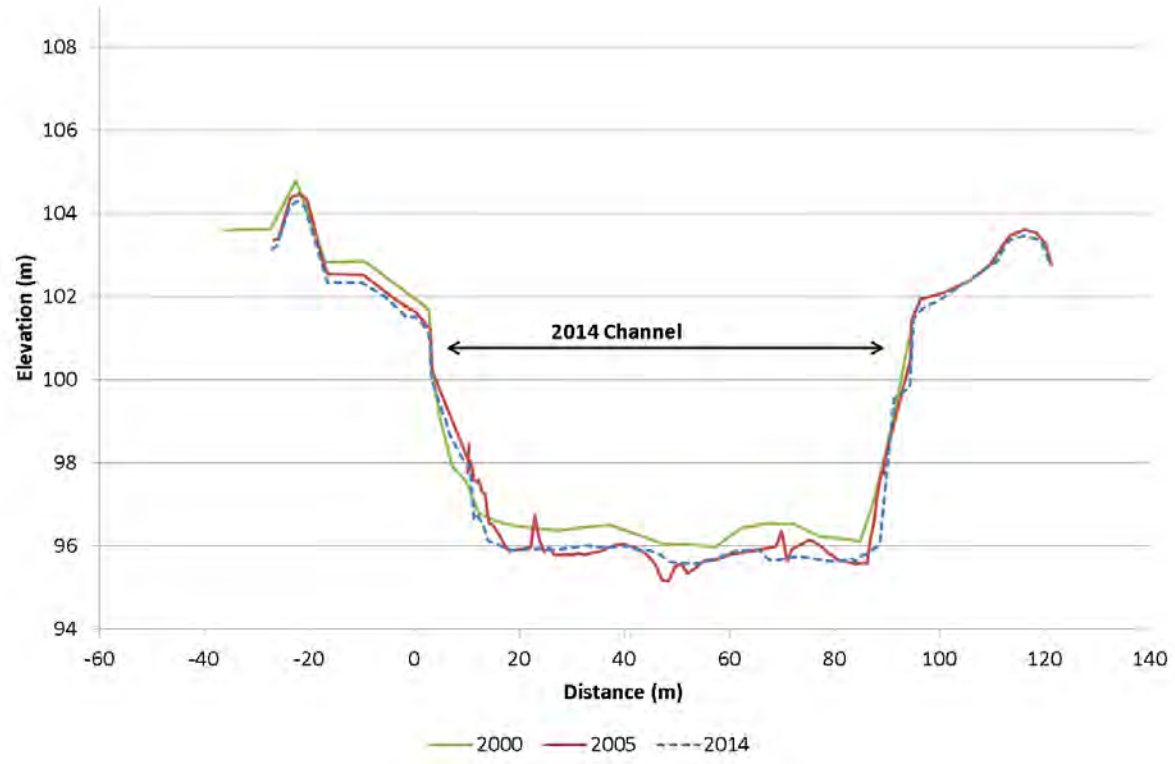


Figure 118. Clutha River/Mata-Au cross-section M147, looking downstream

Figure 119. Clutha River/Mata-Au cross-section M147, looking upstream

Cross-section M147 is located 9.8 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au and the Pacific Ocean. There has been minimal change in the channel between 2005 and 2014 with both aggradation and degradation occurring. The channel has degraded by about 0.5 m between 2000 and 2014.

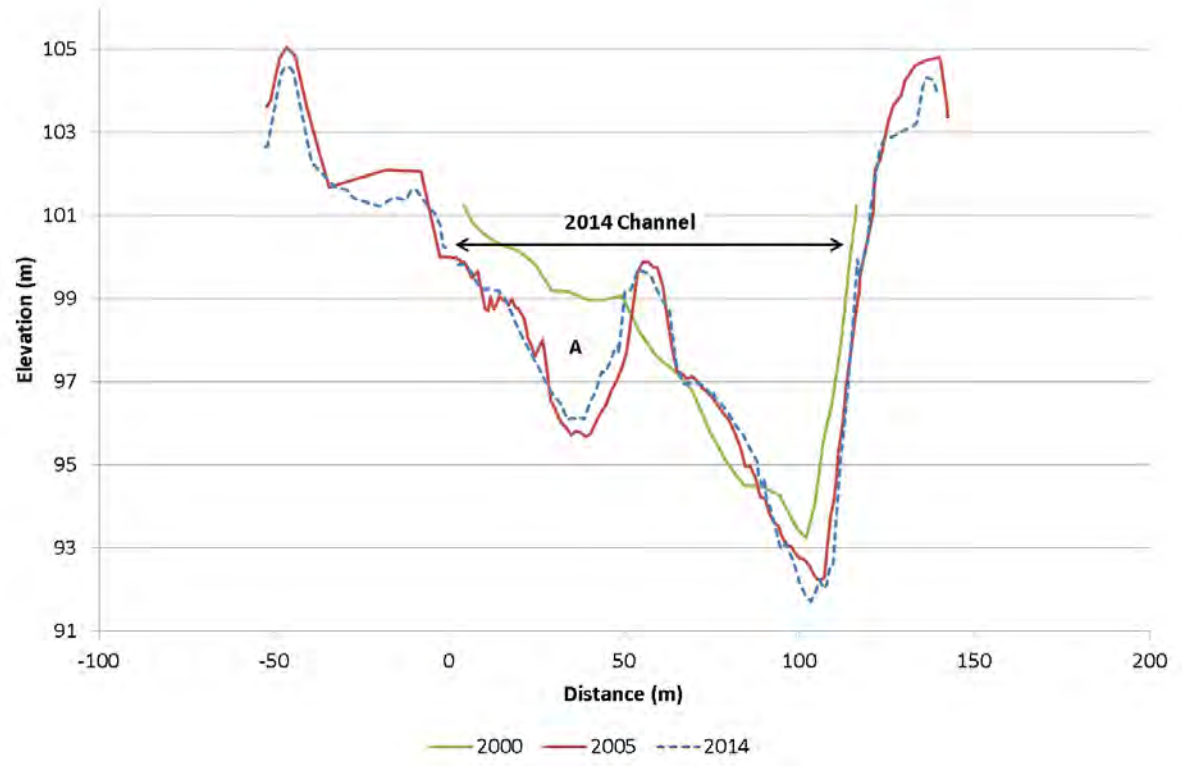


Figure 120. Clutha River/Mata-Au cross-section M140, looking downstream

Figure 121. Clutha River/Mata-Au cross-section M140, looking upstream

Cross-section M140 is located 10.7 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au and the Pacific Ocean. The true left of the channel (point labelled A) forms part of a backwater channel during low flows and has aggraded between 2005 and 2014, but has degraded significantly since 2000. The true right of the channel has degraded between 2005 and 2014 with degradation occurring on both banks.

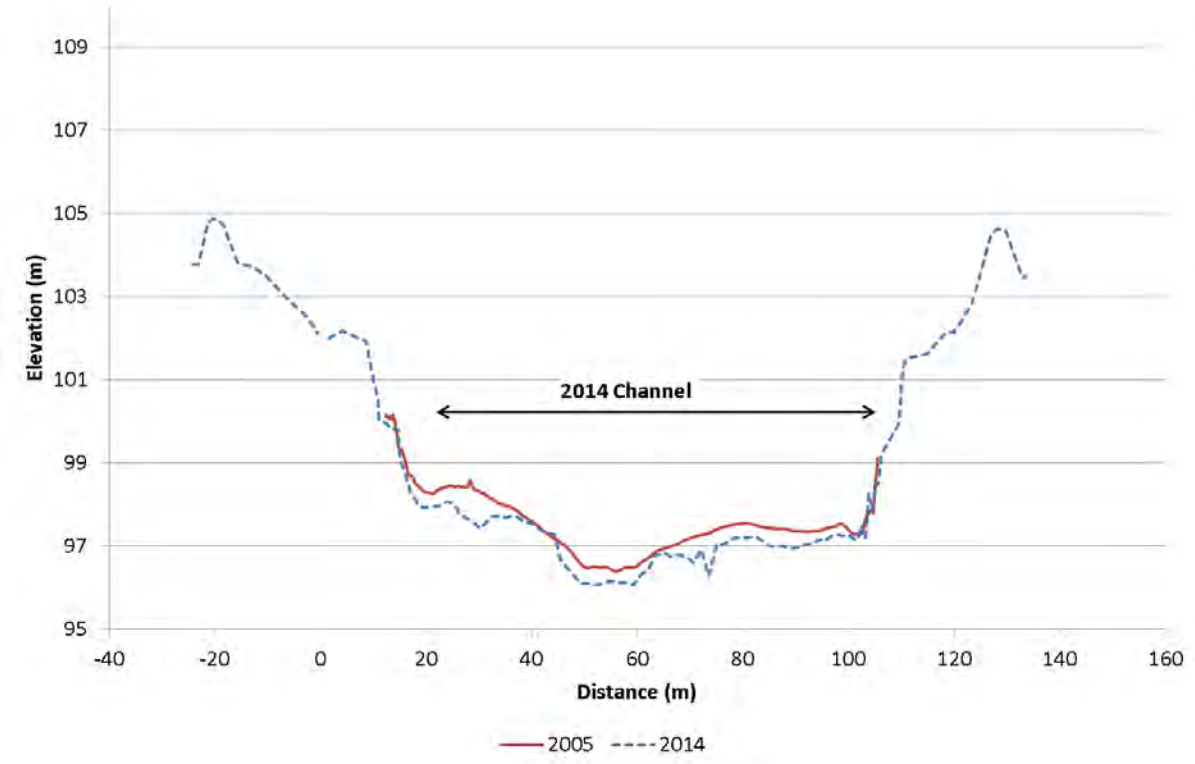


Figure 122. Clutha River/Mata-Au cross-section M128, looking downstream

Figure 123. Clutha River/Mata-Au cross-section M128, looking from true right to left bank

Cross-section M128 is located 11.7 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au and the Pacific Ocean. The main channel has predominately degraded between 2005 and 2014; the 2005 survey did not extend significantly enough on the banks to allow a comparison to be made.

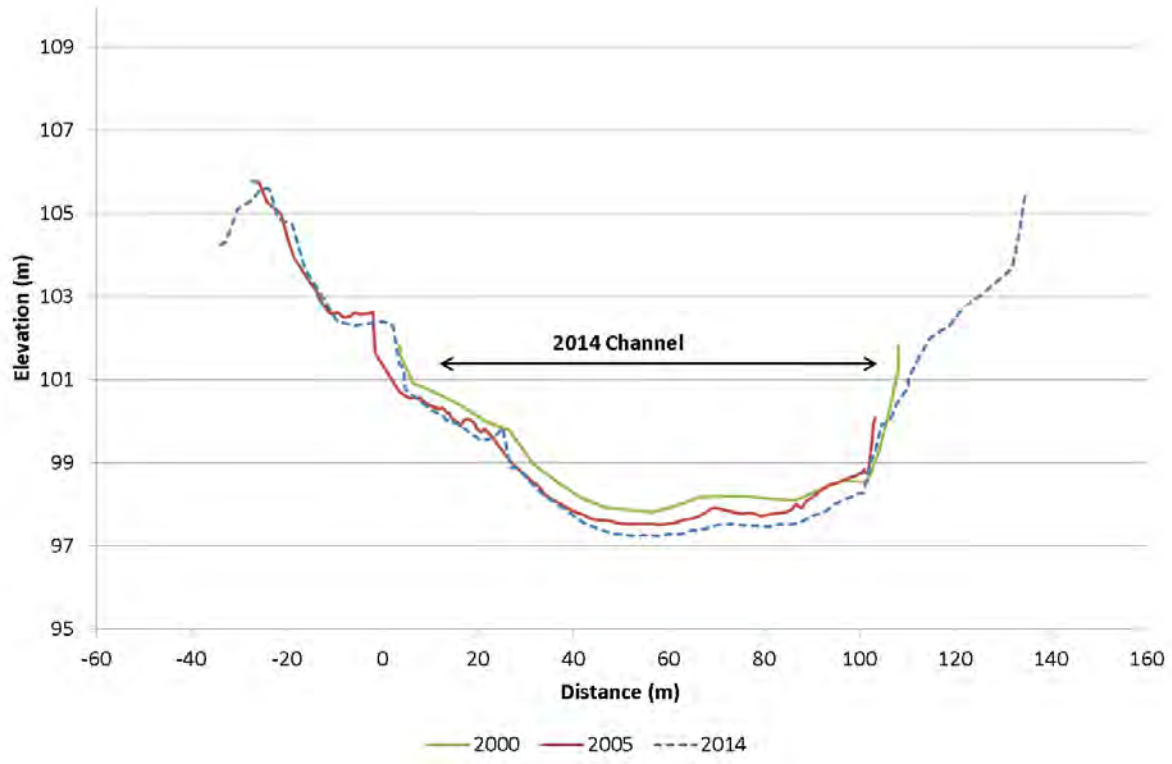


Figure 124. Clutha River/Mata-Au cross-section M99, looking downstream

Figure 125. Clutha River/Mata-Au cross-section M99, looking upstream

Cross-section M99 is located 11.9 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au and the Pacific Ocean. The main channel has degraded between 2005 and 2014 with some aggradation occurring on the true left bank. The 2005 survey did not extend sufficiently enough to allow a comparison of the true right bank to be undertaken.

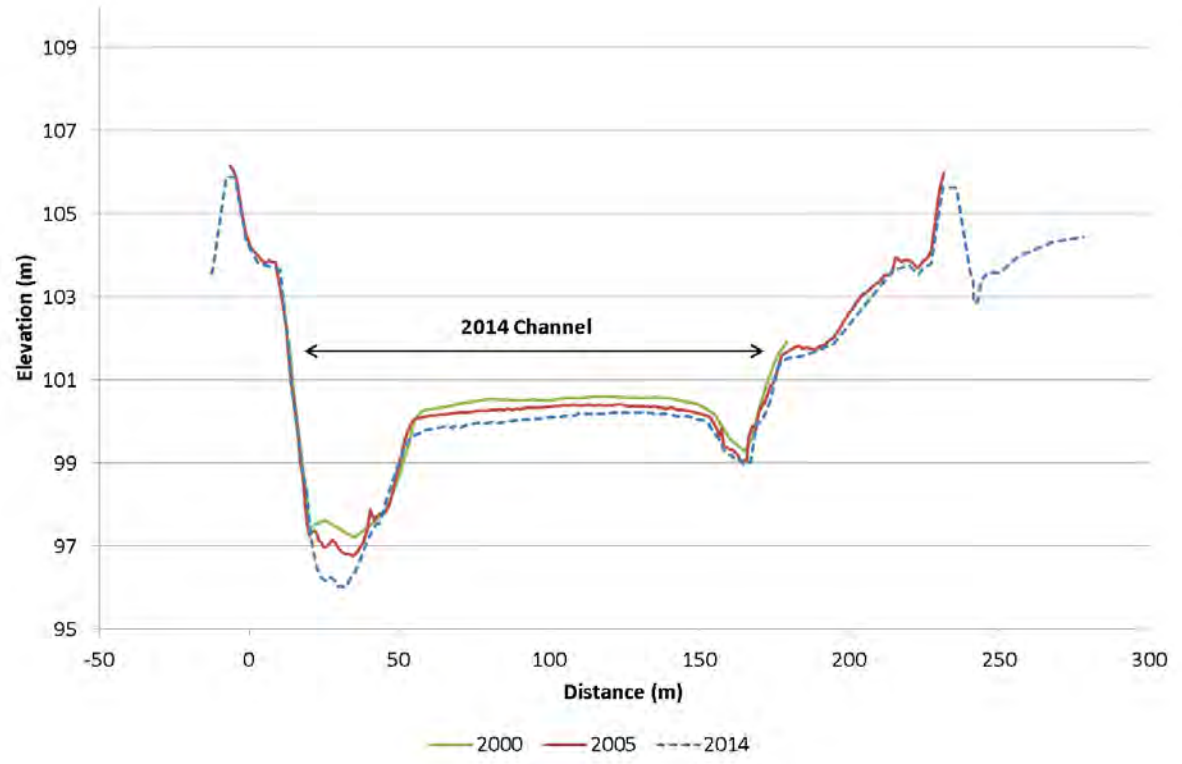


Figure 126. Clutha River/Mata-Au cross-section M94, looking downstream

Figure 127. Clutha River/Mata-Au cross-section M94, looking from true right to left bank

Cross-section M94 is located 15.7 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au and the Pacific Ocean. The channel thalweg has lowered between 2005 and 2014 with degradation occurring across the wider channel between 2005 and 2014. The wider left and right bank floodplains have remained similar between 2005 and 2014.

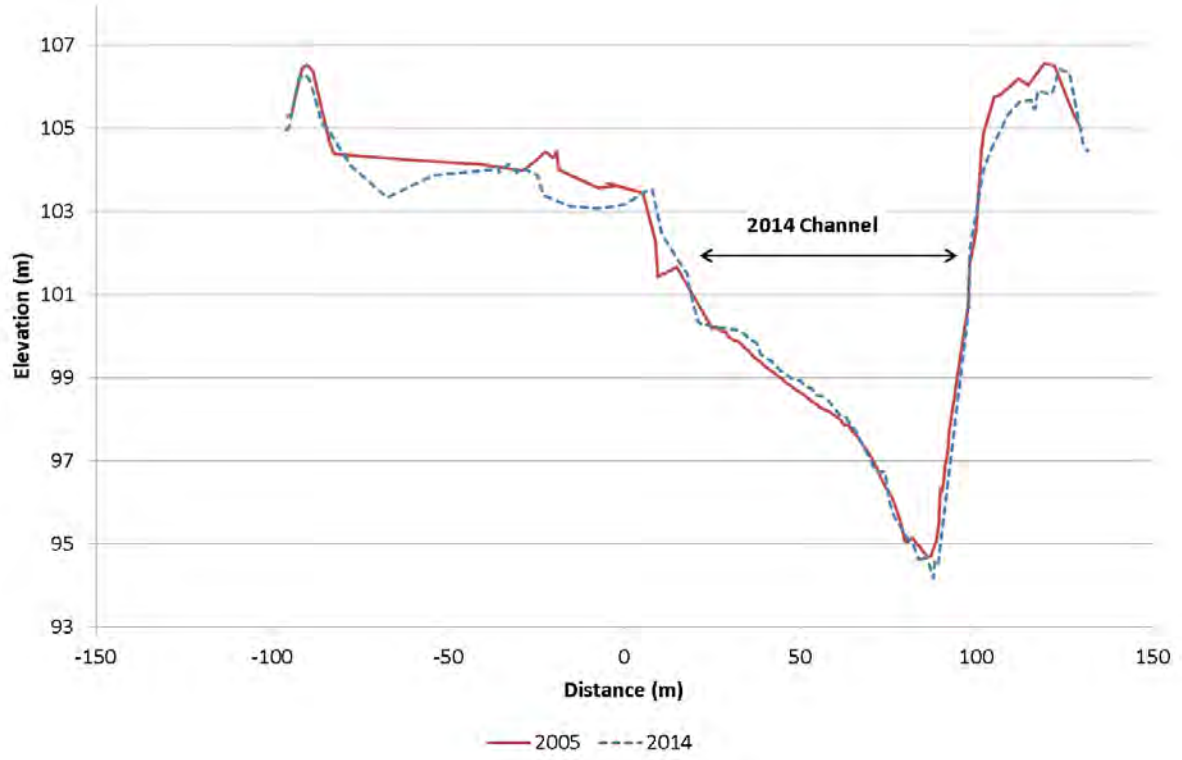


Figure 128. Clutha River/Mata-Au cross-section M5, looking downstream

Figure 129. Clutha River/Mata-Au cross-section M5, looking downstream

Cross-section M5 is located 17.1 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. Minimal change has occurred in the main channel between 2005 and 2014. Both the left and right banks and the wider floodplain have experienced degradation between 2005 and 2014.

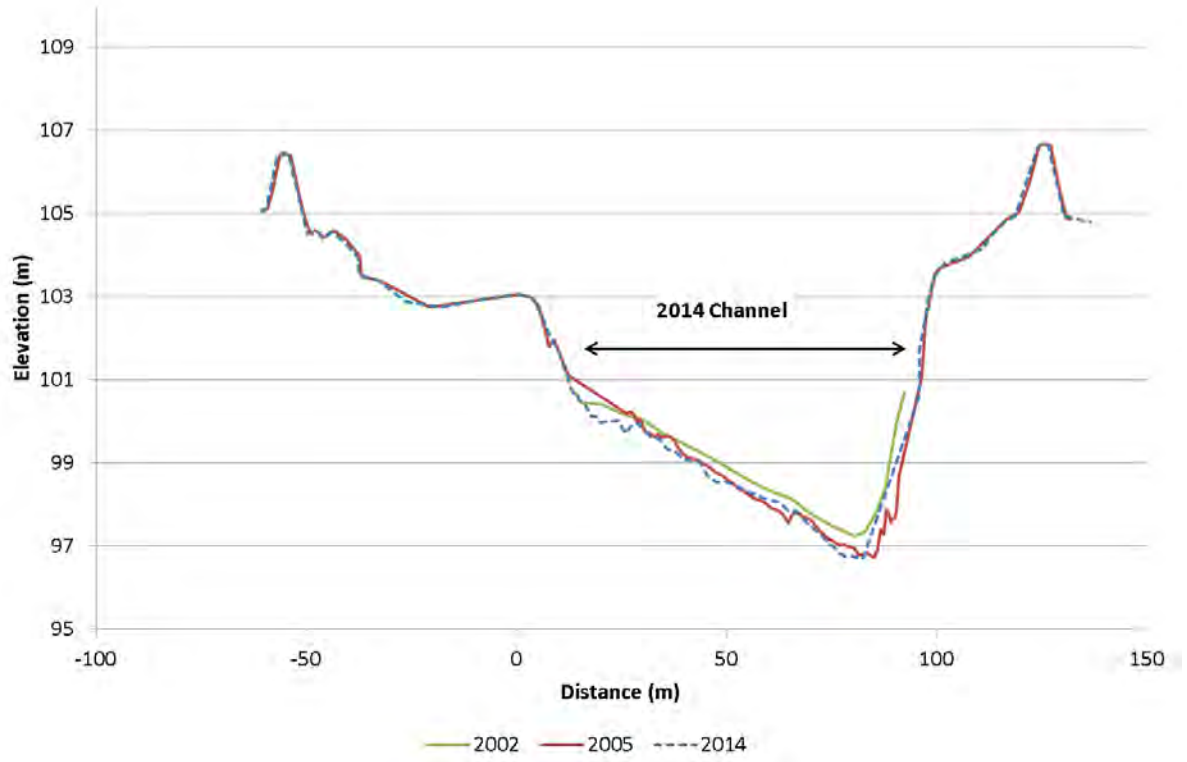


Figure 130. Clutha River/Mata-Au cross-section M6, looking downstream

Figure 131. Clutha River/Mata-Au cross-section M6, looking upstream

Cross-section M6 is located 18.5 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. The thalweg has shifted towards the true left bank between 2005 and 2014 with both aggradation and degradation occurring across the main channel. The wider floodplain has remained similar between 2005 and 2014.

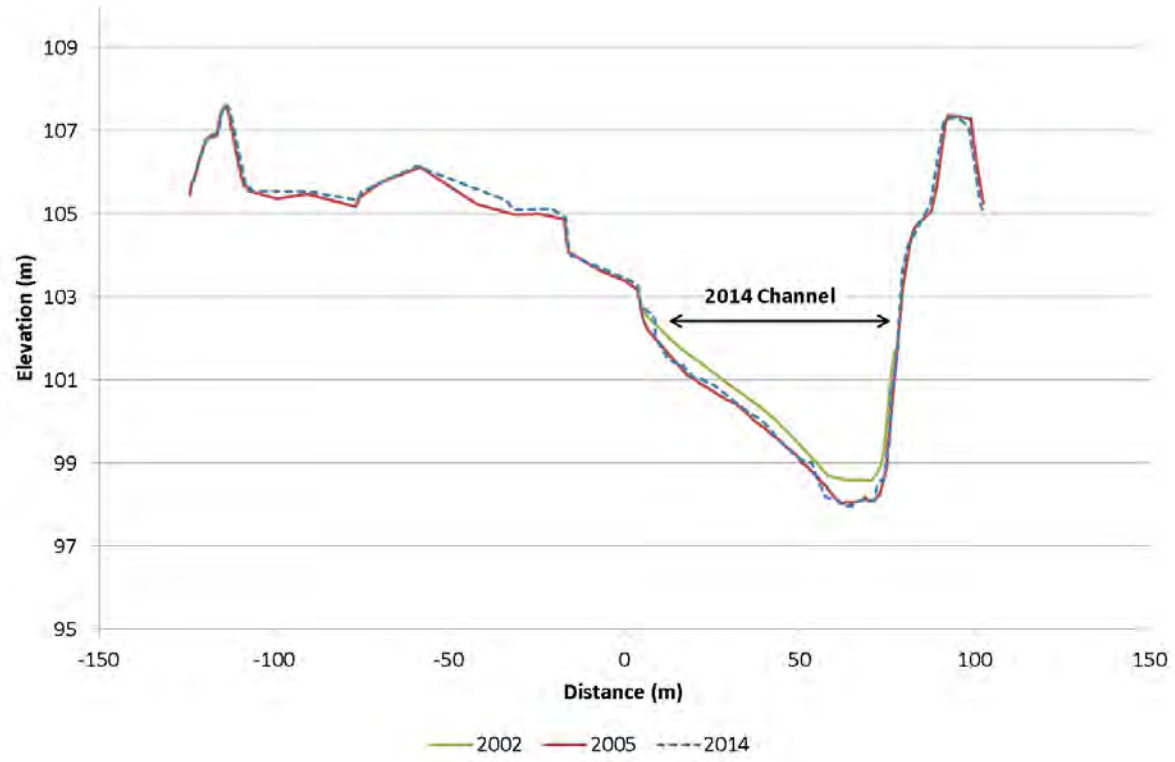


Figure 132. Clutha River/Mata-Au cross-section M7, looking downstream

Figure 133. Clutha River/Mata-Au cross-section M7, looking upstream

Cross-section M7 is located 21.8 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. The channel and wider floodplain has remained similar between 2005 and 2014, but the main channel has degraded between 2002 and 2014.

