

Cardrona River Channel Morphology

May 2016

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Technical summary

This report assesses changes in the morphology of the Cardrona River using visual inspections, aerial and ground photography, and cross-section data collected in 2003, 2007, and 2015. This assessment provides an update on changes in channel morphology that have occurred since the last catchment-wide analysis of long-term trends in 2010 (ORC, 2010). This report is designed to inform decisions relating to the management of the Cardrona River and its margins, including gravel extraction, floodwater conveyance, and asset management.

The analysis contained in this report shows that the Cardrona River between the headwaters and the confluence with the Clutha River/Mata-Au experienced an increase in mean bed level (MBL) at 20 of the 42 survey locations and a decrease in MBL at 19 survey locations, one site experienced no change between 2007 and 2015.¹ The greatest change in MBL occurred at cross-section CR54-2 which showed a decrease in MBL of 0.88 m between 2007 and 2015. The cross-sections in the lower reaches displayed more aggradation, variation (in channel aggradation and degradation) was recorded in the mid reaches, and minimal degradation or aggradation was recorded in the upper reaches. Between 1988 (when the cross-sections were first surveyed) and 2015 the Cardrona River channel at the cross-section locations has (in general) become deeper and wider.

¹ MBL could not be calculated at an additional two survey locations.

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1. Introduction

This report identifies the changes that have occurred in the channel morphology of the Cardrona River between the upper reaches and the confluence with the Clutha River/Mata-Au for the period 2007 to 2015. 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 Cardrona River catchment is located in the upper catchment of the Clutha River/Mata-Au in the Queenstown Lakes District. The Cardrona River drains a catchment area of 337 km² and is located between the Criffle and Pisa Ranges to the east and the Crown Range to the south and west (Figure 1). The river flows in a north easterly direction from the crest of the Crown Range Road to its confluence with the Clutha River/Mata-Au (approximately 40 km). There are several tributary streams including the Branch Burn, Boundary Creek, and Spotts Creek which flow into the Cardrona from the western side of the range. Tussock and low producing grassland is prevalent in the higher catchment, while the lower catchment is dominated by high producing exotic grassland (ORC, 2007). Hillslope erosion in the Cardrona River catchment increases with altitude with most of the lower catchment only experiencing low erosion rates (ORC 2004). Most erosion in the Cardrona River catchment can be attributed to frost heave, wind, and sheet erosion (Prickett, 1984).

The upper reaches of the Cardrona River (above Cardrona Village) are steep and incised in bedrock. Downstream of the Cardrona Village the valley floor becomes wider and the channel switches between single thread and braided forms (ORC, 2010). The channel narrows at the Mount Barker flow recorder, then the channel becomes wider and braided until the State Highway 6 bridge where the river becomes confined by willows. The channel gradient in the lower reaches is shallower than the upper reaches and creates a zone of greater sediment deposition as the stream can no longer transport larger material. The Cardrona River experiences changes in river morphology through geological and recent time scales, Figure 2 shows the changes in the form of the Cardrona River between 1958 and 2006 and highlights how the river can vary in form.

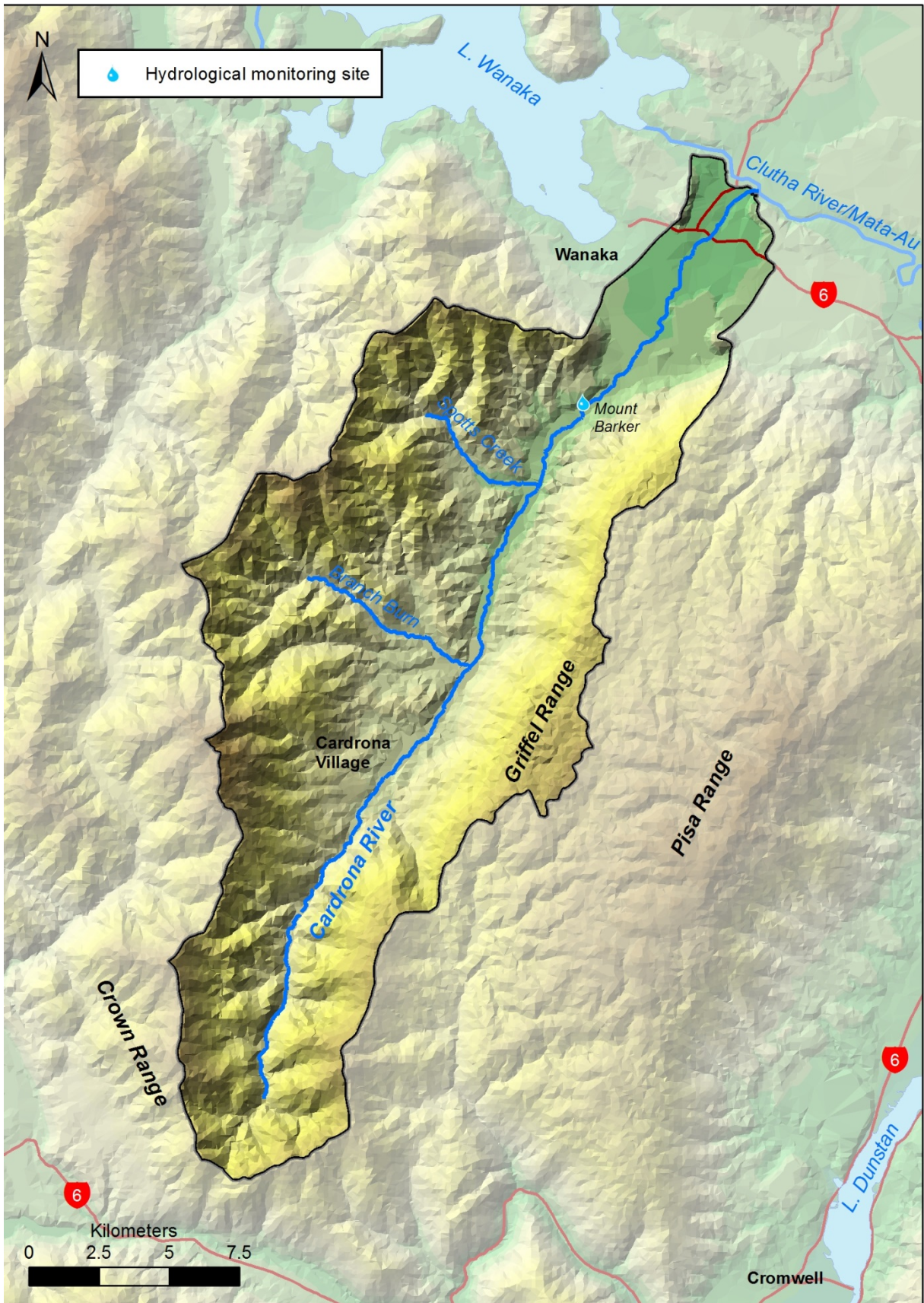


Figure 1. Cardrona River catchment map



Figure 2. Cardrona River - left 1958, right 2006

2. Results

The active channel of the Cardrona River is a dynamic system where flood events and sediment movement regularly cause changes in the channel morphology. Changes in the longitudinal profile are constantly occurring, due to aggradation and degradation² along the channel and lateral bank erosion. This report summarises the changes that have occurred since the last survey in 2007, and places these changes within the context of longer term trends (Appendix 1, Appendix 2)

2.1. Historic change

² The term ‘degradation’ in this case refers to the wearing down of the channel by the erosive action of water

Appendix 1 shows the year of cross-section surveys and Appendix 2 shows the changes at 28 cross-sections between the first (1988) and latest (2015) survey period³. Between 1988 and 2015 the Cardrona River has generally become more incised and/or deeper. At some cross-sections there has been minimal change e.g. CR18-1 (Figure 16), CR48-1 (Figure 40). At some cross-sections the main channel has switched location from one bank to another e.g. CR8 (Figure 20), CR5 (Figure 21). 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 (gravel extraction, protection works). Figure 2 shows the lower Cardrona River between 1958 and 2006 highlighting the area of active channel fairway and the size and location of secondary channels.

2.2. Mean bed level

Changes in mean bed level (MBL) at each cross-section between 2007 to 2015 and 2003 to 2007, and the net change over the entire period⁴ are shown in Figure 3. Cross-section locations, the magnitude of MBL change between 2007 and 2015, and areas of bank erosion are shown in Figure 4 to Figure 8. Individual cross-sections are shown in Appendix 3. The variability in MBL change between cross-section locations and survey years is shown in Figure 3. The top graph in Figure 3 (2015 to 2007) shows that there was aggradation in the lowest reaches (as shown in Figure 4 and Figure 5) with large variation in the mid reaches (as shown in Figure 6 and Figure 7) and minimal degradation or aggradation in the upper reaches (as shown in Figure 8). The middle graph in Figure 3 (2007 to 2003) shows less variation in MBL with greatest change being at cross-section CR46-1 (Figure 115) which experienced an increase in MBL of 0.49 m. The bottom graph in Figure 3 shows the net change in MBL over the period 2015 to 2003 which also highlights the variability in MBL.

³ The length of the cross-sections surveyed in 1988 do not cover the same extent as those surveyed in 2015 as such comparison cannot be made in areas outside of the 1988 coverage.

⁴ Not all cross-sections were surveyed in each year, Table 1 (Appendix 1) lists which year each cross-section was surveyed

For the most recent survey period (2007 to 2015) the lower reaches of the surveyed reach of the Cardrona River (cross-section CR39 to CR52-1) (Figure 4) experienced areas of aggradation, degradation, and areas of minimal change. MBL changes could not be calculated for two cross-sections in the lowest reach (CR47-1 and CR46).

The reach of the Cardrona River between cross-section CR3 and CR39 (Figure 5) experienced areas of aggradation, degradation, and minimal change between 2007 and 2015, areas of degradation were at the downstream end of the reach while areas of aggradation were located at the upstream end (Figure 5).

Two of the four cross-sections in the reach of the Cardrona River between cross-section CR11-1 and CR5 (Figure 6) experienced minimal change between 2007 and 2015 with one cross-section (CR9) experiencing 0.34 m of aggradation.

Between 2007 and 2015 the reach of the Cardrona River between cross-section CR25-2 and CR16 (Figure 7) experienced greater than 0.2 m of aggradation at two of the five cross-sections with two sections experiencing degradation (CR25-1, CR16).

Cross-sections in the upper reaches of the Cardrona River (cross-section CR25-9 to CR25-3) (Figure 8) experienced minimal change in MBL or aggradation at all seven of the surveyed cross-section locations.

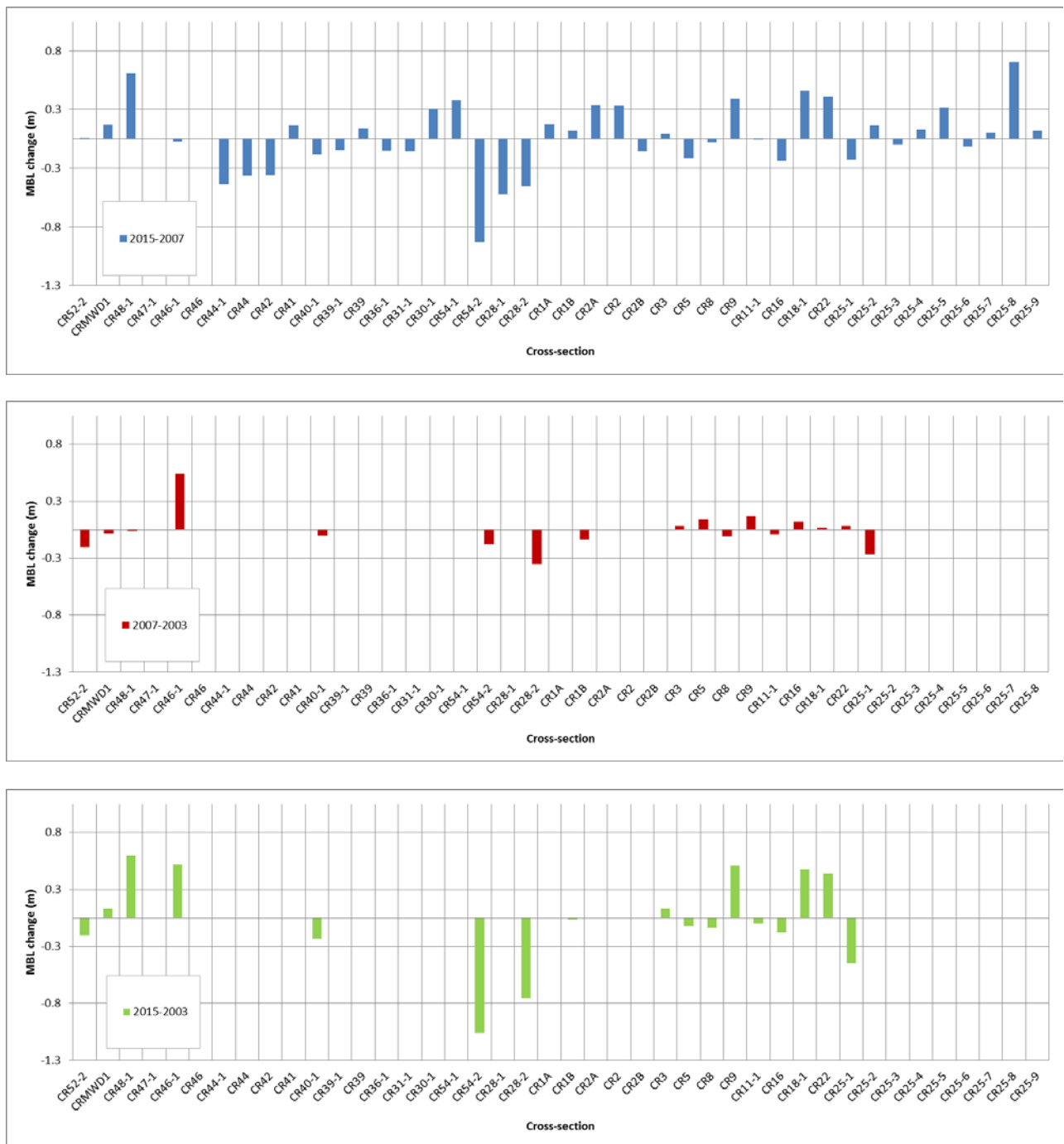


Figure 3. Changes in MBL at cross-sections on the Cardrona River between 2007 and 2015, 2003 and 2007 and the net change over the entire period. The location of each cross-section is shown in Figure 4 to Figure 8 (MBL could not be calculated at all locations as not all cross-sections were surveyed each year (Appendix 1)).

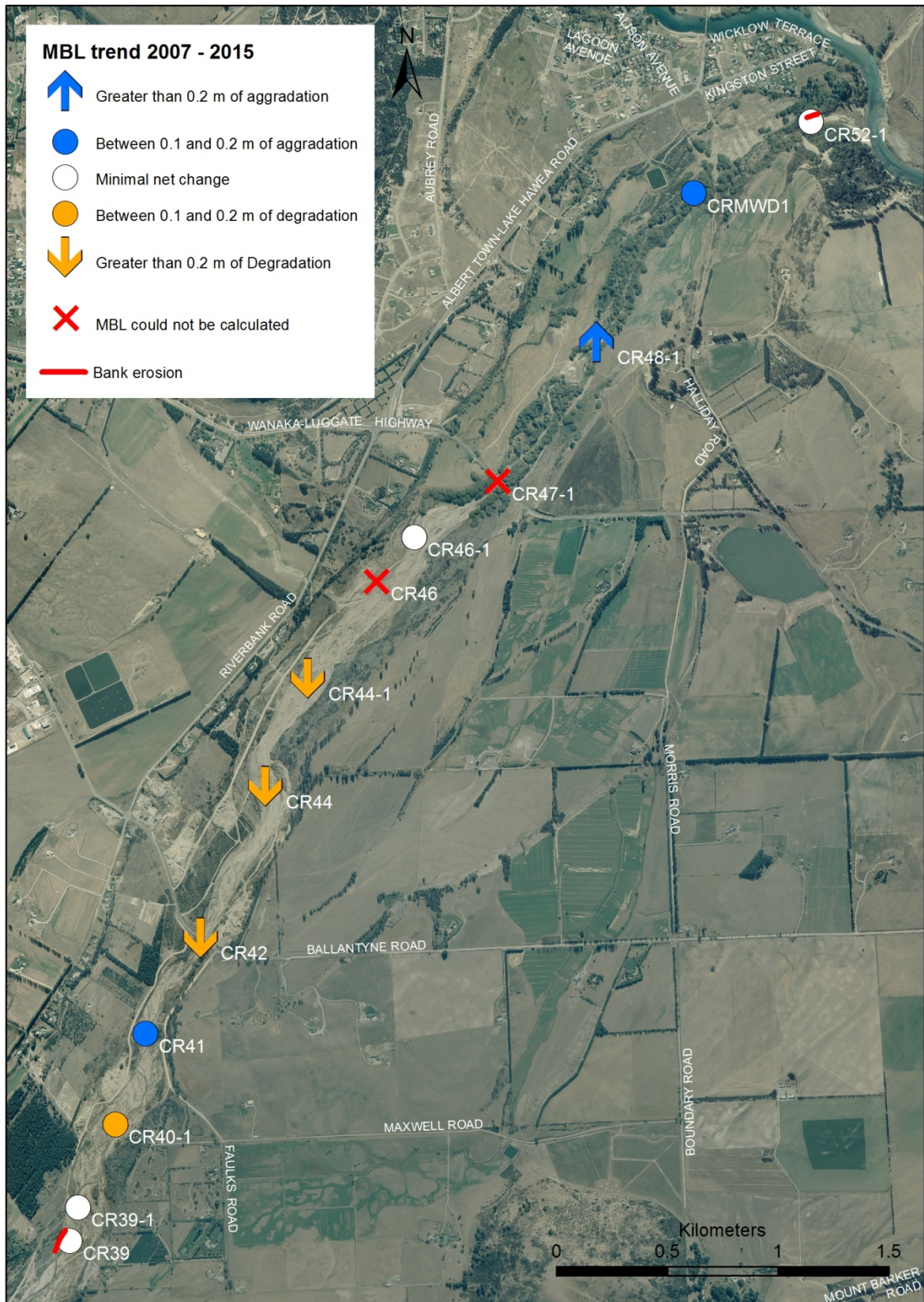


Figure 4. Location of Cardrona River cross-sections. The white, orange, and blue symbols show the magnitude of MBL change at each cross-section between 2007 and 2015. Locations where significant bank erosion has been observed are shown as red lines, a red cross indicates a cross-section where MBL could not be calculated. Individual cross-sections are shown in Appendix 3.

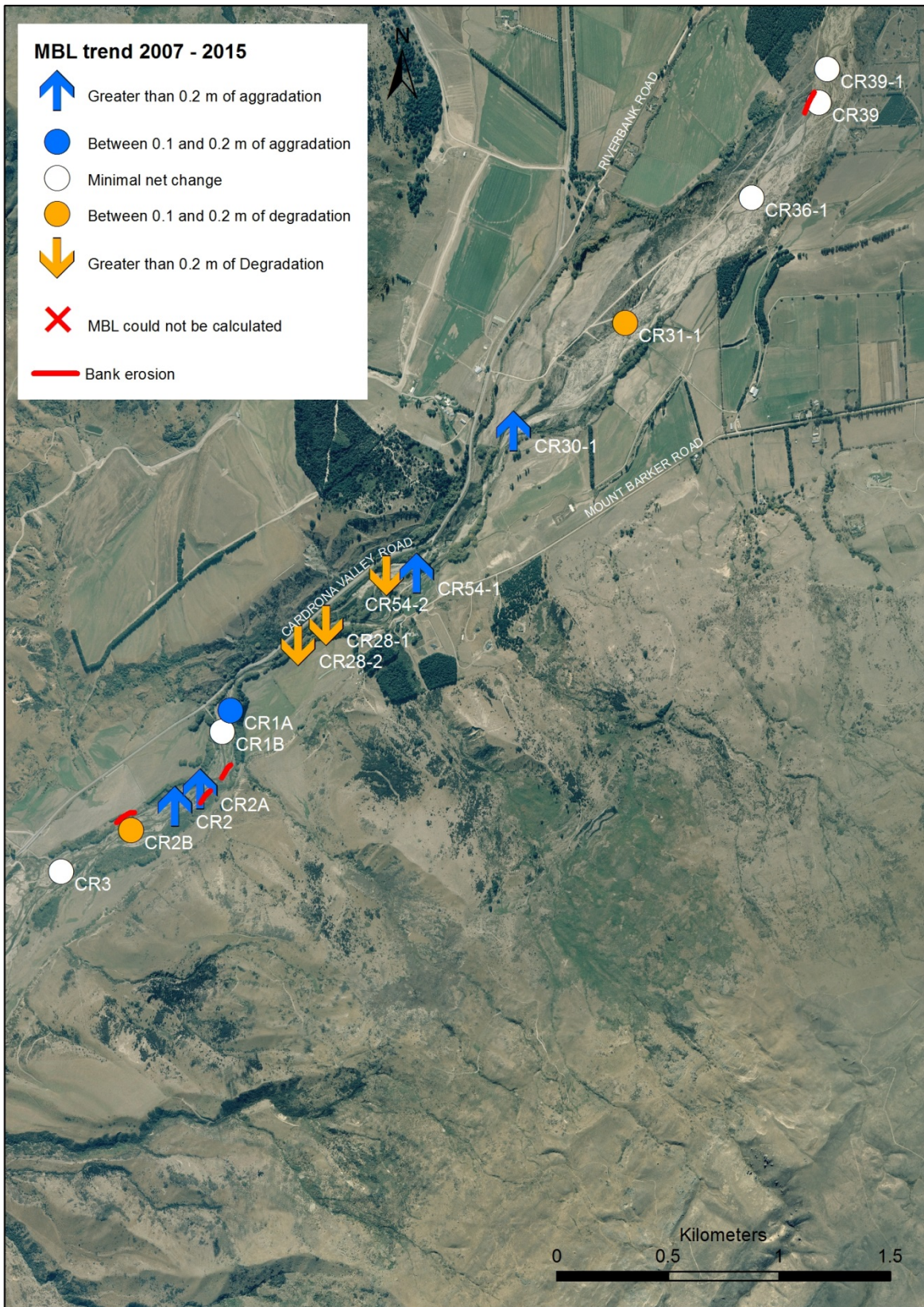


Figure 5 Location of Cardrona River cross-sections. The white, orange, and blue symbols show the magnitude of MBL change at each cross-section between 2007 and 2015. Locations where significant bank erosion has been observed are shown as red lines, a red cross indicates a cross-section where MBL could not be calculated. Individual cross-sections are shown in Appendix 3.



Figure 6. Location of Cardrona River cross-sections. The white, orange, and blue symbols show the magnitude of MBL change at each cross-section between 2007 and 2015. Locations where significant bank erosion has been observed are shown as red lines, a red cross indicates a cross-section where MBL could not be calculated. Individual cross-sections are shown in Appendix 3.

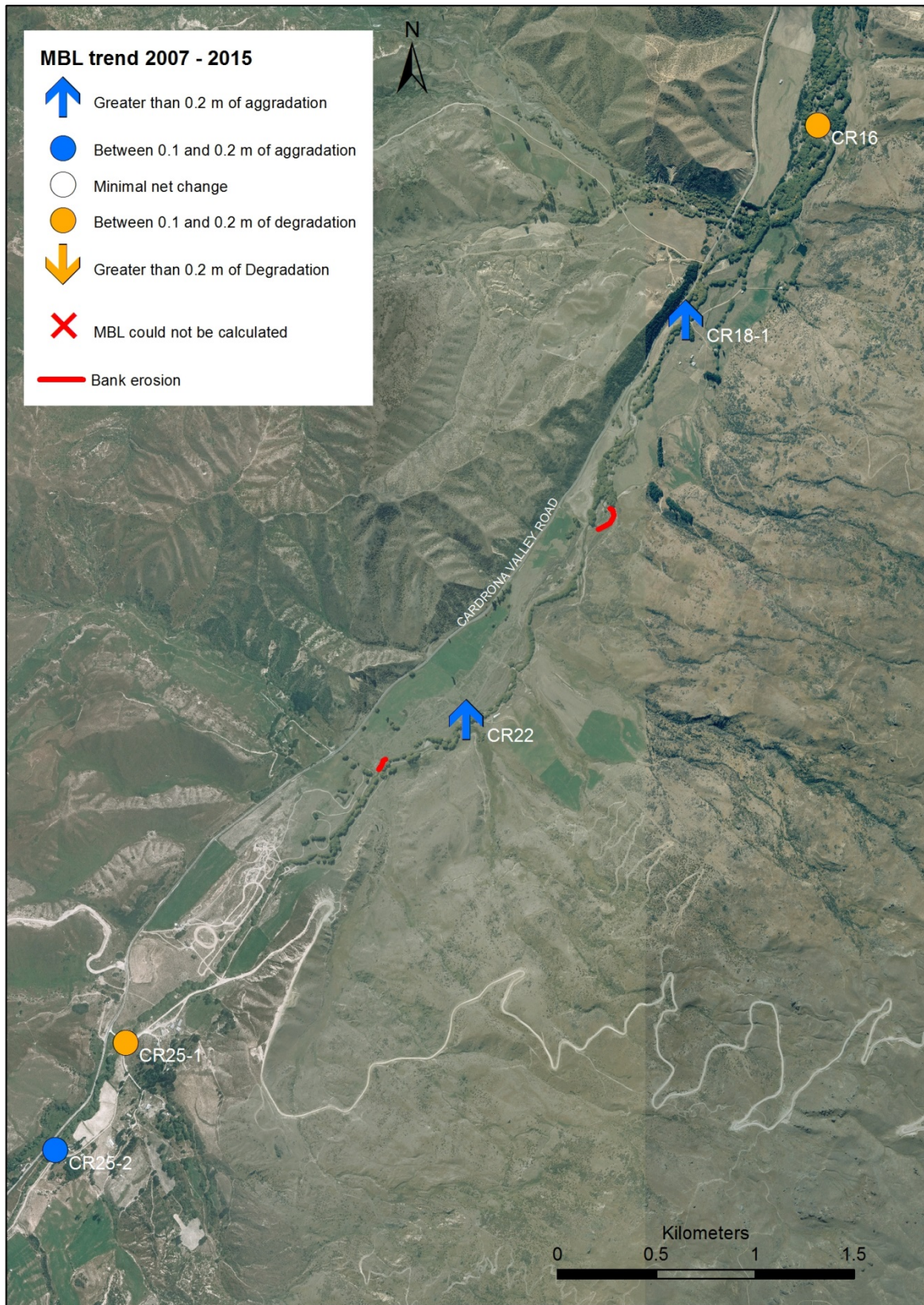


Figure 7. Location of Cardrona River cross-sections. The white, orange, and blue symbols show the magnitude of MBL change at each cross-section between 2007 and 2015. Locations where significant bank erosion has been observed are shown as red lines, a red cross indicates a cross-section where MBL could not be calculated. Individual cross-sections are shown in Appendix 3.

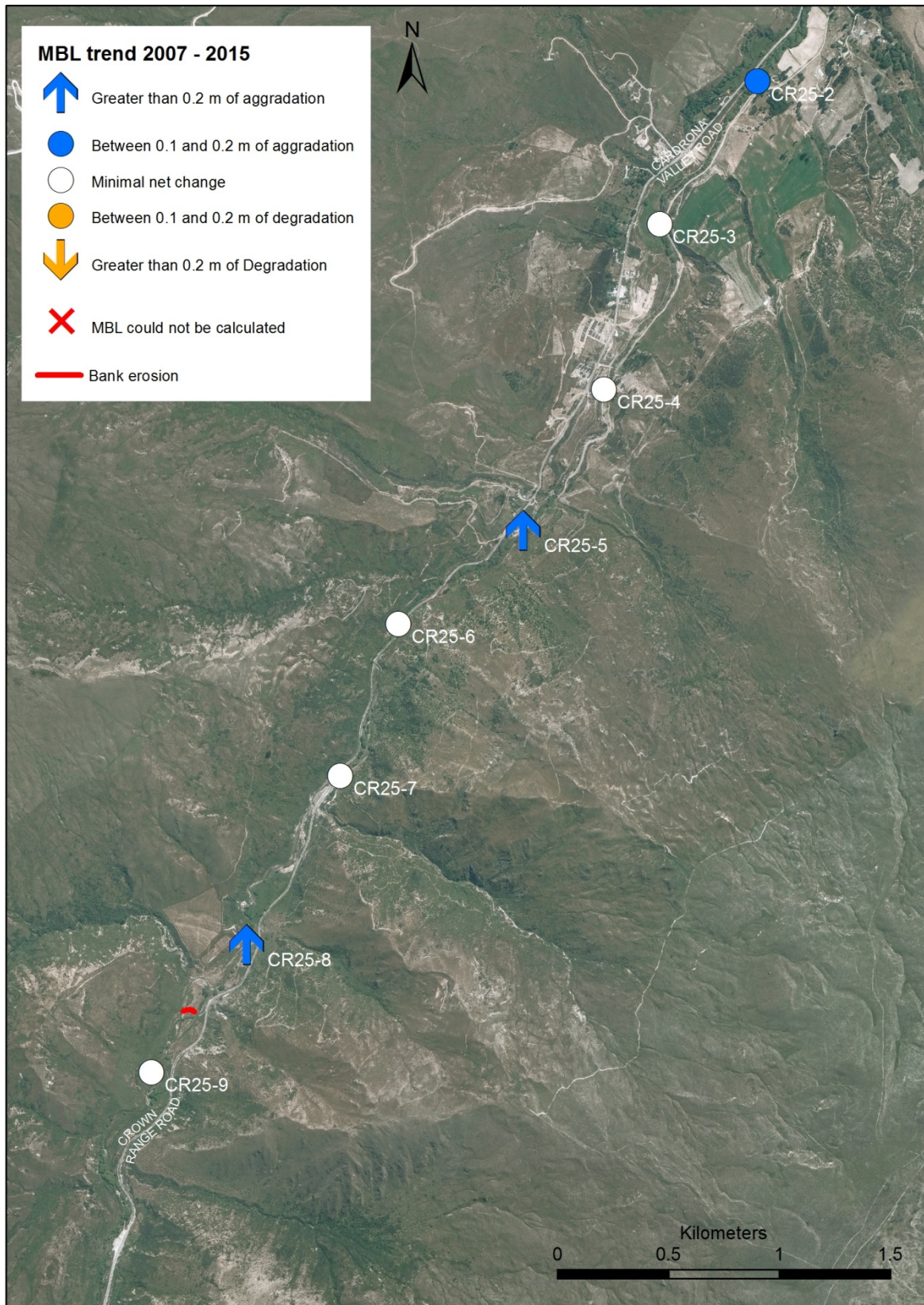


Figure 8. Location of Cardrona River cross-sections. The white, orange, and blue symbols show the magnitude of MBL change at each cross-section between 2007 and 2015. Locations where significant bank erosion has been observed are shown as red lines, a red cross indicates a cross-section where MBL could not be calculated. Individual cross-sections are shown in Appendix 3.

2.3. Longitudinal profile

Rivers generally increase in size (width/depth) as they flow in a downstream direction as they receive additional flow from tributary waterways. This is the case for the Cardrona River during normal and flood flow conditions, however during low flow conditions the Cardrona River (downstream of the Mount Barker flow recorder) is subject to flow losses due to groundwater recharge and irrigation abstraction (ORC, 2007). 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 Cardrona River will change over time in response to changes in the factors discussed above, it displays a typical concave shape with steeper areas in the upper catchment and a shallower profile closer to the confluence with the Clutha River/Mata-Au (Figure 9).

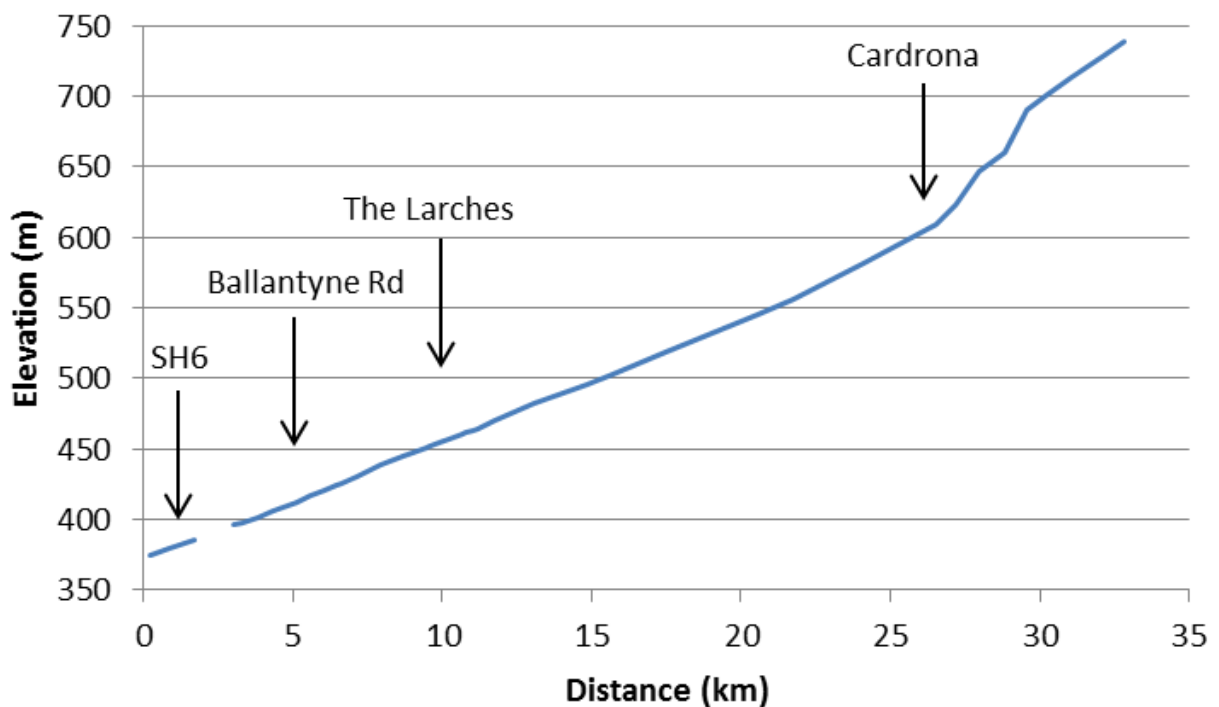


Figure 9. Longitudinal profile (showing the MBL) of the Cardrona River (from the 2015 survey)

2.4. Hydrology and flood hazard

Changes in the morphology of the Cardrona River are in part driven by the hydrological characteristics of the river including the magnitude and frequency of flood flows. Between 2007 and 2015 there were three flood events in the study area that ranked in the top 10 largest flood events at the Mount Barker flow recorder (Figure 10).⁵ The Cardrona River has

⁵ There is missing record at the Mount Barker flow recorder between 1988 to 2001.

experienced big flood events in the past with the November 1999 event being the largest on record at the Albert Town flow recorder (Figure 11). The November 1999 event caused significant damage to the bed and banks of the Cardrona River as well as destroying the Ballantyne Road bridge (Figure 12). The mapped flood hazard area for the Cardrona River can be seen in the ORC report '*Natural Hazards in the Cardrona Valley*' (2010).

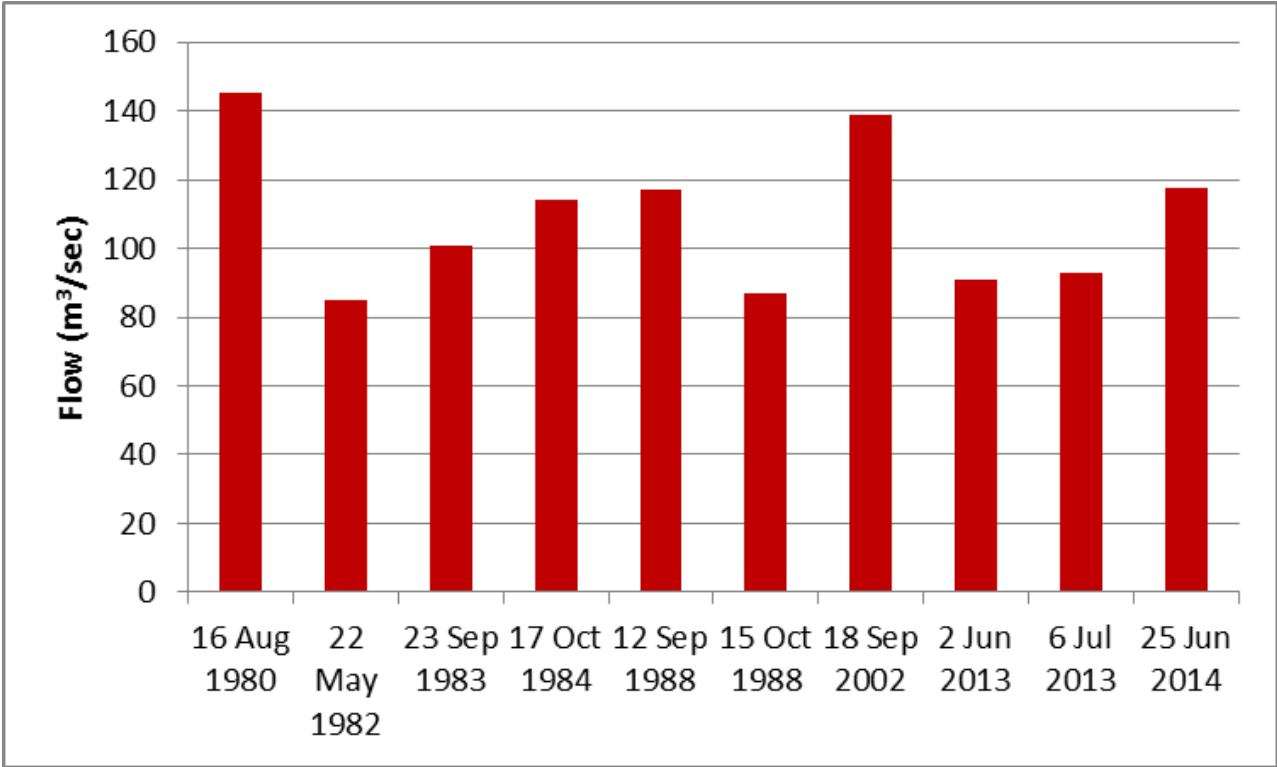


Figure 10. Ten highest flows in the Cardrona River at the Mount Barker recorder, since records began in 1976 (there is missing record for the period 1988 to 2001)

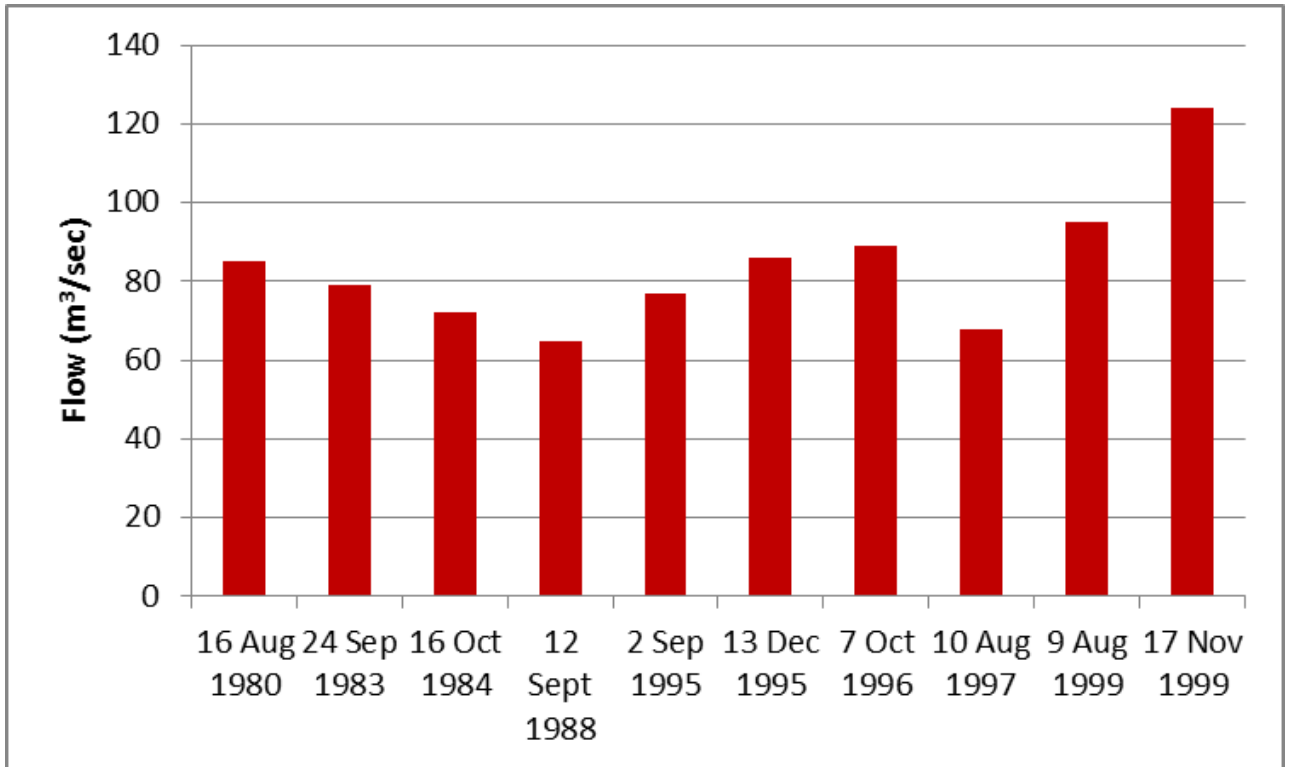


Figure 11. Ten highest flows in the Cardrona River at the Albert Town recorder, since records began in 1978 (records finish in 2002)



Figure 12. Ballantyne Road bridge (Cardrona River), looking upstream (photography taken after the peak of the flood, November 1999)

2.5. 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 channel or channel braid migration. Bank erosion was observed at five of the forty two surveyed cross-sections. Other areas of bank erosion outside of the surveyed cross-sections were identified using aerial photography and site visits (Figure 4 to Figure 8). An example of bank erosion is shown in Figure 13.



Figure 13. Bank erosion of the true left bank downstream of cross-section CR11-1 (Figure 6)

2.6. Gravel extraction

Gravel extraction has historically taken place in the Cardrona River with the main gravel extraction locations being between the SH6 bridge to 2 km upstream of the Ballantyne Road bridge and between the confluence with Coes Creek (located between Spotts Creek and Branch Burn) and Spotts Creek (ORC, 2004). Gravel extraction typically occurs from these locations as they are areas where sediment accumulates due to several factors e.g. a decrease in the channel gradient or tributary streams depositing sediment. Significant gravel extraction activity was undertaken after the November 1999 flood which transported large volumes of gravel into the Cardrona River system. Approximately 650,000 m³ of gravel has been extracted from the Cardrona River between 1984 and 2009 (ORC, 2010). No gravel returns have been submitted to the ORC for the period 2010 to 2015 indicating that there

has not been any gravel removed from the Cardrona River for this period. There is currently one active resource consent to extract gravel from the Cardrona River (near cross-section CR54-2) for an annual volume of up to 3,000 m³ and a total volume (over the entire consent period) of 10,000 m³, this consent expires in 2022.

If gravel were to be removed from the Cardrona River in excess of the natural replenishment rate can lead to issues at downstream locations such as undermining of river protection works and other assets (e.g. water intakes, bridges, and roads) as well as increased bank erosion and bed degradation. Gravel extraction can have a negative effect on the local ecology, with the severity of the effects dependent on the extraction methods used and the environment from which the gravel is extracted from.

3. Conclusion

The results of this report show that the Cardrona River between the headwaters and the confluence with the Clutha River/Mata-Au is a dynamic system with changes constantly occurring. The survey results show that the Cardrona River experienced an increase in mean bed level (MBL) at 20 of the 42 survey locations and a decrease in MBL at 19 survey locations, one site experienced no change between 2007 and 2015.⁶ The greatest change in MBL occurred at cross-section CR54-2 which showed a decrease in MBL of 0.88 m between 2007 and 2015. The cross-sections in the lower reaches displayed more aggradation, variation (in channel aggradation and degradation) was recorded in the mid reaches, and minimal degradation or aggradation was recorded in the upper reaches. Between 1988 (when the cross-sections were first surveyed) and 2015 the Cardrona River channel at the cross-section locations has (in general) become deeper and wider.

⁶ MBL could not be calculated at an additional two survey locations.

Appendix 1. Cardrona River survey dates

Table 1. Cardrona River survey dates (a blank space indicates a survey was not completed for that year)

Cross-section	1988 Feb	2003 Nov	2007 Jan	2015 Oct
CR52-1	X	X	X	X
CRMWD1	X	X	X	X
CR48-1	X	X	X	X
CR47-1	X			X
CR46-1			X	X
CR46	X			X
CR44-1	X		X	X
CR44	X		X	X
CR42	X		X	X
CR41	X		X	X
CR40-1	X	X	X	X
CR39-1	X		X	X
CR39	X		X	X
CR36-1	X		X	X
CR31-1	X		X	X
CR30-1	X		X	X
CR54-1	X		X	X
CR54-2		X	X	X
CR28-1	X		X	X
CR28-2		X	X	X
CR1A	X		X	X
CR1B	X	X	X	X
CR2A			X	X
CR2	X		X	X
CR2B			X	X
CR3	X	X	X	X
CR5	X	X	X	X
CR8	X	X	X	X
CR9	X	X	X	X

CR11-1	X	X	X	X
CR16	X	X	X	X
CR18-1	X	X	X	X
CR22	X	X	X	X
CR25-1	X	X	X	X
CR25-2			X	X
CR25-3			X	X
CR25-4			X	X
CR25-5			X	X
CR25-6			X	X
CR25-7			X	X
CR25-8			X	X
CR25-9			X	X

Appendix 2. Summaries: Cardrona River cross-sections historic change

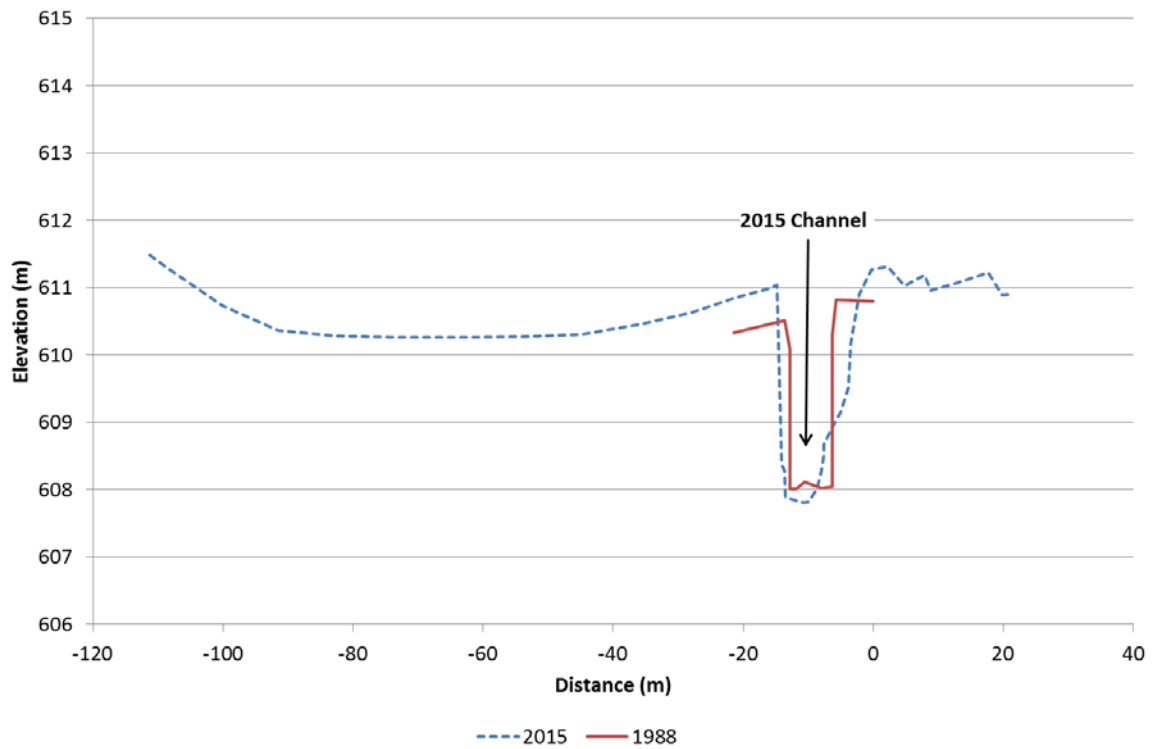


Figure 14. Cardrona River cross-section CR25-1, looking downstream, refer to Figure 7 for location.

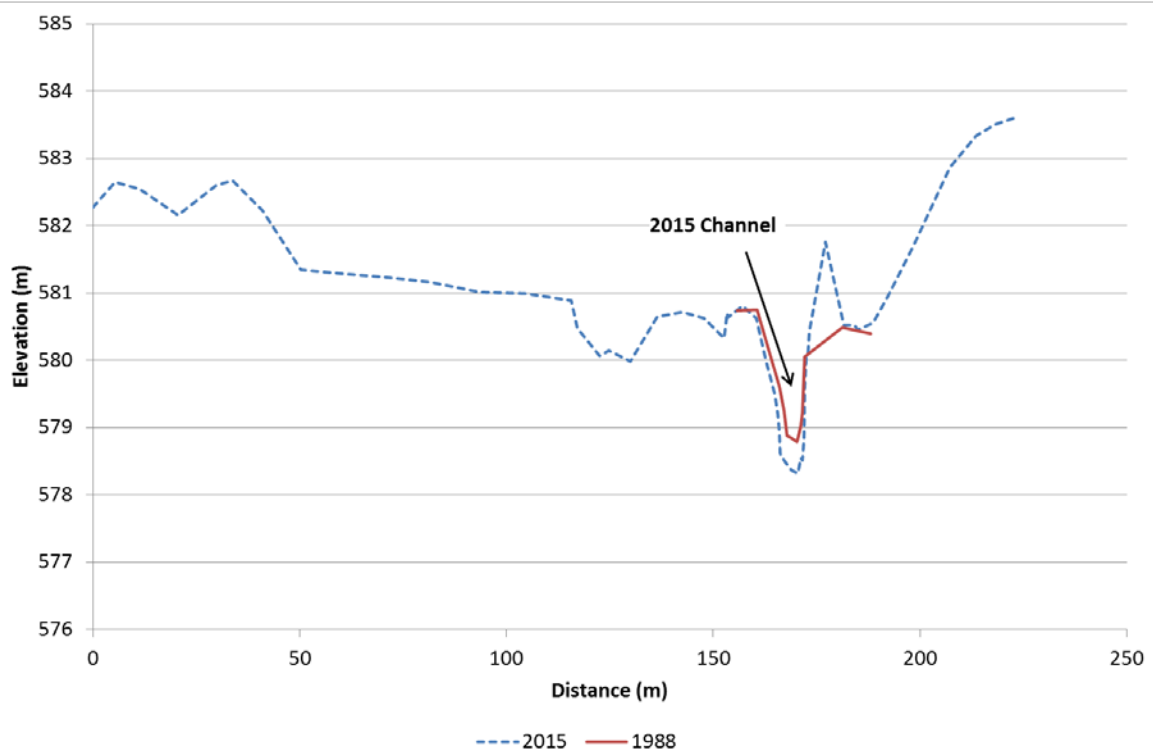


Figure 15. Cardrona River cross-section CR22, looking downstream, refer to Figure 7 for location.

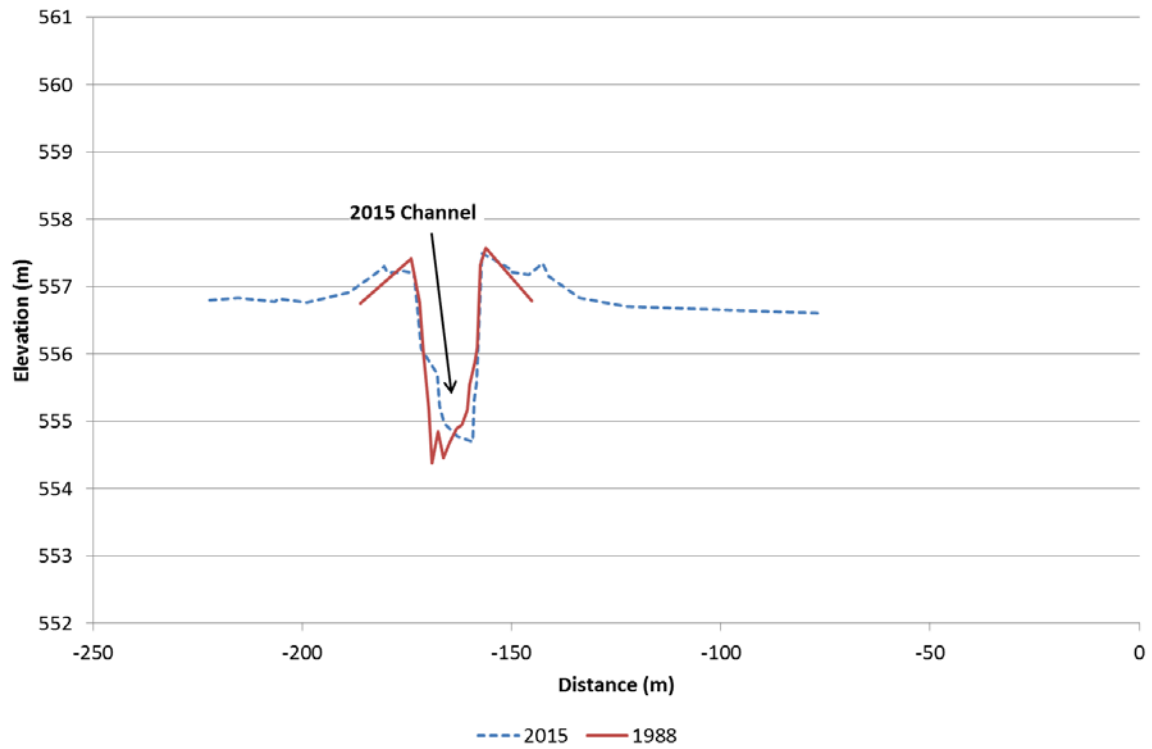


Figure 16. Cardrona River cross-section CR18-1, looking downstream, refer to Figure 7 for location.

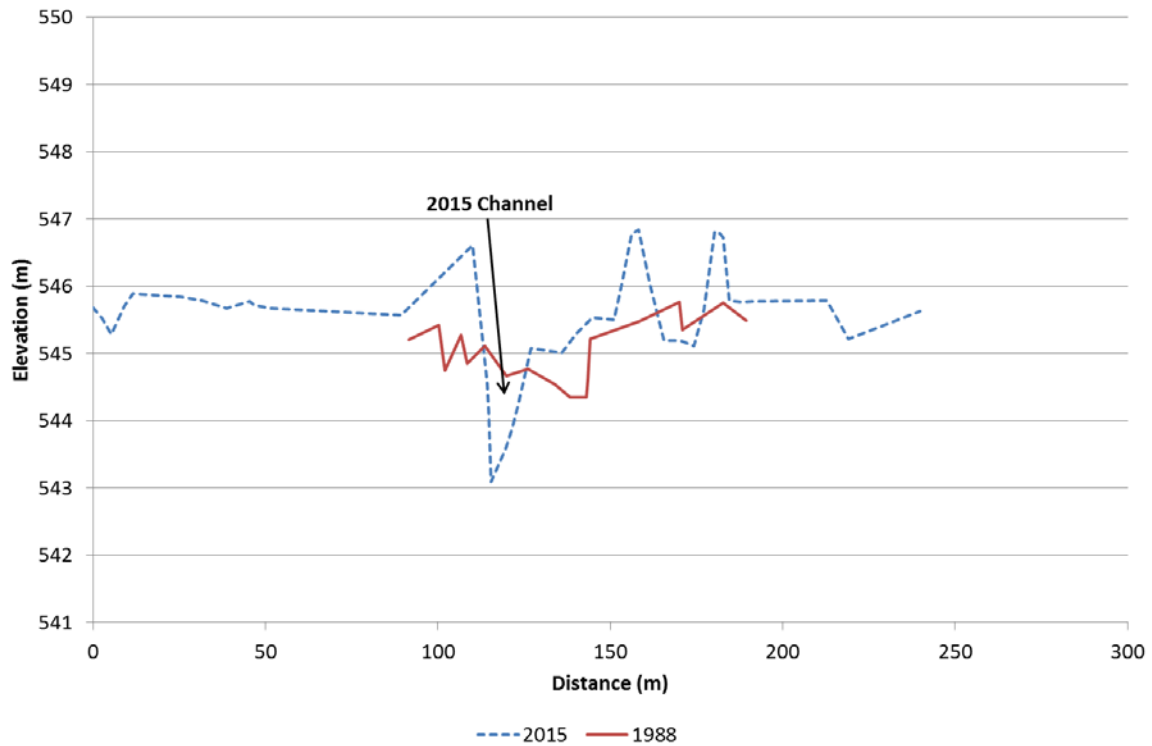


Figure 17. Cardrona River cross-section CR16, looking downstream, refer to Figure 7 for location.