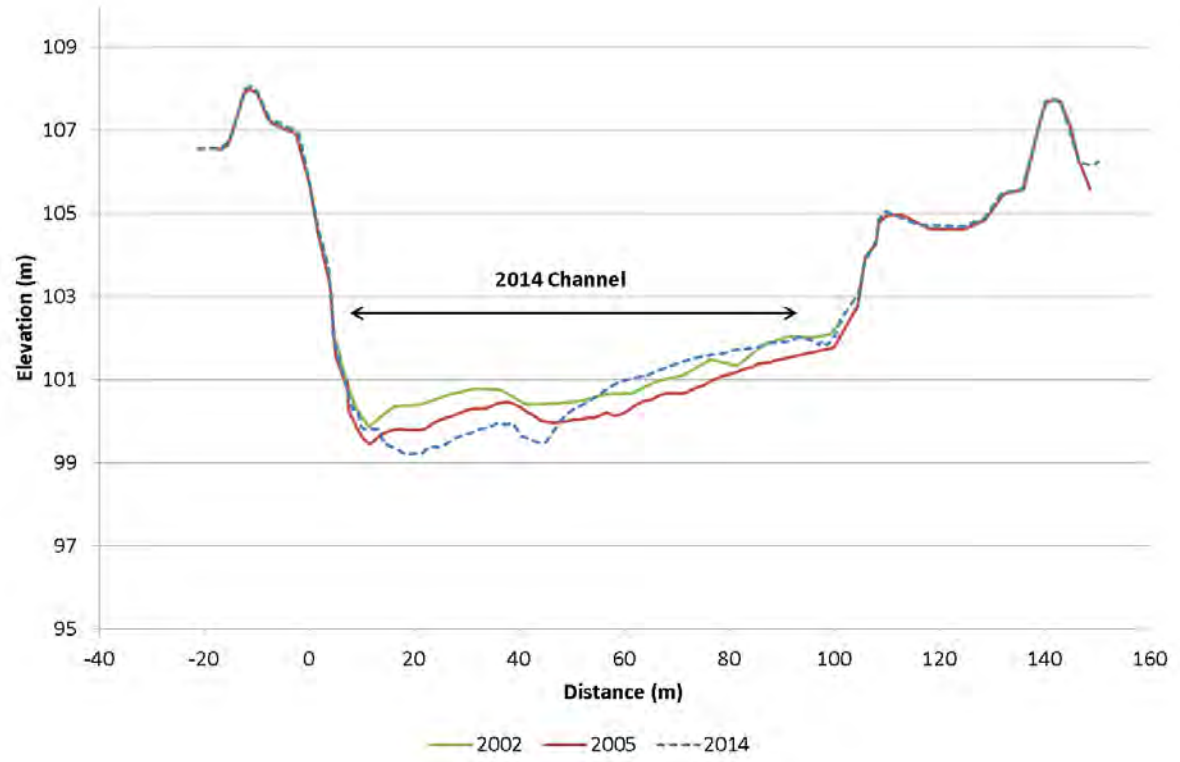


Figure 134. Clutha River/Mata-Au, cross-section M8, looking downstream

Figure 135. Clutha River/Mata-Au cross-section M8, looking from true left to right bank

Cross-section M8 is located 22.6 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. The true left of the channel has degraded with aggradation occurring on the right side between 2005 and 2014 which has caused the channel to become more restricted. The wider floodplain has remained similar between 2005 and 2014.

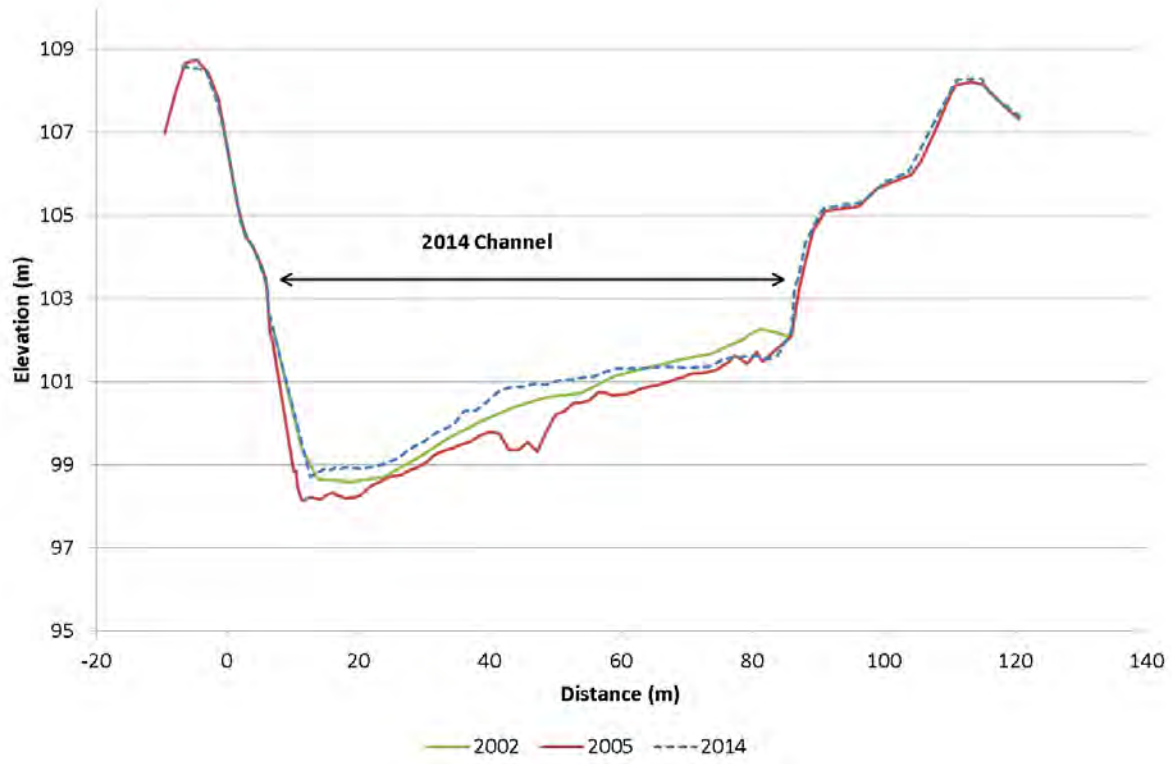


Figure 136. Clutha River/Mata-Au cross-section M9, looking downstream

Figure 137. Clutha River/Mata-Au cross-section M9, looking true right to left bank

Cross-section M9 is located 23.4 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au and the Pacific Ocean at the Riverbank Road bridge. The channel has shown aggraded across its length between 2005 and 2014 with the thalweg being located in a similar horizontal position. The wider floodplain has remained similar between 2005 and 2014.

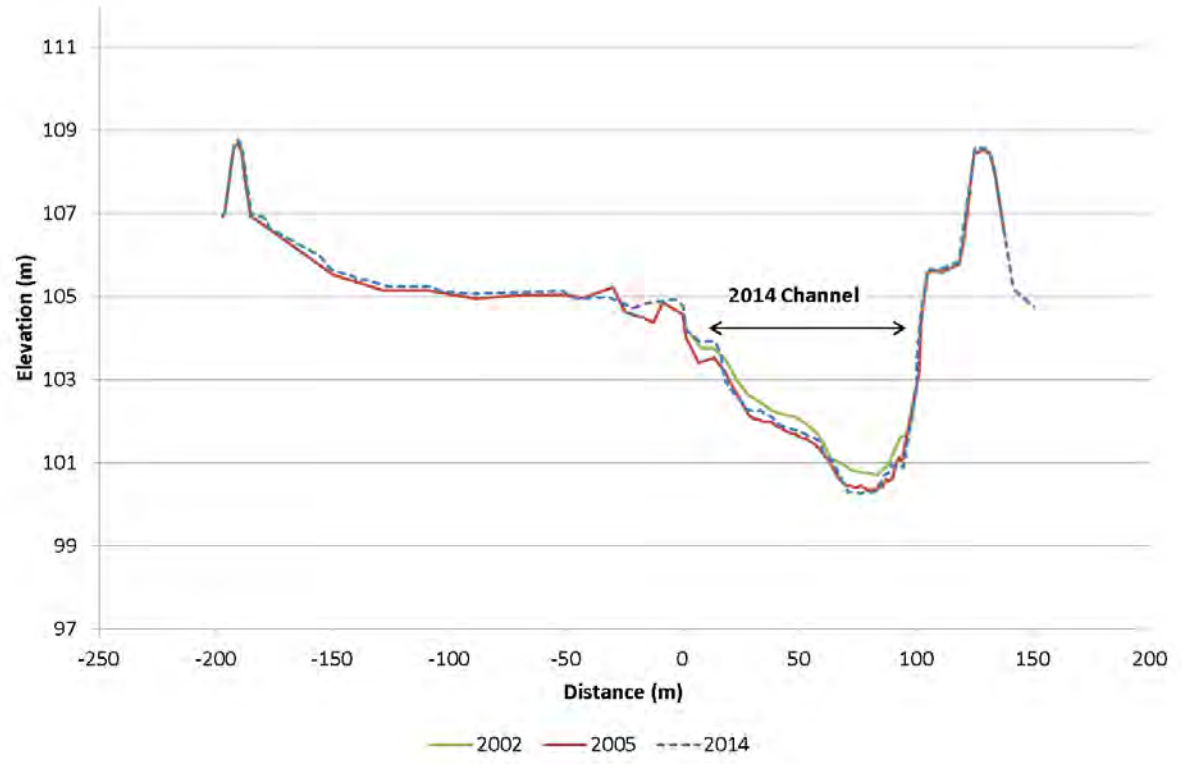


Figure 138. Clutha River/Mata-Au cross-section M10, looking downstream

Figure 139. Clutha River/Mata-Au cross-section M10, looking from true right to left bank

Cross-section M10 is located 25.2 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. The channel has remained similar between 2005 and 2014 with aggradation occurring on the true left bank and minor degradation of the channel thalweg. The wider floodplain has remained similar between 2005 and 2014.

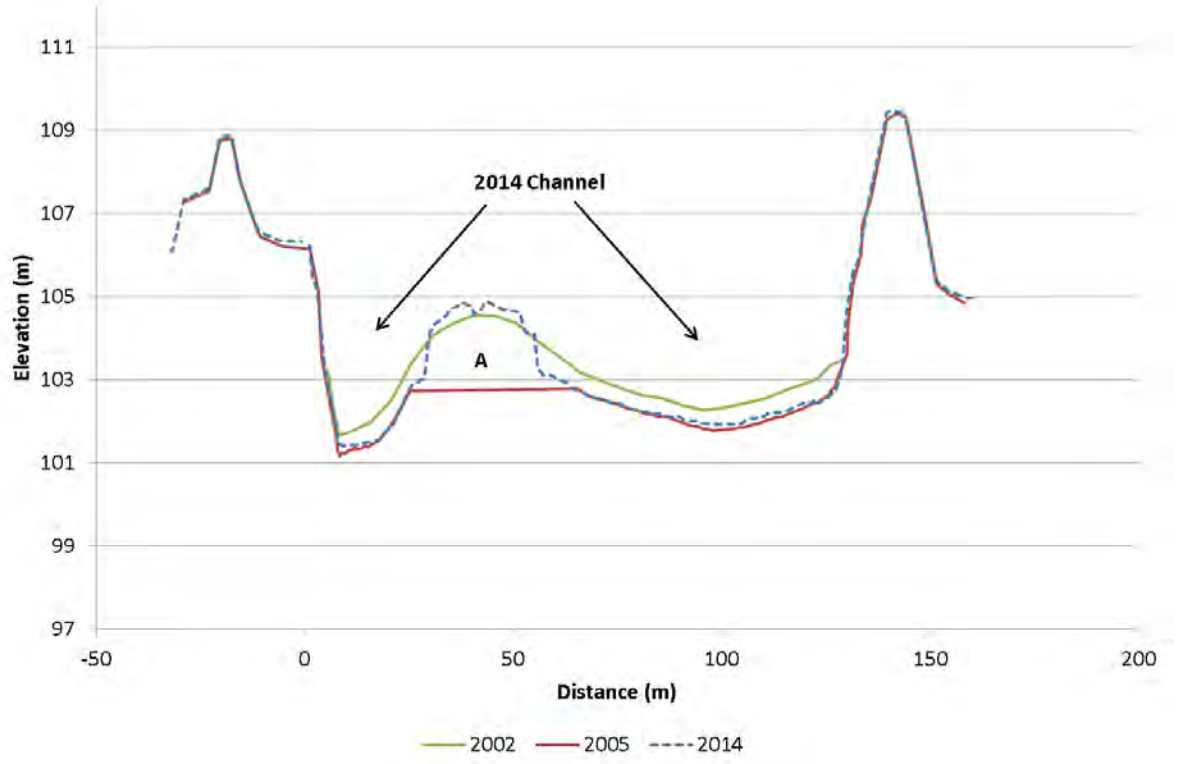


Figure 140. Clutha River/Mata-Au cross-section M11, looking downstream

Figure 141. Clutha River/Mata-Au cross-section M11, looking upstream

Cross-section M11 is located 26.4 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. A mid channel bar is present at this cross-section (point labelled A), there is missing data for this bar evident in the 2005 survey. The true left and right channels have remained similar between 2005 and 2014 but have degraded since 2002. The wider floodplain has remained similar between 2005 and 2014.

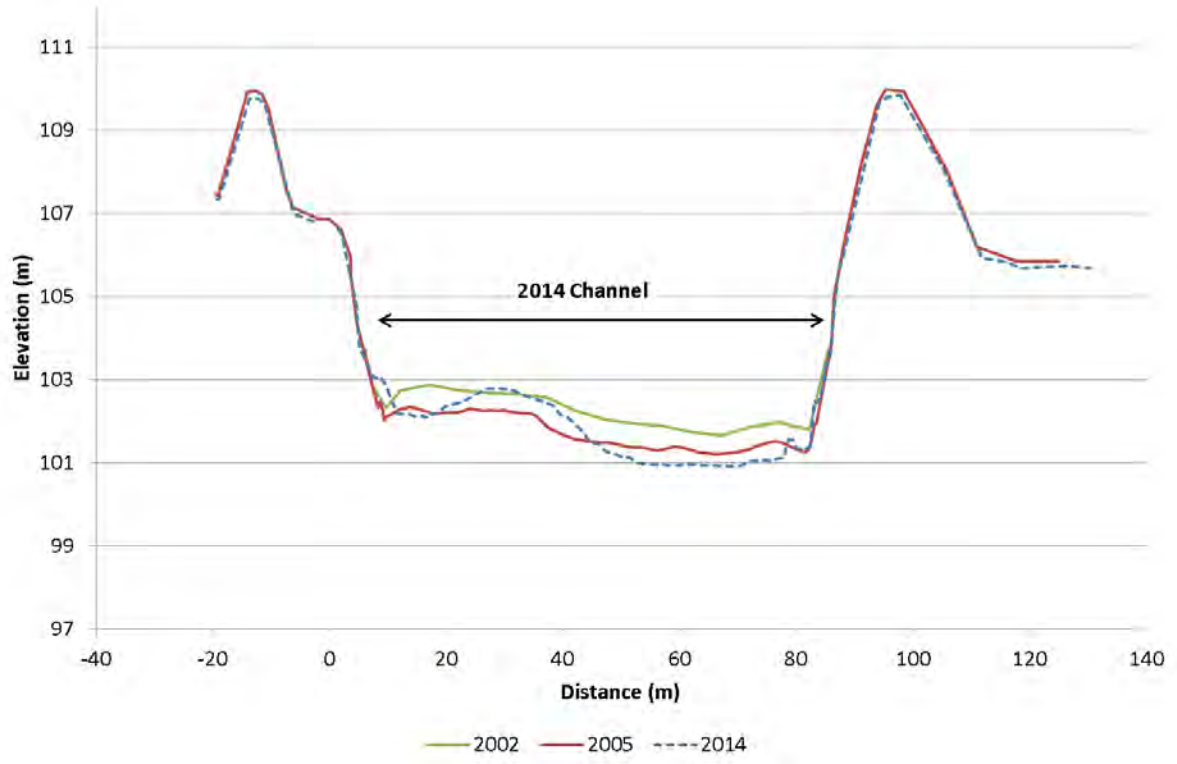


Figure 142. Clutha River/Mata-Au cross-section M12, looking downstream

Figure 143. Clutha River/Mata-Au cross-section M12, looking downstream

Cross-section M12 is located 27 km upstream of the confluence of the Matau Branch of the Clutha River/Mata-Au with the Pacific Ocean. The true left of the channel has aggraded and the true right has degraded between 2005 and 2014 with the wider floodplain remaining similar.

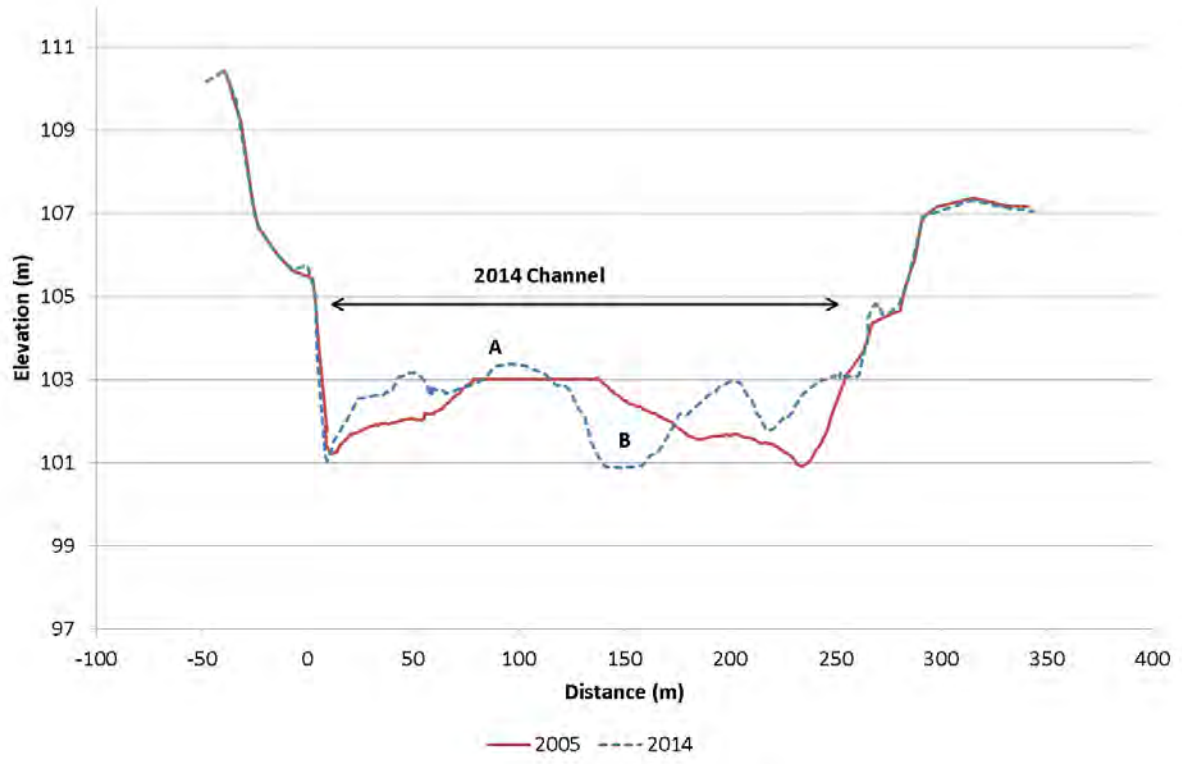


Figure 144. Clutha River/Mata-Au cross-section C1, looking downstream

Figure 145. Clutha River/Mata-Au cross-section C1, looking upstream

Cross-section C1 is located at the bifurcation (channel splitting) of the Clutha River/Mata-Au at Balclutha. The point of the bifurcation can extend into the cross-section C1 at the point labelled A, the 2005 survey did not cover this area of land and therefore can not be compared to previous and subsequent years. Gravel extraction has occurred historically at this location. Between 2005 and 2014 the true left and right channels have aggraded with a new channel forming in the middle (point labelled B) which has eroded into the point of the bifurcation.

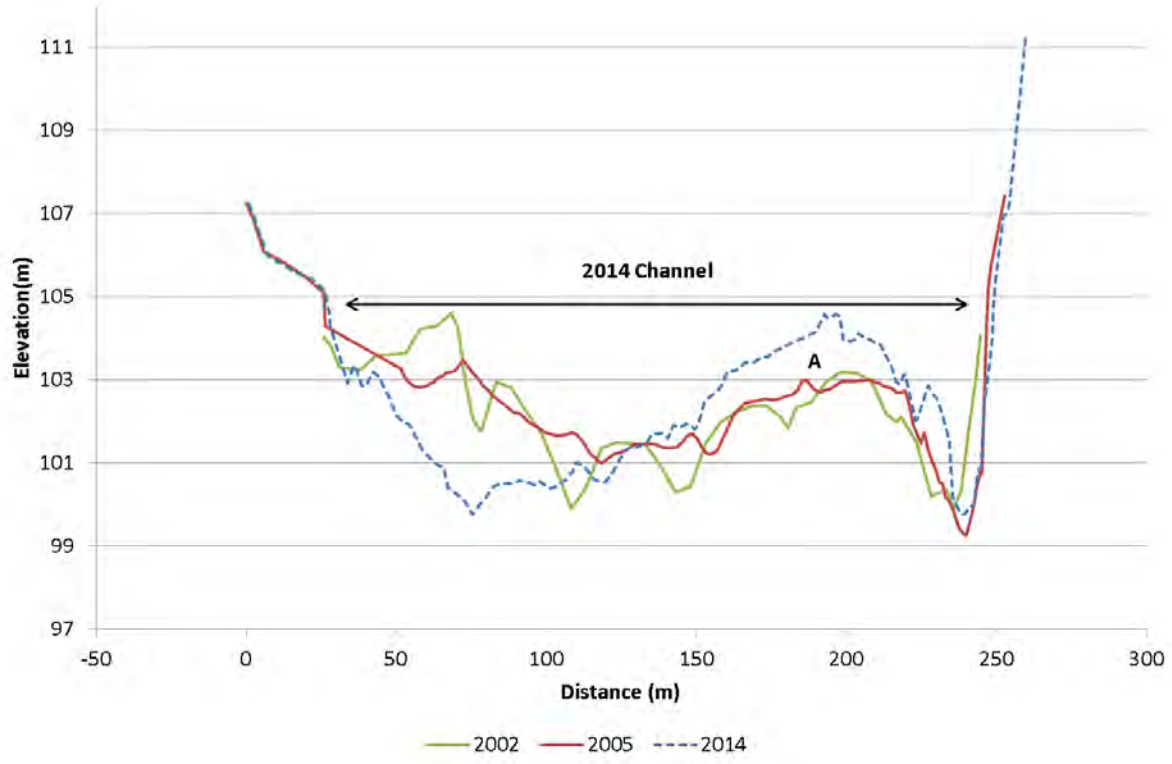


Figure 146. Clutha River/Mata-Au cross-section C2, looking downstream

Figure 147. Clutha River/Mata-Au cross-section C2, looking from true left to right bank

Cross-section C2 is located 0.2 km upstream of the Clutha River/Mata-Au bifurcation at the Balclutha railway bridge. The point labelled A is a mid-channel bar that is often exposed when flows are low enough. The true left of the main channel has degraded by about 4 m at the deepest point between 2005 and 2014, the true right of the channel has subsequently aggraded with a narrowing of the channel creating more distinct channels than in 2005.

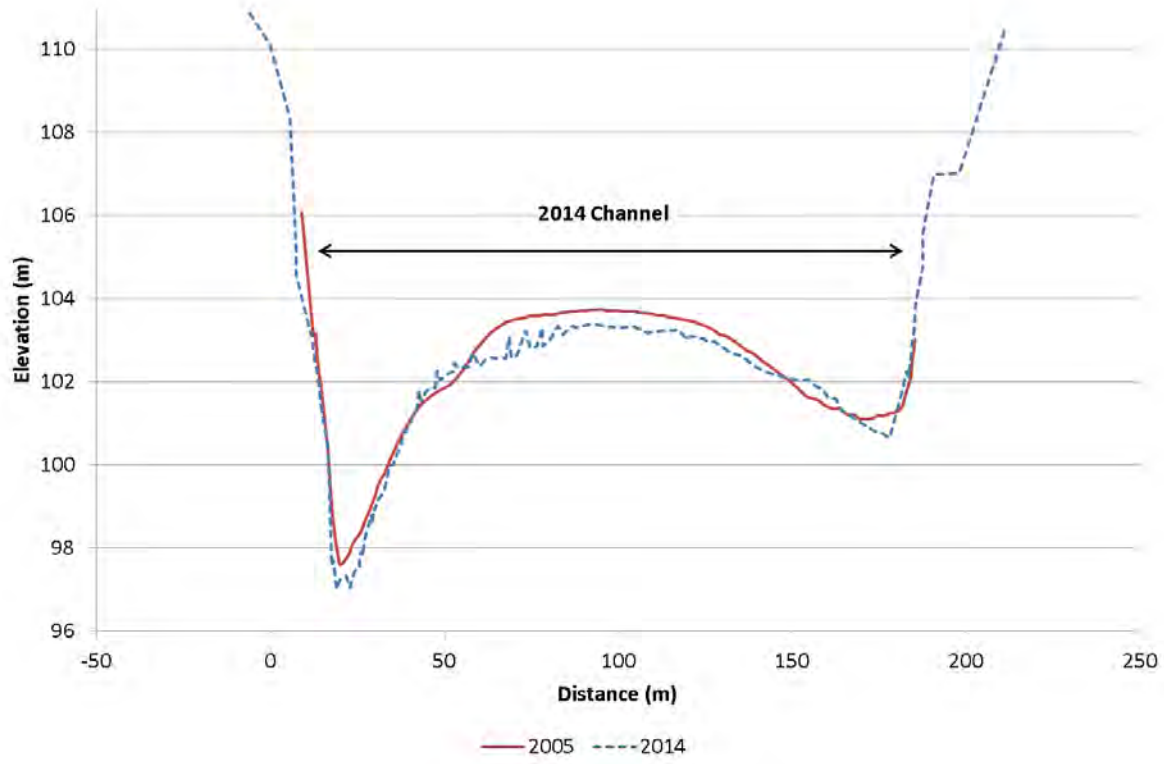


Figure 148. Clutha River/Mata-Au cross-section C3, looking downstream

Figure 149. Clutha River/Mata-Au cross-section C3, looking downstream

Cross-section C3 is located 1 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and 300 m downstream of the SH1 bridge. Between 2005 and 2014, the true left channel and thalweg have lowered, with a decrease in the mid channel bar (which can be located below water level). The true right of the channel has also degraded between 2005 and 2014. The 2005 survey does not extend sufficiently to allow a comparison of the river banks.

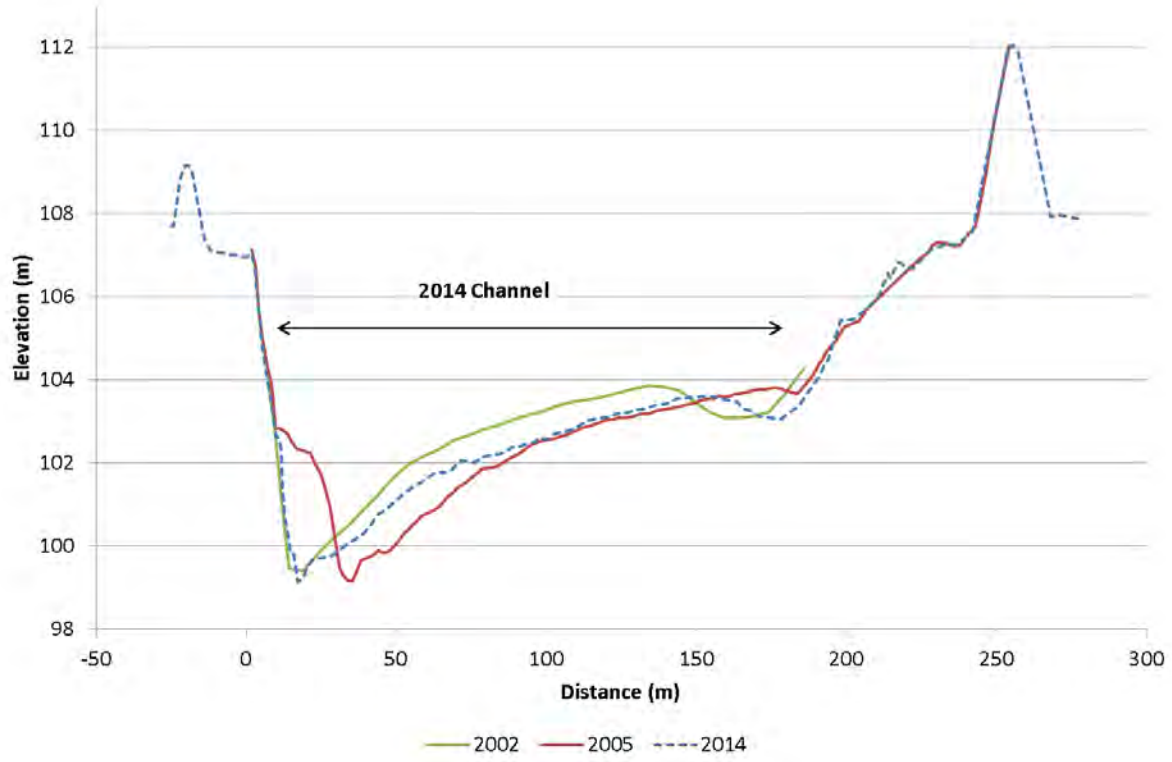


Figure 150. Clutha River/Mata-Au cross-section C5, looking downstream

Figure 151. Clutha River/Mata-Au cross-section C5, looking upstream

Cross-section C5 is located 1.7 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The true left of the channel has eroded between 2005 and 2014 with the thalweg currently positioned against the left bank. The right side of the thalweg channel has aggraded between 2005 and 2014 with minimal change occurring across the rest of the channel and the wider floodplain.

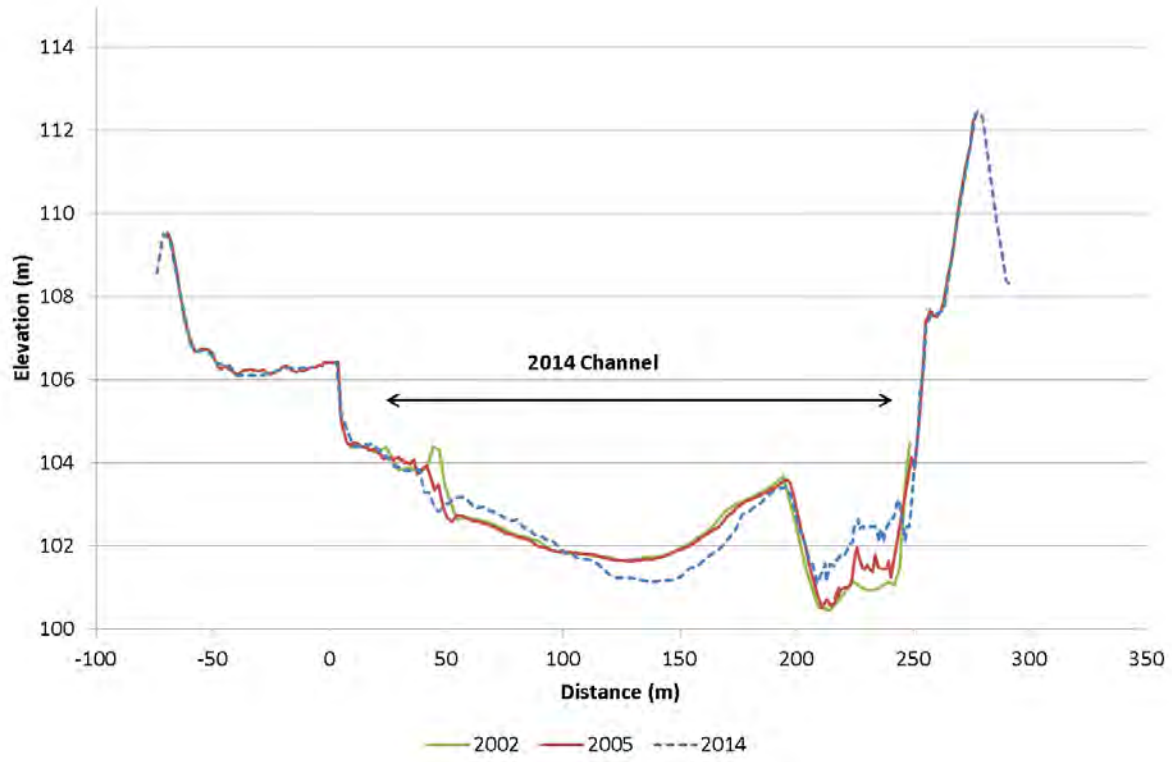


Figure 152. Clutha River/Mata-Au cross-section C6, looking downstream

Figure 153. Clutha River/Mata-Au cross-section C6, looking upstream

Cross-section C6 is located 2 km upstream of the Clutha River/Mata-Au bifurcation at the start of the Balclutha Lagoon. The true left and right of the channel has aggraded with degradation occurring on the true right between 2005 and 2014. The true wider floodplain has remained in a similar position between 2005 and 2014.

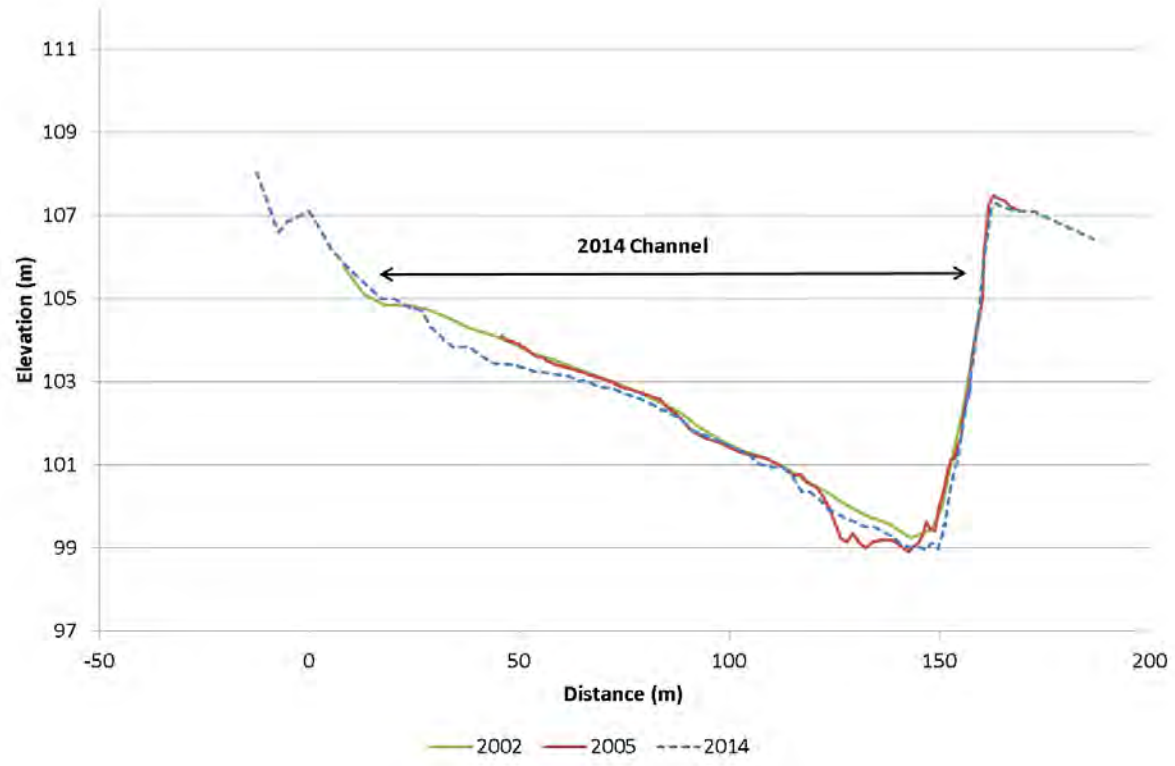


Figure 154. Clutha River/Mata-Au cross-section C7, looking downstream

Figure 155. Clutha River/Mata-Au cross-section C7, looking downstream

Cross-section C7 is located 2.3 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha, adjacent to the Balclutha Lagoon. Between 2005 and 2014 the true left of the channel has degraded with the thalweg section of the channel eroding and moving towards the right bank.

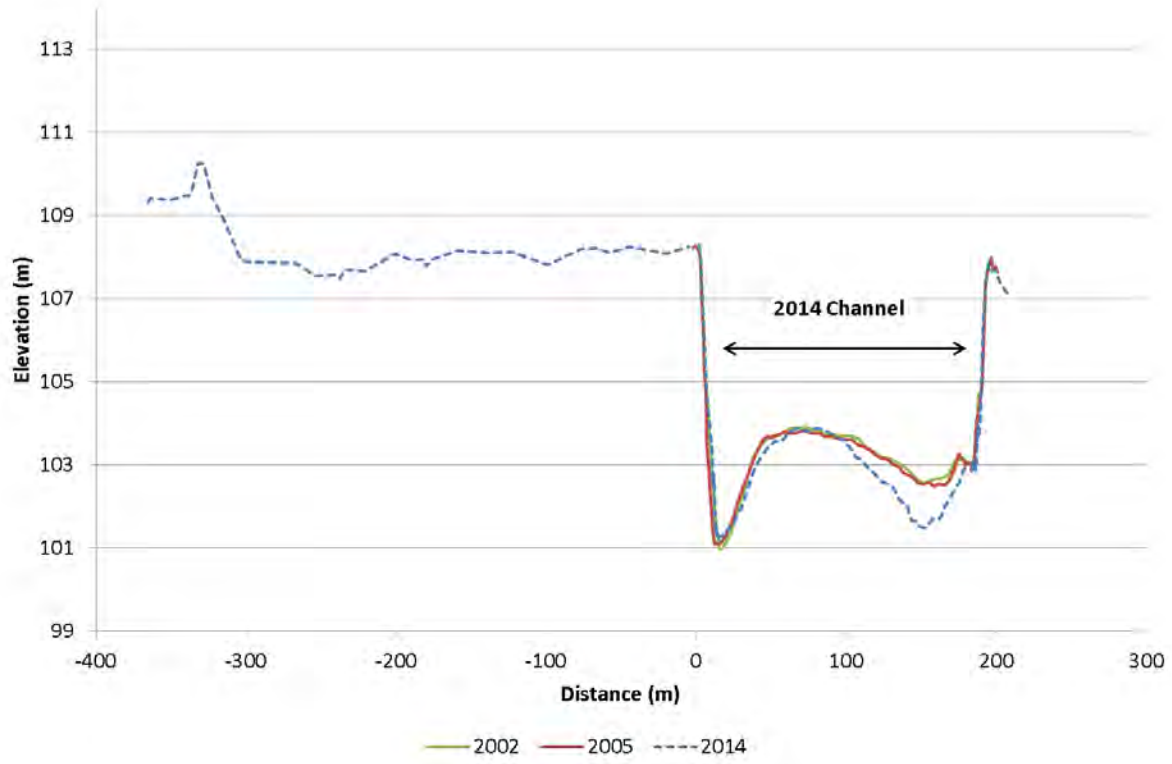


Figure 156. Clutha River/Mata-Au cross-section C8, looking downstream

Figure 157. Clutha River/Mata-Au cross-section C8, looking downstream

Cross-section C8 is located 3.2 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The true left of the main channel has remained similar between 2005 and 2014 with the right side of the channel degrading by 1 m at the deepest location. The 2005 survey did not extend sufficiently on the true left bank to allow a comparison to be made.

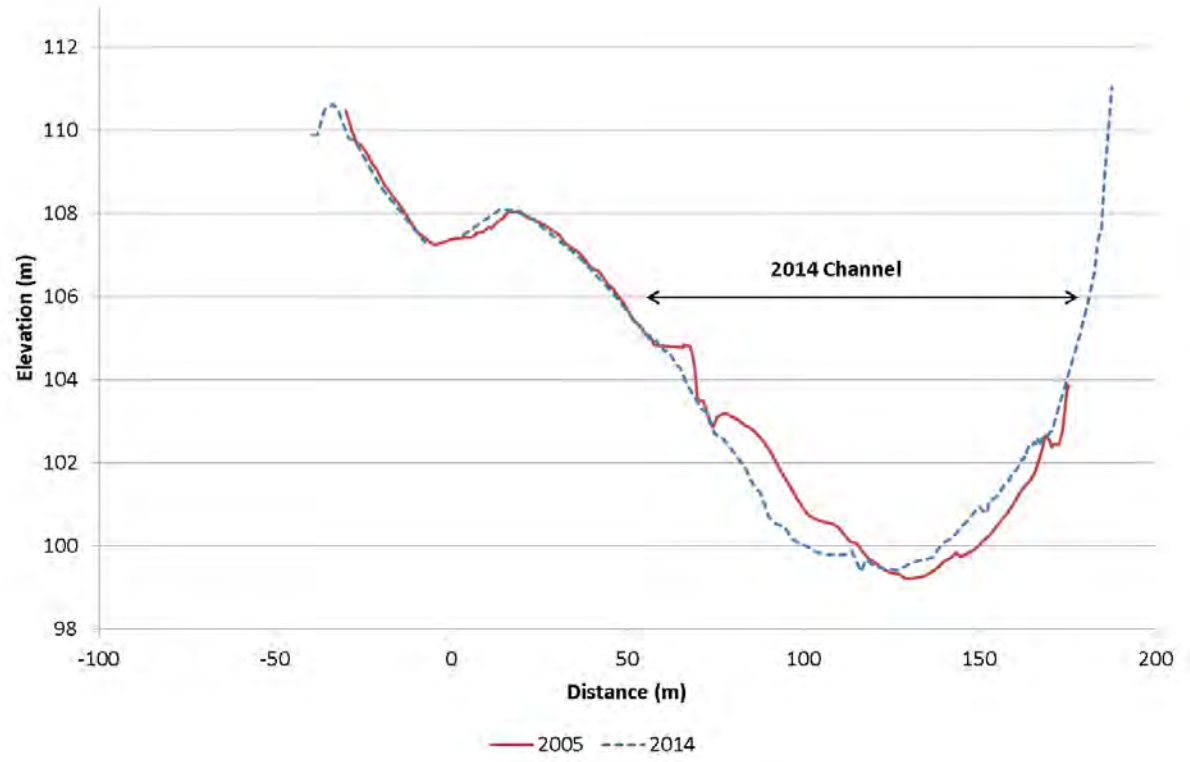


Figure 158. Clutha River/Mata-Au cross-section C9, looking downstream

Figure 159. Clutha River/Mata-Au cross-section C9, looking downstream

Cross-section C9 is located 4 km upstream of the bifurcation of the Clutha River/Mata-Au at Balclutha. Between 2005 and 2014 the channel has shifted towards the true left bank with the thalweg remaining at a similar height. The wider floodplain has remained similar between 2005 and 2014.

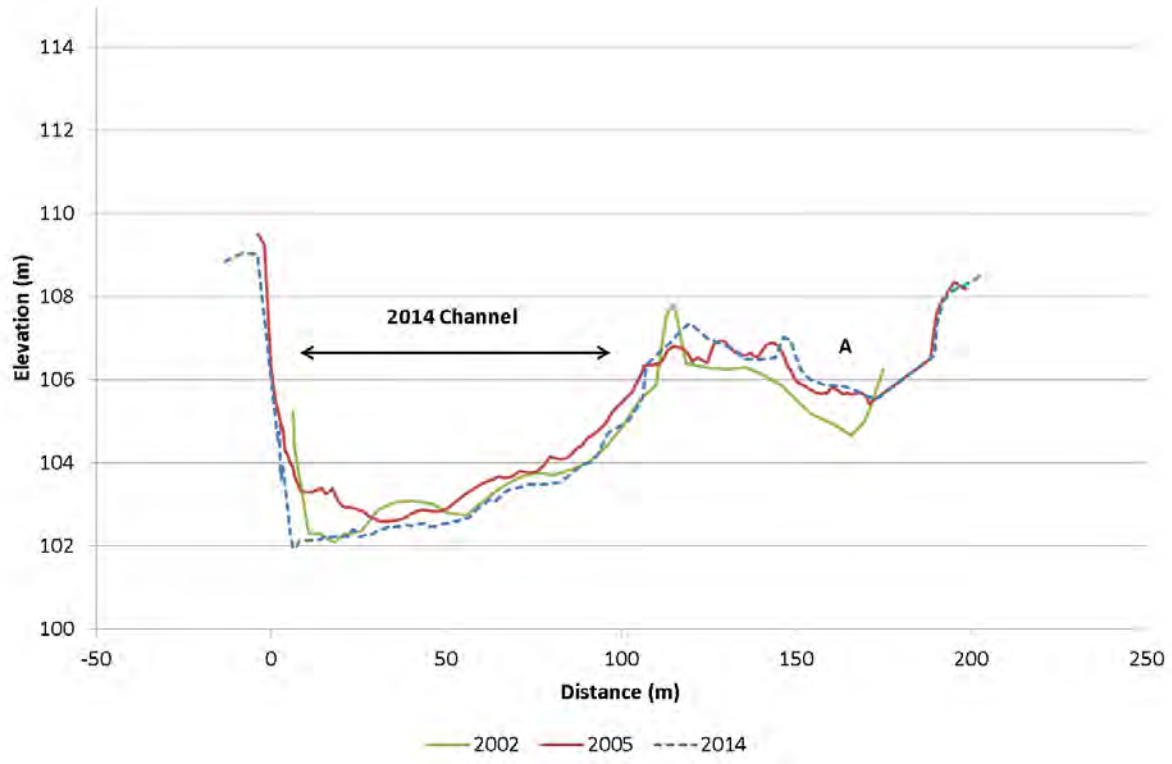


Figure 160. Clutha River/Mata-Au cross-section C10, looking downstream

Figure 161. Clutha River/Mata-Au cross-section C10, looking downstream

Cross-section C10 is located 4.9 km upstream of the Clutha River/Mata-au bifurcation at Balclutha and is on the true right channel that passes an island adjacent to Barnego. The main channel has shown overall degraded between 2005 and 2014 with both aggradation and degradation occurring in the backwater channel (point labelled A).

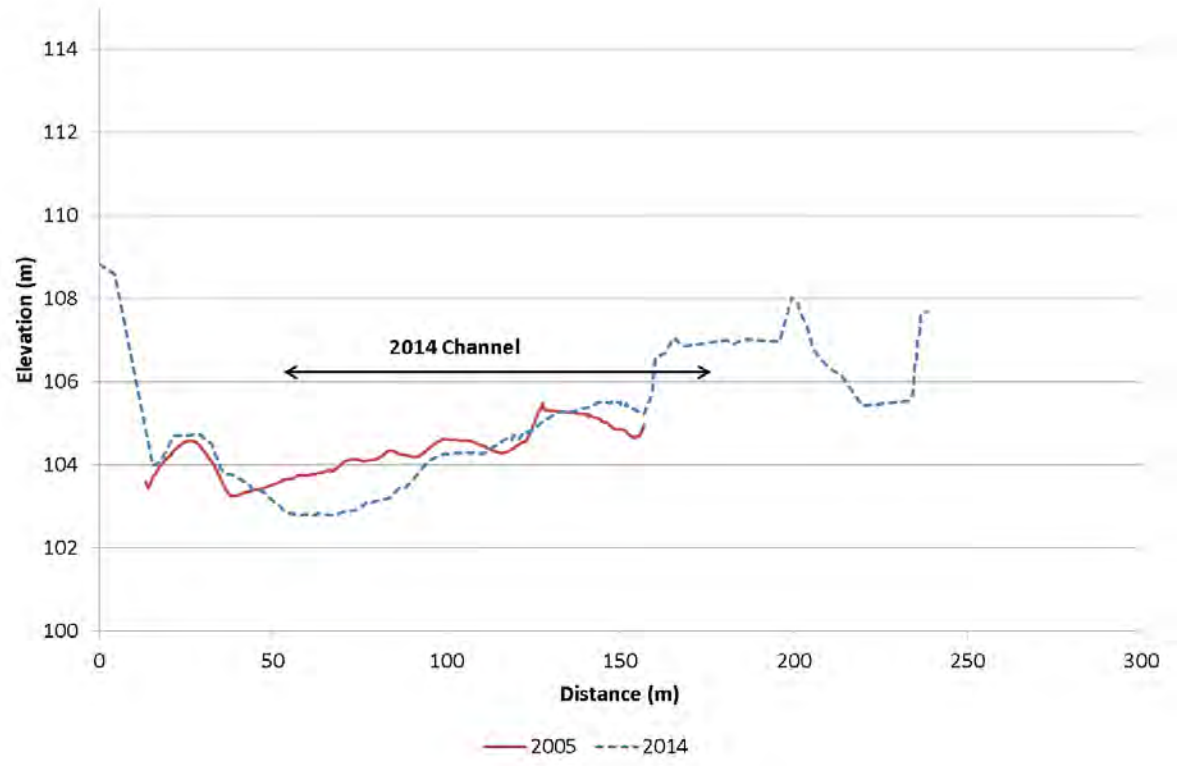


Figure 162. Clutha River/Mata-Au cross-section C11, looking downstream

Figure 163. Clutha River/Mata-Au cross-section C11, looking downstream

Cross-section C11 is located 5.1 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is on the true right channel that passes an island adjacent to Barnego. The channel has degraded in the centre between 2005 and 2014 with both aggradation and degradation occurring on the true right. The 2005 survey did not extend sufficiently to allow a comparison of the wider floodplain.

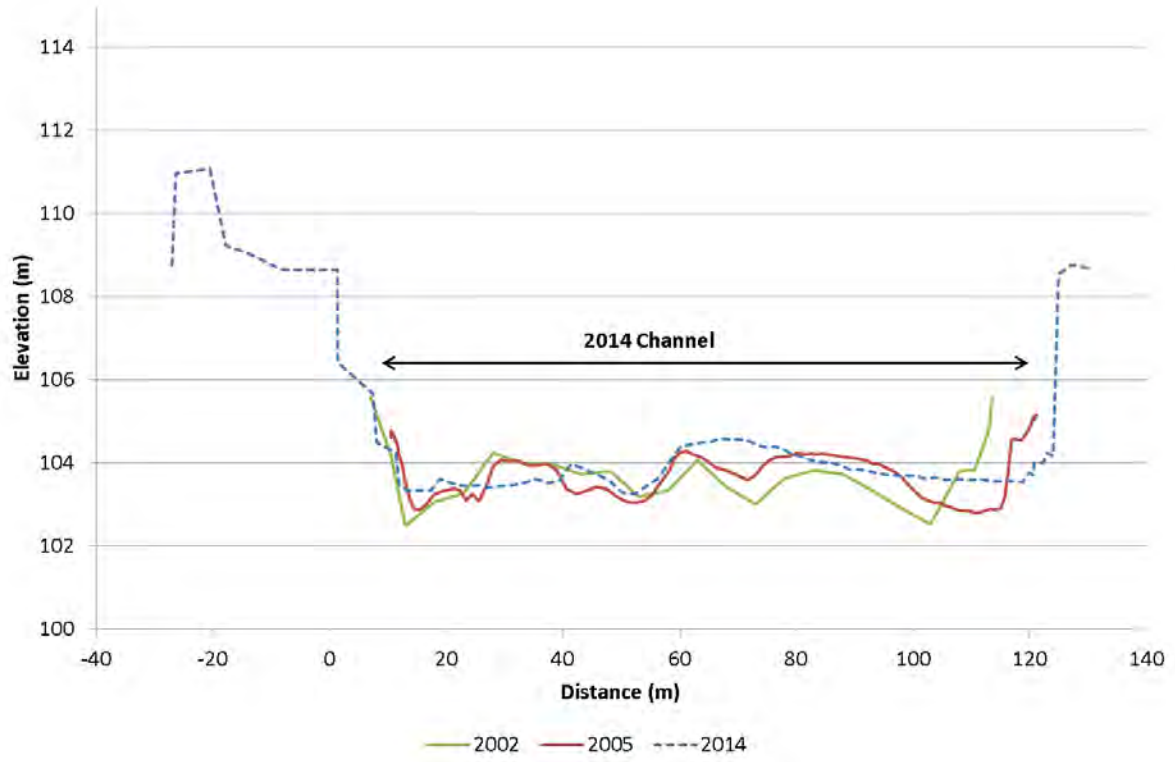


Figure 164. Clutha River/Mata-Au cross-section C12, looking downstream

Figure 165. Clutha River/Mata-Au cross-section C12, looking downstream

Cross-section C12 is located 5 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is on the true left channel that passes an island adjacent to Barnego. Between 2005 and 2014 the channel has both aggraded and degraded, the thalweg has moved towards the true left bank. The 2005 survey did not extend sufficiently to allow a comparison of the wider floodplain.