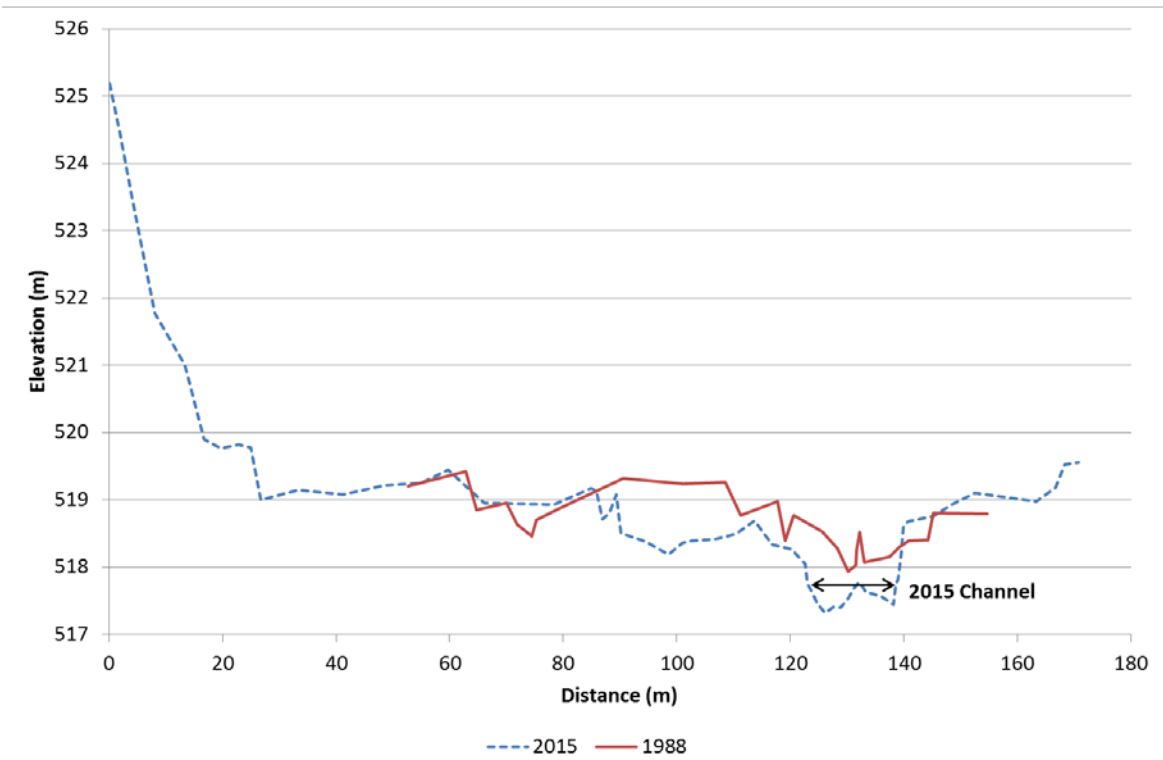


Figure 18. Cardrona River cross-section CR11-1, looking downstream, refer to Figure 6 for location.

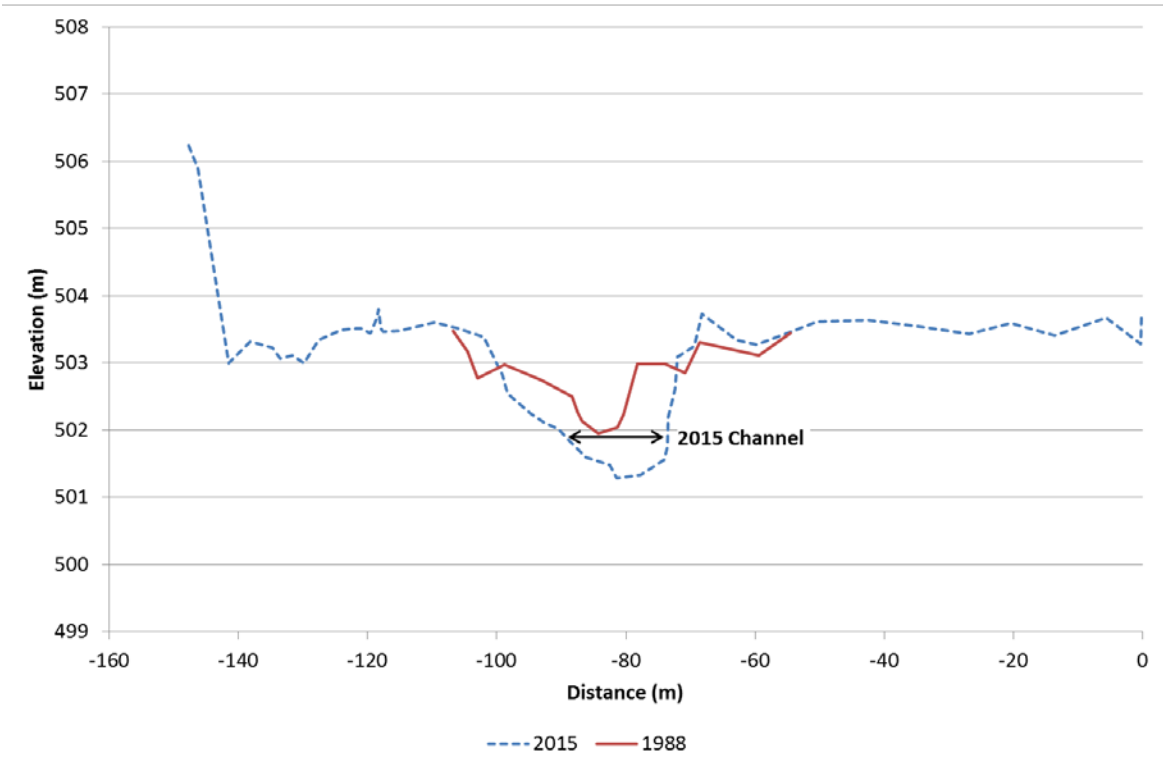


Figure 19. Cardrona River cross-section CR9, looking downstream, refer to Figure 6 for location.

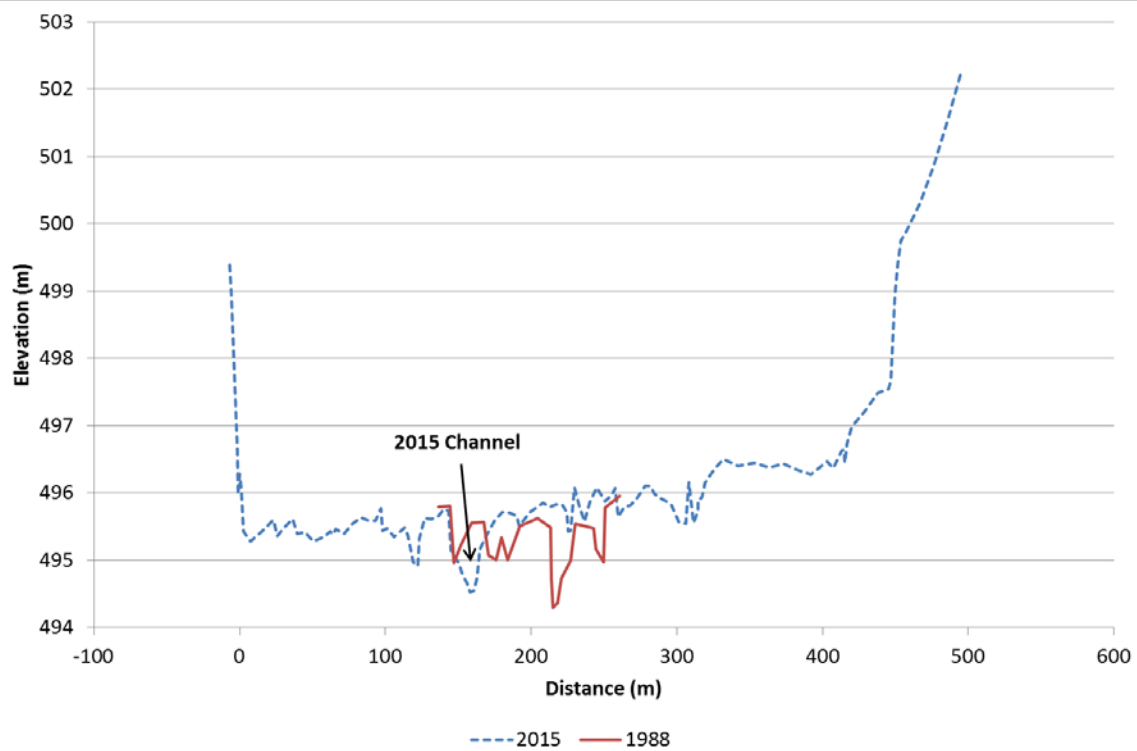


Figure 20. Cardrona River cross-section CR8, looking downstream, refer to Figure 6 for location.

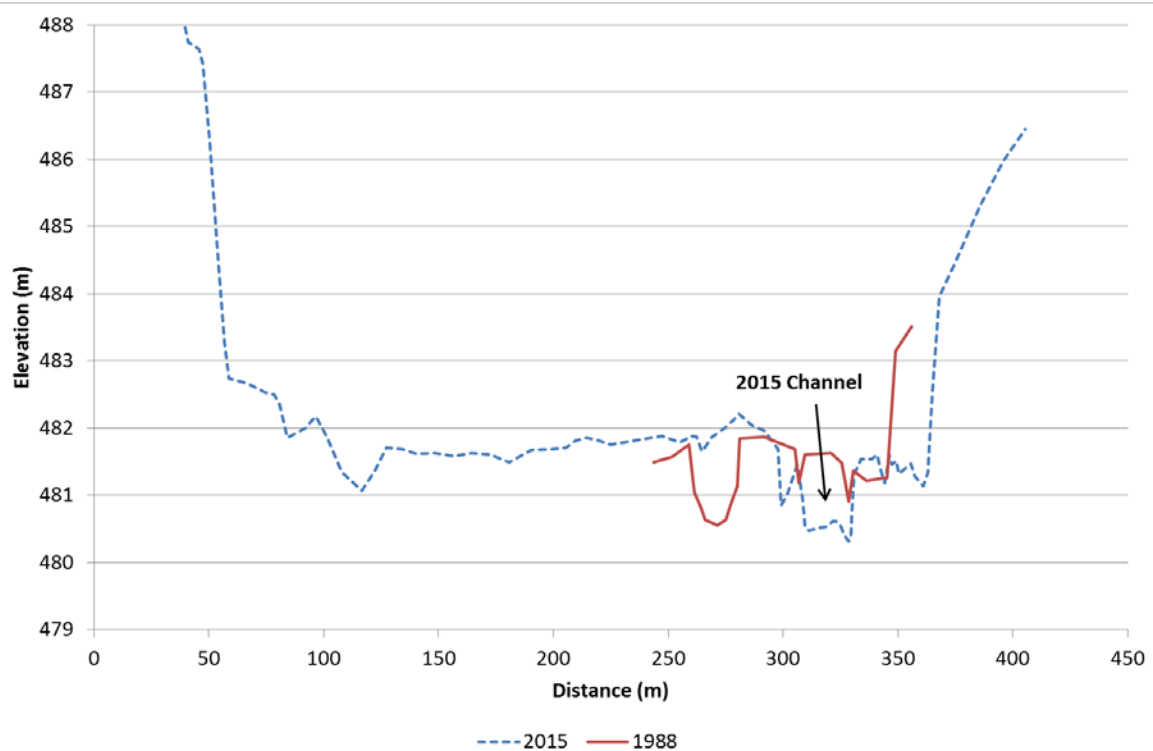


Figure 21. Cardrona River cross-section CR5, looking downstream, refer to Figure 6 for location.

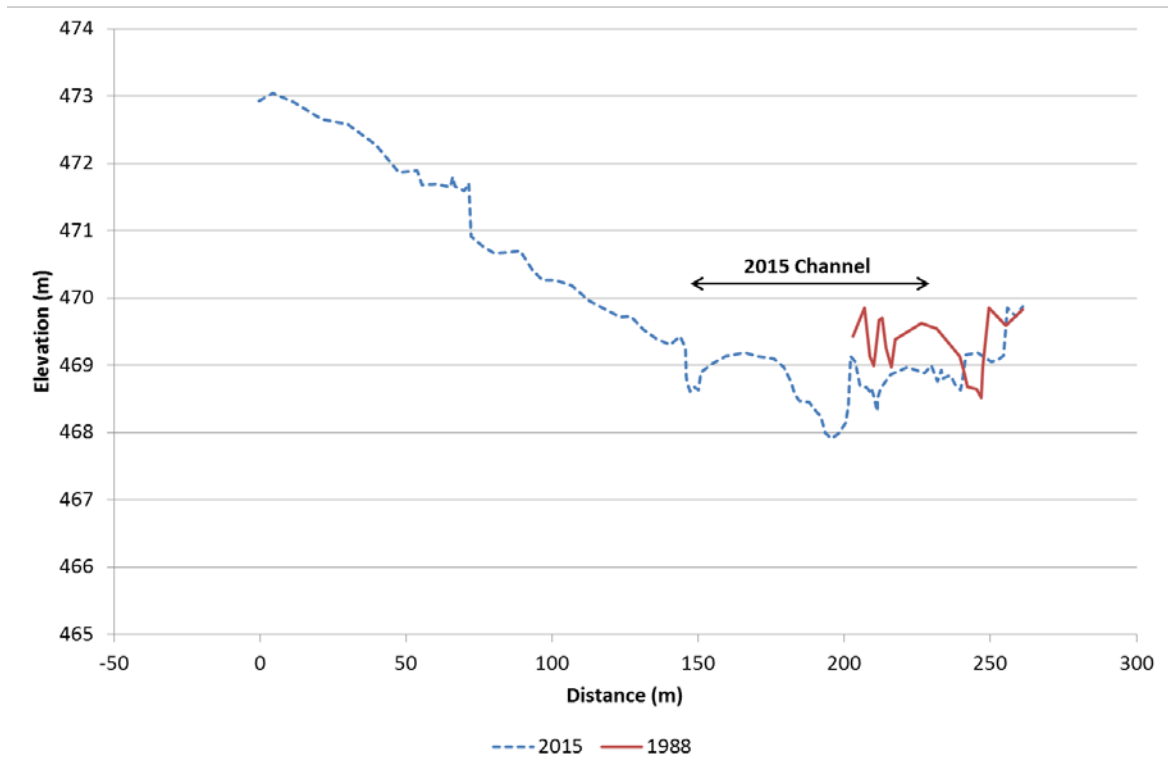


Figure 22. Cardrona River cross-section CR3, looking downstream, refer to Figure 5 for location.

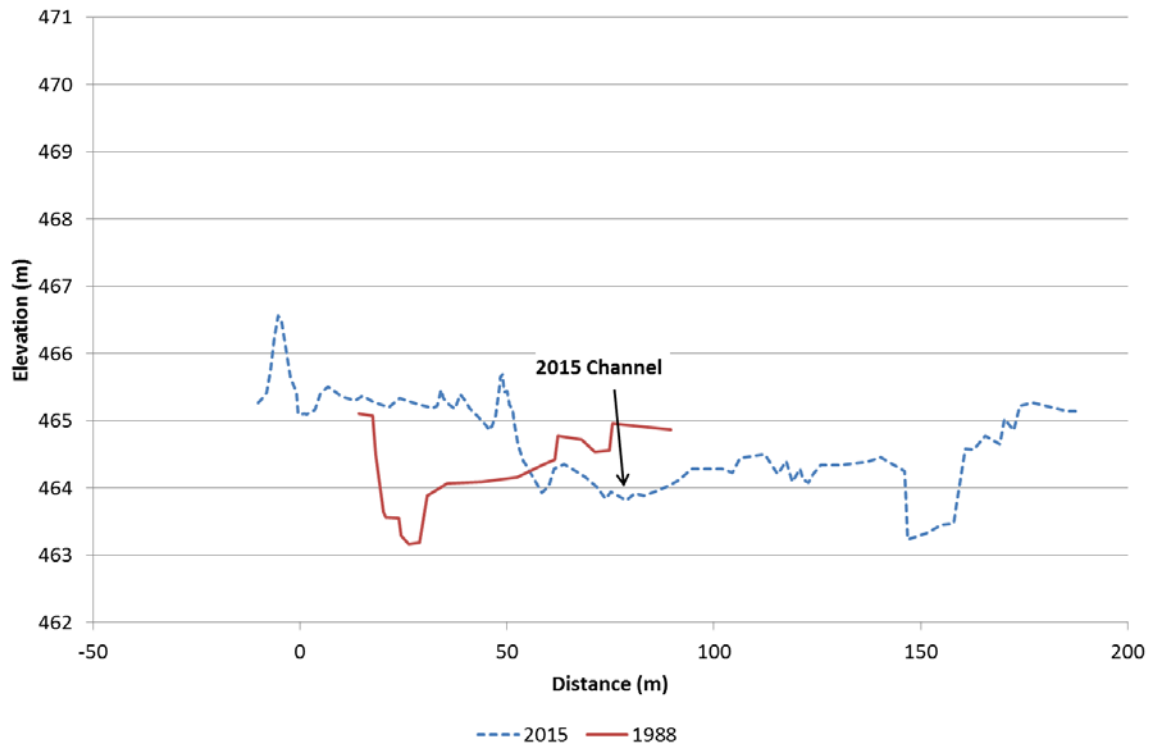


Figure 23. Cardrona River cross-section CR2, looking downstream, refer to Figure 5 for location.

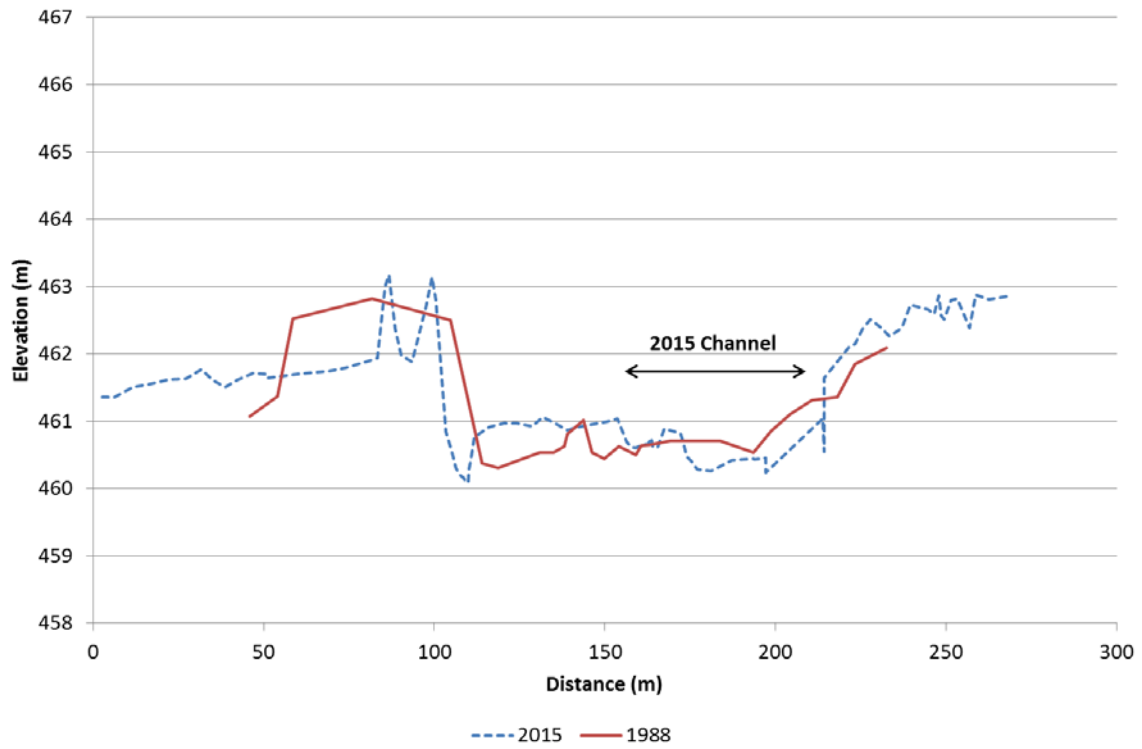


Figure 24. Cardrona River cross-section CR1B, looking downstream, refer to Figure 5 for location.

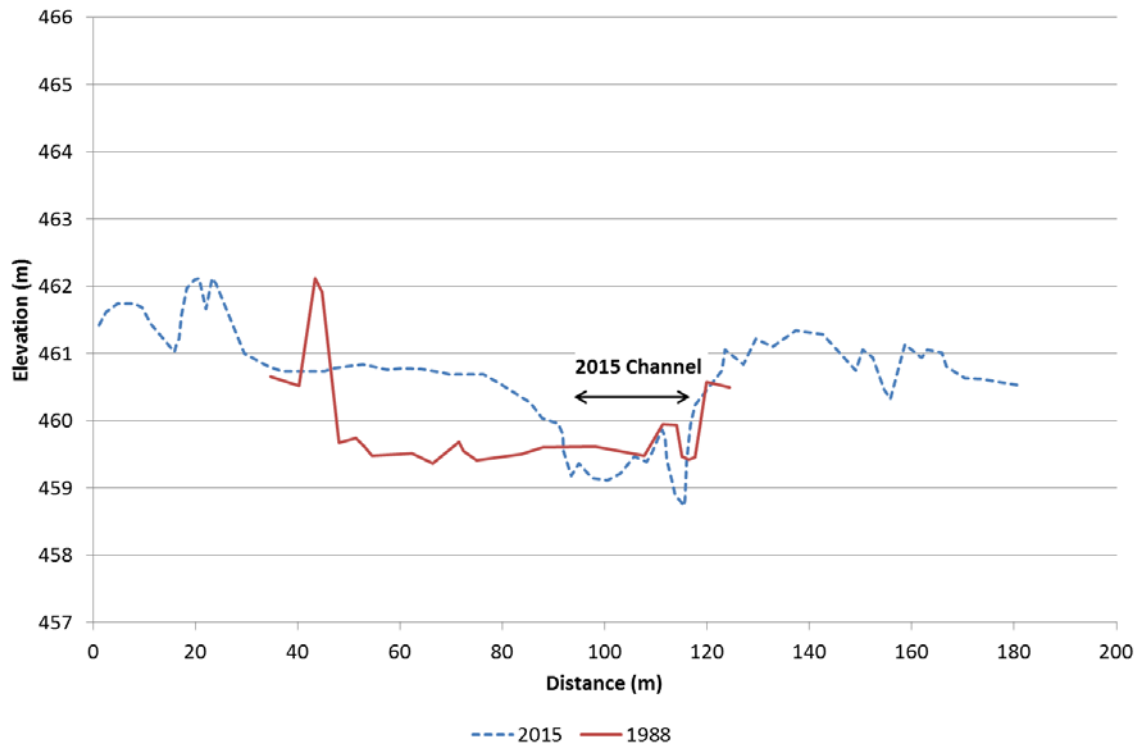


Figure 25. Cardrona River cross-section CR1A, looking downstream, refer to Figure 5 for location.

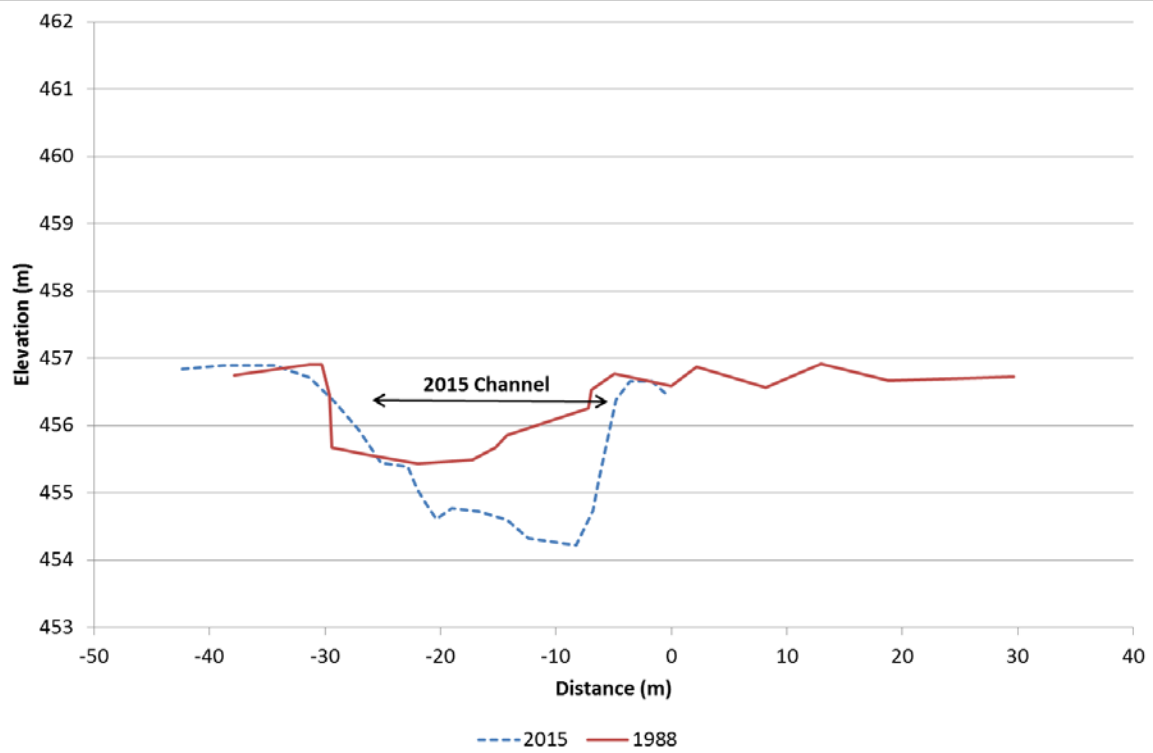


Figure 26. Cardrona River cross-section CR28-1, looking downstream, refer to Figure 5 for location.

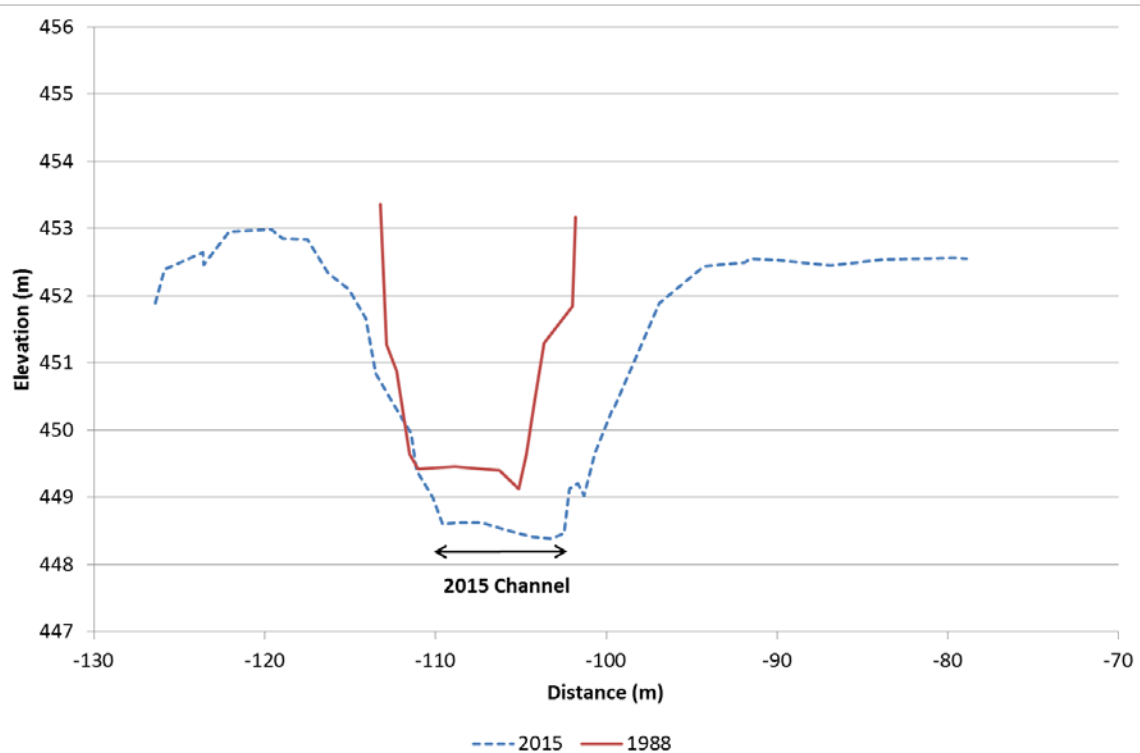


Figure 27. Cardrona River cross-section CR54-1, looking downstream, Figure 5 for location.

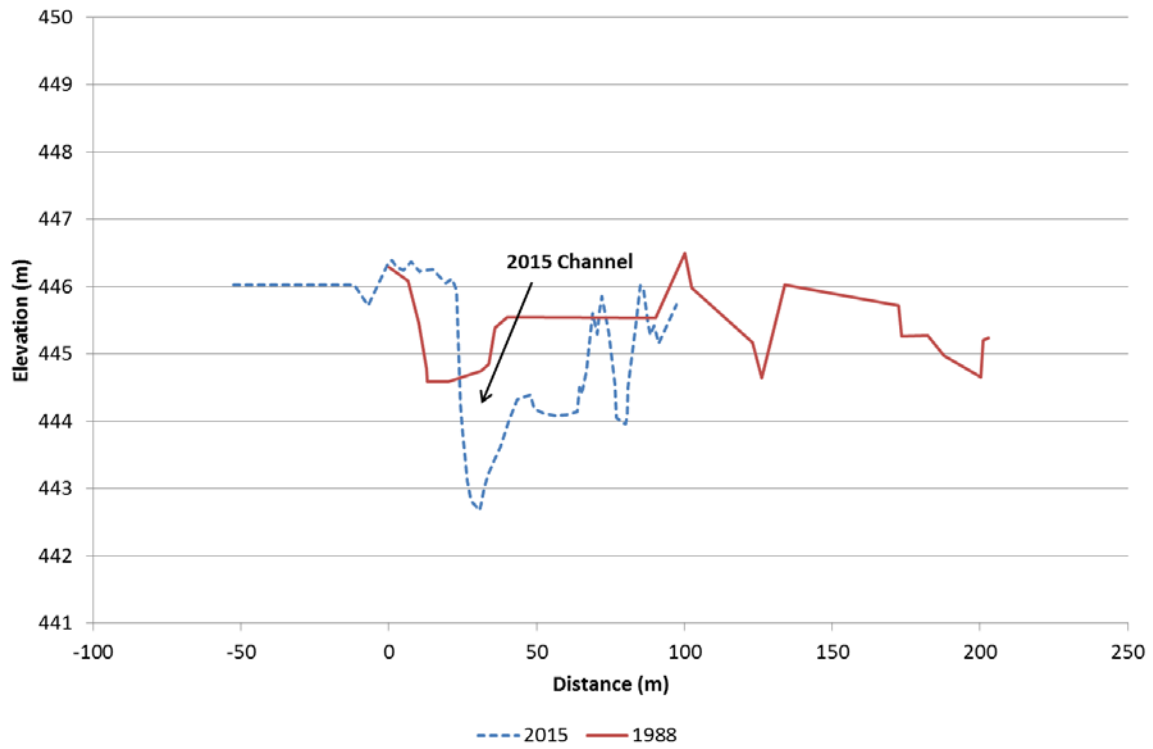


Figure 28. Cardrona River cross-section CR30-1, looking downstream, refer to Figure 5 for location.

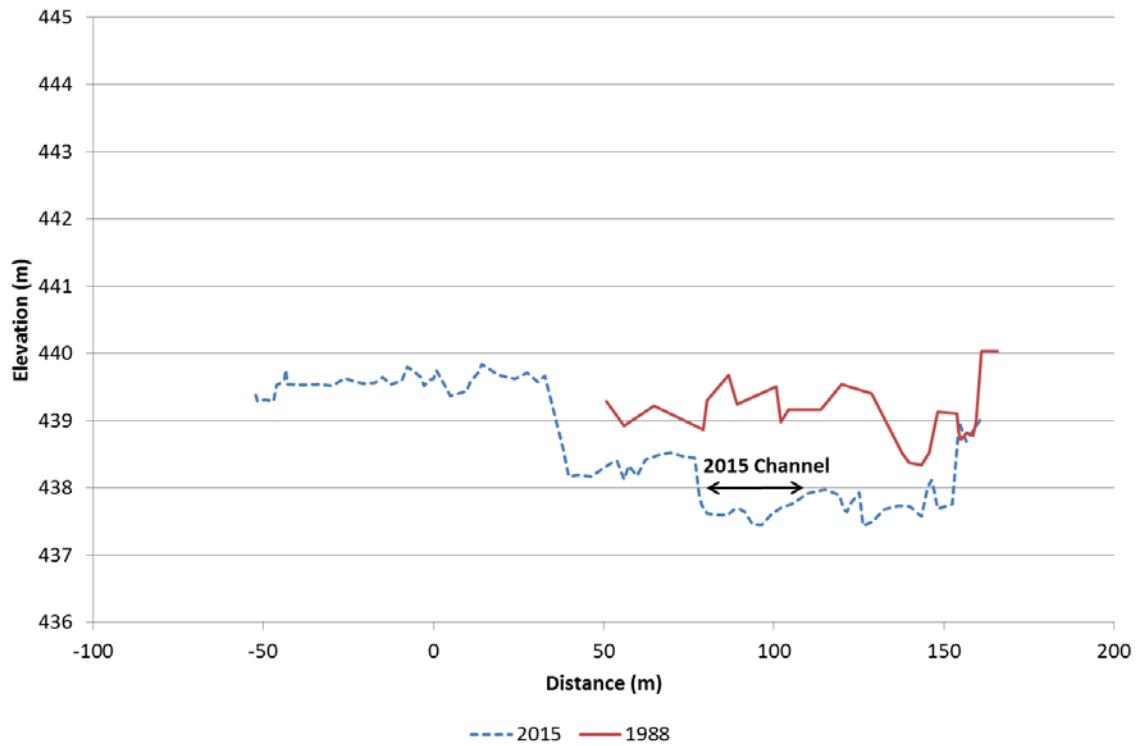


Figure 29. Cardrona River cross-section CR31-1, looking downstream, refer to Figure 5 for location.

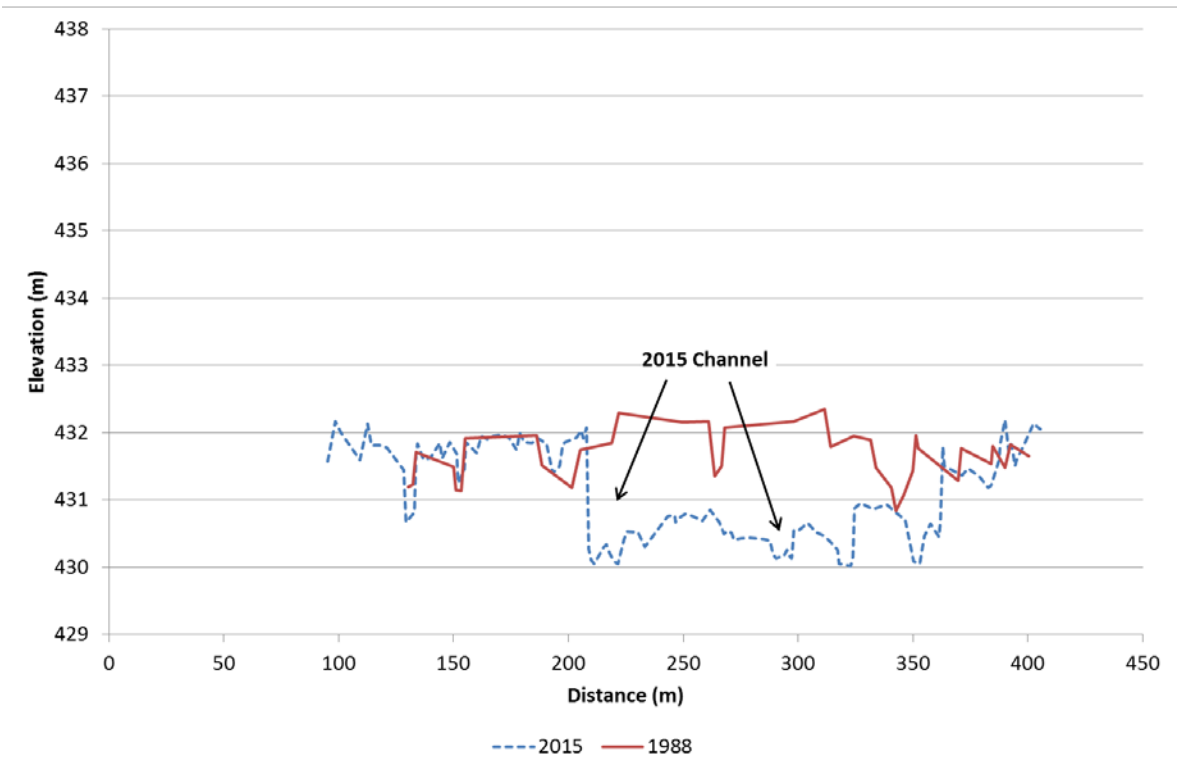


Figure 30. Cardrona River cross-section CR36-1, looking downstream, refer to Figure 5 for location.

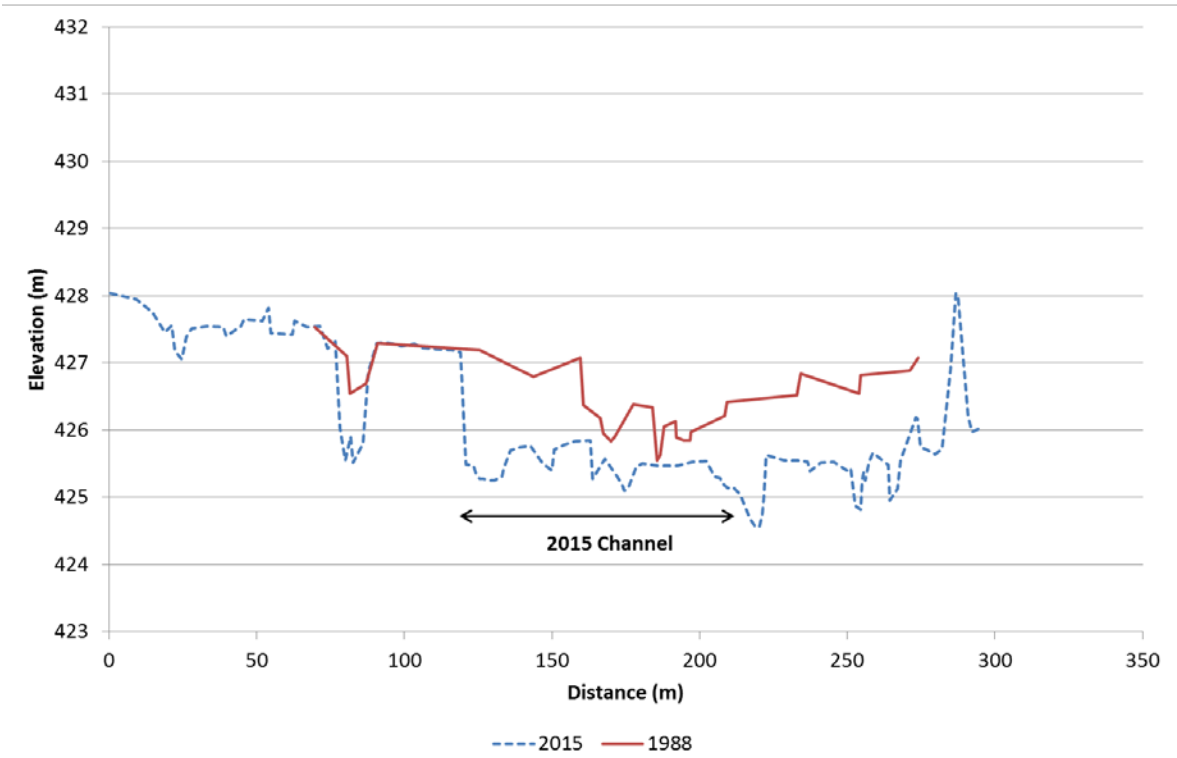


Figure 31. Cardrona River cross-section CR39, looking downstream, refer to Figure 5 for location.

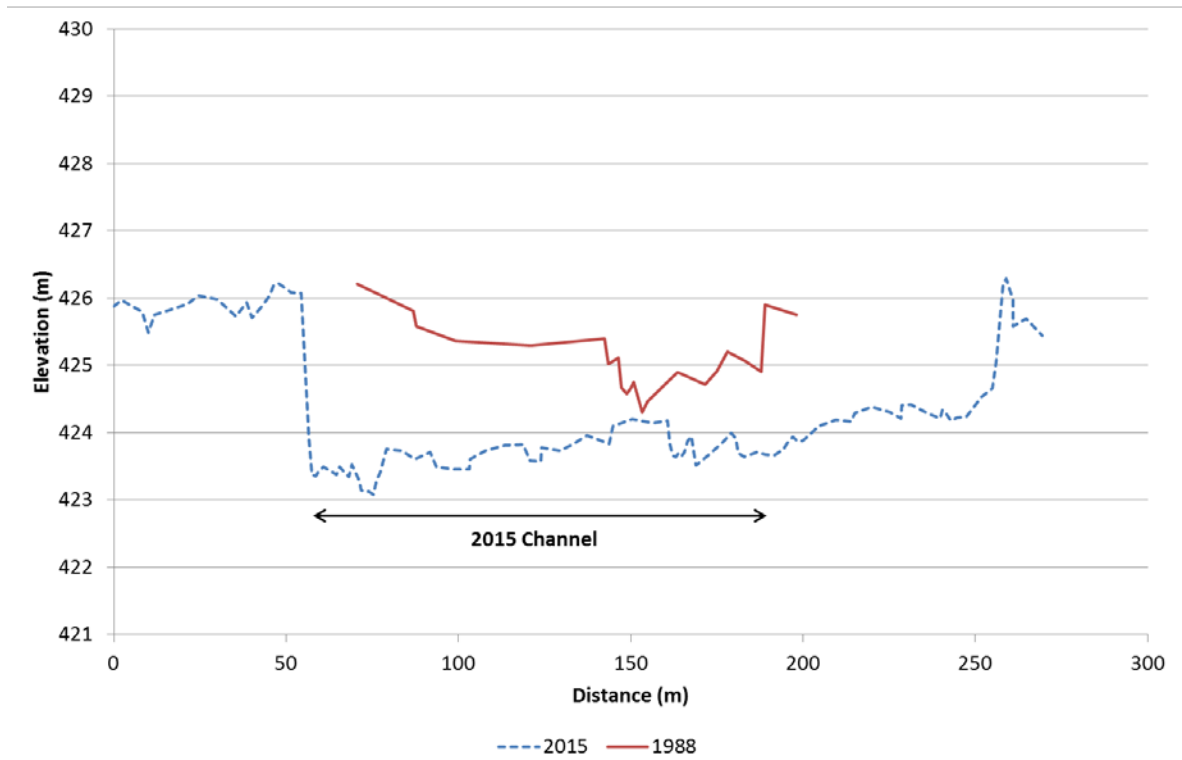


Figure 32. Cardrona River cross-section CR39-1, looking downstream, refer to Figure 5 for location.

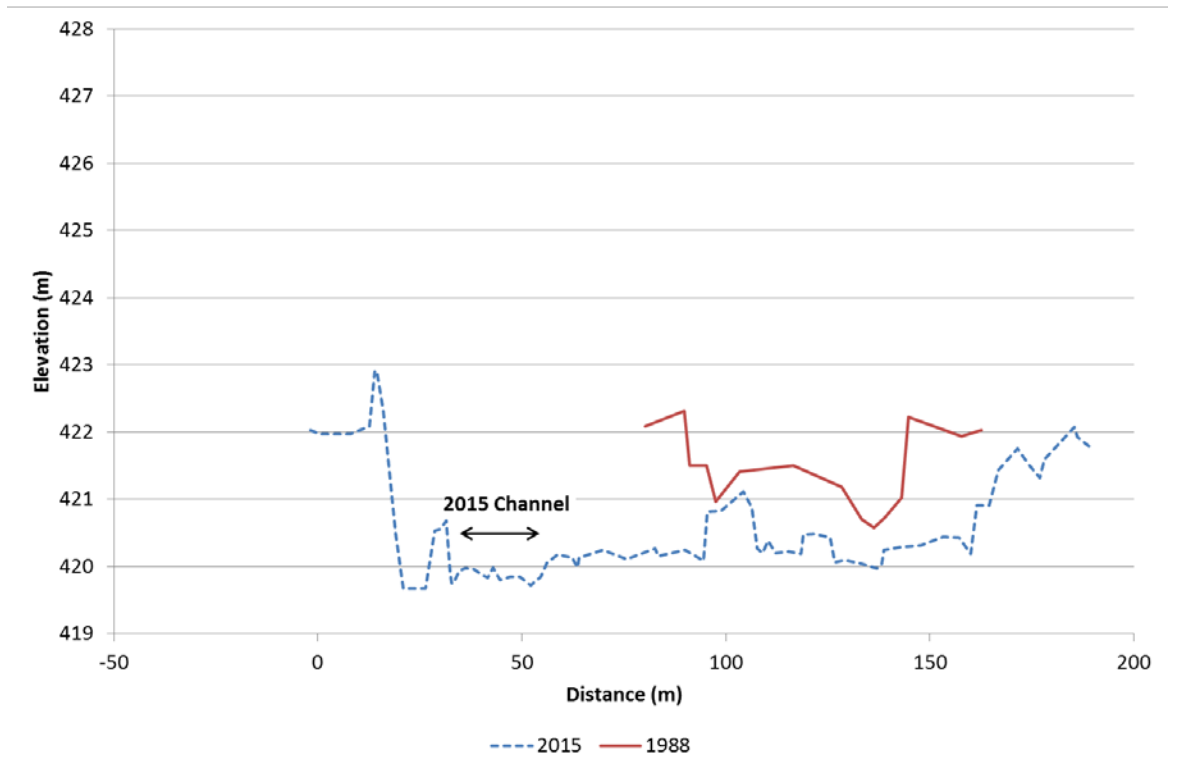


Figure 33. Cardrona River cross-section CR40-1, looking downstream, refer to Figure 4 for location.

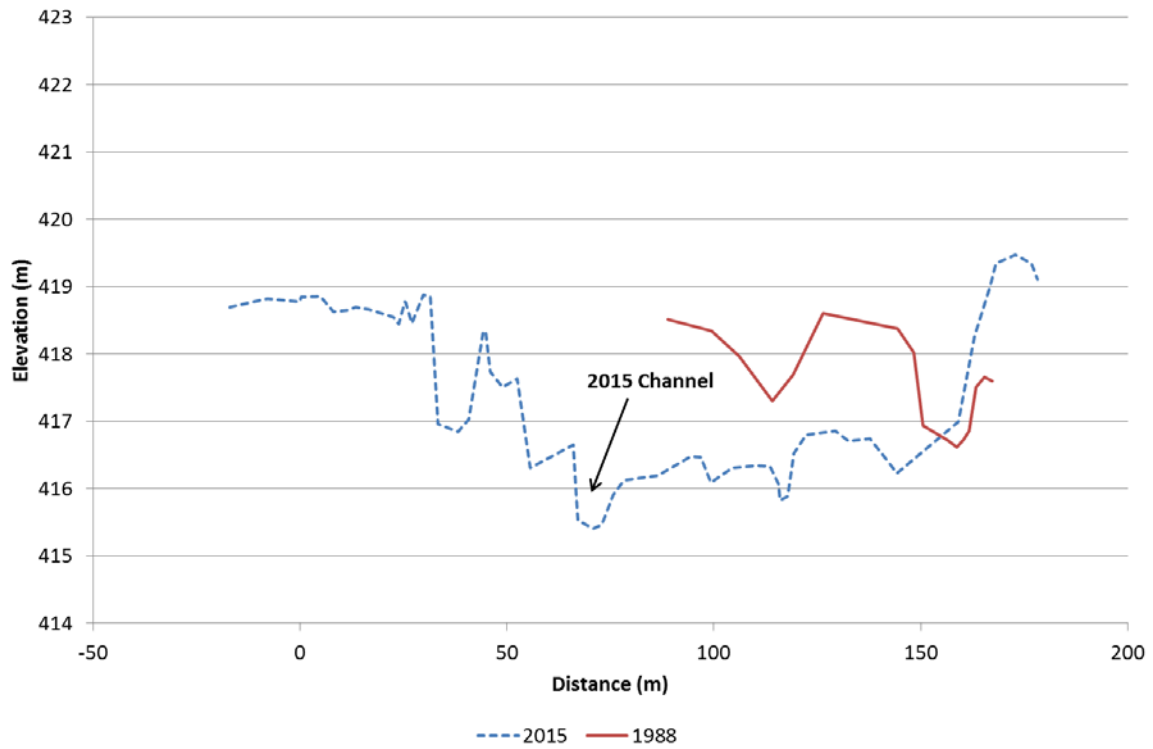


Figure 34. Cardrona River cross-section CR41, looking downstream, refer to Figure 4 for location.

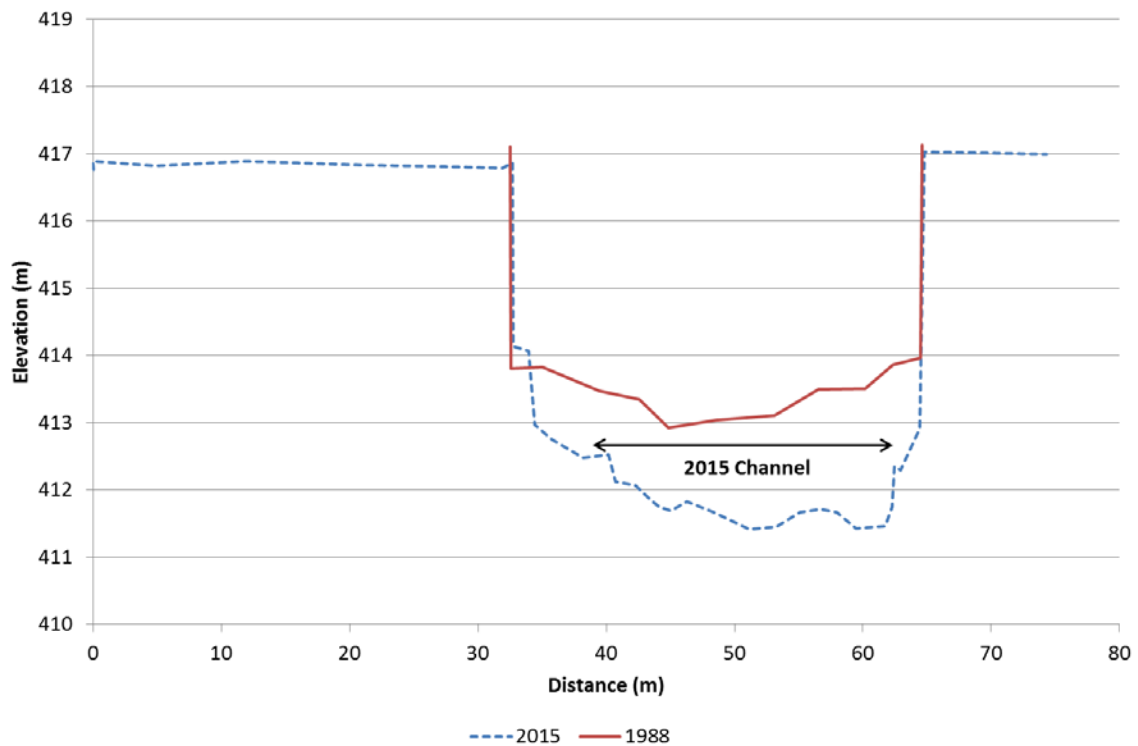


Figure 35. Cardrona River cross-section CR42, looking downstream, refer to Figure 4 for location.

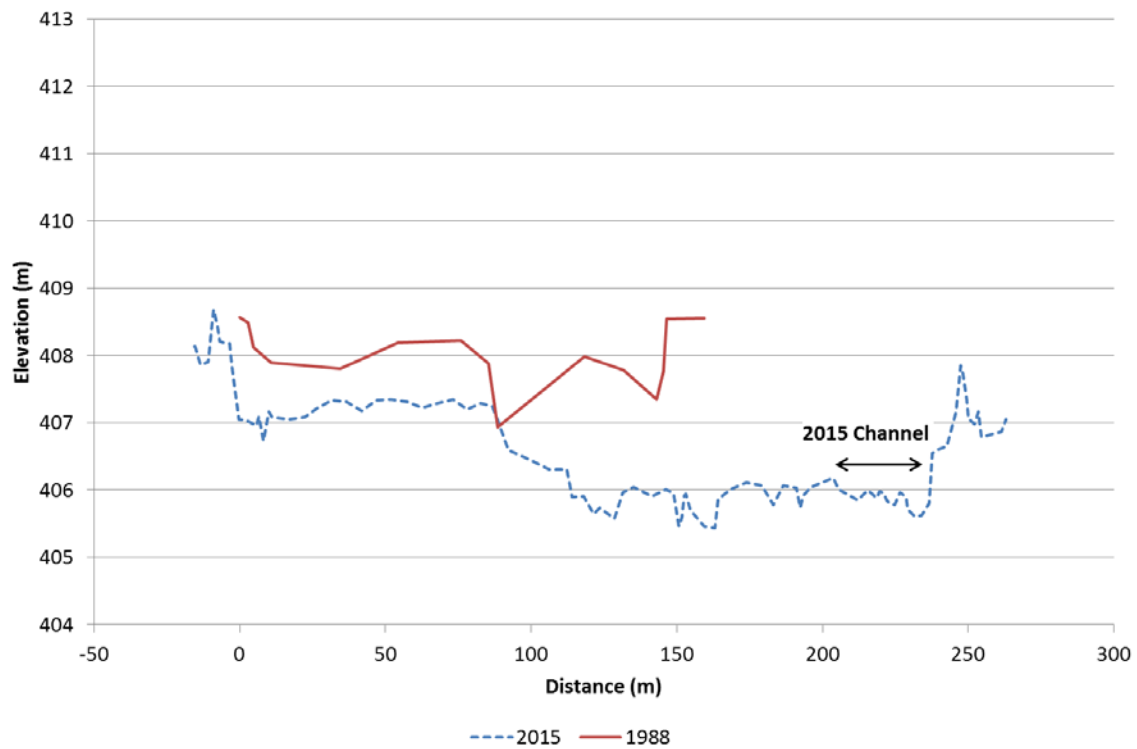


Figure 36. Cardrona River cross-section CR44, looking downstream, refer to Figure 4 for location.

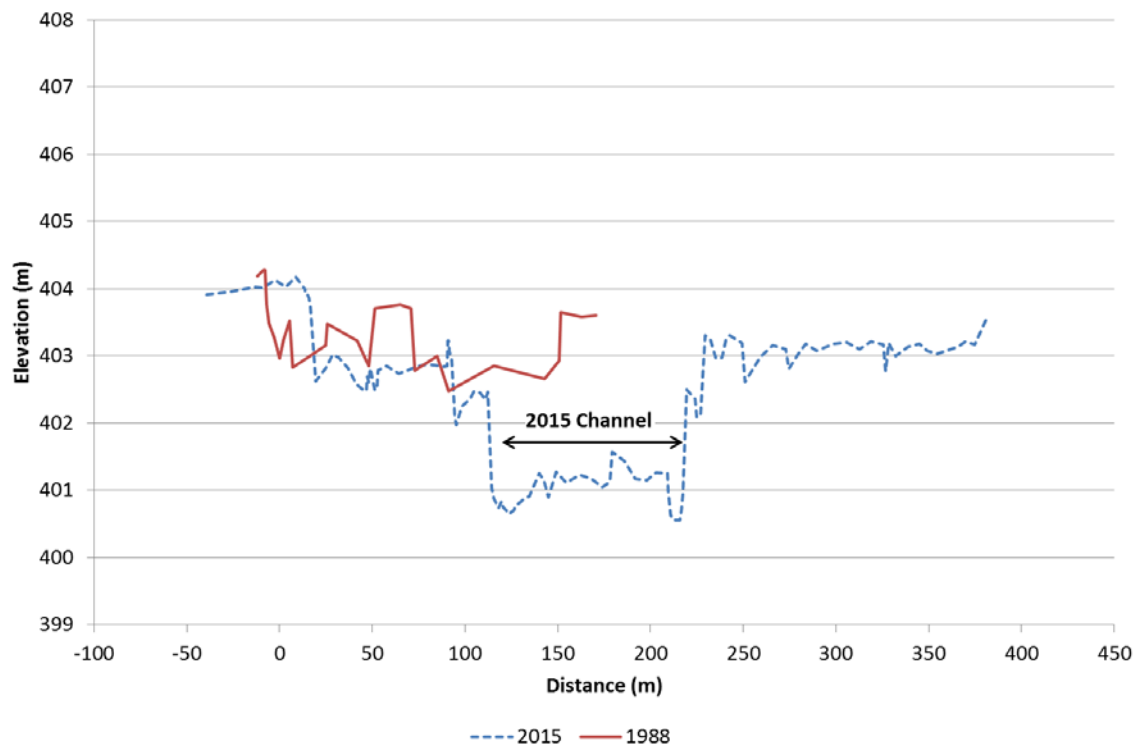


Figure 37. Cardrona River cross-section CR44-1, looking downstream, refer to Figure 4 for location.