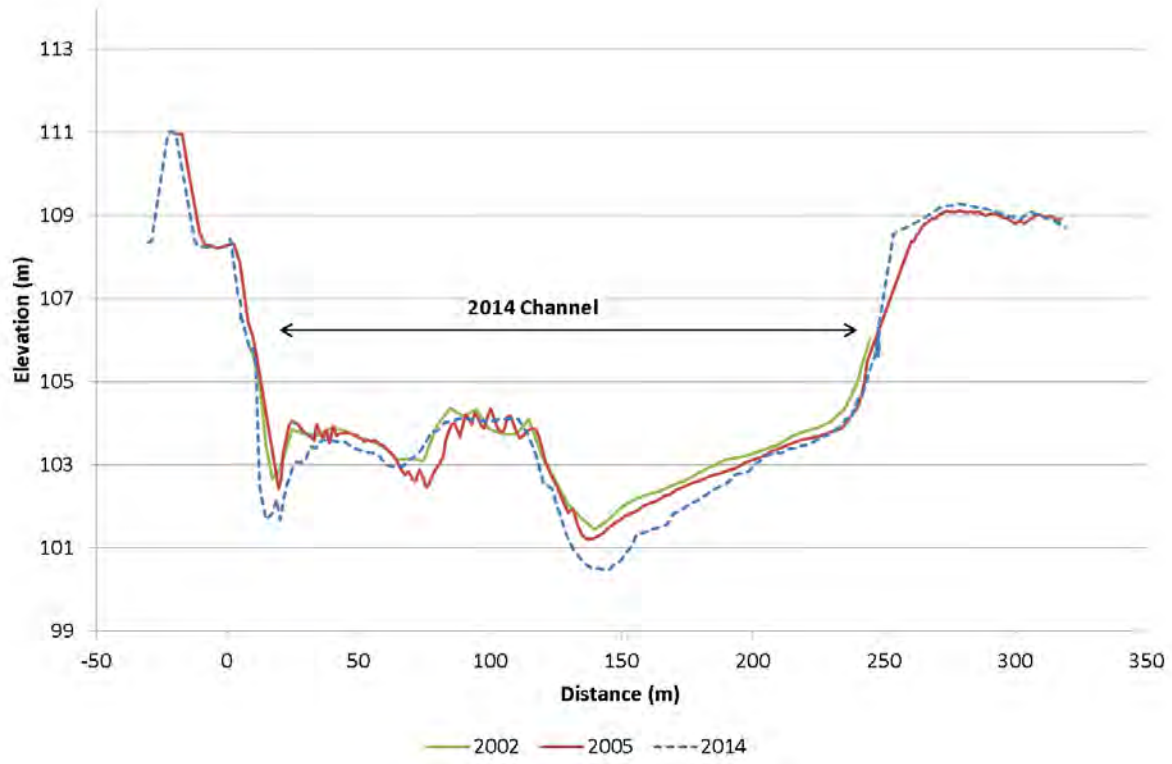


Figure 166. Clutha River/Mata-Au cross-section C13, looking downstream

Figure 167. Clutha River/Mata-Au cross-section C13, looking true right to left bank.

Cross-section C13 is located 5.5 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The true left of the channel has widened and degraded between 2005 and 2014 with degradation also occurring in the centre of the channel. The true right bank has aggraded between 2005 and 2014.

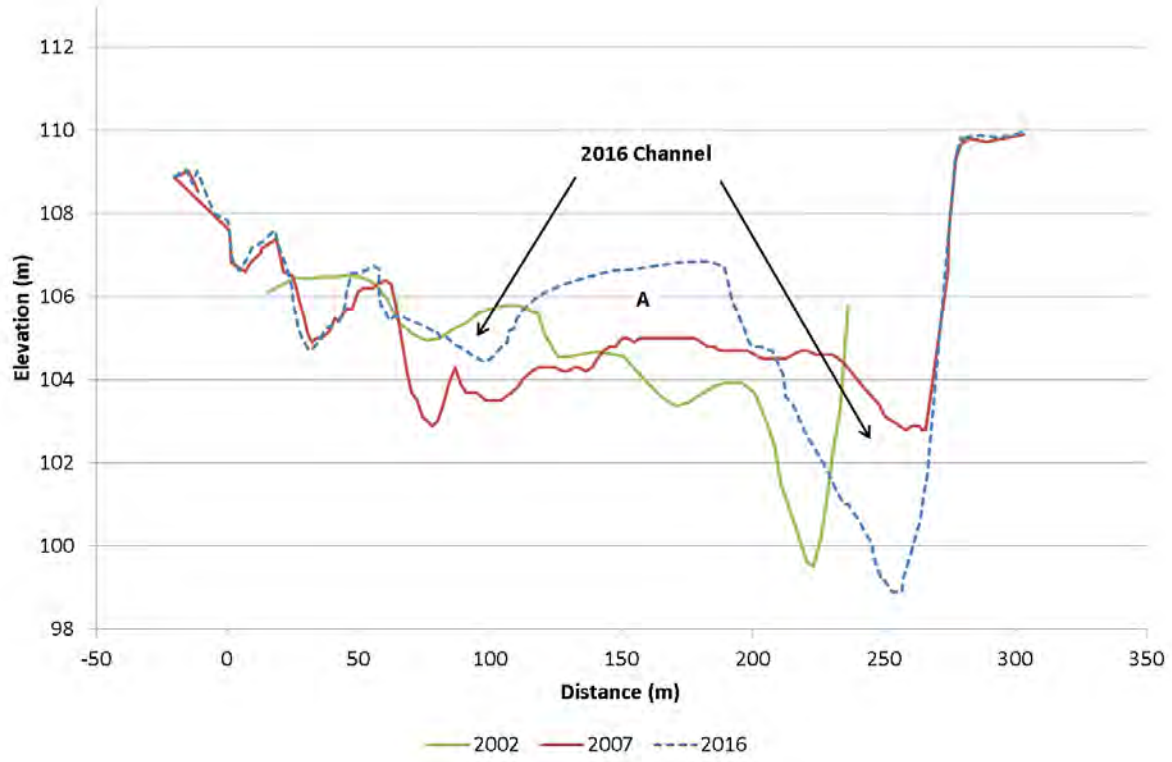


Figure 168. Clutha River/Mata-Au cross-section C14, looking downstream

Figure 169. Clutha River/Mata-Au cross-section C14, looking upstream

Cross-section C14 is located 6.4 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The centre of the cross-section (point labelled A) is a mid channel gravel bar which can be seen in Figure 169. The true left channel and mid channel bar have aggraded by up to 1.8 m between 2007 and 2016, the true right channel has degraded significantly during this same timeframe. The wider floodplain has remained similar between 2007 and 2016.

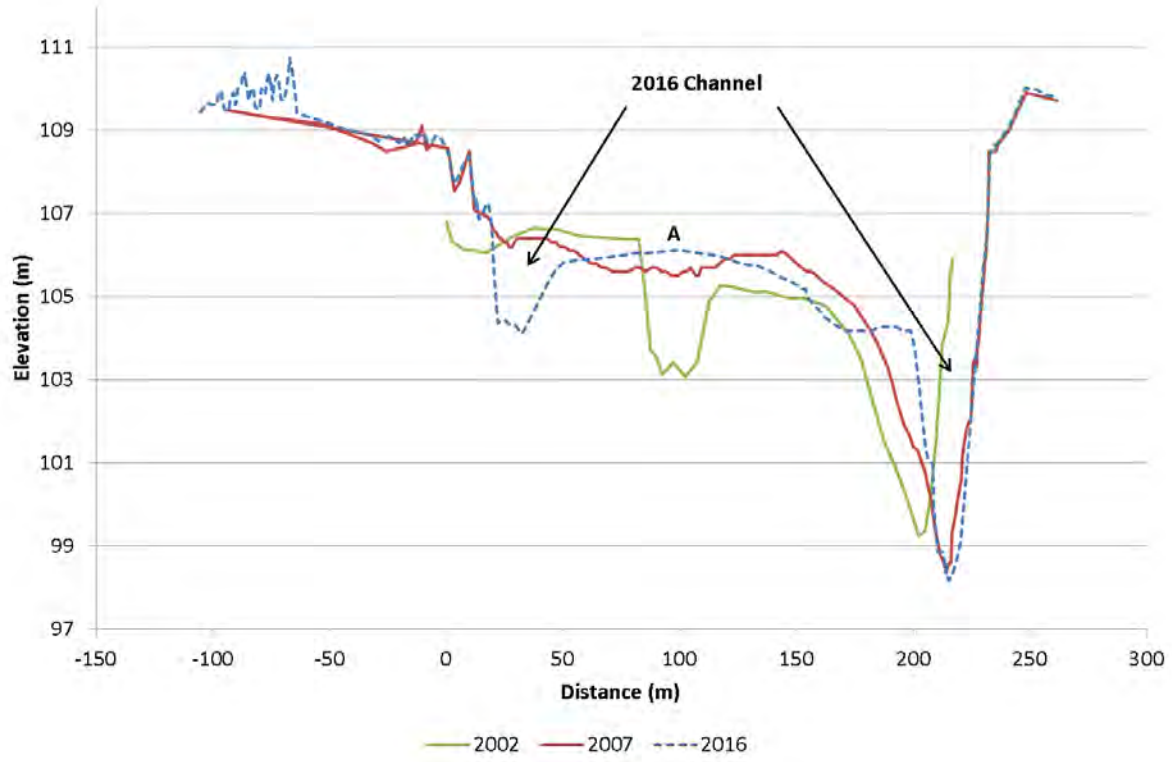


Figure 170. Clutha River/Mata-Au cross-section C15, looking downstream

Figure 171. Clutha River/Mata-Au cross-section C15, looking downstream

Cross-section C15 is located 6.7 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The centre of the cross-section (point labelled A) is a mid channel gravel bar which can be seen in Figure 171. The true left channel has eroded and moved towards the true left bank between 2007 and 2016 possibly due to the growth of the mid channel bar. The 2007 true left channel has become infilled and the true right channel has become more confined in 2016.

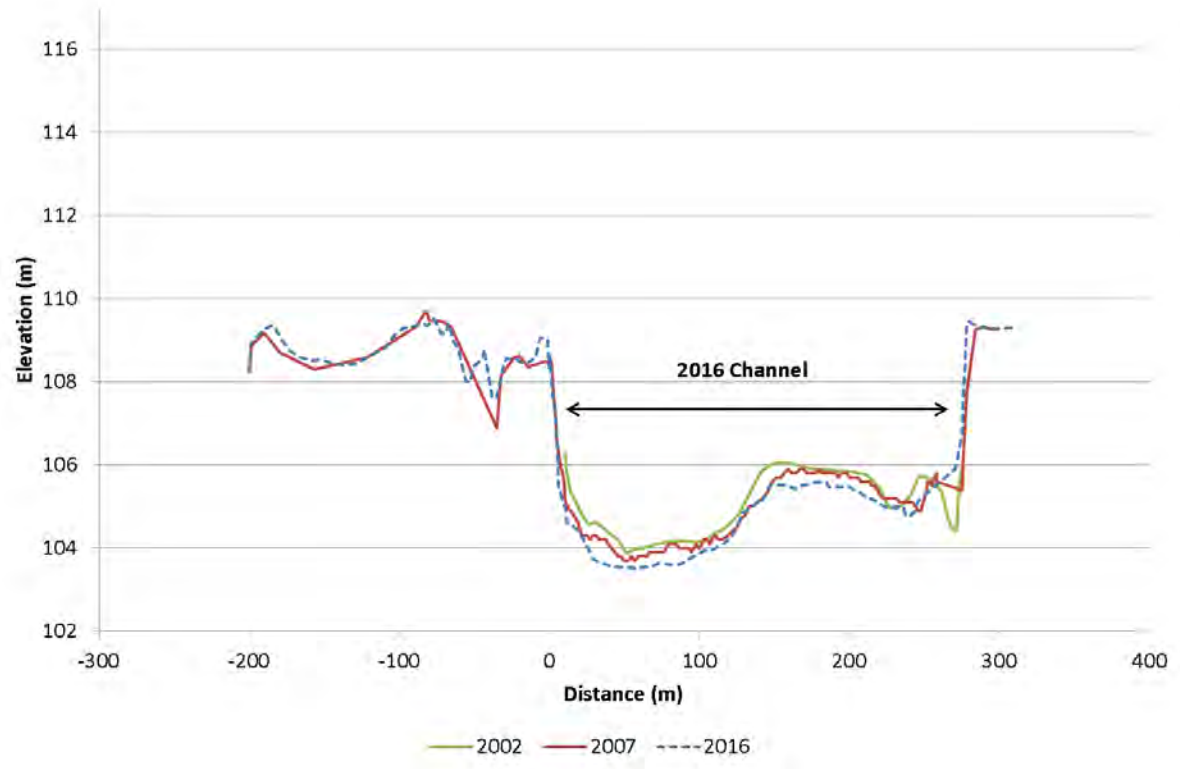


Figure 172. Clutha River/Mata-Au cross-section C16, looking downstream

Figure 173. Clutha River/Mata-Au cross-section C16, looking upstream

Cross-section C16 is located 7.1 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated at the downstream end of Manuka Island. The channel has predominantly degraded between 2007 and 2016 with minimal change occurring in the wider floodplain.

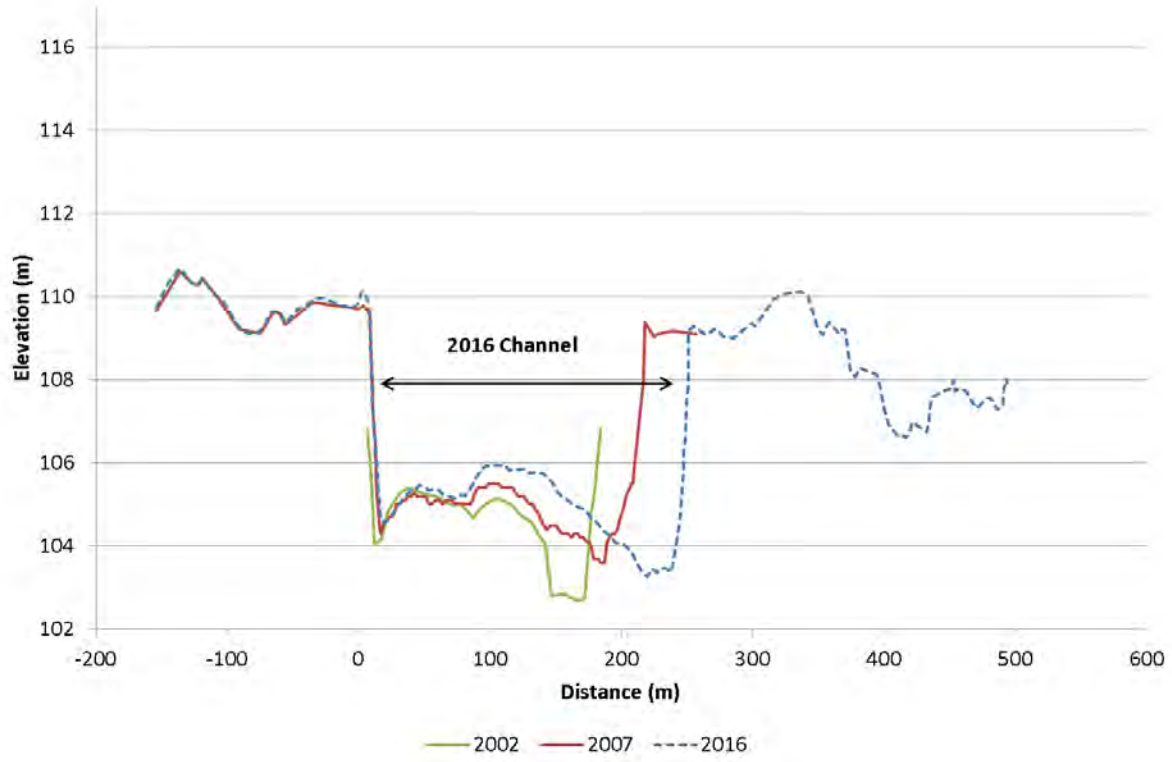


Figure 174. Clutha River/Mata-Au cross-section C17, looking downstream

Figure 175. Clutha River/Mata-Au cross-section C17, looking downstream

Cross-section C17 is located 8.1 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated adjacent to Manuka Island. The channel has eroded into the true right bank by about 37 m and the thalweg has moved further towards the right bank between 2007 and 2016. The centre of the channel has aggraded with minimal change on the true left floodplain between 2007 and 2016.

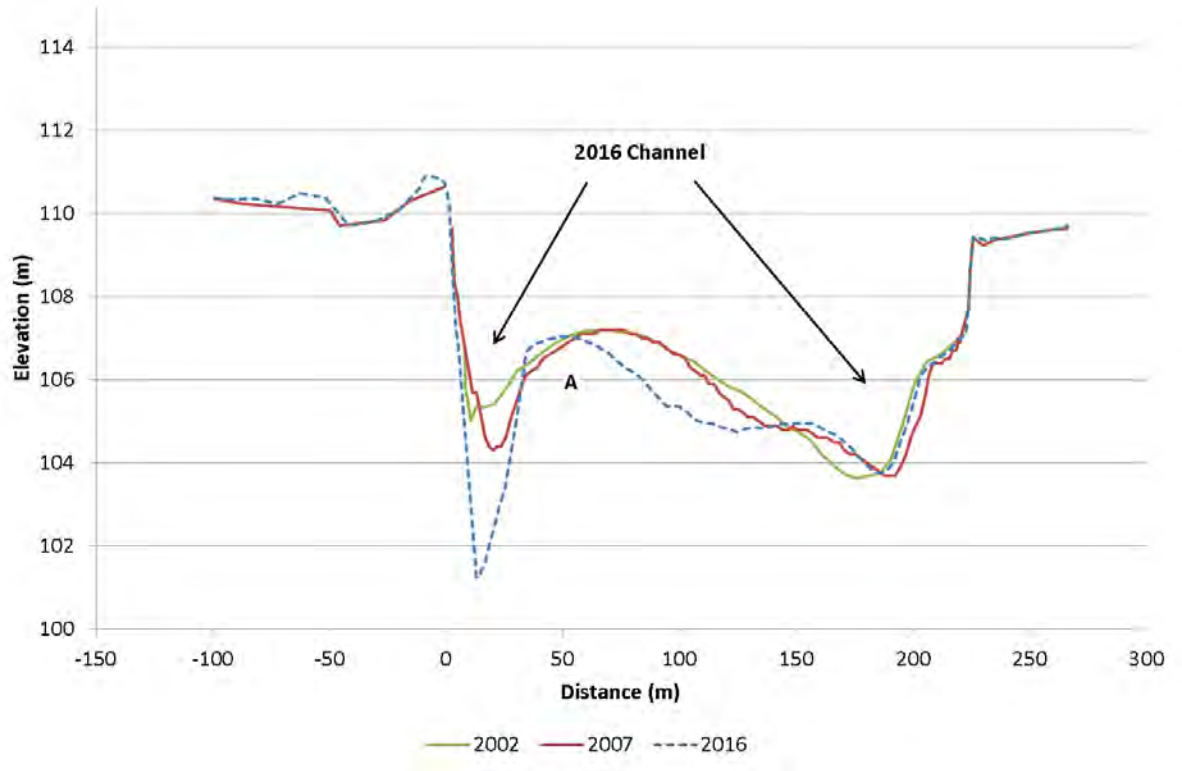


Figure 176. Clutha River/Mata-Au cross-section C18, looking downstream

Figure 177. Clutha River/Mata-Au cross-section C18, looking upstream

Cross-section C18 is located 8.6 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The point labelled A is a mid channel bar that becomes exposed at low flows. The true left channel has degraded by 3 m and become more confined between 2007 and 2016. The true right side of the gravel has degraded and the true right channel has remained in a similar position between 2007 and 2016.

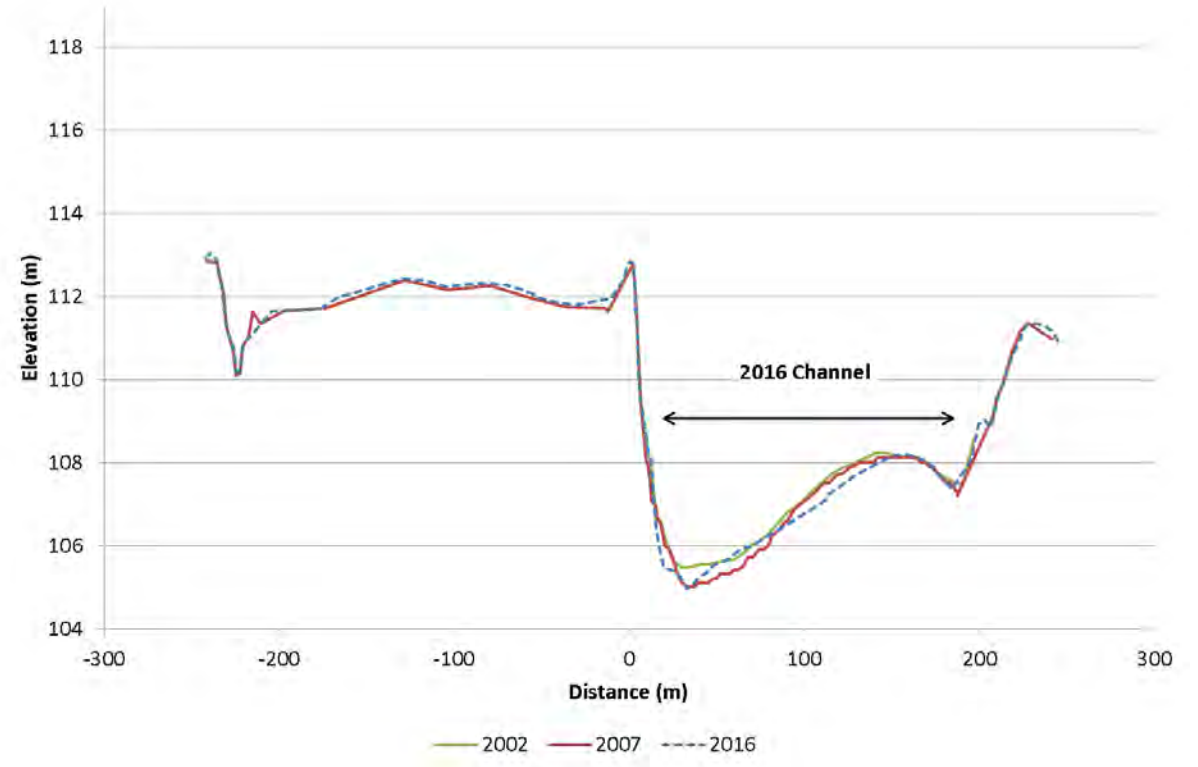


Figure 178. Clutha River/Mata-Au cross-section C19, looking downstream

Figure 179. Clutha River/Mata-Au cross-section C19, looking upstream

Clutha River/Mata-Au cross-section C19 is located 13.3 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. Between 2007 and 2016 the true left of the channel has aggraded with degradation occurring in the centre of the channel, the true right of the channel has remained in a similar position. The true left floodplain has remained similar between 2007 and 2016.