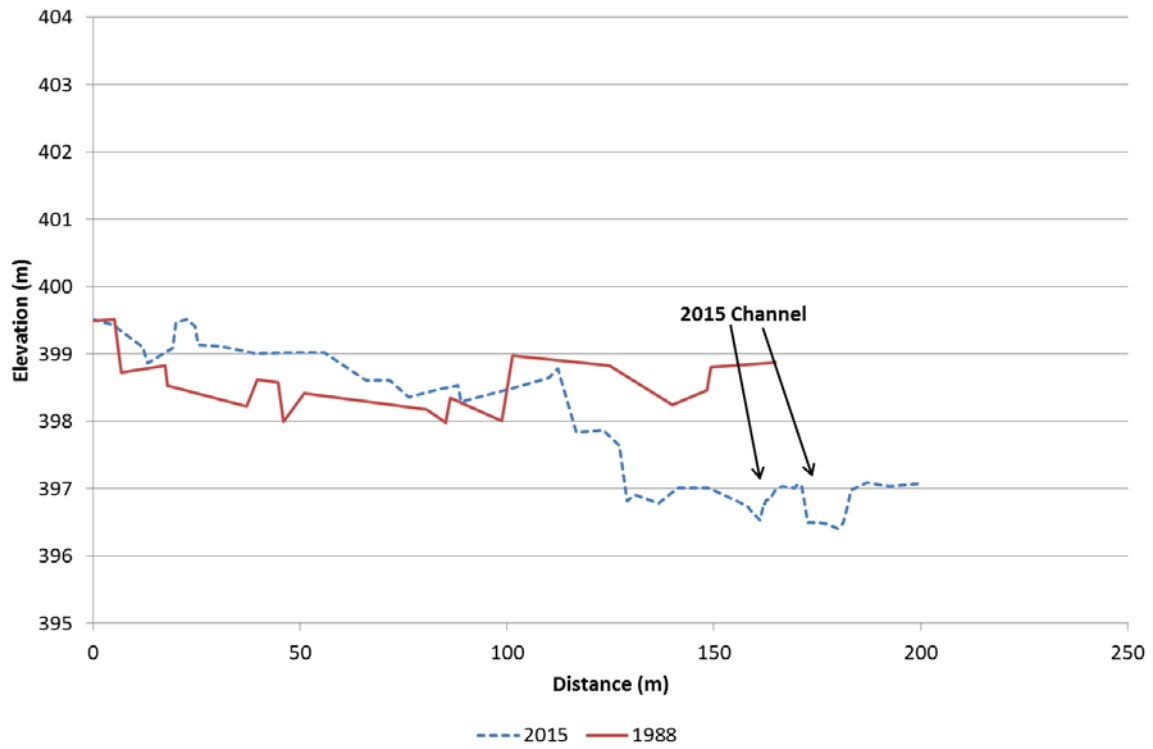


Figure 38. Cardrona River cross-section CR46, looking downstream, refer to Figure 4 for location.

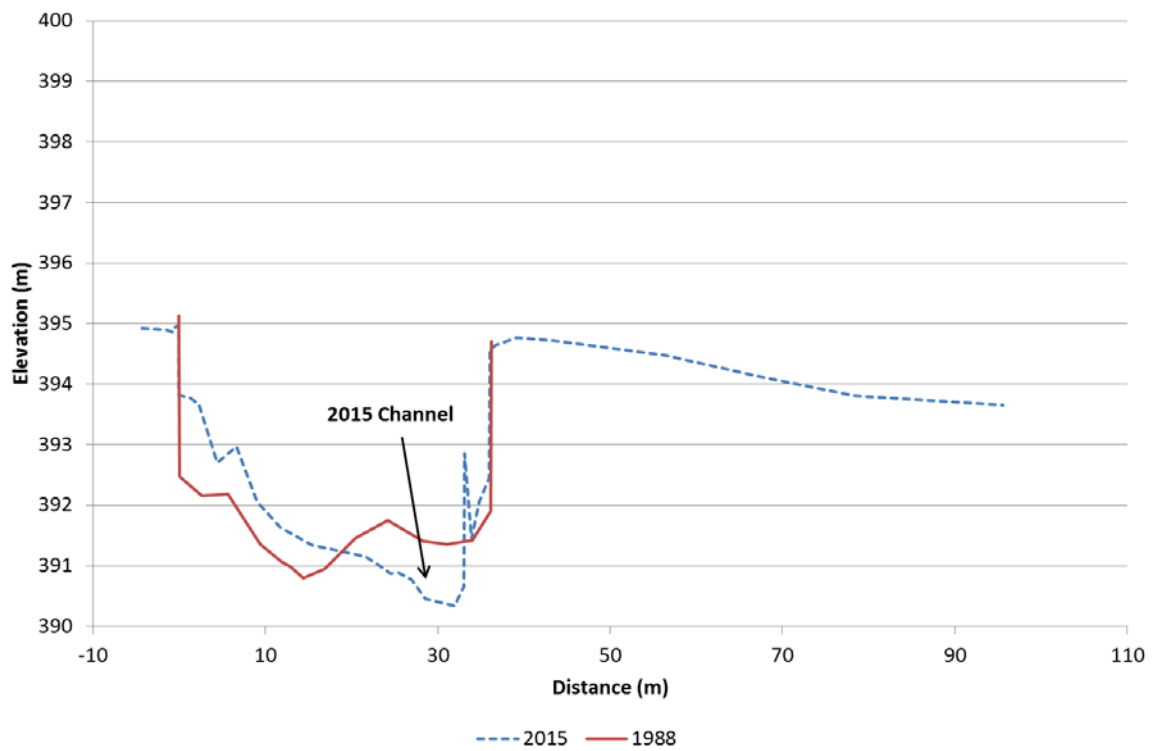


Figure 39. Cardrona River cross-section CR47-1, looking downstream, refer to Figure 4 for location.

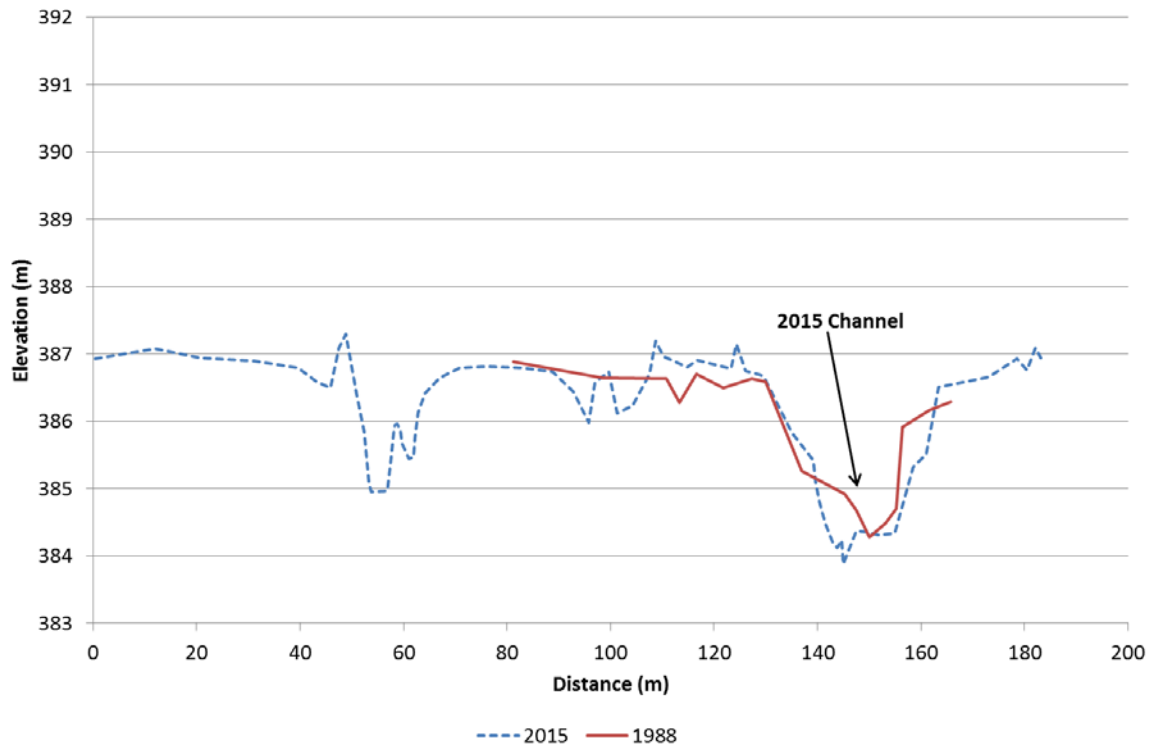


Figure 40. Cardrona River cross-section CR48-1, looking downstream, refer to Figure 4 for location.

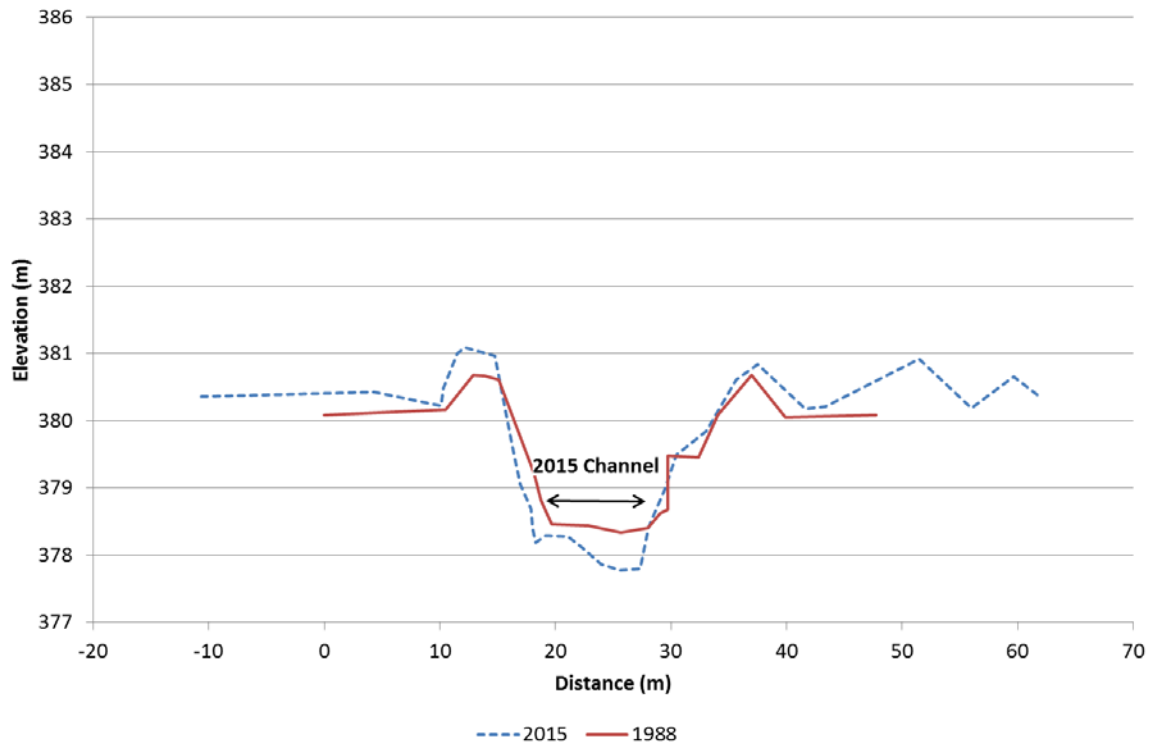


Figure 41. Cardrona River cross-section CRMWD1, looking downstream, refer to Figure 4 for location.

Appendix 3. Summaries: Cardrona River cross-sections

Cardrona River cross-section CR25-9

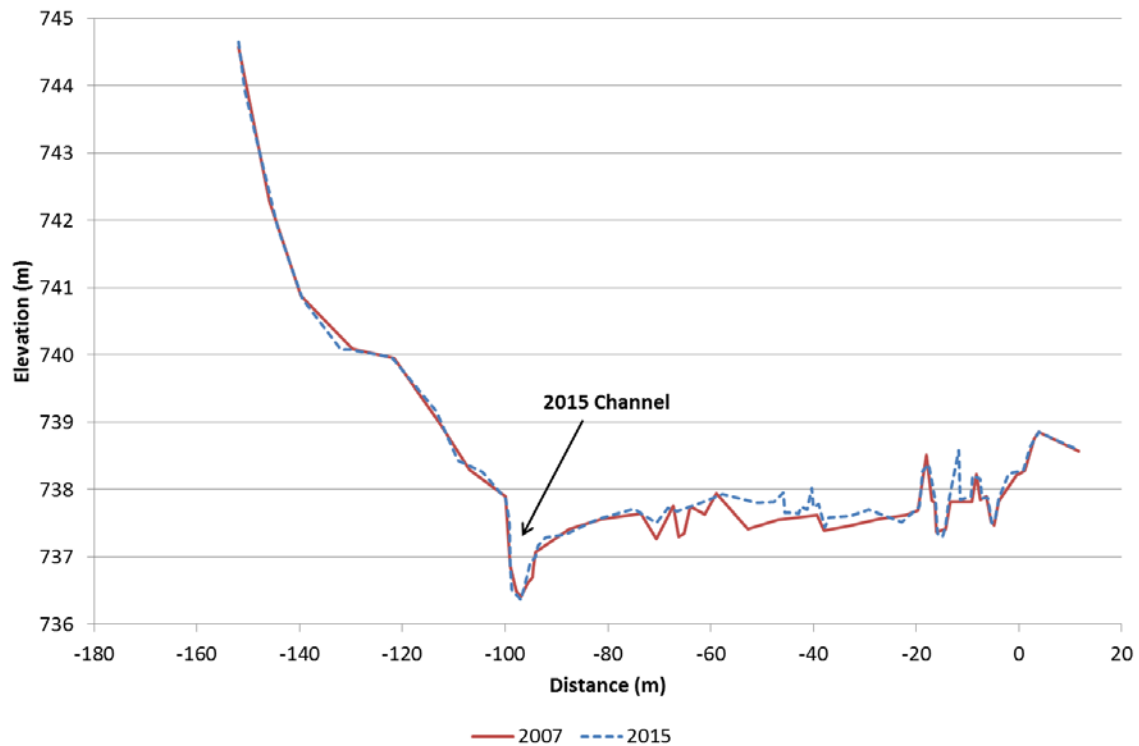


Figure 42. Cardrona River cross-section CR25-9, looking downstream refer to Figure 8 for location



Figure 43. Cardrona River cross-section CR25-9, looking downstream, November 2015

Cross-section CR25-9 is located 32.8 km upstream of the confluence with the Clutha River/Mata-Au and is the most upstream survey location. The channel has remained in the same position between 2007 and 2015. The true right floodplain has aggraded between 2007 and 2015.

Cardrona River cross-section CR25-8

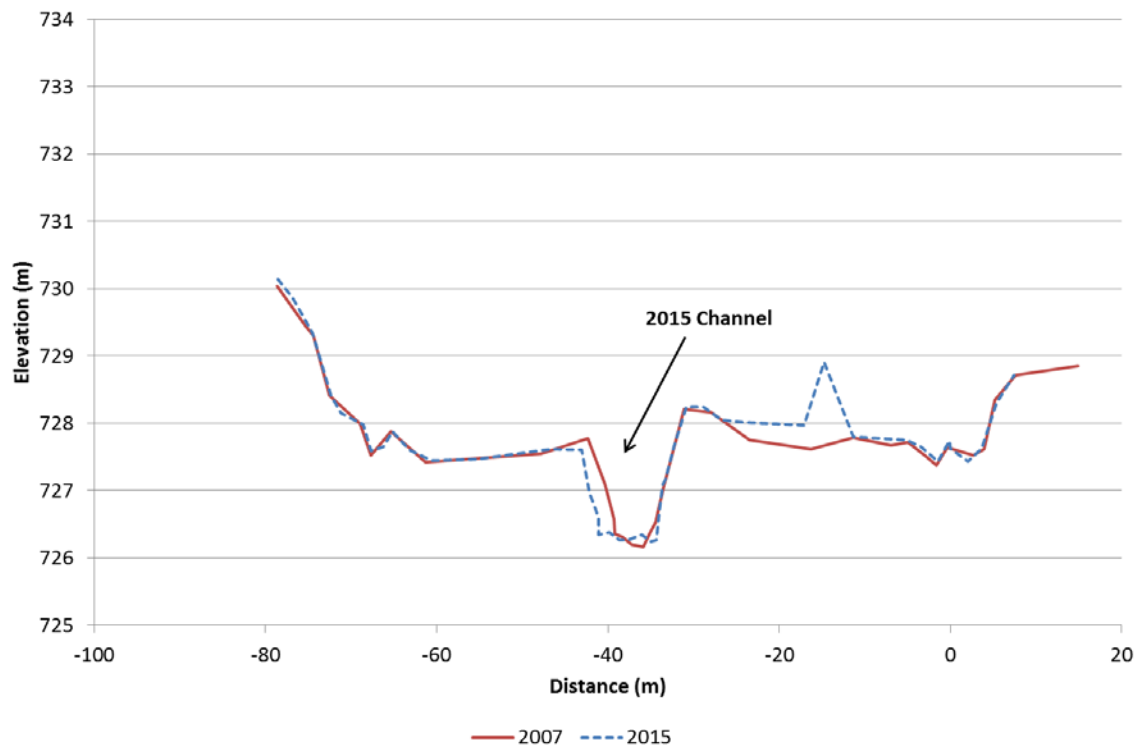


Figure 44. Cardrona River cross-section CR25-8, looking downstream refer to Figure 8 for location



Figure 45. Cardrona River cross-section CR25-8, looking upstream, November 2015

Cross-section CR25-8 is located 32.1 km upstream of the confluence with the Clutha River/Mata-Au. There has been erosion of the true left bank and some aggradation of the true right floodplain.

Cardrona River cross-section CR25-7

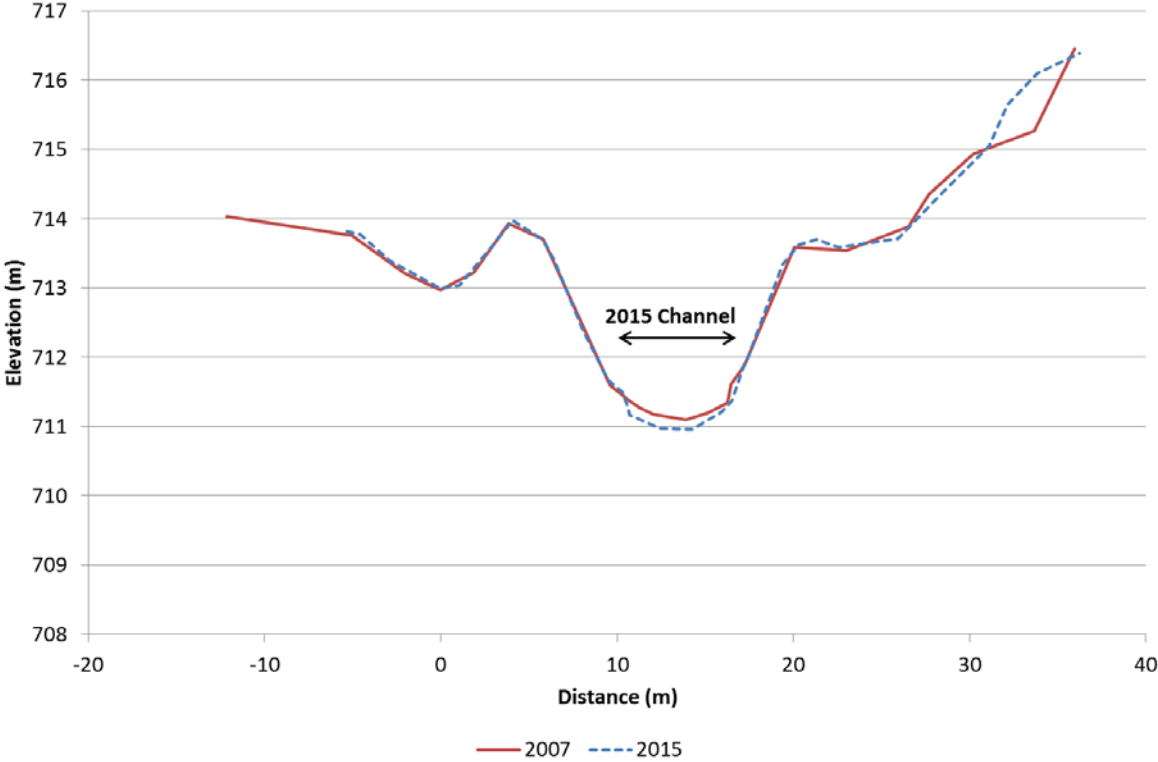


Figure 46. Cardrona River cross-section CR25-7, looking downstream refer to Figure 8 for location

Cross-section CR25-7 is located 31 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has degraded at this location between 2007 and 2015 with minimal change across the wider of the floodplain.

Cardrona River cross-section CR25-6

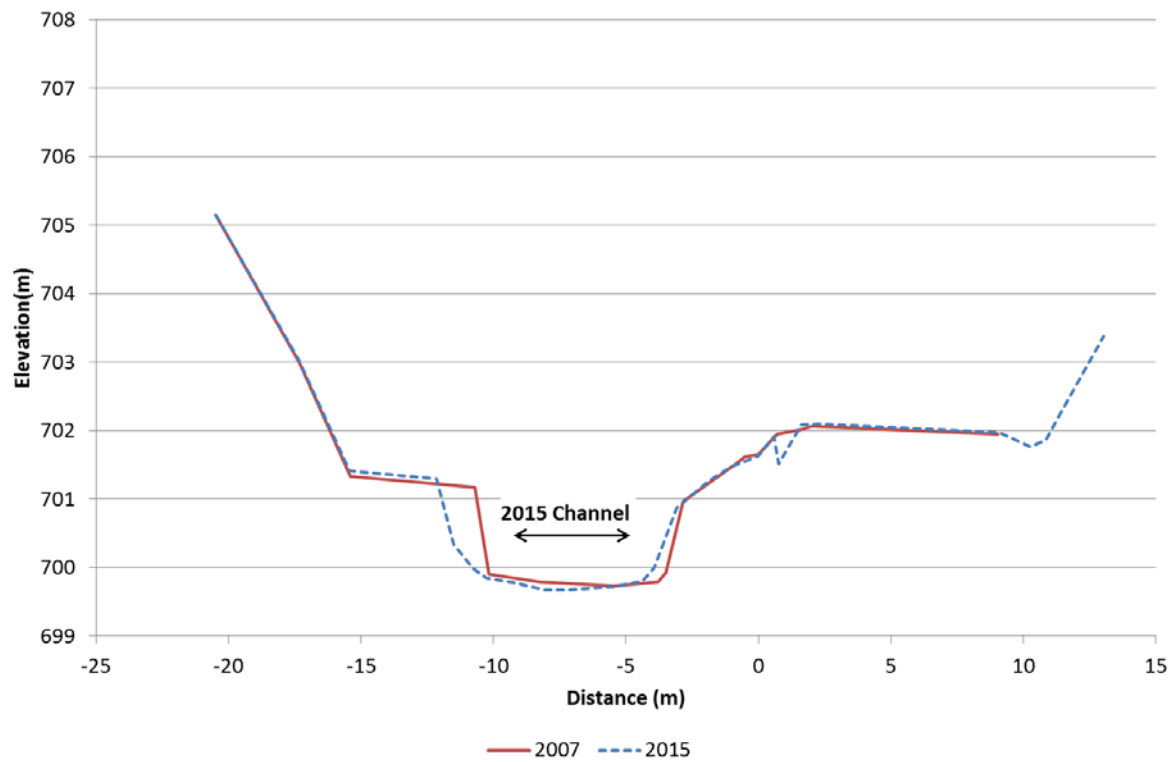


Figure 47. Cardrona River cross-section CR25-6, looking downstream refer to Figure 8 for location



Figure 48. Cardrona River cross-section CR25-6, looking upstream, November 2015

Cross-section CR25-6 is located 30.2 km upstream of the confluence with the Clutha River/Mata-Au. The true left bank eroded and the true right bank aggraded between 2007 and 2015 with minimal change occurring across the wider floodplain.

Cardrona River cross-section CR25-5

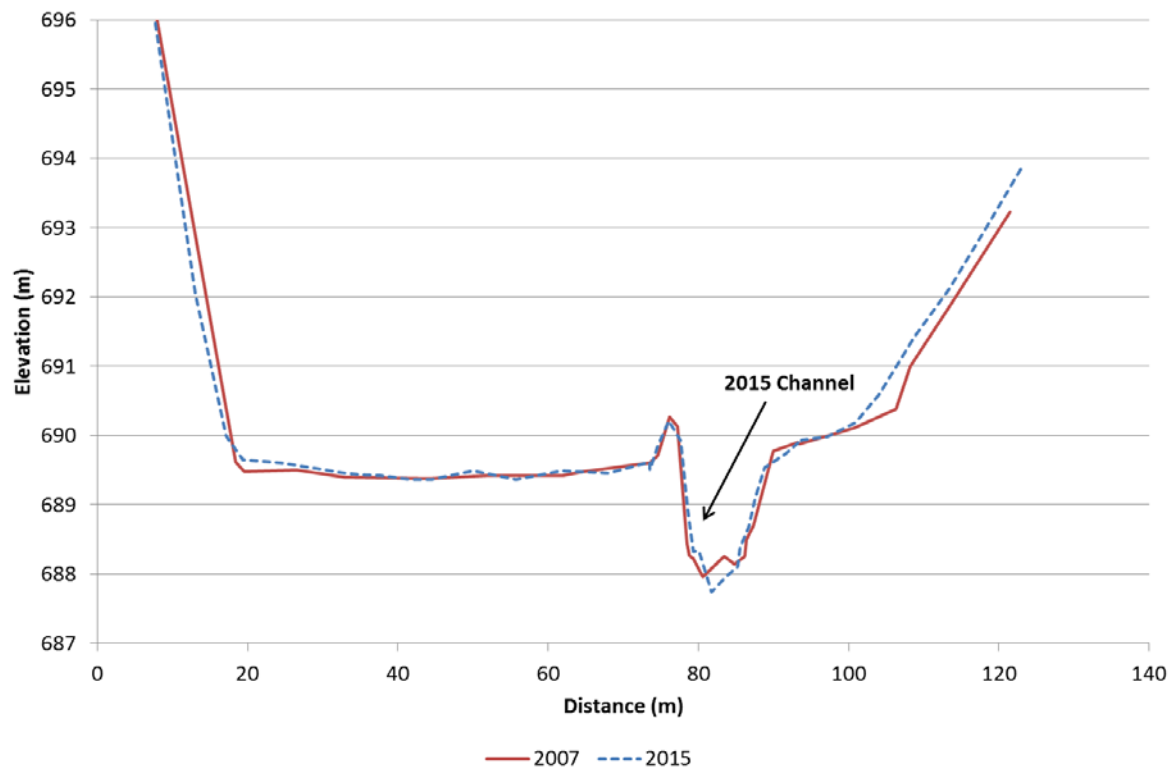


Figure 49. Cardrona River cross-section CR25-5, looking downstream refer to Figure 8 for location



Figure 50. Cardrona River cross-section CR25-5, looking from true right to true left bank, November 2015

Cross-section CR25-5 is located 29.5 km upstream of the confluence with the Clutha River/Mata-Au. The channel has degraded between 2007 and 2015 with aggradation occurring on the true right bank.