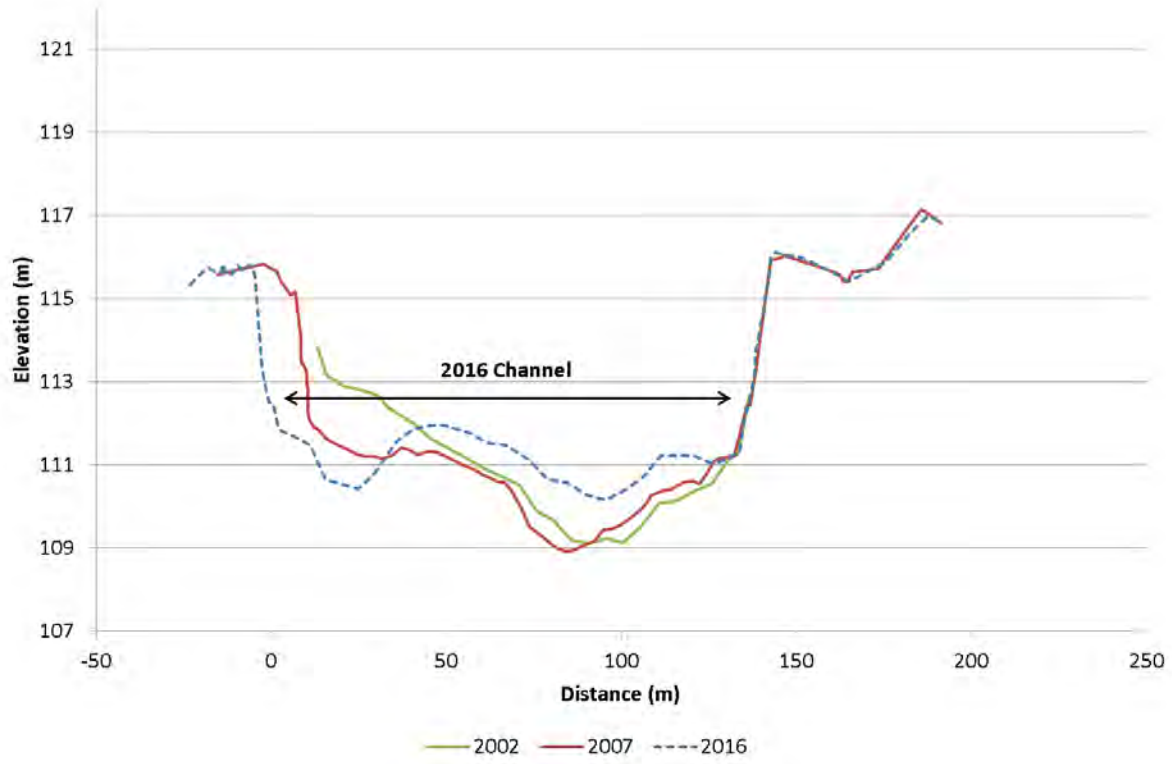


Figure 180. Clutha River/Mata-Au cross-section C20, looking downstream

Figure 181. Clutha River/Mata-Au cross-section C20, looking upstream

Cross-section C20 is located 24.2 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The true left bank has eroded by about 12 m and the channel bed has aggraded between 2007 and 2016. The true right floodplain has experienced minimal change between 2007 and 2016.

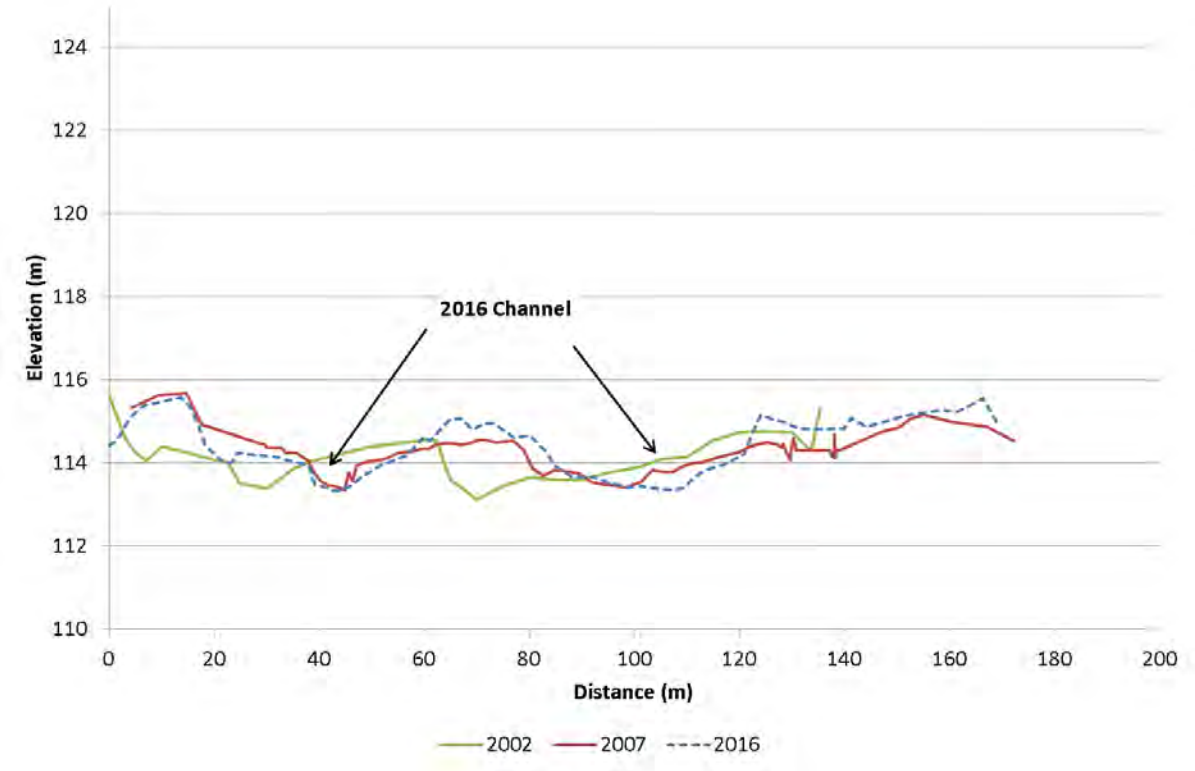


Figure 182. Clutha River/Mata-Au cross-section C21, looking downstream

Figure 183. Clutha River/Mata-Au cross-section C21, looking downstream

Cross-section C21 is located 25.6 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated on a secondary channel that flows around a gravel island just downstream of the Allangrange Road bridge in Clydevale. The channel has both aggraded and degraded with the creation of two, more defined, channels between 2007 and 2016.

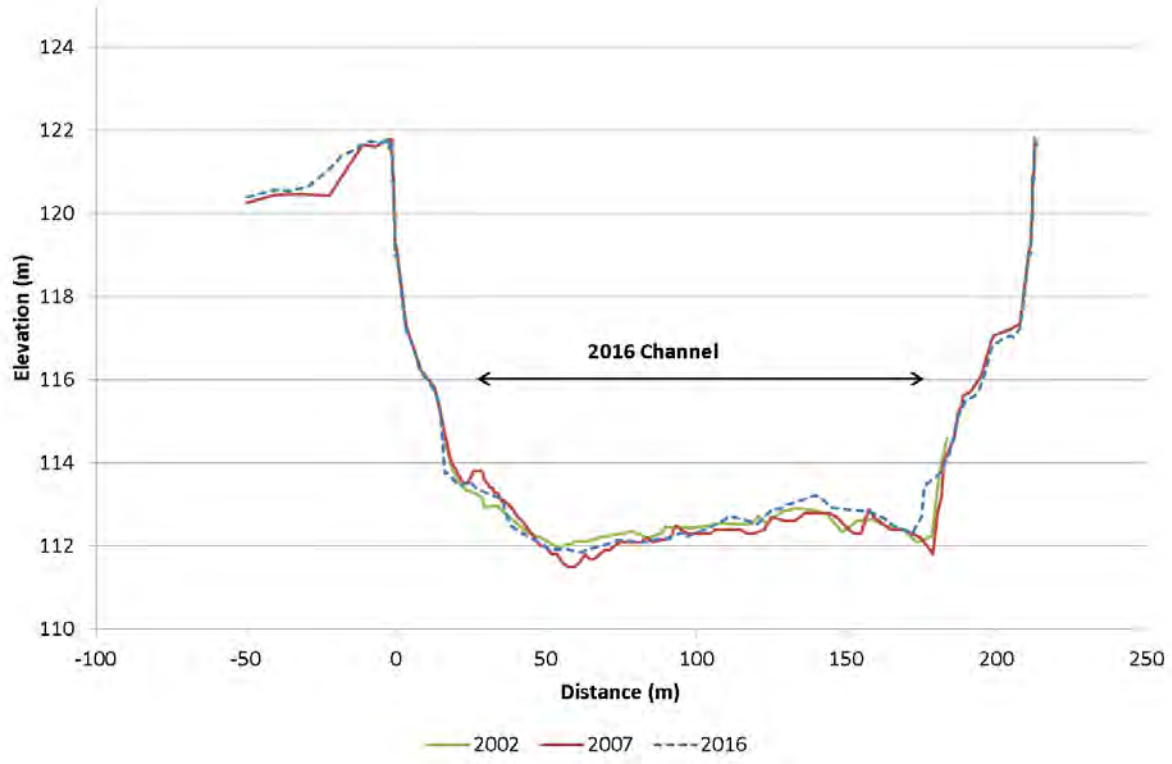


Figure 184. Clutha River/Mata-Au cross-section C22, looking downstream

Figure 185. Clutha River/Mata-Au cross-section C22, looking upstream

Cross-section C22 is located 26.7 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated at the Allangrange Road bridge in Clydevale. The channel has mostly aggraded at this location with minor degradation occurring in the centre of the channel between 2007 and 2016.

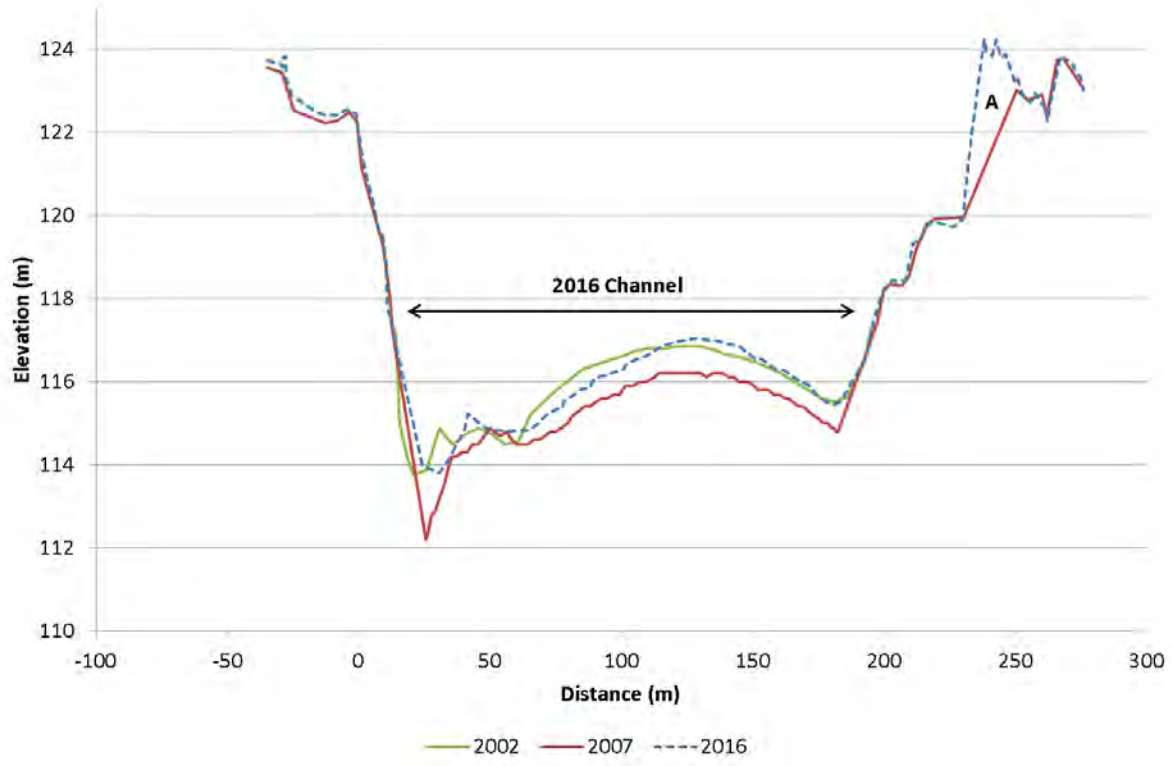


Figure 186. **Clutha River/Mata-Au cross-section C23, looking downstream**

Figure 187. **Clutha River/Mata-Au cross-section C23, looking downstream**

Cross-section C23 is located 32.6 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. Between 2007 and 2016 the channel has experienced mostly aggradation of about 0.8 m; the thalweg has increased in height by about 1.6 m. A bank has formed on the true right bank at the point labelled A between 2007 and 2016 which may be associated with the emplacement of a power pole.

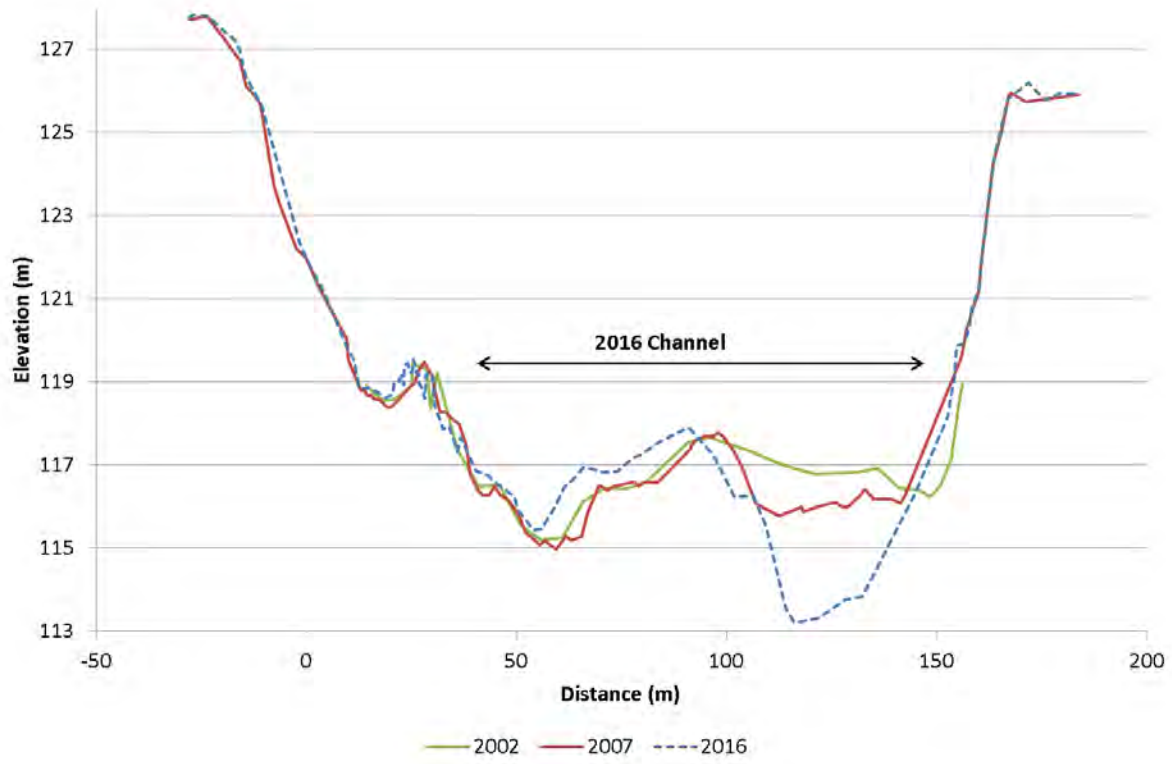


Figure 188. Clutha River/Mata-Au cross-section C24, looking downstream

Figure 189. Clutha River/Mata-Au cross-section C24, looking downstream

Cross-section C24 is located 36.9 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated at the Tuapeka Mouth ferry crossing. The true left of the channel has aggraded between 2007 and 2016 while the true right of the channel has degraded by about 2.8 m. The banks have remained in a similar position between 2007 and 2016.

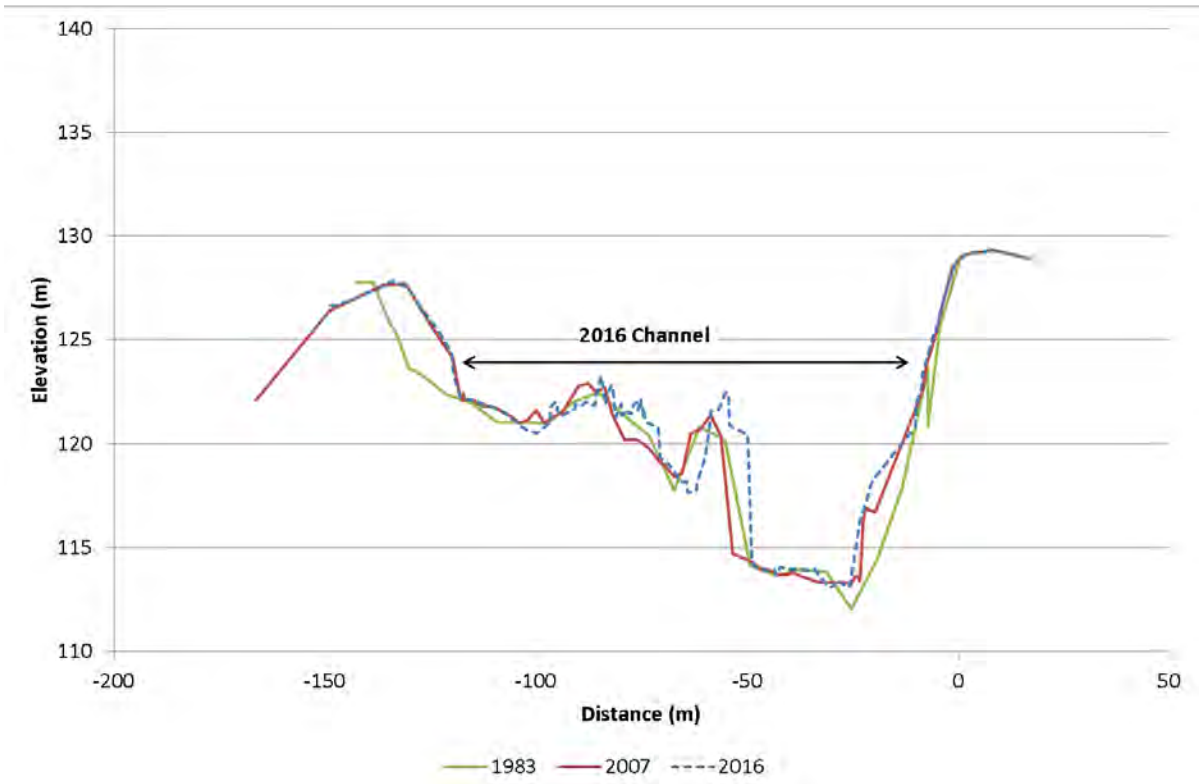


Figure 190. Clutha River/Mata-Au cross-section C25, looking downstream

Figure 191. Clutha River/Mata-Au cross-section C25, looking upstream

Cross-section C25 is located 41.2 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. Between 2007 and 2016 the true right of the channel became more confined with some minor aggradation and degradation on the true left. The thalweg has remained in the same horizontal and vertical position between 2007 and 2016.

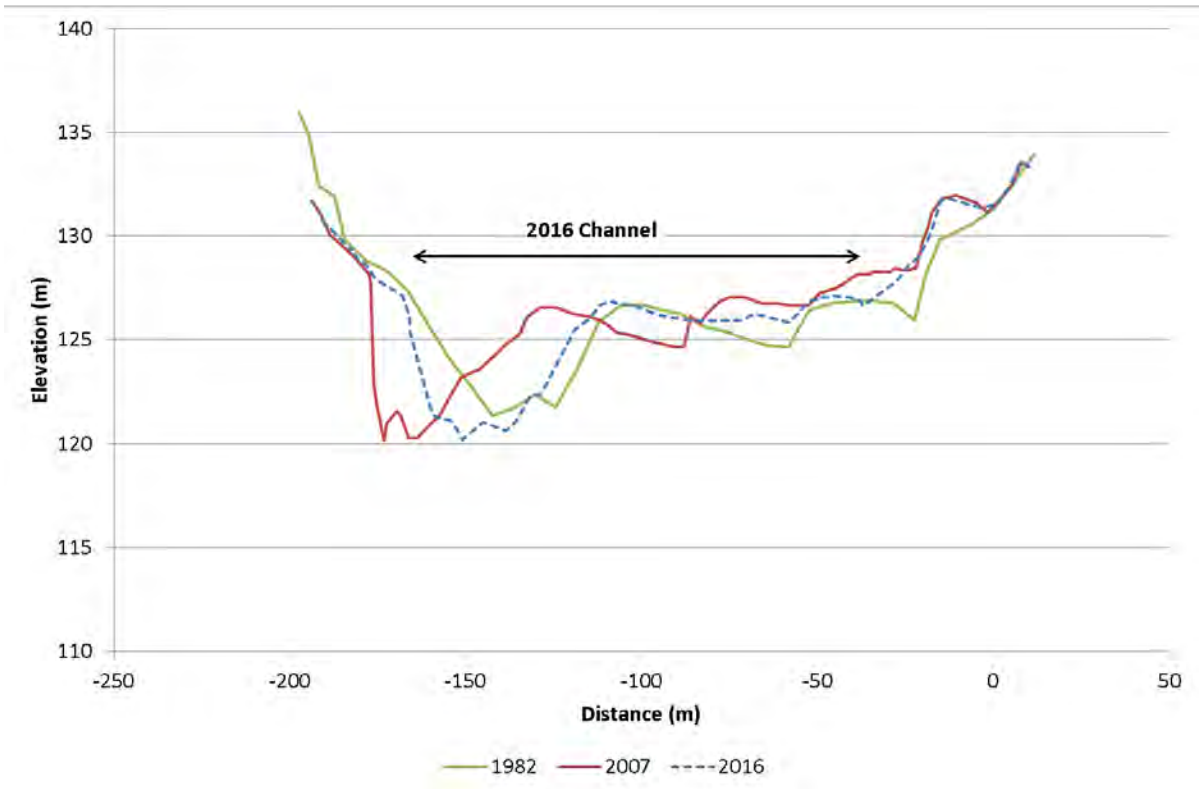


Figure 192. Clutha River/Mata-Au cross-section C26, looking downstream

Figure 193. Clutha River/Mata-Au cross-section C26, looking downstream

Cross-section C26 is located 51.5 km upstream of the Clutha River/Mata-Au bifurcation in Balclutha and is situated in the Rongahere Gorge. The true left (thalweg section) of the channel has moved to the right of the cross-section between 2007 and 2016 with both aggradation and degradation occurring on the right side of the channel.

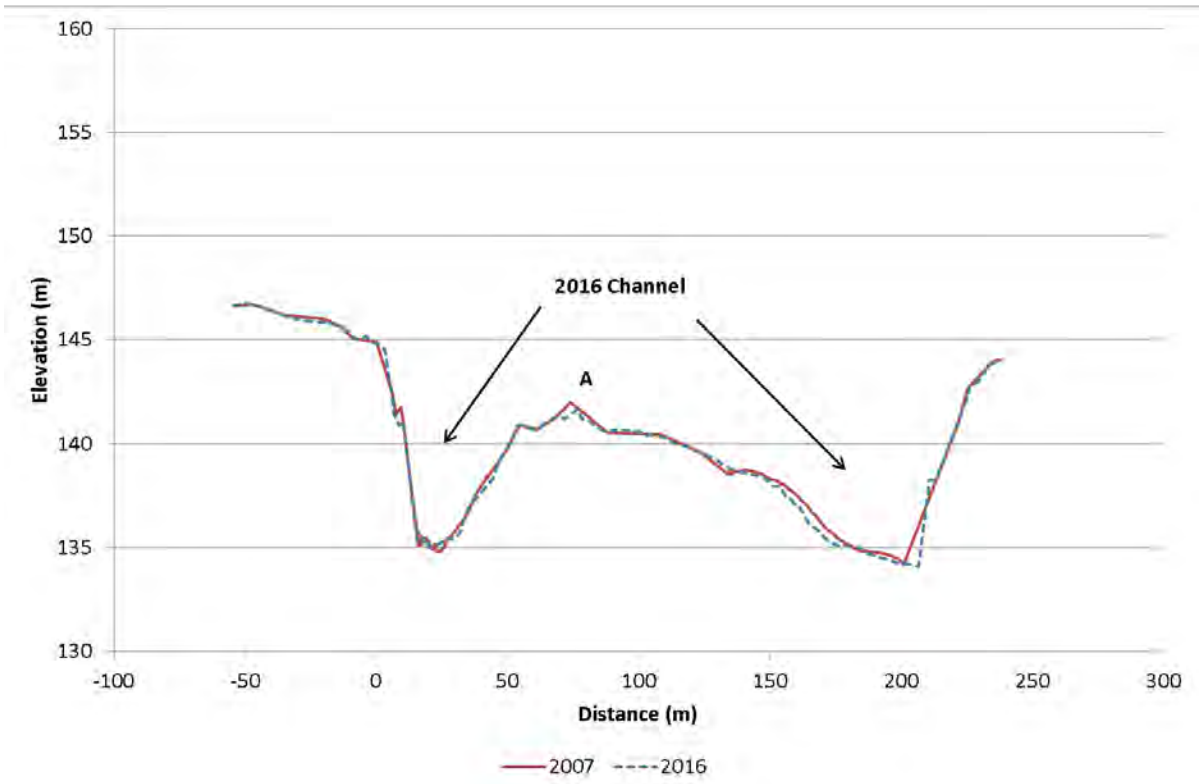


Figure 194. Clutha River/Mata-Au cross-section C27, looking downstream

Figure 195. Clutha River/Mata-Au cross-section C27, looking upstream

Cross-section C27 is located 62.1 km upstream of the Clutha River Mata-Au bifurcation at Blaclutha. A mid channel bar is present at his location and is located at the point labelled A and is visible in Figure 195. There has been minimal change at this cross-section between 2007 and 2016 with small amount of degradation and bank erosion occurring in the true right channel.

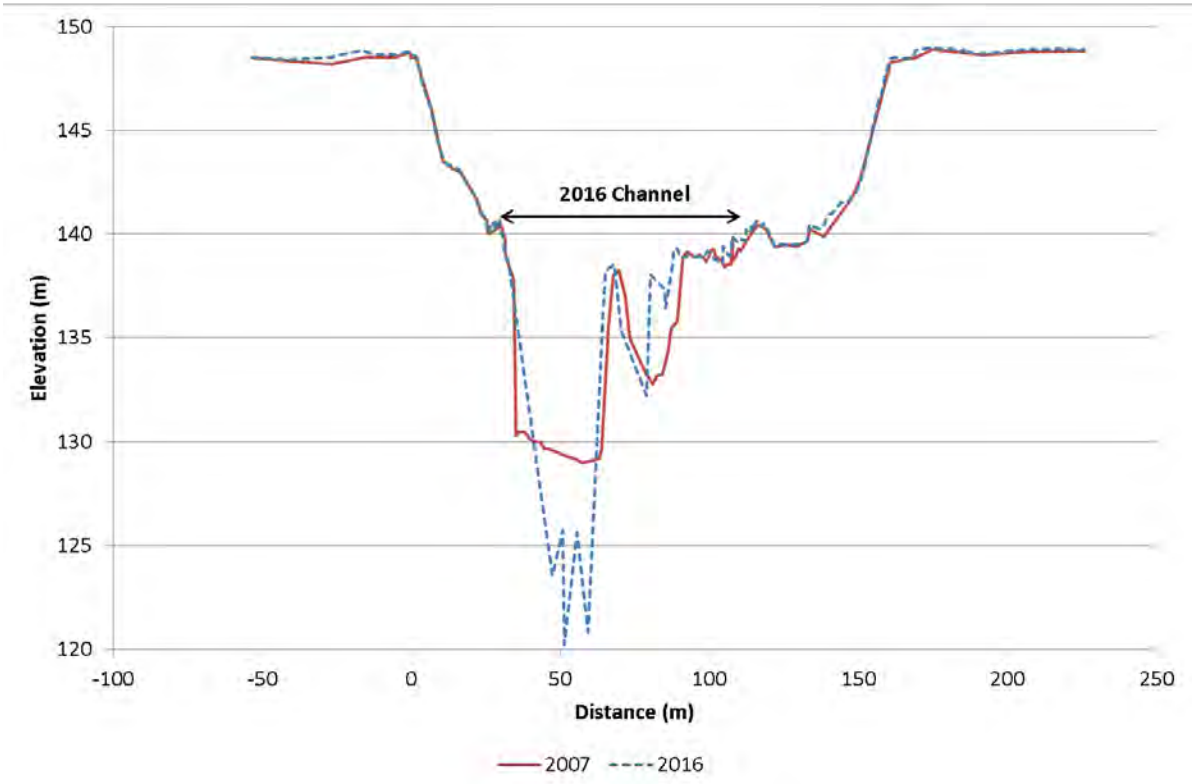


Figure 196. Clutha RIver/Mata-Au cross-section C28, looking downstream

Figure 197. Clutha River/Mata-Au cross-section C28, looking upstream

Cross-section C28 is located 62.8 km upstream of the Clutha River-Mata-Au bifurcation at Balclutha and is situated at the SH8 bridge in Beaumont. Issues were experienced during the bed survey in 2016; as such the surveyed levels of the main part of the channel are indicative only and at best indicate the uneven channel bottom. The true right of the channel has become more confined between 2007 and 2016 with minimal change occurring across the wider floodplain.

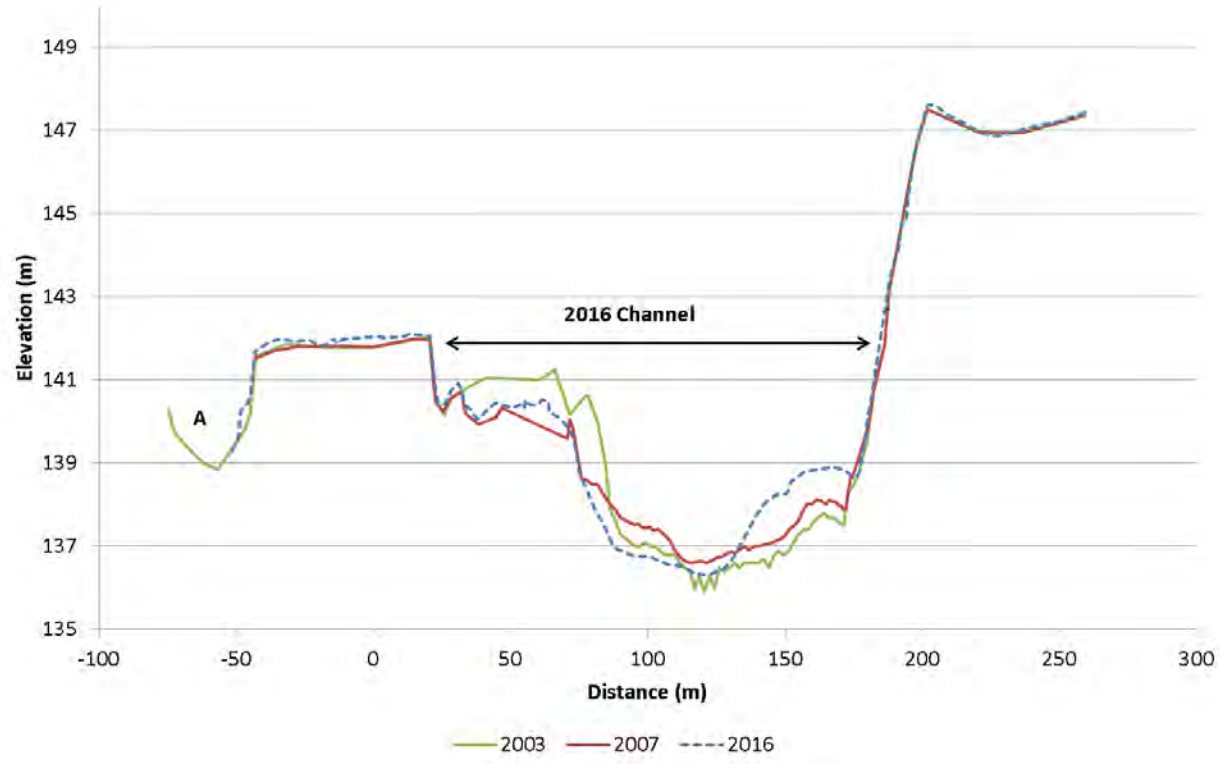


Figure 198. Clutha River/Mata-Au cross-section B10, looking downstream

Figure 199. Clutha River/Mata-Au cross-section B10, looking upstream

Cross-section B10 is located 63.3 km upstream of the Clutha River/Mata-Au Bifurcation at Balclutha. Between 2007 and 2016 the main channel has degraded on the true left and aggraded on the true right with the thalweg staying in the same horizontal position. The point labelled A is a secondary channel that contains water during higher flows.

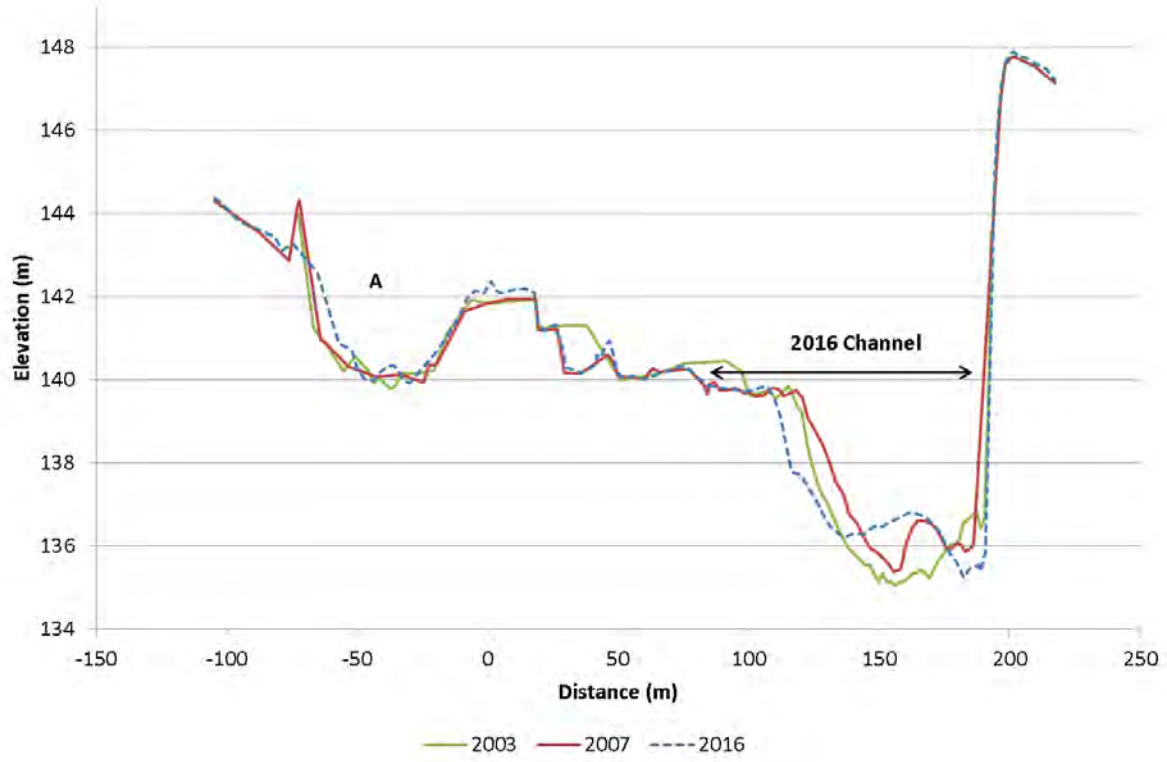


Figure 200. Clutha River/Mata-Au cross-section B11, looking downstream

Figure 201. Clutha River/Mata-Au cross-section B11, looking upstream

Cross-section B11 is located 63.4 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. Between 2007 and 2016 the main channel has eroded on the true left, aggraded in the centre and degraded on the true right to create a less confined channel. The secondary channel (point labelled A) has aggraded on the true left bank between 2007 and 2016.

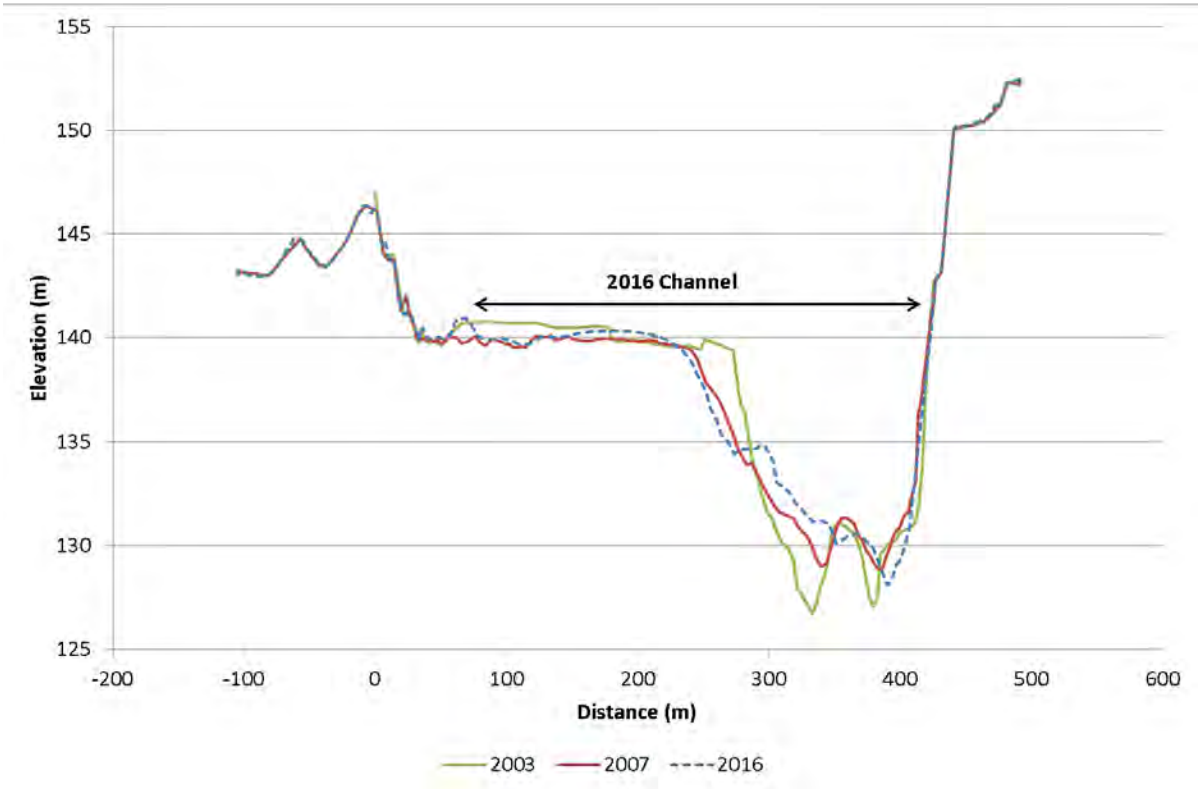


Figure 202. Clutha River/Mata-Au cross-section B12, looking downstream

Figure 203. Clutha River/Mata-Au cross-section B12, looking upstream

Cross-section B12 is located 63.5 km upstream of the Clutha River/Mata-Au bifurcation in Balclutha. The true left of the main channel is a gravel bar that is often exposed when flows are low with majority of the flow being located on the true right of the channel. Between 2007 and 2016 the main section of the channel has become more confined with aggradation on the true left and degradation in the thalweg section. The rest of the channel and wider floodplain has remained similar between 2007 and 2016.

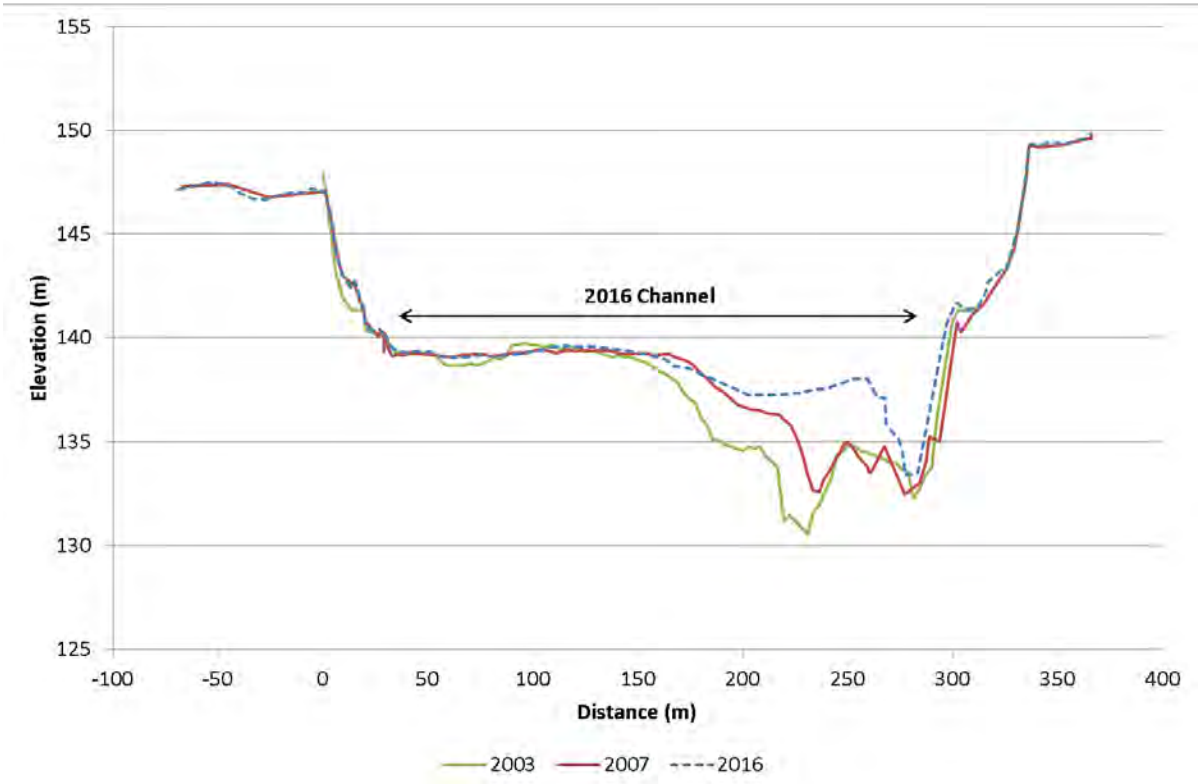


Figure 204. Clutha River/Mata-Au cross-section B13, looking downstream

Cross-section B13 is located 63.6 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The channel has experienced maximum aggradation of about 5 m and a confining of the thalweg section of the channel between 2007 and 2016. The wider floodplain and true left of the channel have remained similar between 2007 and 2016.

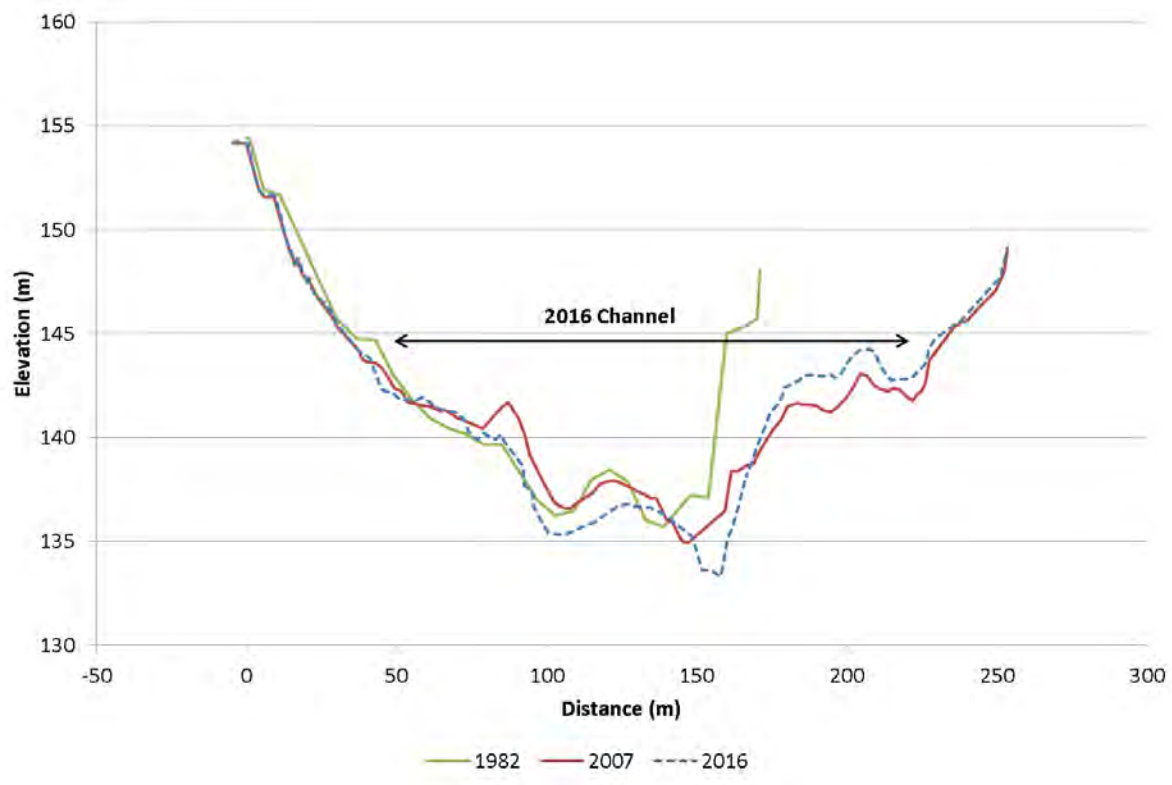


Figure 205. Clutha River/Mata-Au cross-section C29, looking downstream

Figure 206. Clutha River/Mata-Au cross-section C29, looking upstream

Cross-section C29 is located 66.5 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The centre of the main channel has experienced degradation with the true right showing aggradation between 2007 and 2016.

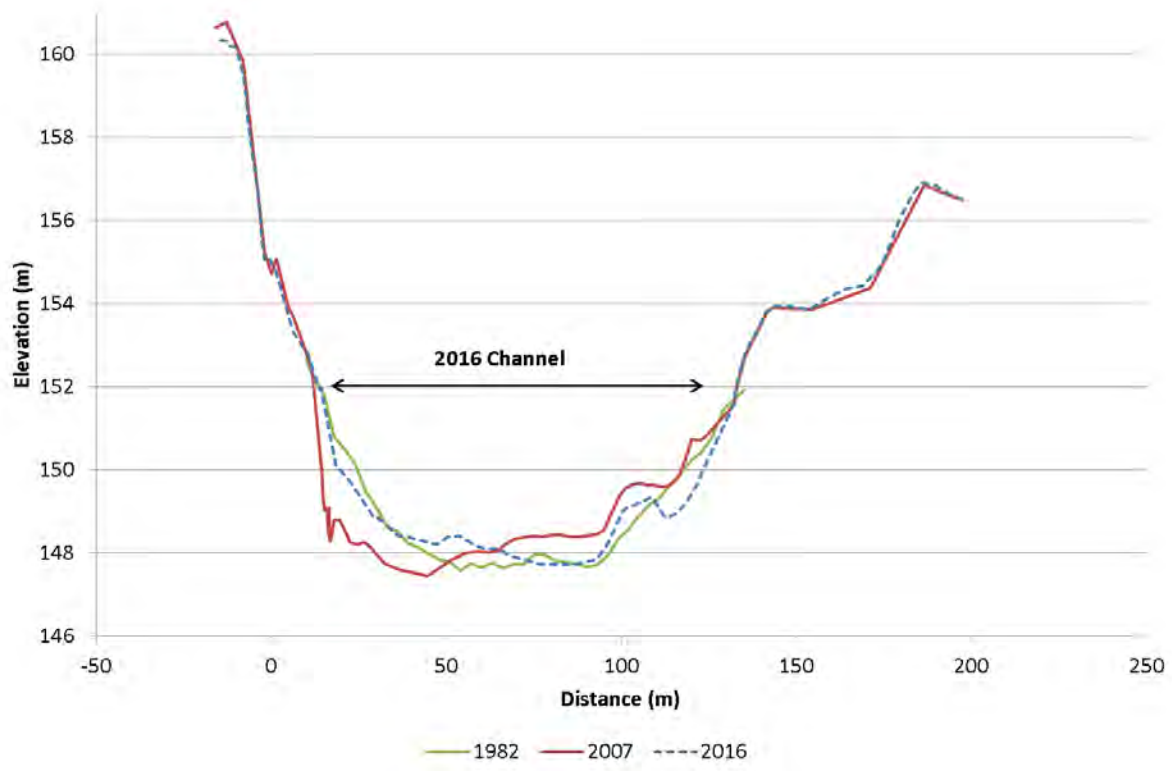


Figure 207. Clutha River/Mata-Au cross-section C30, looking downstream

Figure 208. Clutha River/Mata-Au cross-section C30, looking upstream

Cross-section C30 is located 71.9 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. Between 2007 and 2016 the true left of the main channel has aggraded by about 0.9 m and the right of the channel has degraded by about 0.6 m with the thalweg shifting towards the right bank.

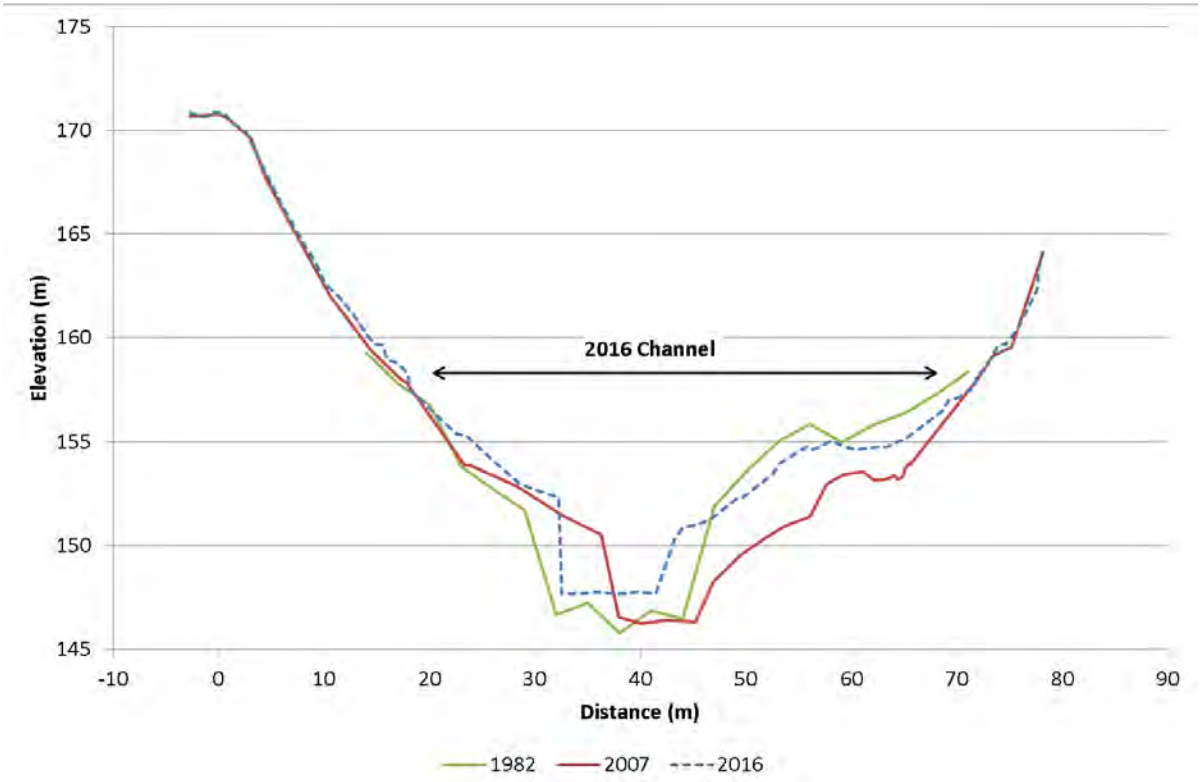


Figure 209. Clutha River/Mata-Au cross-section C31, looking downstream

Figure 210. Clutha River/Mata-Au cross-section C31, looking upstream

Cross-section C31 is located 78.9 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. Between 2007 and 2016 the channel has eroded the true left bank with the thalweg section increasing in height. The true right of the channel has aggraded by a maximum of about 3 m.