Cardrona River cross-section CR25-4

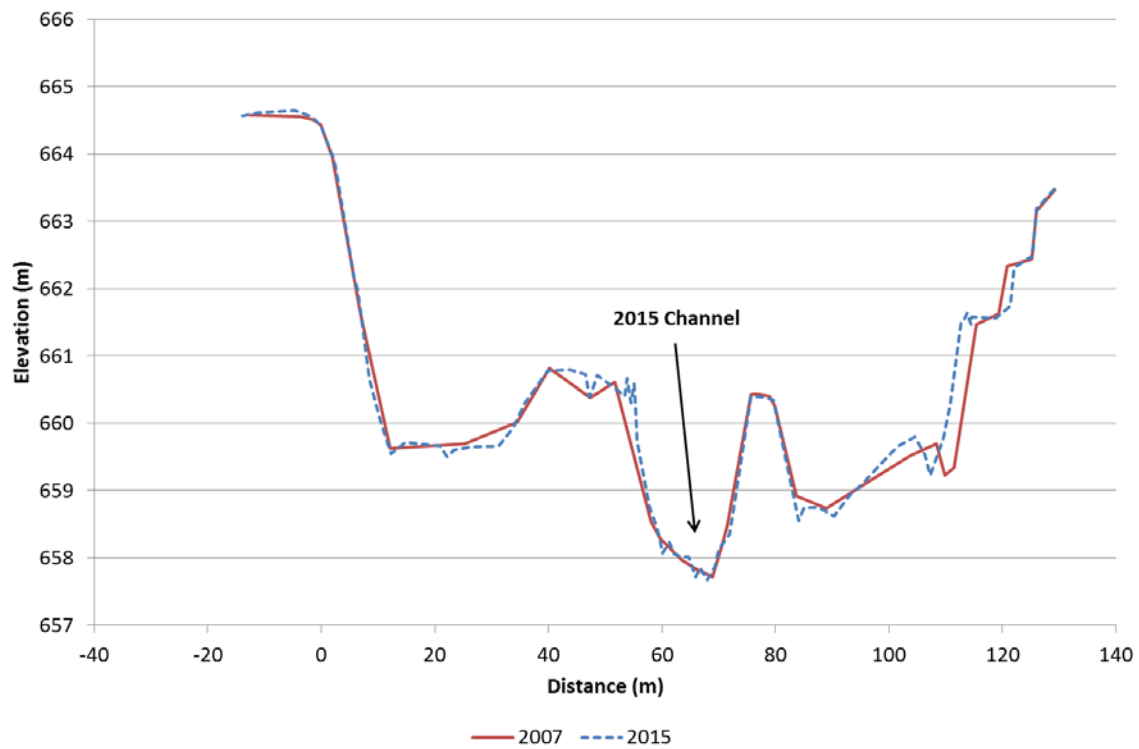


Figure 51. Cardrona River cross-section CR25-4, looking downstream refer to Figure 8 for location



Figure 52. Cardrona River cross-section CR25-4, looking downstream, November 2015

Cross-section CR25-4 is located 28.8 km upstream of the confluence with the Clutha River/Mata-Au. There has been little change in the main channel between 2007 and 2015, the true right floodplain bank and the true left channel bank aggraded during this period.

Cardrona River cross-section CR25-3

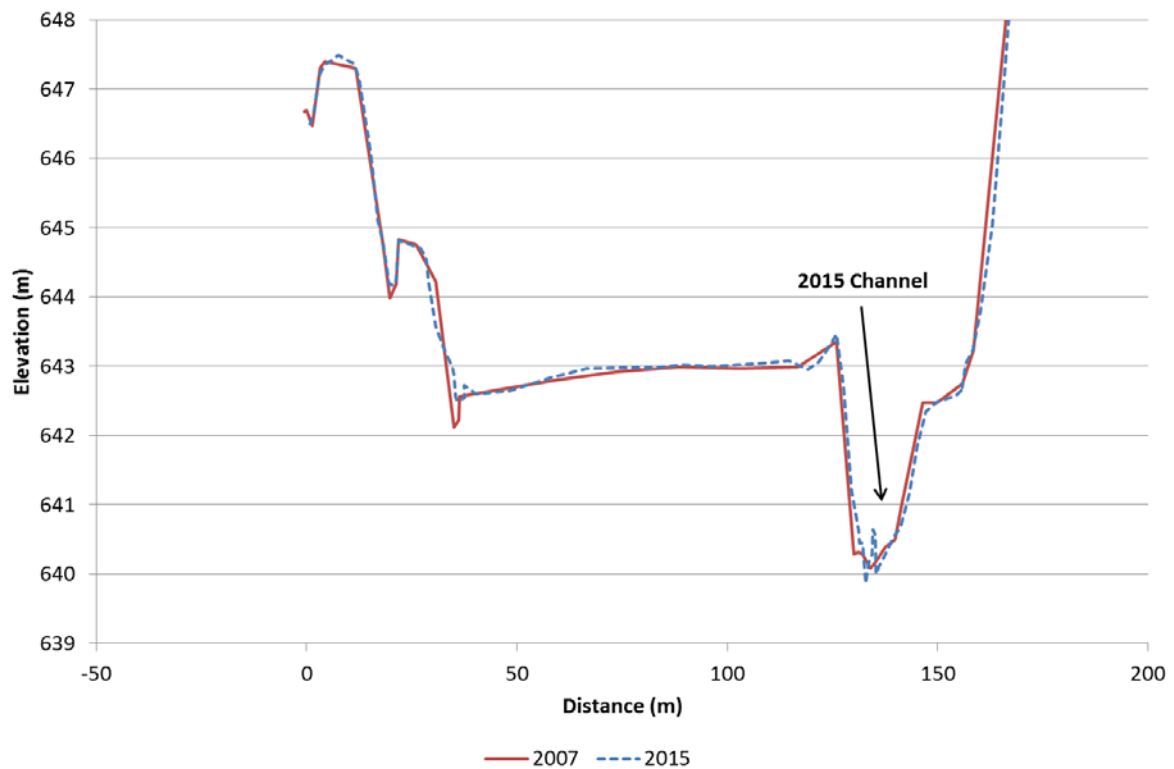


Figure 53. Cardrona River cross-section CR25-3, looking downstream refer to Figure 8 for location



Figure 54. Cardrona River cross-section CR25-3, looking from true right to true left bank, November 2015

Cross-section CR25-3 is located 27.9 km upstream of the confluence with the Clutha River/Mata-Au. Minimal change in the main channel and wider floodplain occurred between 2007 and 2015.

Cardrona River cross-section CR25-2

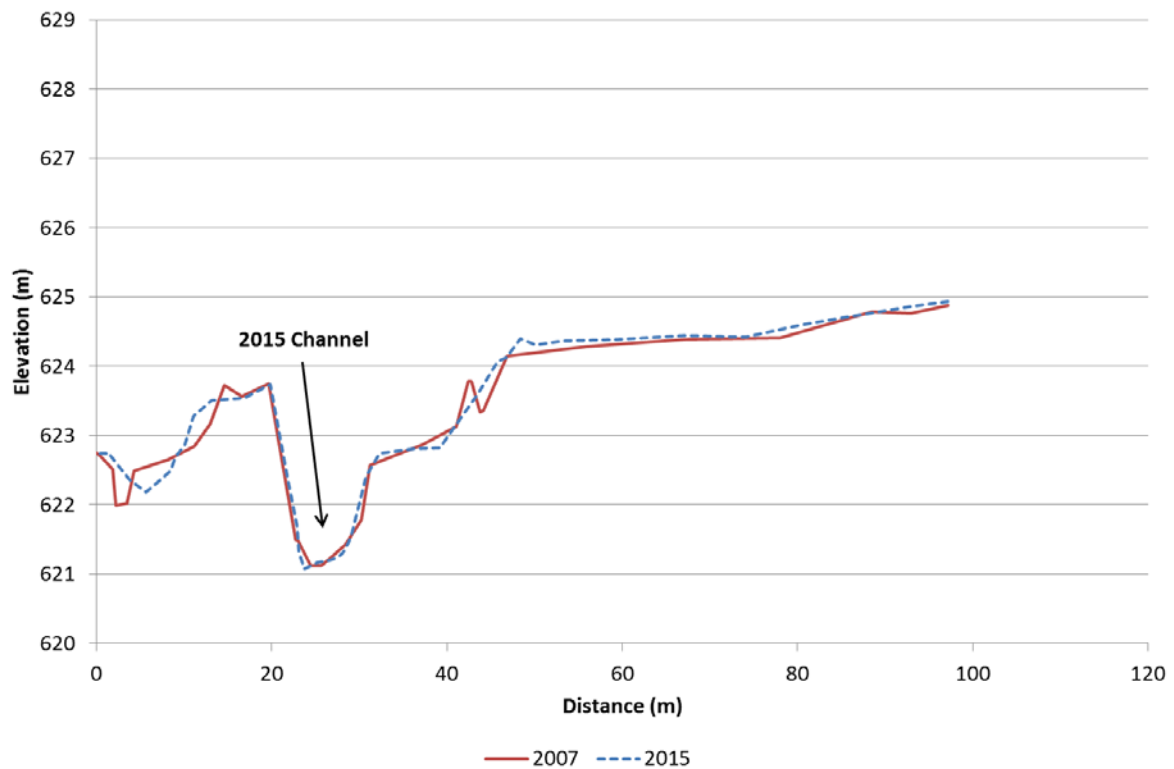


Figure 55. Cardrona River cross-section CR25-2, looking downstream refer to Figure 7 for location



Figure 56. Cardrona River cross-section CR25-2, looking upstream, November 2015

Cross-section CR25-2 is located 27.1 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has remained in a similar position between 2007 and 2015. The true left floodplain has both aggraded and degraded between 2007 and 2015.

Cardrona River cross-section CR25-1

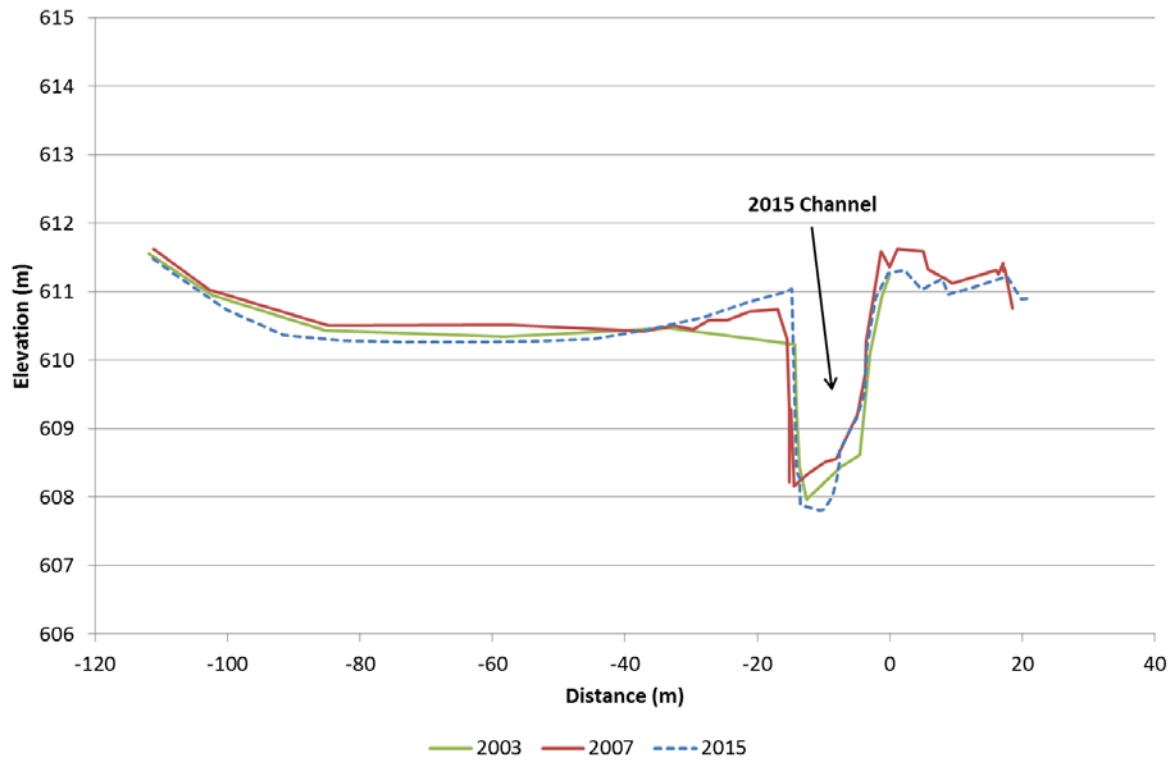


Figure 57. Cardrona River cross-section CR25-1, looking downstream refer to Figure 7 for location



Figure 58. Cardrona River cross-section CR25-1, looking downstream, November 2015

Cross-section CR25-1 is located 26.5 km upstream of the confluence with the Clutha River/Mata-Au. Between 2003 and 2015 the main channel has experienced degradation. Aggradation has occurred on the true left channel bank between 2003 and 2015 with degradation occurring on the wider true left and right bank floodplain between 2007 and 2015.

Cardrona River cross-section CR22

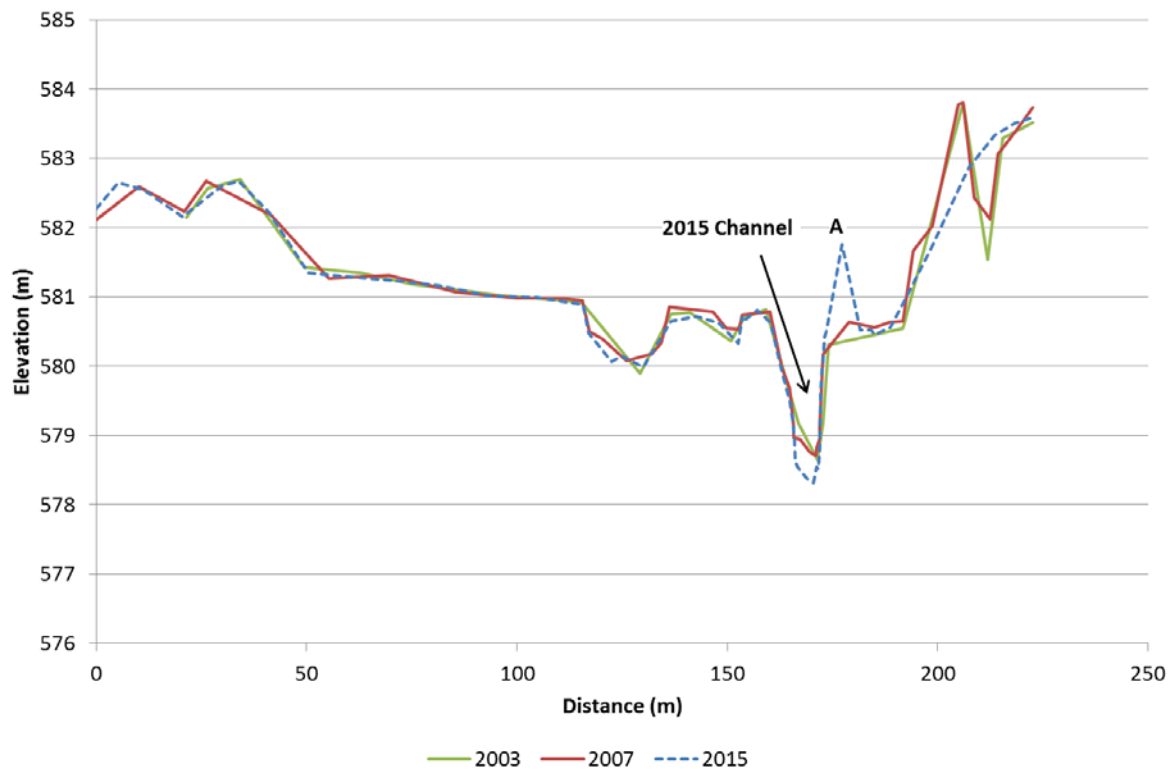


Figure 59. Cardrona River cross-section CR22, looking downstream refer to Figure 7 for location



Figure 60. Cardrona River cross-section CR22, looking upstream, November 2015

Cross-section CR22 is located 24.1 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has degraded between 2003 and 2015 with the creation of a feature at the point labelled A. Bank erosion occurred on the true right bank between 2003 and 2015.

Cardrona River cross-section CR18-1

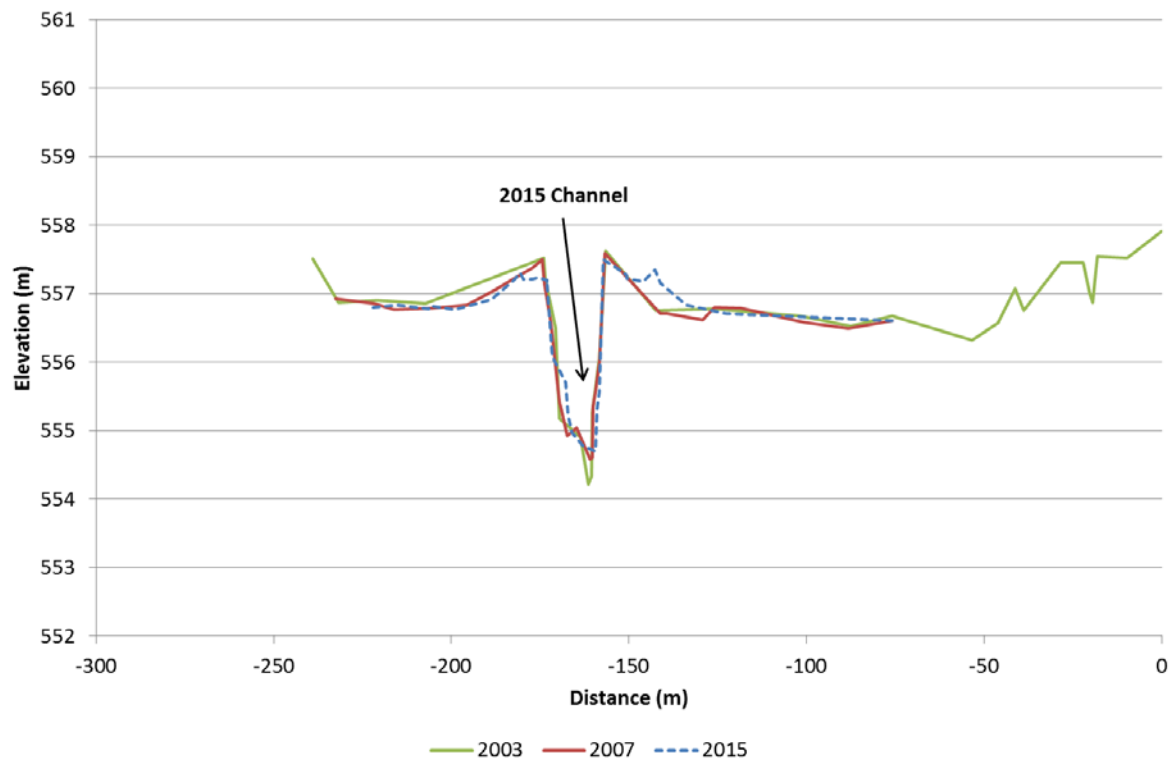


Figure 61. Cardrona River cross-section CR18-1, looking downstream refer to Figure 7 for location



Figure 62. Cardrona River cross-section CR18-1, looking upstream, November 2015

Cross-section CR18-1 is located 21.74 km upstream of the confluence with the Clutha River/Mata-Au. The channel has aggraded between 2003 and 2015 but has remained in a similar position between 2007 and 2015. The true right floodplain has aggraded between 2003 and 2015. The true left floodplain has degraded between 2003 and 2015 but has remained in a similar position between 2007 and 2015.

Cardrona River cross-section CR16

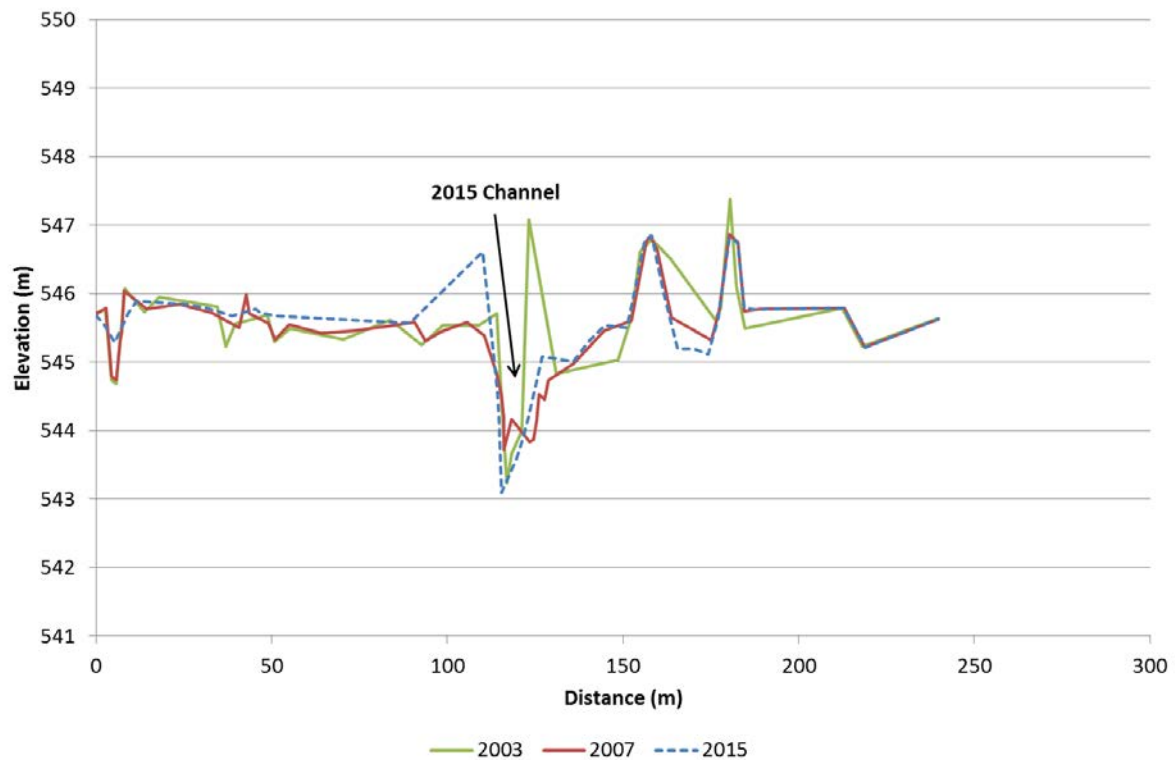


Figure 63. Cardrona River cross-section CR16, looking downstream refer to Figure 7 for location



Figure 64. Cardrona River cross-section CR16, looking downstream, November 2015

Cross-section CR16 is located 20.5 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has become more confined between 2007 and 2015 with aggradation occurring on the true right bank. The top of the true left berm has aggraded between 2003 and 2015.

Cardrona River cross-section CR11-1

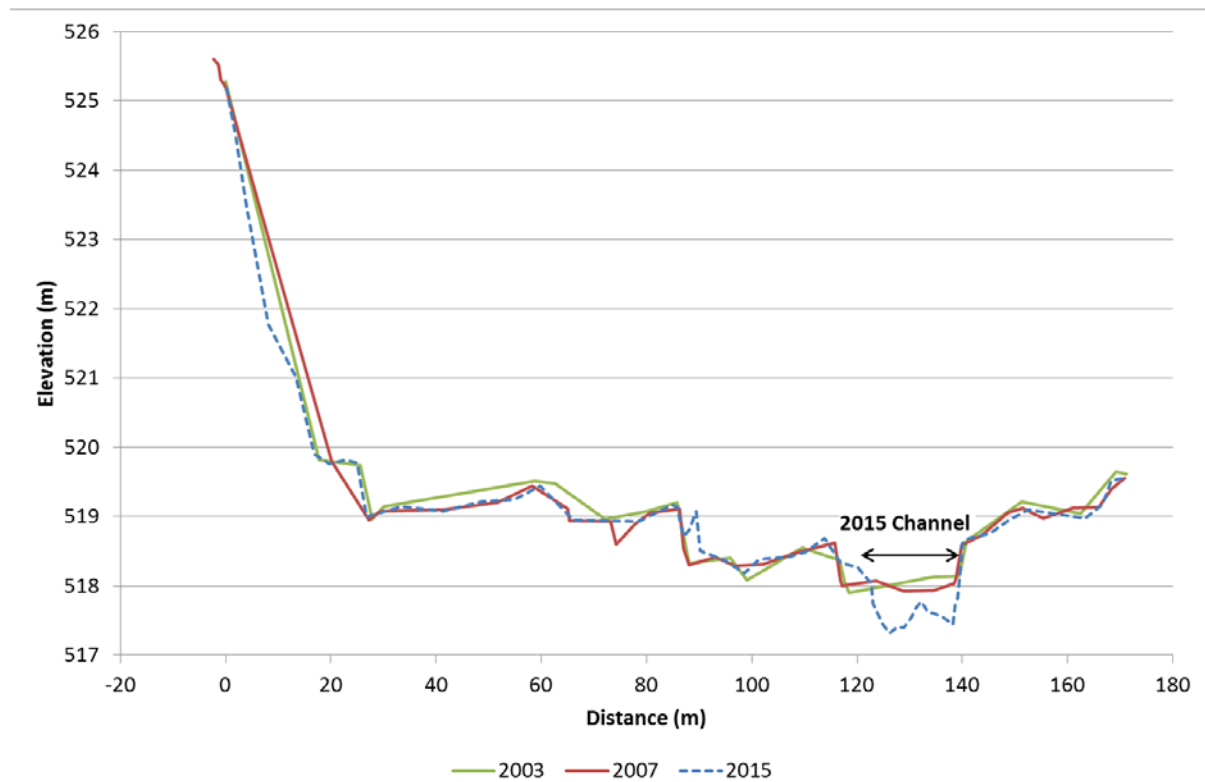


Figure 65. Cardrona River cross-section CR11-1, looking downstream refer to Figure 6 for location

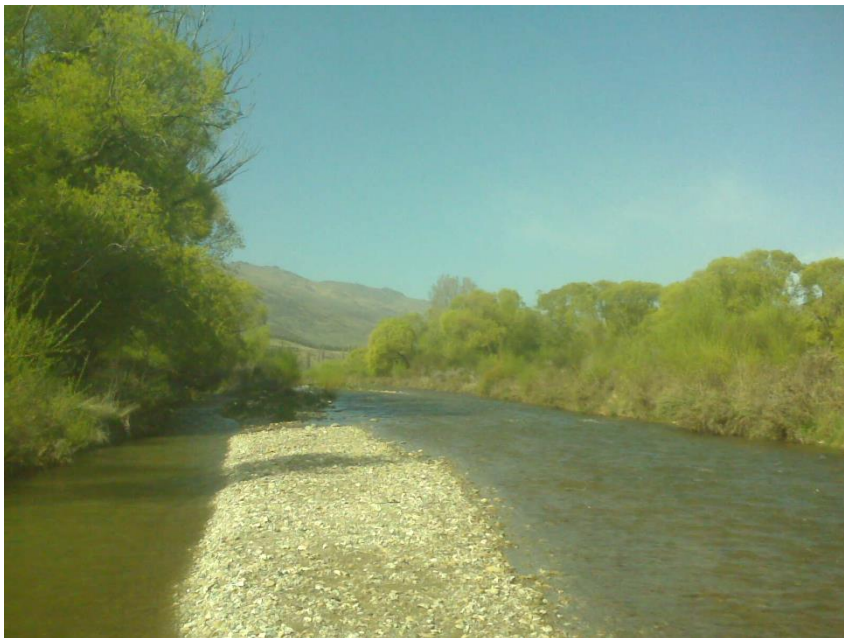


Figure 66. Cardrona River cross-section CR11-1, looking upstream, November 2015

Cross-section CR11-1 is located 17.5 km upstream of the confluence with the Clutha River/Mata-Au. Between 2003 and 2015 the main channel has degraded and become more confined. The true left floodplain has aggraded between 2007 and 2015.