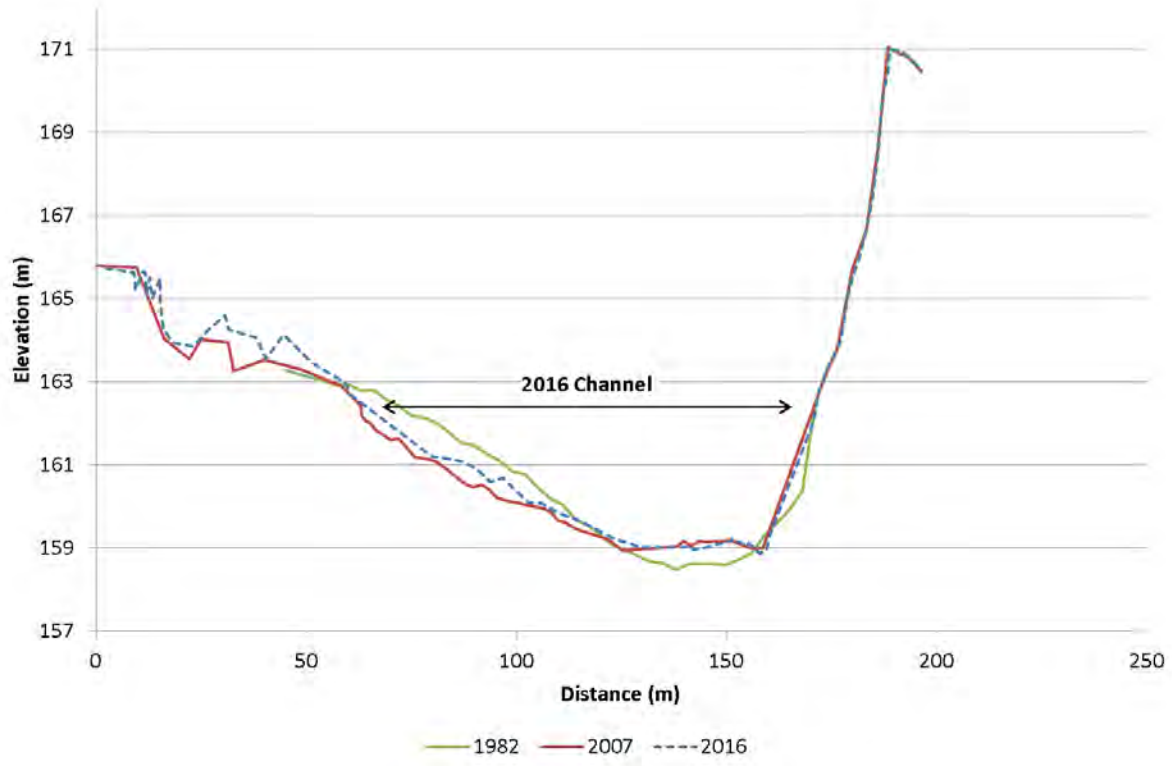


Figure 211. Clutha River/Mata-Au cross-section C32, looking downstream

Figure 212. Clutha River/Mata-Au cross-section C32, looking upstream

Cross-section C32 is located 82.8 km upstream of the Clutha River/Mata-Au Bifurcation at Balclutha. The true left floodplain and berm area has aggraded between 2007 and 2016 with aggradation also occurring on the true left of the channel. The true right of the channel and the right bank have remained similar between 2007 and 2016.

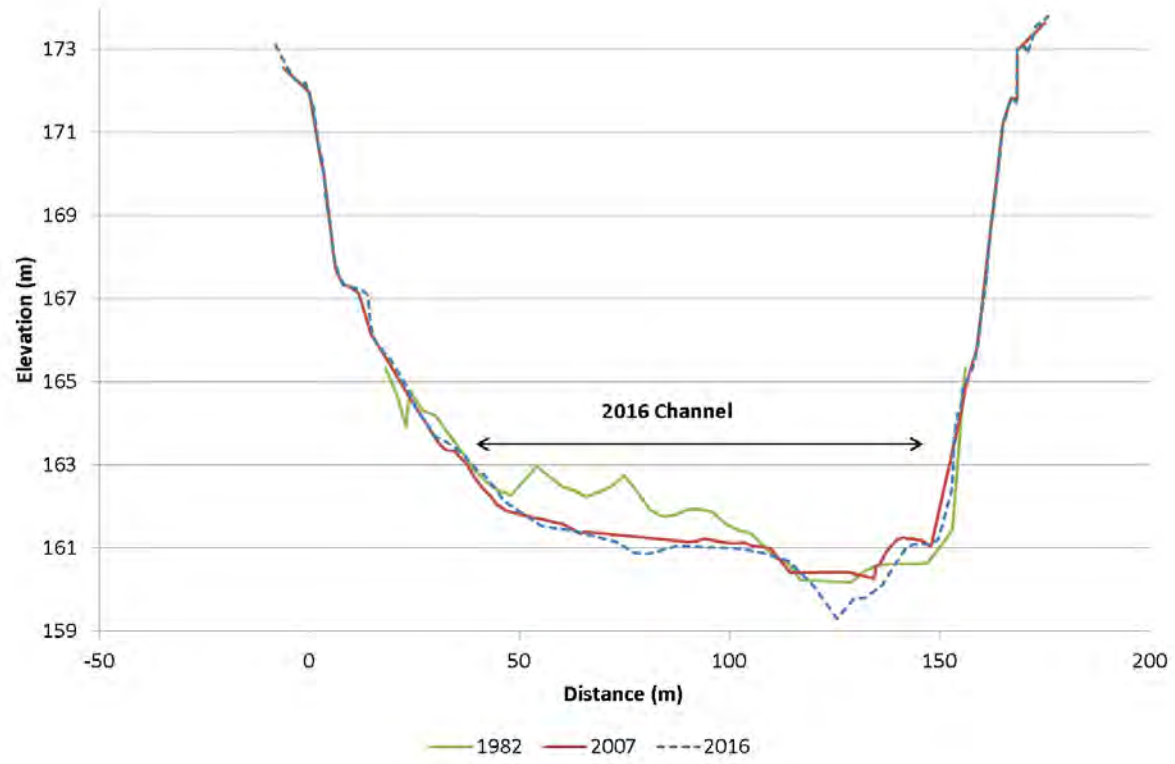


Figure 213. Clutha River/Mata-Au cross-section C33, looking downstream

Figure 214. Clutha River/Mata-Au cross-section C33, looking upstream

Cross-section C33 is located 85 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated at the Miller Flat bridge. The wider floodplain has remained similar between 2007 and 2016 with mostly degradation occurring in the channel. The thalweg has lowered by about 1 m between 2007 and 2016.

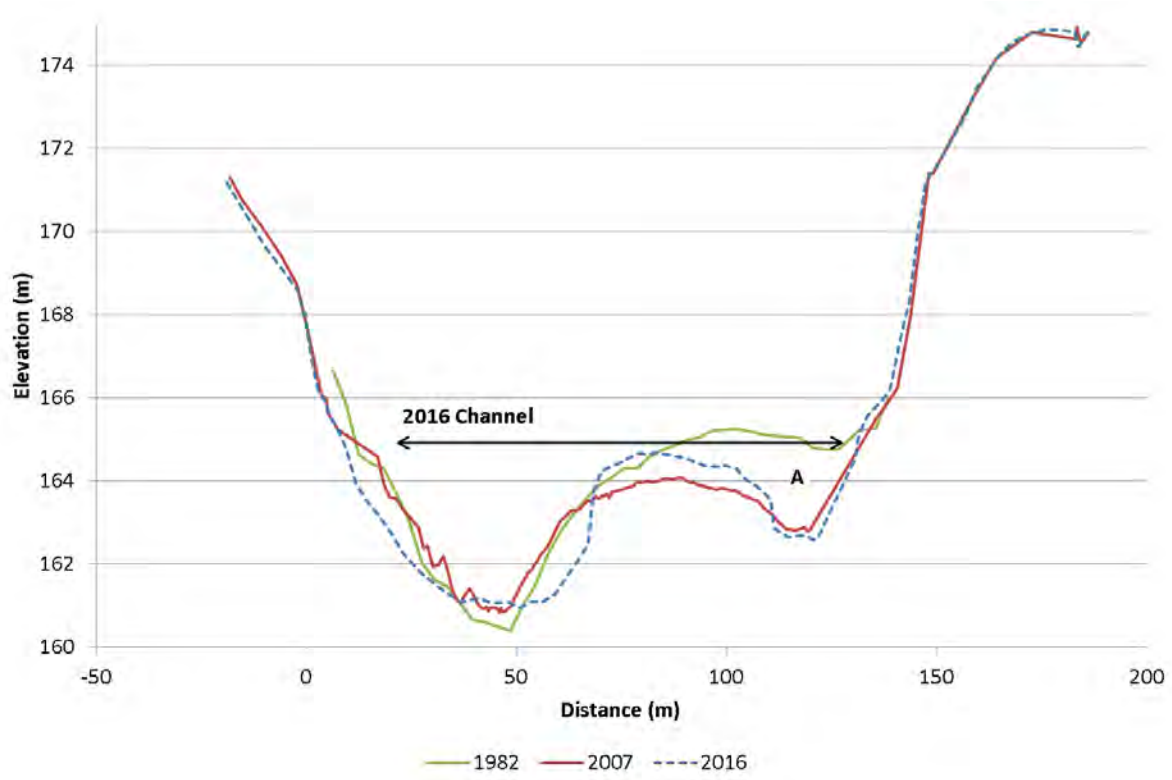


Figure 215. Clutha River/Mata-Au cross-section C34, looking downstream

Figure 216. Clutha River/Mata-Au cross-section C34, looking downstream

Cross-section C34 is located 87 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The true left of the channel has eroded its banks with no change in the thalweg section of the channel between 2007 and 2016. The centre of the channel has aggraded with the true right of the channel becoming more confined (point labelled A) between 2007 and 2016.

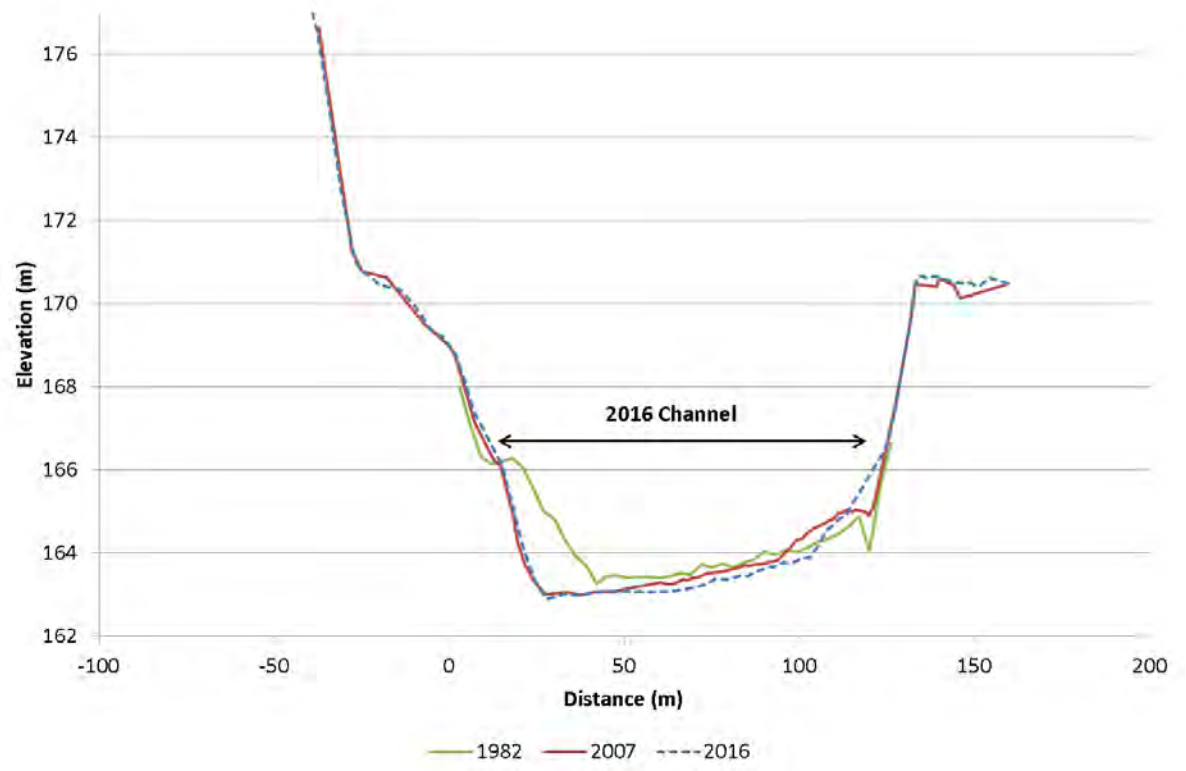


Figure 217. Clutha River/Mata-Au cross-section C35, looking downstream

Figure 218. Clutha River/Mata-Au cross-section C35, looking from true left to right bank

Cross-section C35 is located 88.9 km upstream of the Clutha River/Mata-Au bifurcation in Balclutha. The channel has remained similar between 2007 and 2016 with minor degradation occurring in the centre and aggradation occurring on the true right bank of the channel.

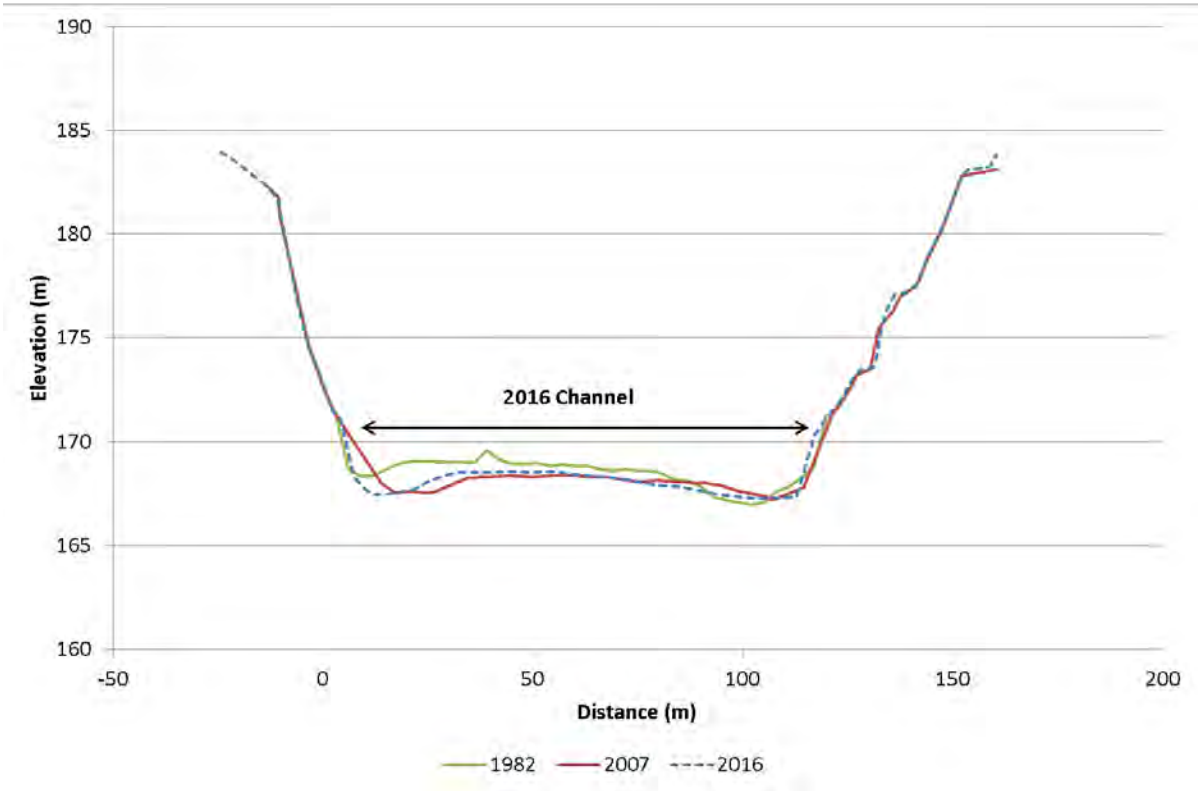


Figure 219. Clutha River/Mata-Au cross-section C36, looking downstream

Figure 220. Clutha River/Mata-Au cross-section C36, looking downstream

Cross-section C36 is located 93.9 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The channel has remained similar between 2007 and 2016 with erosion occurring on the true left bank and minor aggradation and degradation occurring across the channel. Both banks have remained similar between 2007 and 2016.

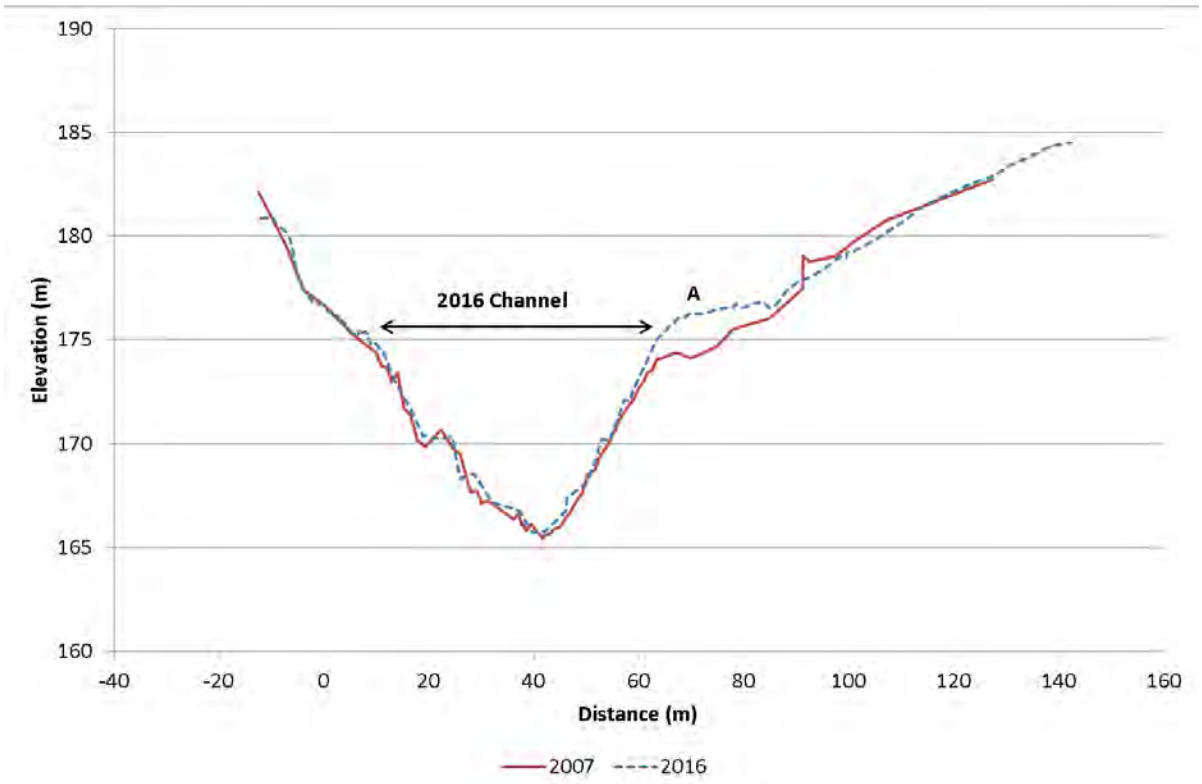


Figure 221. Clutha River/Mata-Au cross-section C37, looking downstream

Figure 222. Clutha River/Mata-Au cross-section C37, looking downstream, Black Jacks Creek meets the Clutha River/Mata-Au on the right of the photograph

Cross-section C37 is located 99 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated where Black Jacks Creek meets the Clutha River/Mata-Au. The true left bank and the channel have remained similar between 2007 and 2016 with the true right bank showing experiencing aggradation which may be attributed to sediment deposited by Black Jack's Creek (point labelled A).

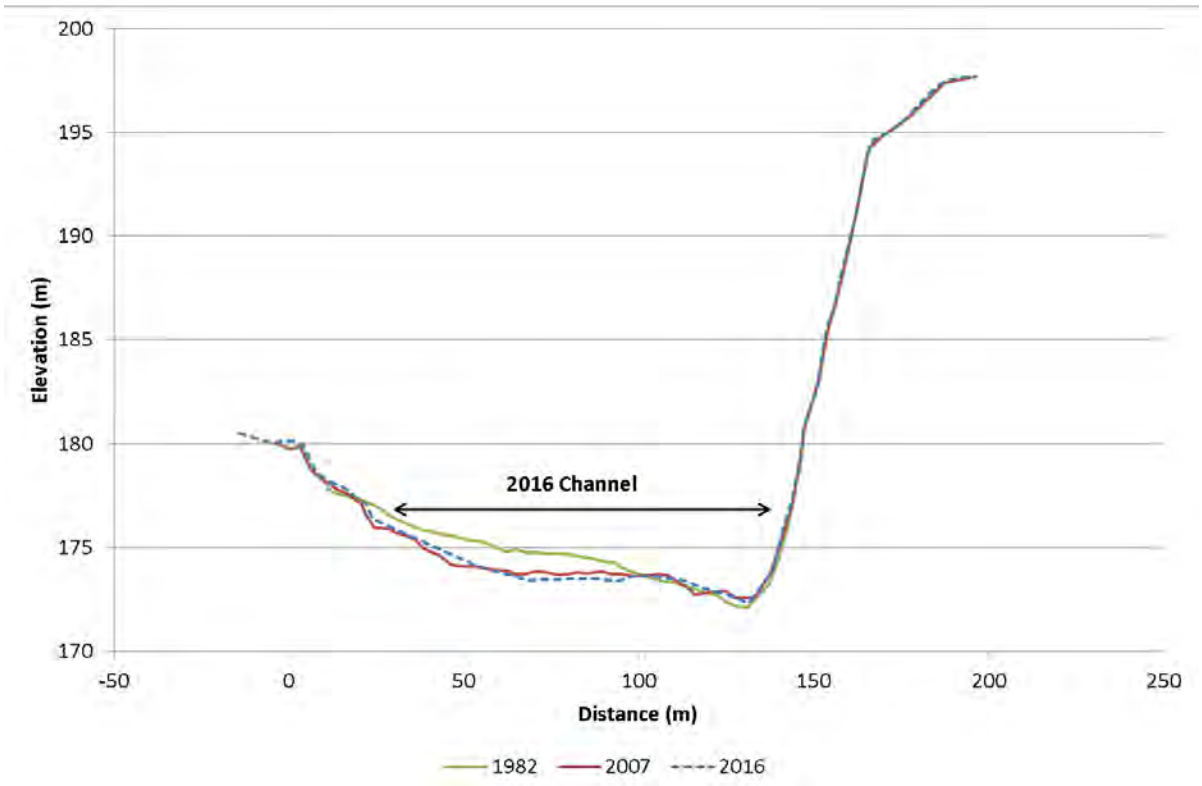


Figure 223. Clutha River/Mata-Au cross-section C38, looking downstream

Figure 224. Clutha River/Mata-Au cross-section C38, looking upstream

Cross-section C38 is located 100.8 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The channel has remained similar between 2007 and 2016 with both minor aggradation and degradation occurring.

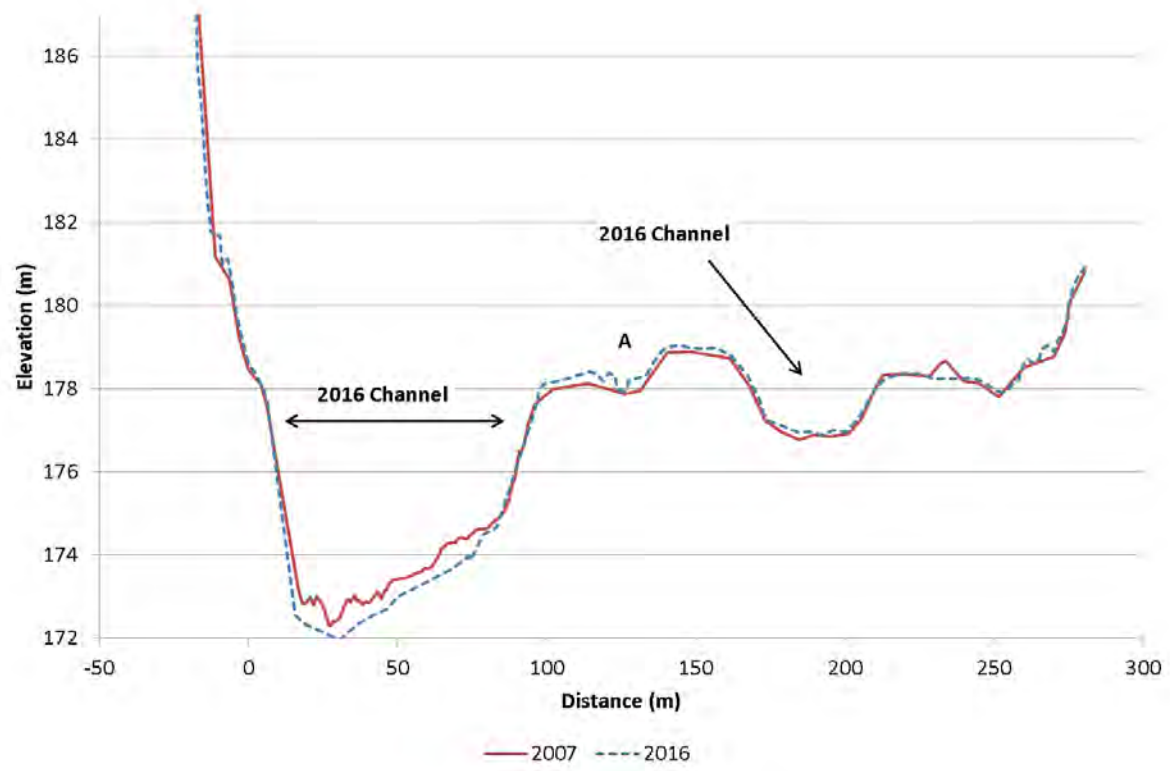


Figure 225. Clutha River/Mata-Au cross-section C39, looking downstream

Figure 226. Clutha River/Mata-Au cross-section C39, looking downstream

Cross-section C39 is located 101.6 km downstream of the Clutha River/Mata-Au bifurcation in Balclutha. At this cross-section a large gravel bar is present (point labelled A) with the channel splitting into two and passing around the bar. Between 2007 and 2016 the true left channel has degraded, and the mid channel bar and true right channel have experienced minor aggradation.