Cardrona River cross-section CR9

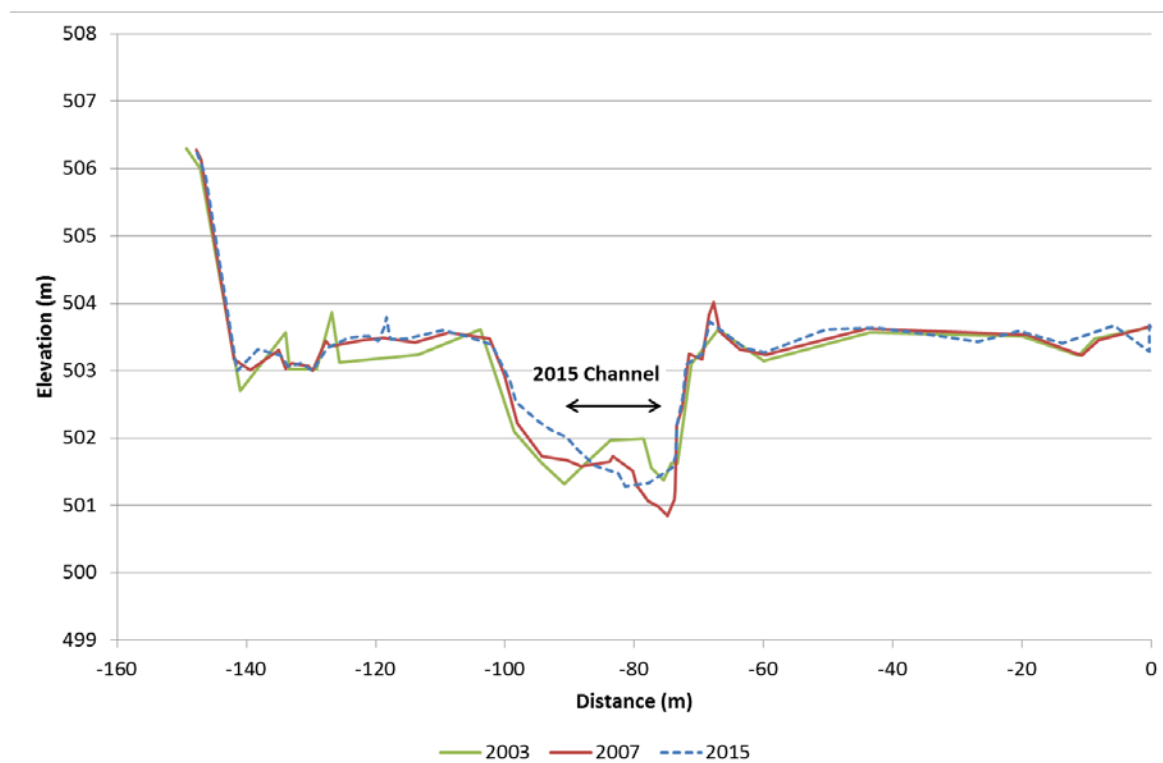


Figure 67. Cardrona River cross-section CR9, looking downstream refer to Figure 6 for location



Figure 68. Cardrona River cross-section CR9, looking upstream, November 2015

Cross-section CR9 is located 15.7 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has aggraded on the true left and true right, but has degraded in the centre between 2007 and 2015 creating a more confined channel. The wider floodplain has remained similar between 2007 and 2015 but has experienced aggradation between 2003 and 2015.

Cardrona River cross-section CR8

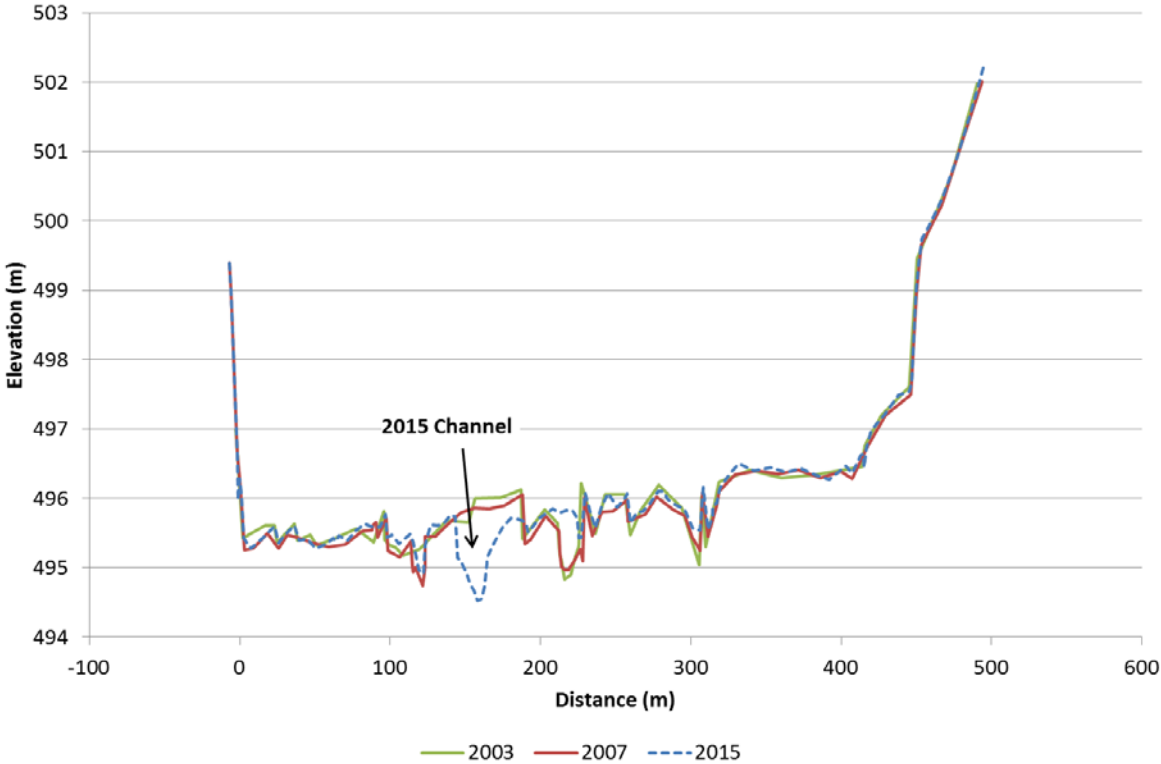


Figure 69. Cardrona River cross-section CR8, looking downstream refer to Figure 6 for location



Figure 70. Cardrona River cross-section CR8, looking upstream, November 2015

Cross-section CR8 is located 14.8 km upstream of the confluence with the Clutha River/Mata-Au. Between 2007 and 2015 there has been some infilling of previous channel with the main channel now occupying the centre of the active fairway.

Cardrona River cross-section CR5

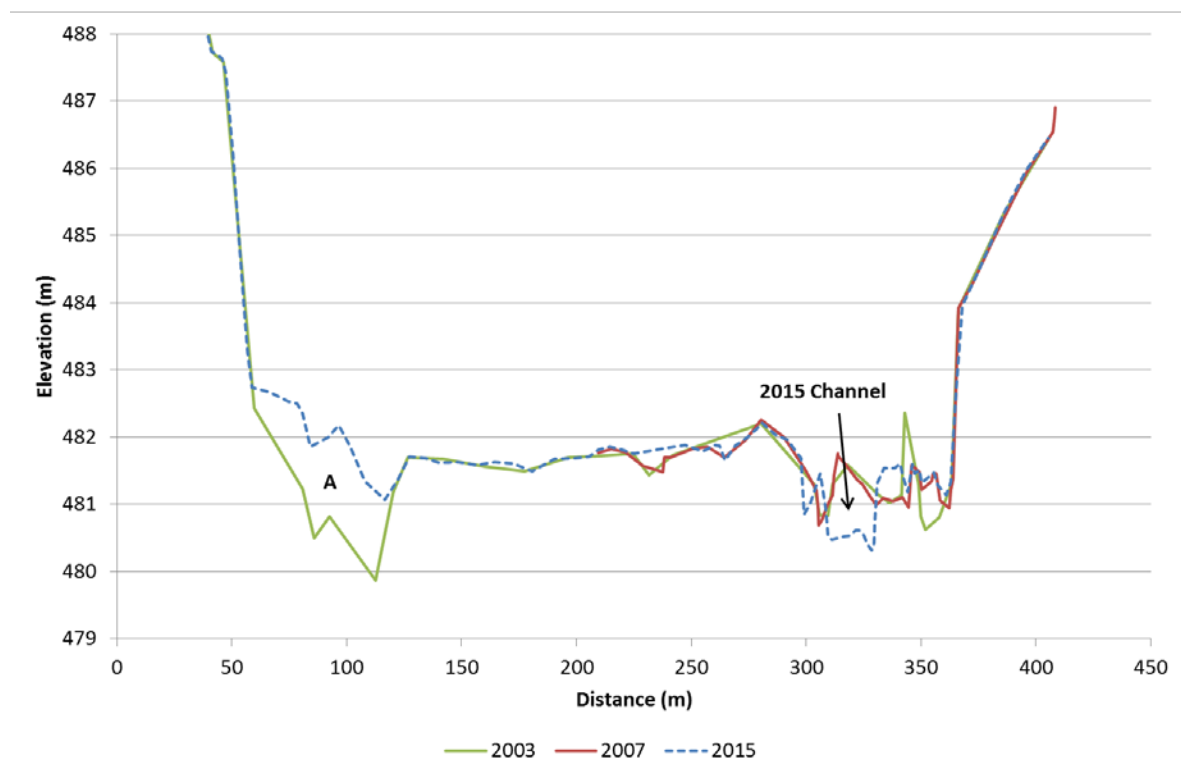


Figure 71. Cardrona River cross-section CR5, looking downstream refer to Figure 6 for location



Figure 72. Cardrona River cross-section CR5, looking downstream, November 2015

Cross-section CR5 is located 13 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has become more defined between 2007 and 2015 with aggradation occurring in the 2003 and 2007 secondary channels. Aggradation of the true left bank floodplain at the point labelled A occurred between 2003 and 2015.

Cardrona River cross-section CR3

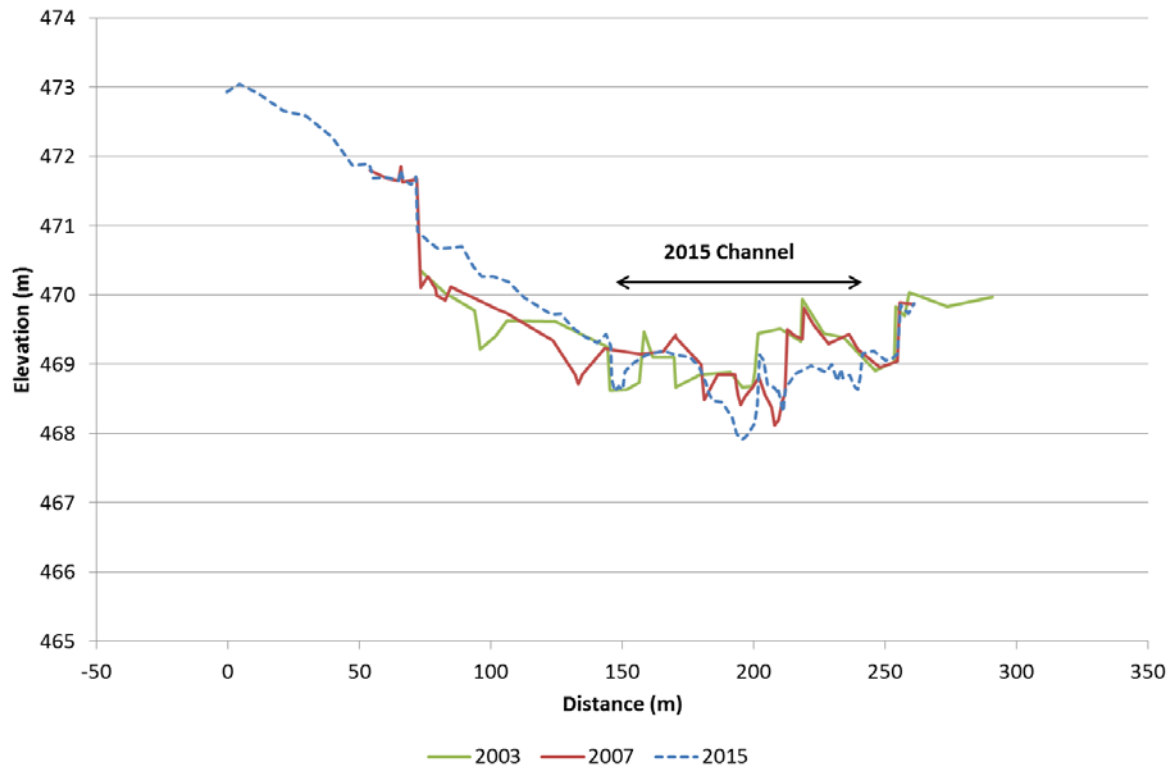


Figure 73. Cardrona River cross-section CR3, looking downstream refer to Figure 5 for location



Figure 74. Cardrona River cross-section CR3, looking upstream, November 2015

Cross-section CR3 is located 11.7 km upstream of the confluence with the Clutha River/Mata-Au. The channel at this location is braided with one main channel in the centre of the active fairway and several low flow channels. These channels have both aggraded and degraded between 2003 and 2007. Aggradation of the true left bank terrace has occurred between 2007 and 2015.

Cardrona River cross-section CR2B

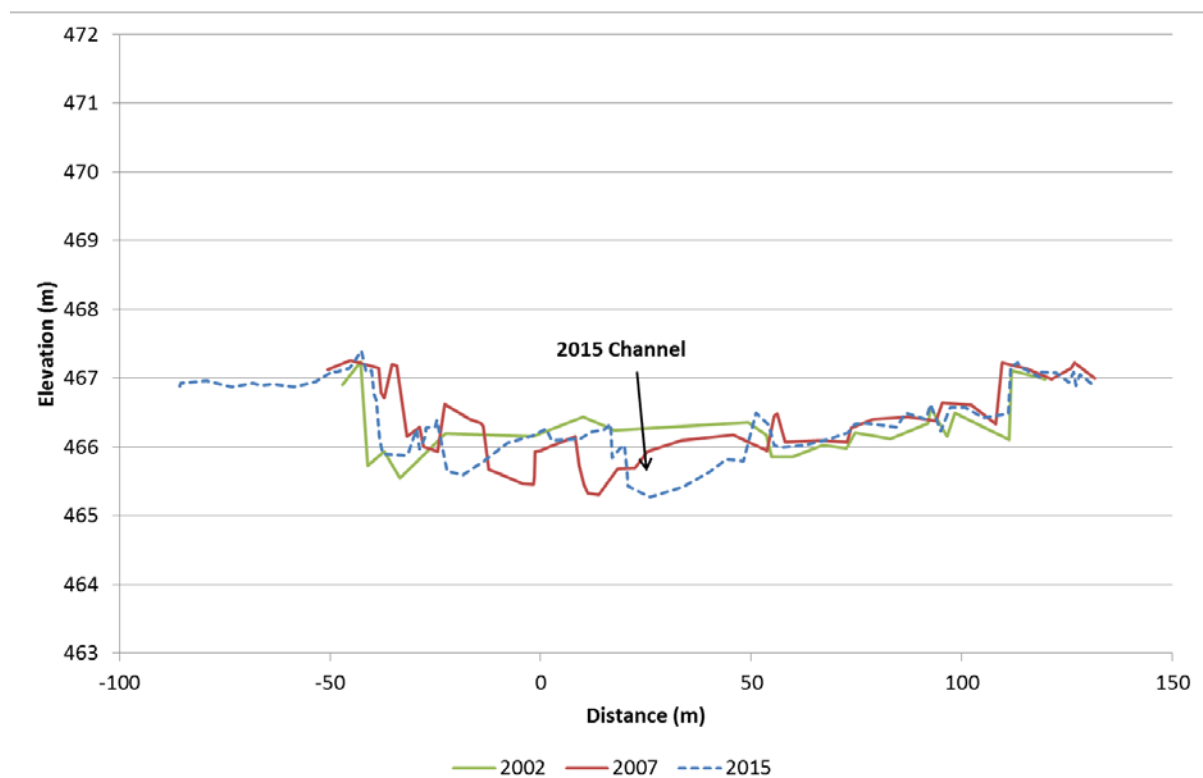


Figure 75. Cardrona River cross-section CR2B, looking downstream refer to Figure 5 for location



Figure 76. Cardrona River cross-section CR2B, looking downstream, November 2015

Cross-section CR2B is located 11.4 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has been migrating towards the true right bank between 2003 and 2015 with both aggradation and degradation occurring as previous channel became infilled. The true left bank floodplain has eroded between 2007 and 2015.

Cardrona River cross-section CR2

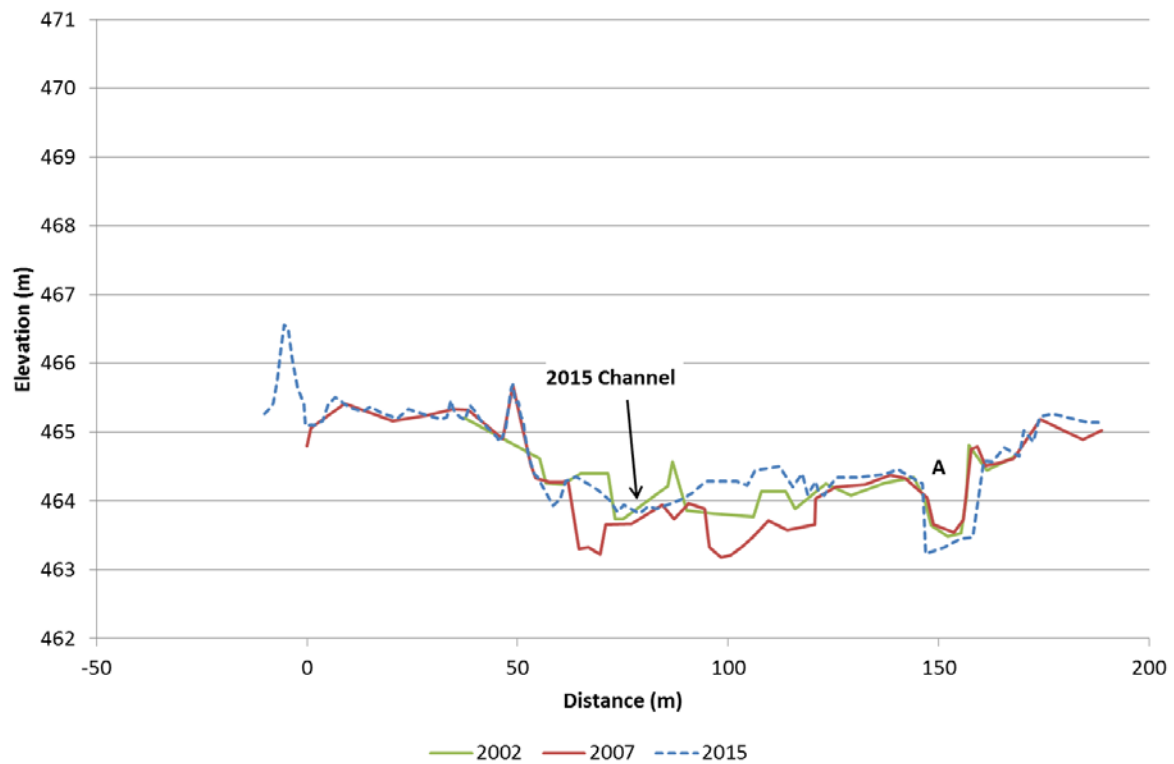


Figure 77. Cardrona River cross-section CR2, looking downstream refer to refer to Figure 5 for location



Figure 78. Cardrona River cross-section CR2, looking downstream, November 2015

Cross-section CR2 is located 11.2 km upstream of the confluence with the Clutha River/Mata-Au. The wider braid network has experienced aggradation between 2007 and 2015 with the exception of a secondary channel at the point labelled A, which has degraded between 2007 and 2015 as well as eroding the true right bank.

Cardrona River cross-section CR2A

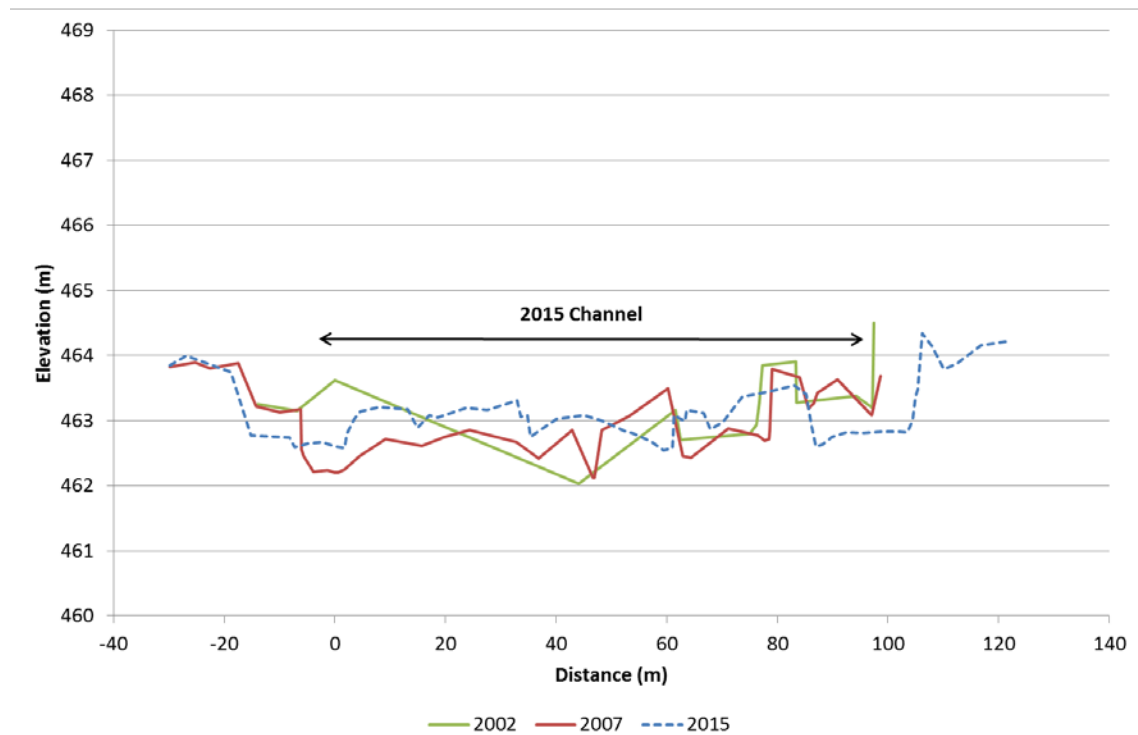


Figure 79. Cardrona River cross-section CR2A, looking downstream refer to Figure 5 for location

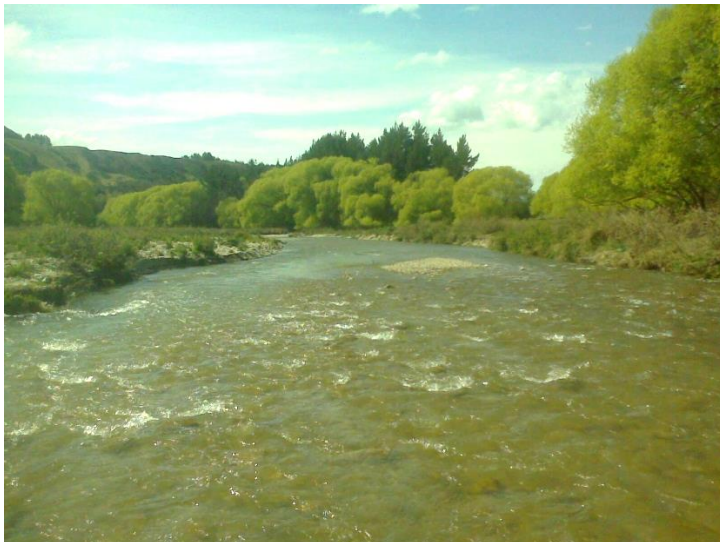


Figure 80. Cardrona River cross-section CR2A, looking downstream, November 2015

Cross-section CR2A is located 11 km upstream of the confluence with the Clutha River/Mata-Au. The true left bank has eroded between 2007 and 2015, with aggradation of the true left side of the braid network occurring. Bank erosion occurred on the true right bank (between 2007 and 2015 with the creation of a new secondary channel).⁷

⁷ The 2003 and 2007 cross-sections did not extend sufficiently on the true right bank to allow a complete comparison to be made with the 2015 cross-section

Cardrona River cross-section CR1B

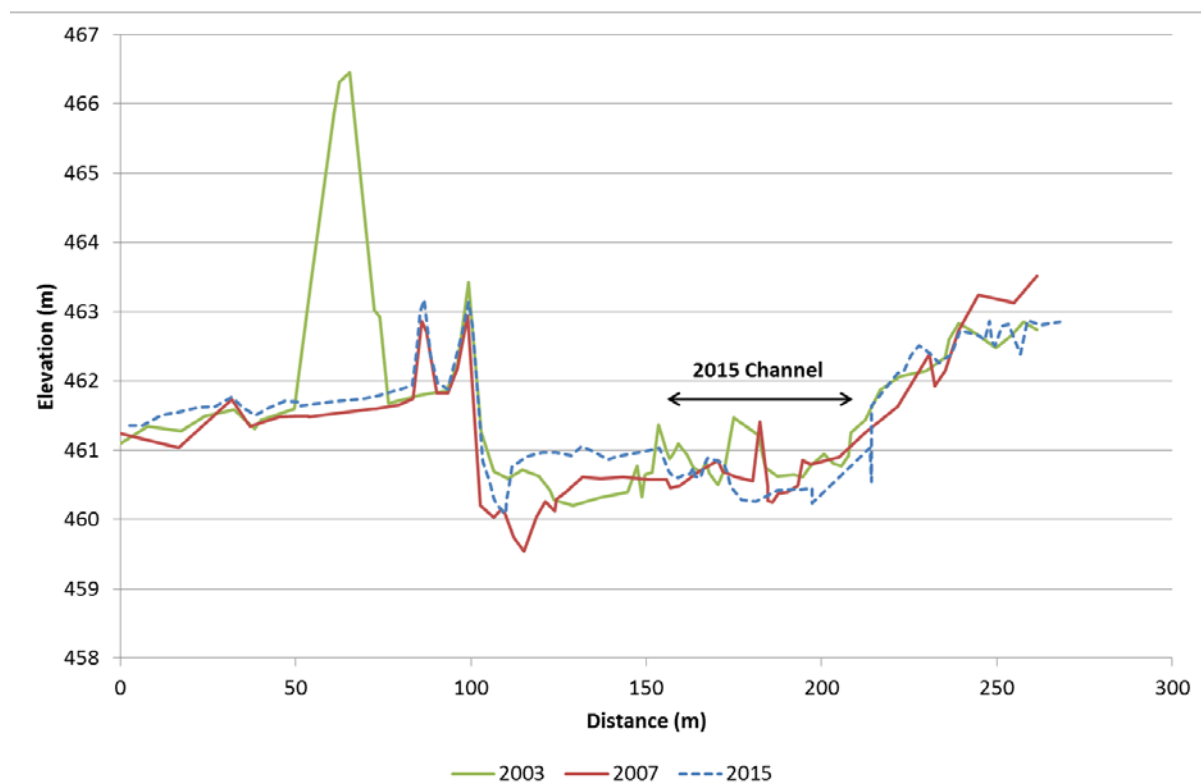


Figure 81. Cardrona River cross-section CR1B, looking downstream refer to refer to Figure 5 for location



Figure 82. Cardrona River cross-section CR1B, looking upstream, November 2015

Cross-section CR1B is located 10.7 km upstream of the confluence with the Clutha River/Mata-Au. Aggradation has occurred on the true left of the fairway with degradation occurring on the true right between 2007 and 2015. The main channel has switched from the true left of the fairway in 2007 to the true right side of the fairway in 2015. Aggradation has occurred on the true right bank between 2007 and 2015.

Cardrona River cross-section CR1A

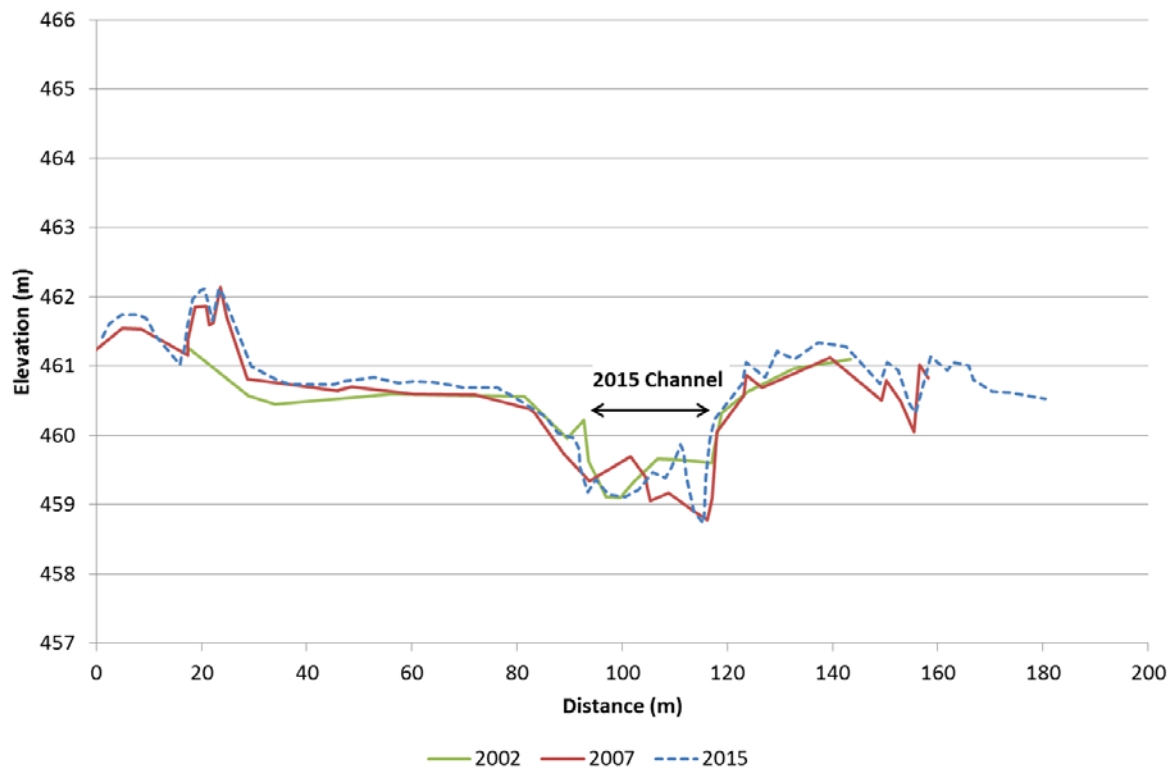


Figure 83. Cardrona River cross-section CR1A, looking downstream refer to Figure 5 for location



Figure 84. Cardrona River cross-section CR1A, looking upstream, November 2015

Cross-section CR1A is located 10.6 km upstream of the confluence with the Clutha River/Mata-Au. Aggradation has occurred across the wider floodplain between 2003 and 2007. A mid channel bar has formed in the main channel between 2007 and 2015.