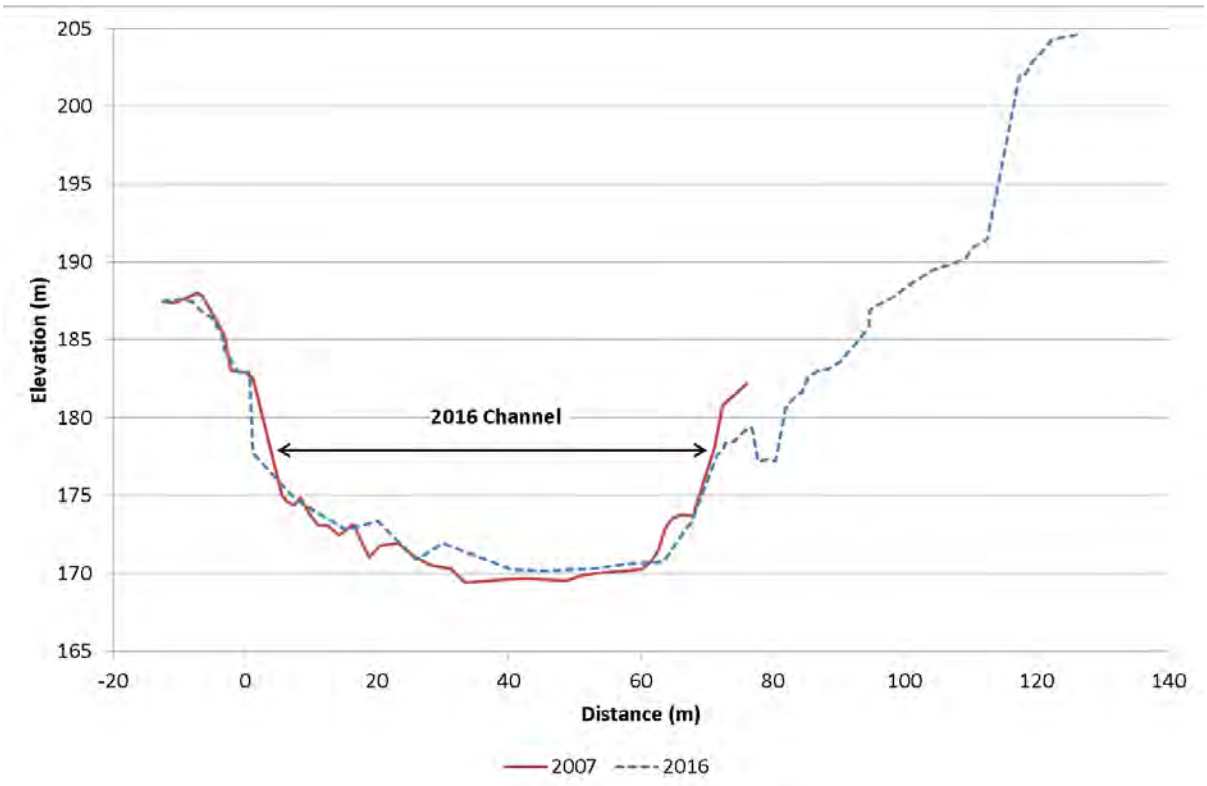


Figure 227. Clutha River/Mata-Au cross-section C40, looking downstream

Figure 228. Clutha River/Mata-Au cross-section C40, looking from true right to left bank

Cross-section C40 is located 102.3 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The true left bank has eroded with aggradation occurring across most of the channel bed between 2007 and 2016. The 2007 survey of the true right bank does not contain sufficient survey points to allow a comparison to be made with the 2016 survey.

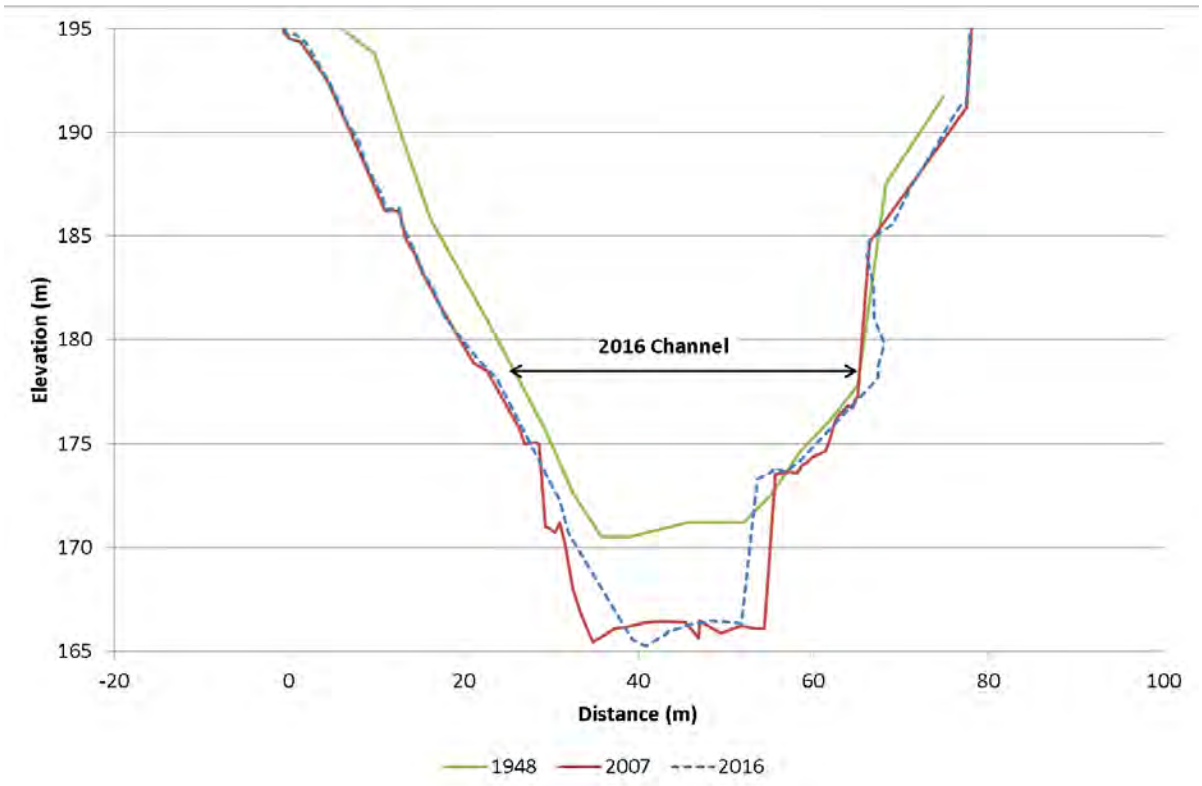


Figure 229. Clutha River/Mata-Au cross-section C41, looking downstream

Figure 230. Clutha River/Mata-Au cross-section C41, looking downstream

Cross-section C41 is located 103 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated at the Roxburgh township bridge. The channel has become more confined with aggradation occurring on the true left and right banks between 2007 and 2016, the centre of the channel has degraded between this period.

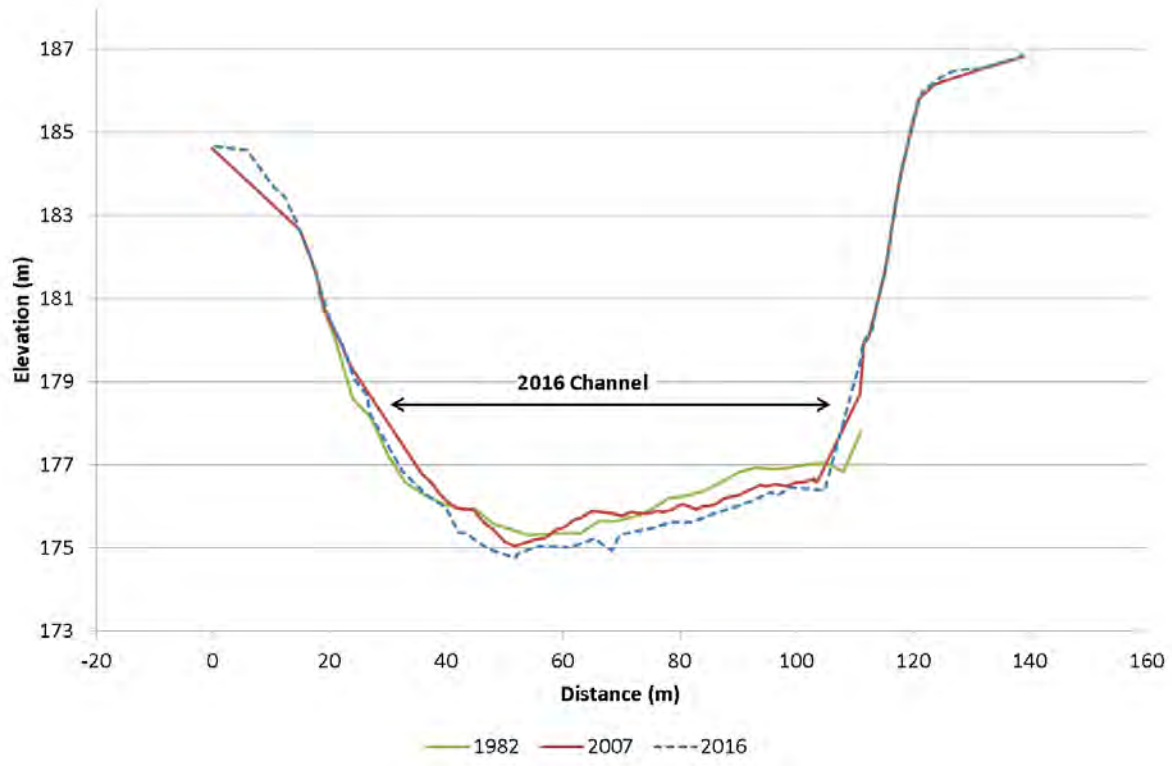


Figure 231. Clutha River/Mata-Au cross-section C42, looking downstream

Figure 232. Clutha River/Mata-Au cross-section C42, looking downstream

Cross-section C42 is located 104.3 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. Between 2007 and 2016 the channel has degraded with the true left and right banks remaining in a similar position.

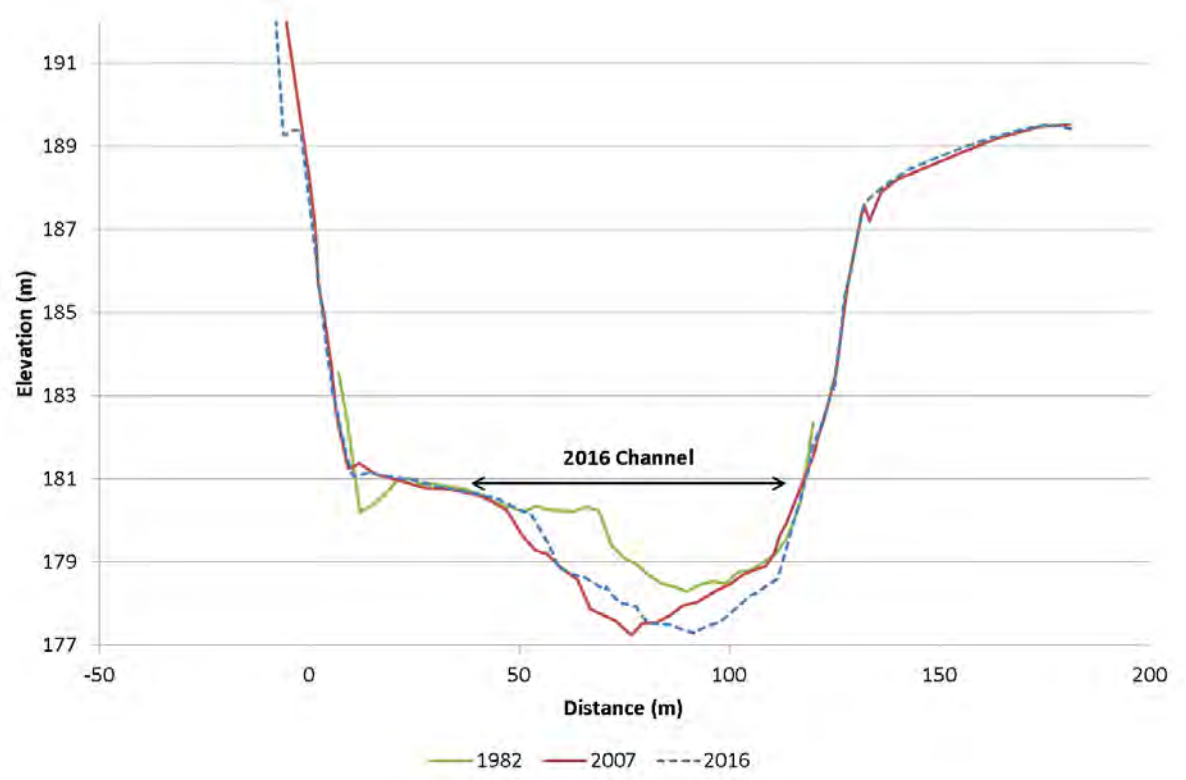


Figure 233. Clutha River/Mata-Au cross-section C43, looking downstream

Figure 234. Clutha River/Mata-Au cross-section C43, looking from true left to right bank

Cross-section C43 is located 107.2 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. The thalweg section of the channel has moved towards the true right bank between 2007 and 2016 with aggradation occurring on the true left of the channel and degradation on the true right.

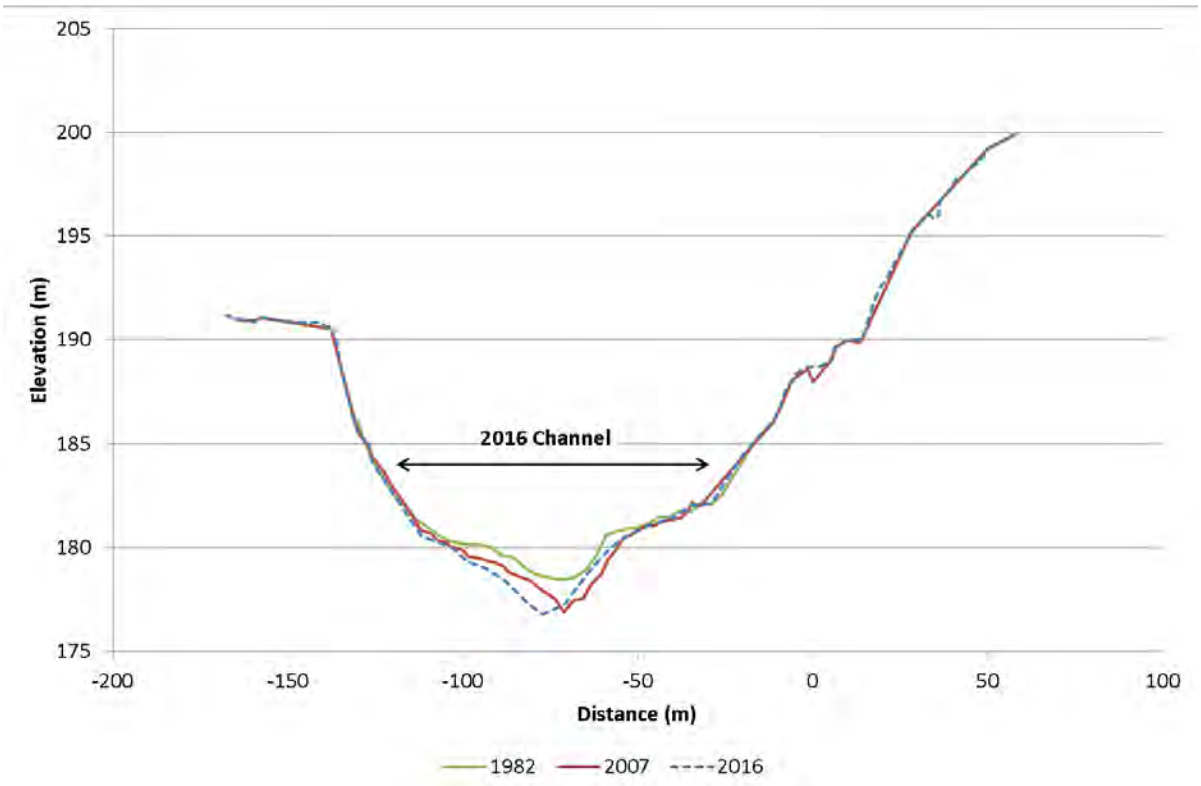


Figure 235. Clutha River/Mata-Au cross-section C44, looking downstream

Figure 236. Clutha River/Mata-Au cross-section C44, looking downstream

Cross-section C44 is located 110.3 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha. Between 2007 and 2016 the thalweg section of the channel has moved towards and eroded the true left channel bank, the thalweg has remained in the same vertical position. The true right of the channel has aggraded with the wider floodplain remaining similar between 2007 and 2016.

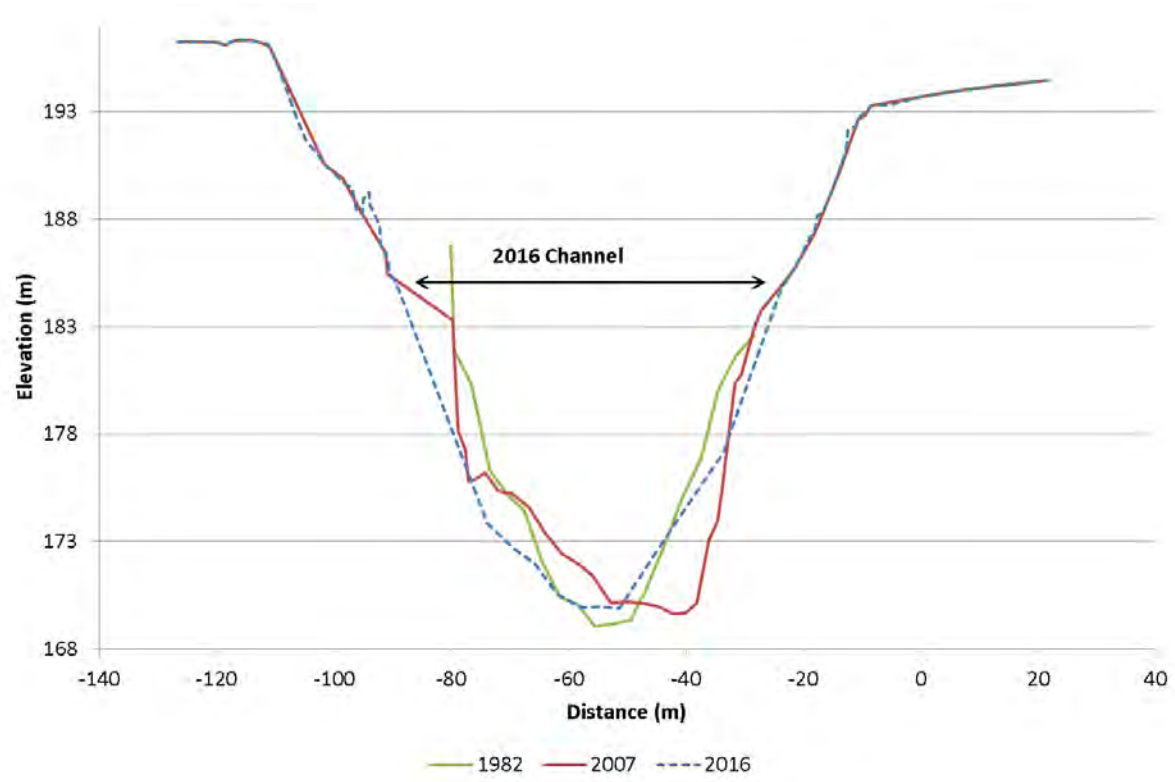


Figure 237. Clutha River/Mata-Au cross-section C45, looking downstream

Figure 238. Clutha River/Mata-Au cross-section C45, looking upstream

Cross-section C45 is located 111.2 km upstream of the Clutha River/Mata-Au bifurcation at Balclutha and is situated 0.8 km downstream of the Roxburgh Dam which can be seen in Figure 238. The channel has moved towards and eroded the true left bank with aggradation occurring on the true right bank between 2007 and 2016. The wider floodplain has remained similar between 2007 and 2016.

Appendix D. Methods

Background

ORC has collected cross-section survey information on the Clutha River/Mata-Au from Roxburgh Dam to the Pacific Ocean (Figure 1). The monitoring programme dates back to 1940, although cross-sections have been added since. The analysis contained in this report is intended to show the changes in morphology that have occurred since the last comprehensive survey was undertaken in 2008 for the reach between Balclutha and Roxburgh Dam and the first analysis of the Koau and Matau branches. Although changes before this time are described more fully in ORC (2008), this report places the more recent changes within the context of longer term trends.

Parameters

The MBL is described as the “area below a certain datum divided by a prescribed channel width” (Sriboonlue & Basher, 2003). This can be represented as a horizontal line across the channel where there is as much bed above the line as below it. MBL was calculated in excel using the below formula:

$$MBL = \frac{\sum d_n(\frac{L_n + L_{n+1}}{2})}{ACW}$$

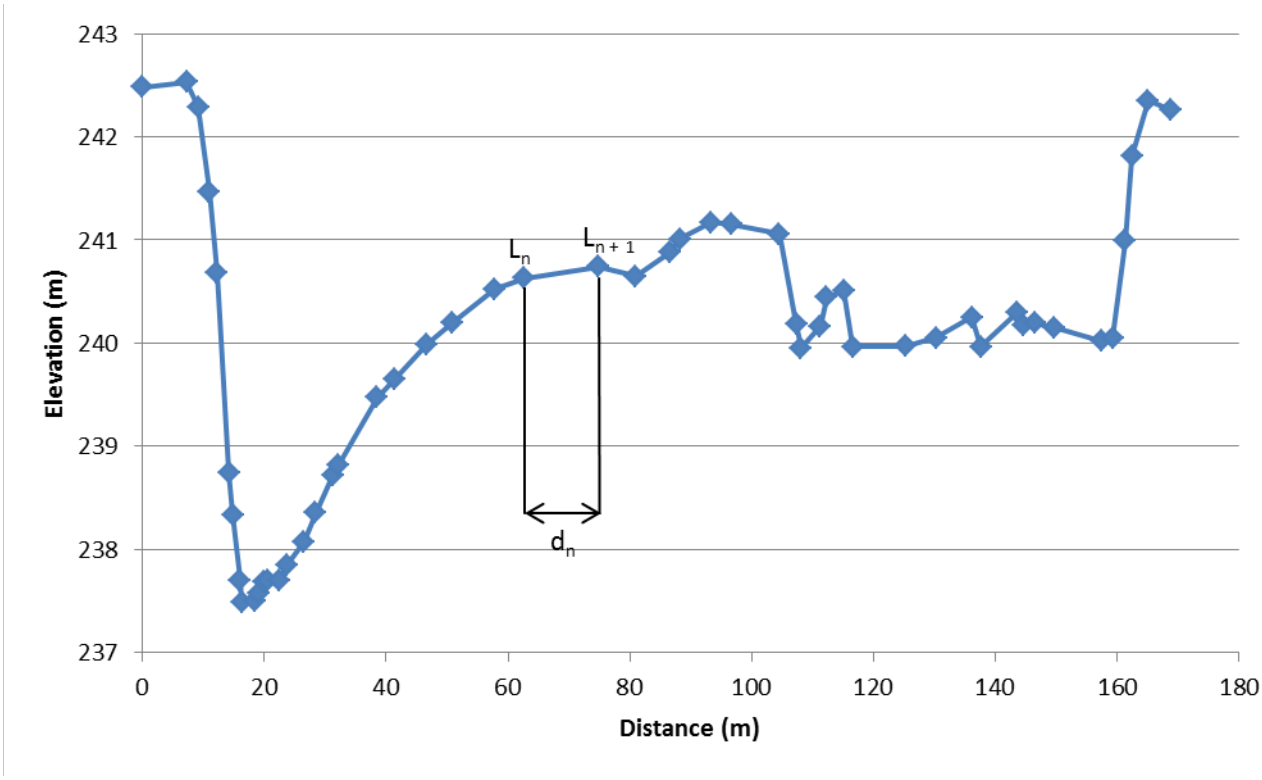


Figure 239. MBL calculation - definition of variables

The active channel width (ACW) is calculated as the bank top of the channel, the point at which floodwater would begin to overtop the channel, and spill out onto the wider floodplain (Griffiths, 1979) or the widest extent of survey data where such a point was not obvious. The ACW and the location of the top of bank can vary between years which allows for a full analysis of the cross-section changes to occur i.e. where bank erosion has significantly widened the channel between surveys. This method does not always directly compare the same portion of riverbed between survey years but allows trend analysis to be completed and areas of aggradation and degradation to be located.

The extent of survey coverage varies between years with some years only surveying the active channel a small amount of the bank. In these instances a shorter ACW was used to allow a better comparison to be made (cross-sections K64, K48, K10, M202, M128, M99, C3, C9, C12). At cross-sections where coverage extended further and included backwaters and banks, a larger ACW width was used to better reflect changes in the wider river morphology.

Two vertical scales were used to display the cross-section graphs, a 30 m scale was used for cross-sections C25, C26, C28, B13, C29, C36, C37, C38, C40, C41, C44, C45. A 15 m scale was used for all other cross-sections not listed above.

Limitations

A limitation of the cross-section data is that it shows the river as it was at the time the survey was undertaken; therefore, it provides a snapshot view of the river morphology for that particular time and place. Furthermore, survey methods involve taking an elevation and distance measurement at every major break in slop. This method has limitation in terms of transect resolution. The interpretations should therefore be viewed within the context that the data were collected.

All cross-section graphs are looking downstream, with the true left of the river being on the left side of the graph. All elevation measurements are expressed in Otago Datum, which lies 100 m above the Dunedin Vertical Datum (1958).

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