Cardrona River cross-section CR28-2

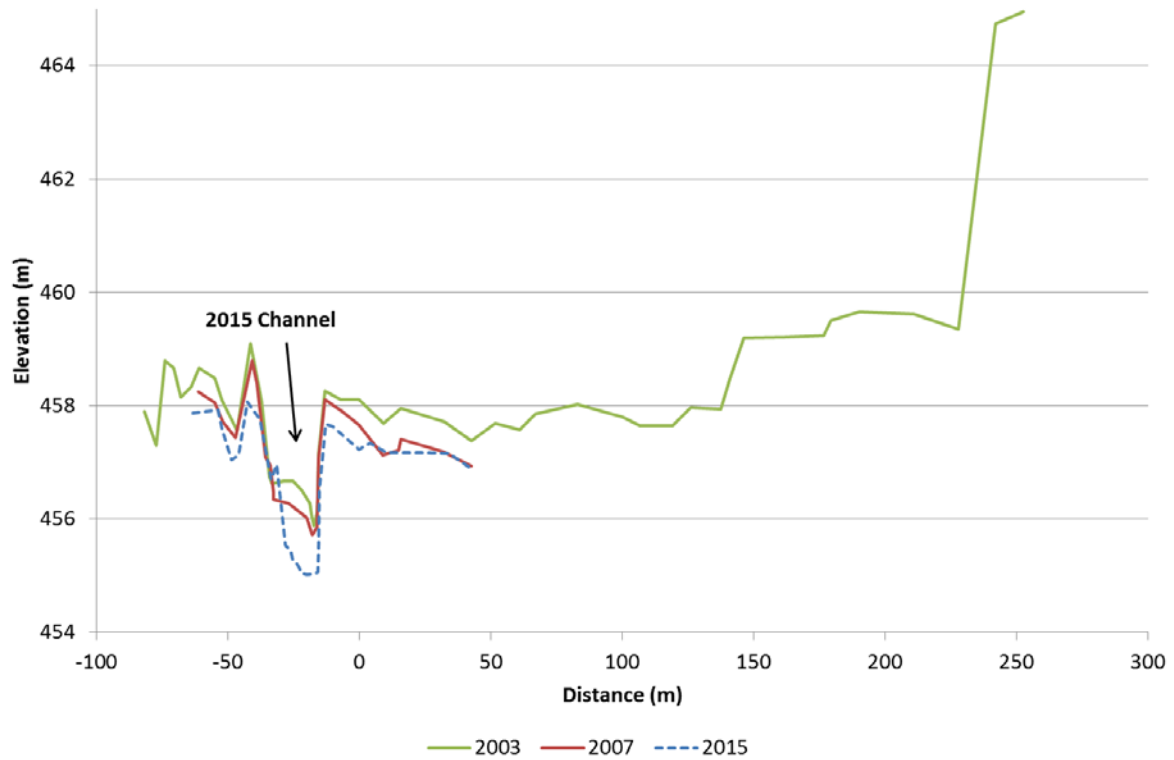


Figure 85. Cardrona River cross-section CR28-2, looking downstream refer to Figure 5 for location



Figure 86. Cardrona River cross-section CR28-2, looking downstream, November 2015

Cross-section CR28-2 is located 10.18 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has degraded between 2007 and 2015 with degradation occurring on the true left and right bank floodplain.

Cardrona River cross-section CR28-1

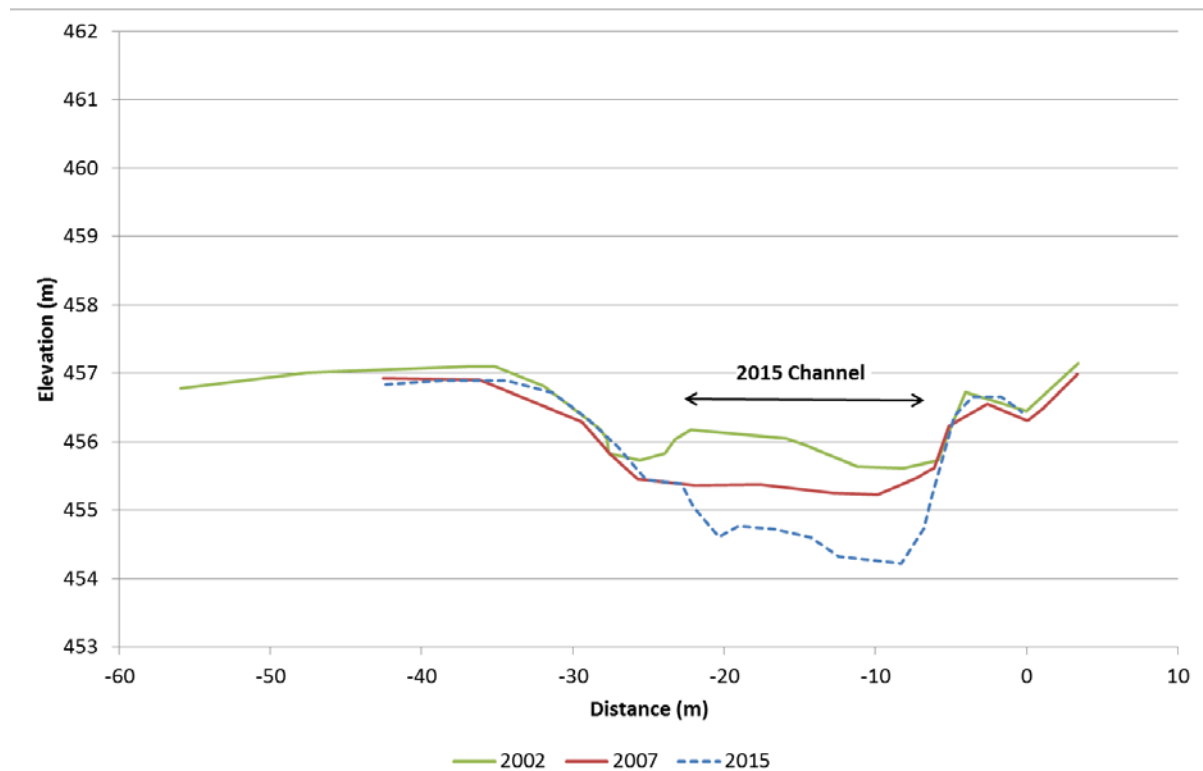


Figure 87. Cardrona River cross-section CR28-1, looking downstream refer to Figure 5 for location



Figure 88. Cardrona River cross-section CR28-1, looking downstream, November 2015

Cross-section CR28-1 is located 10 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has degraded between 2002 and 2015 with minimal change occurring across the wider floodplain.

Cardrona River cross-section CR54-2

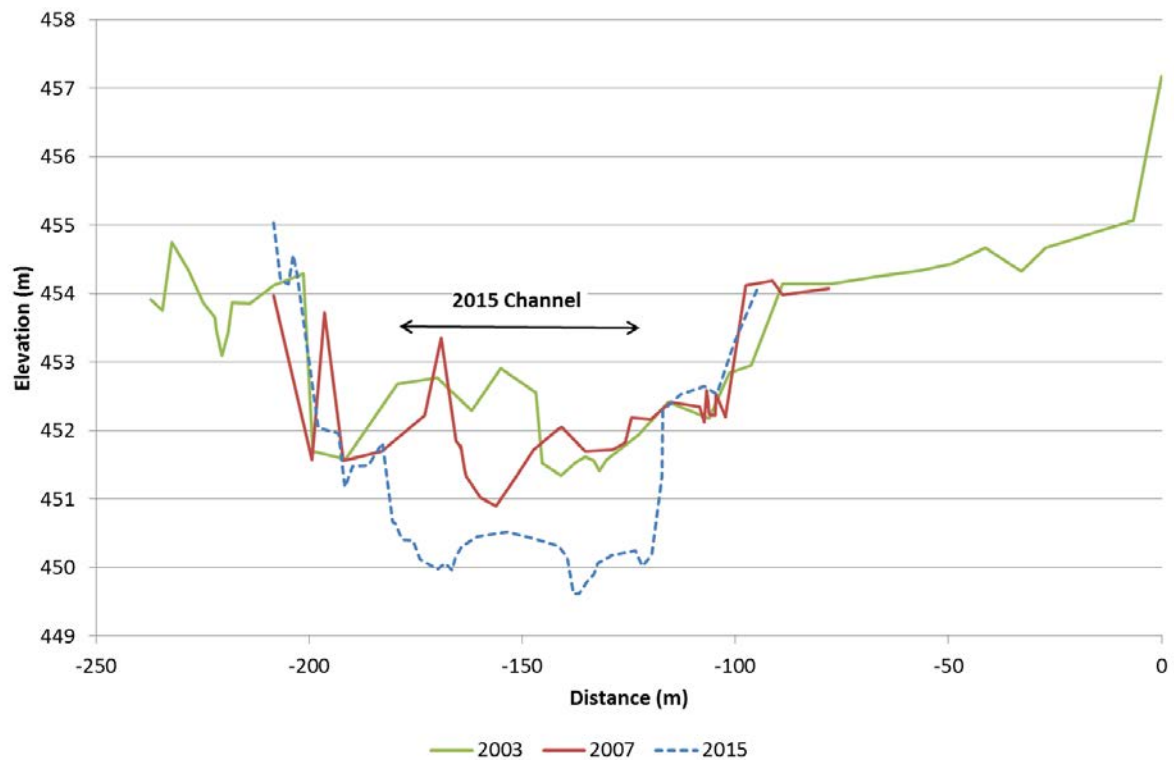


Figure 89. Cardrona River cross-section CR54-2, looking downstream refer to Figure 5 for location



Figure 90. Cardrona River cross-section CR54-2, looking downstream, November 2015

Cross-section CR54-2 is located 9.5 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has degraded between 2007 and 2015 which has created a more confined channel.⁸

⁸ The surveyed cross-sections did not extend sufficiently on the true left and right banks to allow a complete comparison to be made between years.

Cardrona River cross-section CR54-1

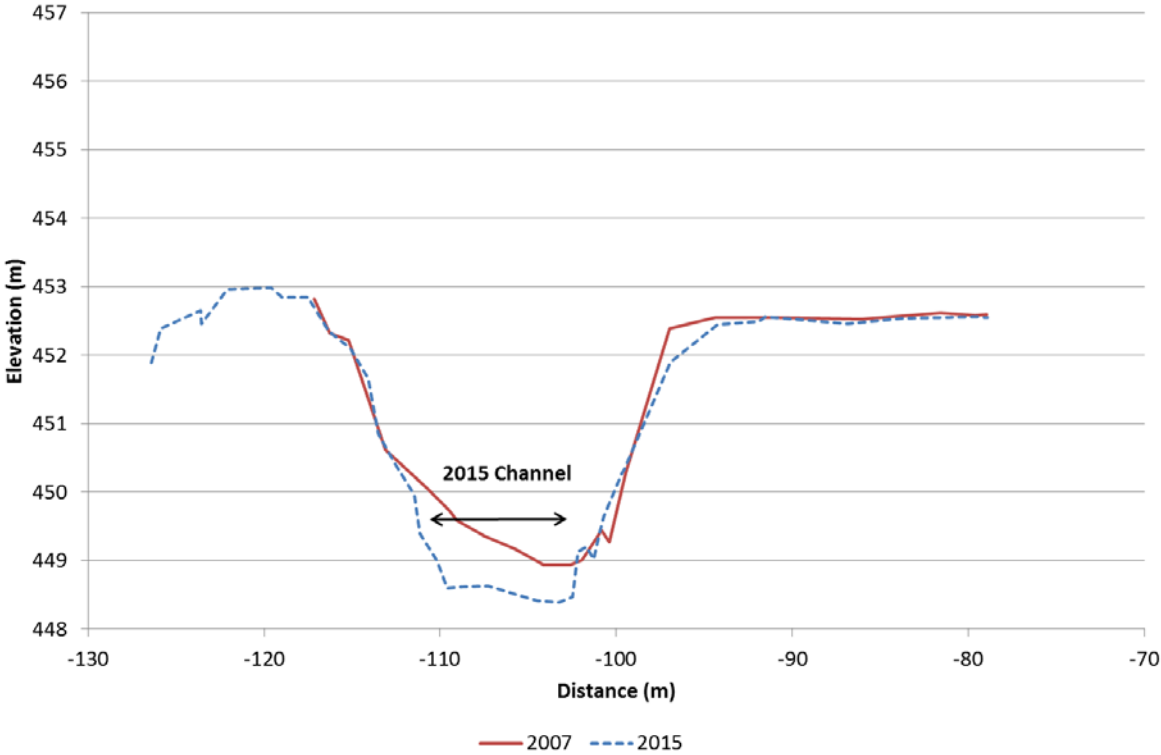


Figure 91. Cardrona River cross-section CR54-1, looking downstream refer to Figure 5 for location



Figure 92. Cardrona River cross-section CR54-1, looking downstream, November 2015

Cross-section CR54-1 is located 9.4 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has degraded between 2007 and 2015 with some degradation occurring on the true right bank floodplain.

Cardrona River cross-section CR30-1

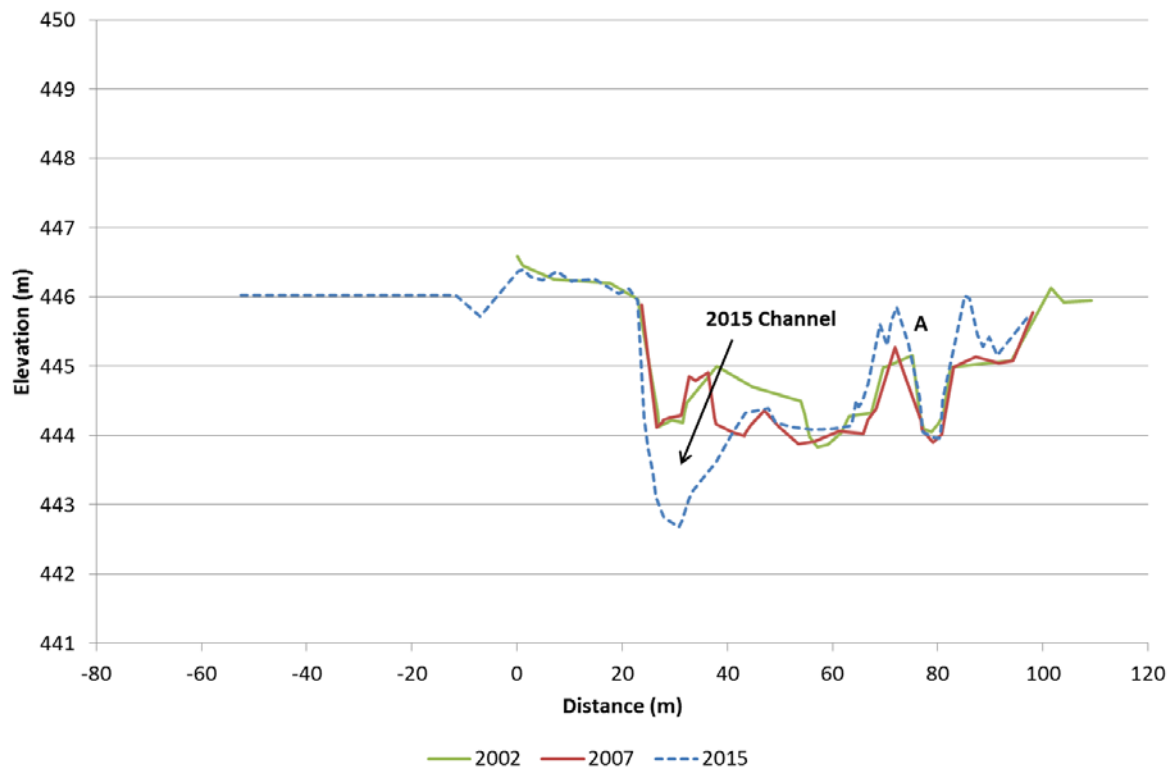


Figure 93. Cardrona River cross-section CR30-1, looking downstream refer to Figure 5 for location



Figure 94. Cardrona River cross-section CR30-1, looking upstream, November 2015

Cross-section CR30-1 is located 8.6 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has shifted to the true left of the active fairway and degraded between 2007 and 2015 creating a more confined channel. The secondary channel at the point labelled A has become more confined between 2007 and 2015.

Cardrona River cross-section CR31-1

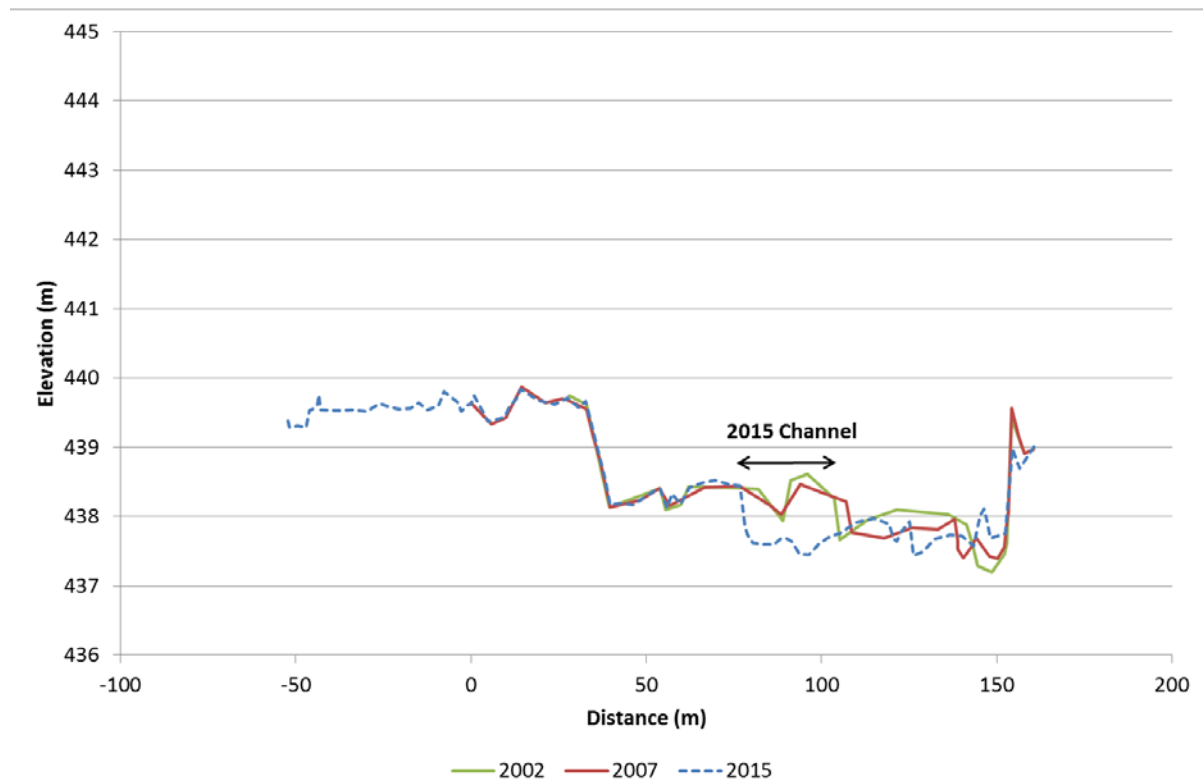


Figure 95. Cardrona River cross-section CR31-1, looking downstream refer to Figure 5 for location



Figure 96. Cardrona River cross-section CR31-1, looking upstream, November 2015

Cross-section CR31-1 is located 7.9 km upstream of the confluence with the Clutha River/Mata-Au. The main channel shifted to the true left of the active fairway between 2007 and 2015, the true right of the active fairway both aggraded and degraded between 2003 and 2015.

Cardrona River cross-section CR36-1

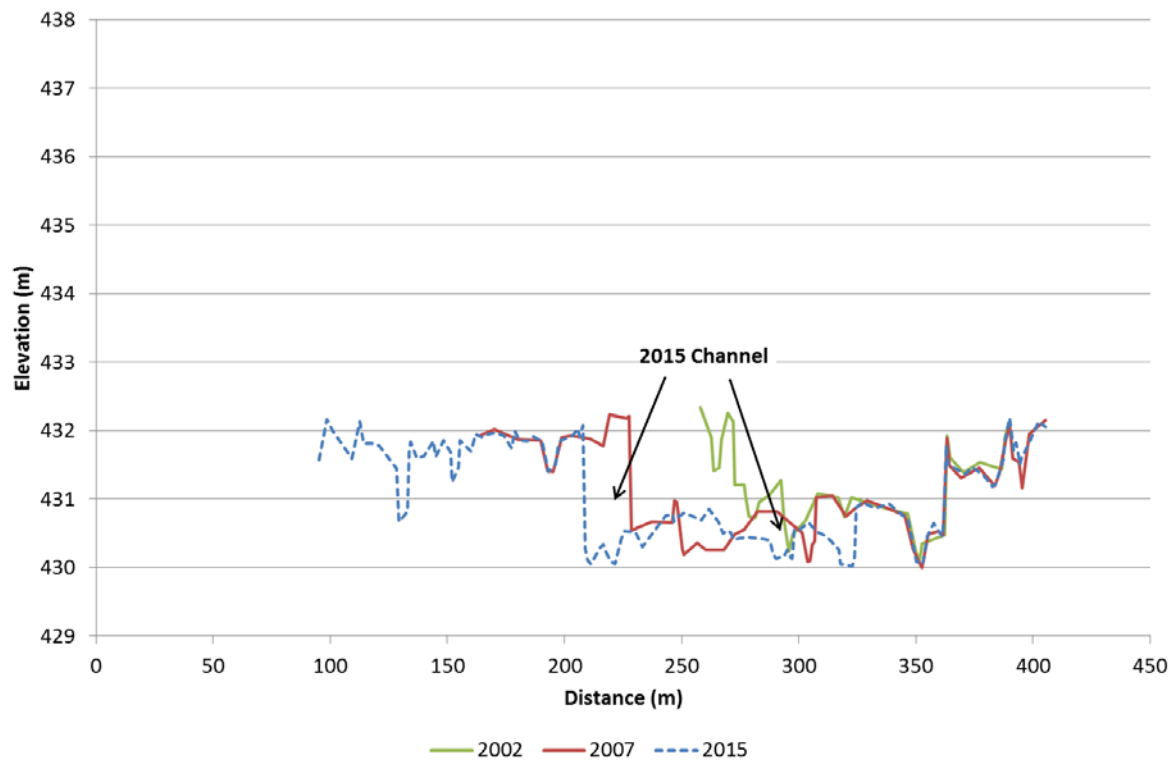


Figure 97. Cardrona River cross-section CR36-1, looking downstream refer to Figure 5 for location

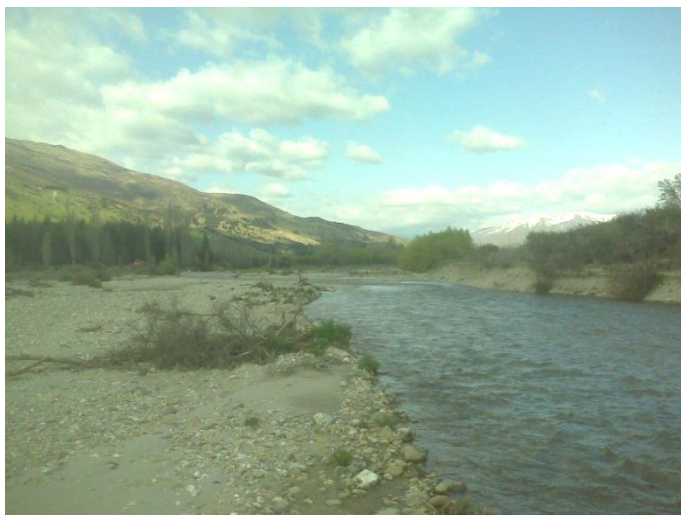


Figure 98. Cardrona River cross-section CR36-1, looking downstream, November 2015

Cross-section CR36-1 is located 7.1 km upstream of the confluence with the Clutha River/Mata-Au. The true left and right banks of the active fairway have continued to erode between 2002 and 2015 creating a wider active fairway. Both aggradation and degradation has occurred between 2007 and 2015 in the active river fairway as the river braids migrate.⁹

⁹ The surveyed cross-sections did not extend sufficiently on the true left bank to allow a complete comparison to be made between years.

Cardrona River cross-section CR39

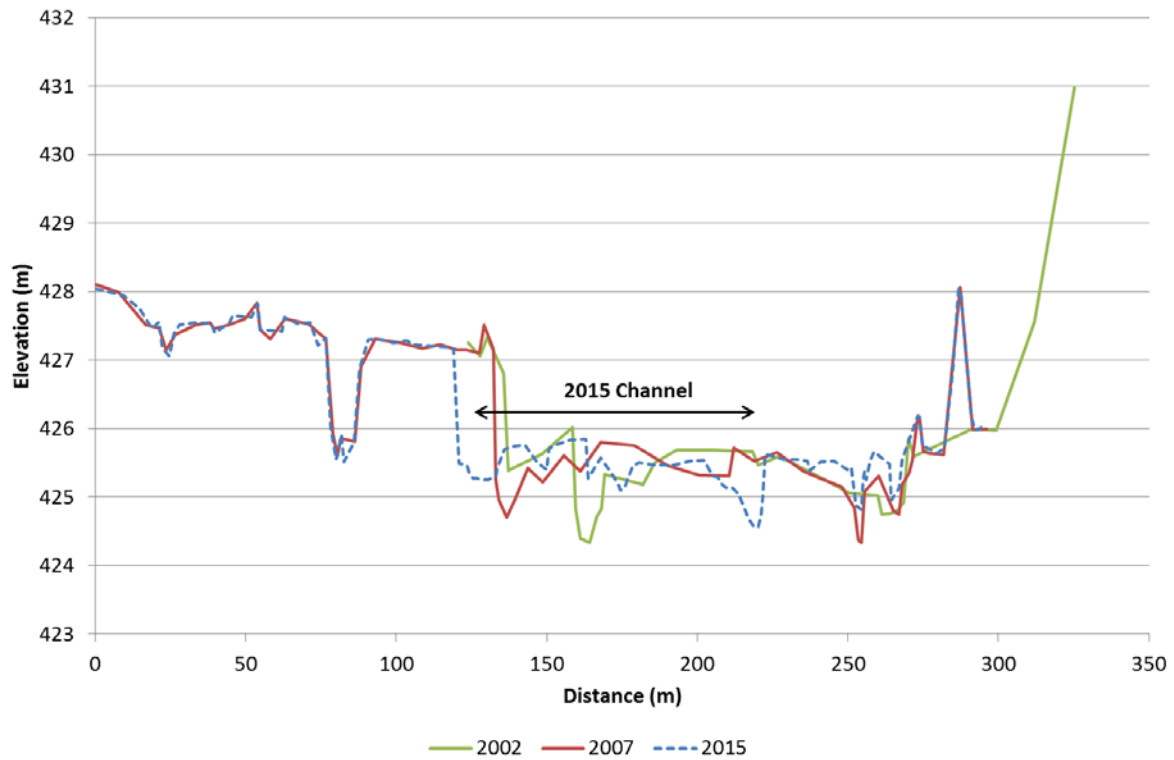


Figure 99. Cardrona River cross-section CR39, looking downstream refer to Figure 5 for location



Figure 100. Cardrona River cross-section CR39, looking upstream, November 2015

Cross-section CR39 is located 6.6 km upstream of the confluence with the Clutha River/Mata-Au. The true left bank of the active fairway has eroded between 2007 and 2015. The active fairway has both aggraded and degraded between 2007 and 2015 as the river braids migrate across the river fairway.

Cardrona River cross-section CR39-1

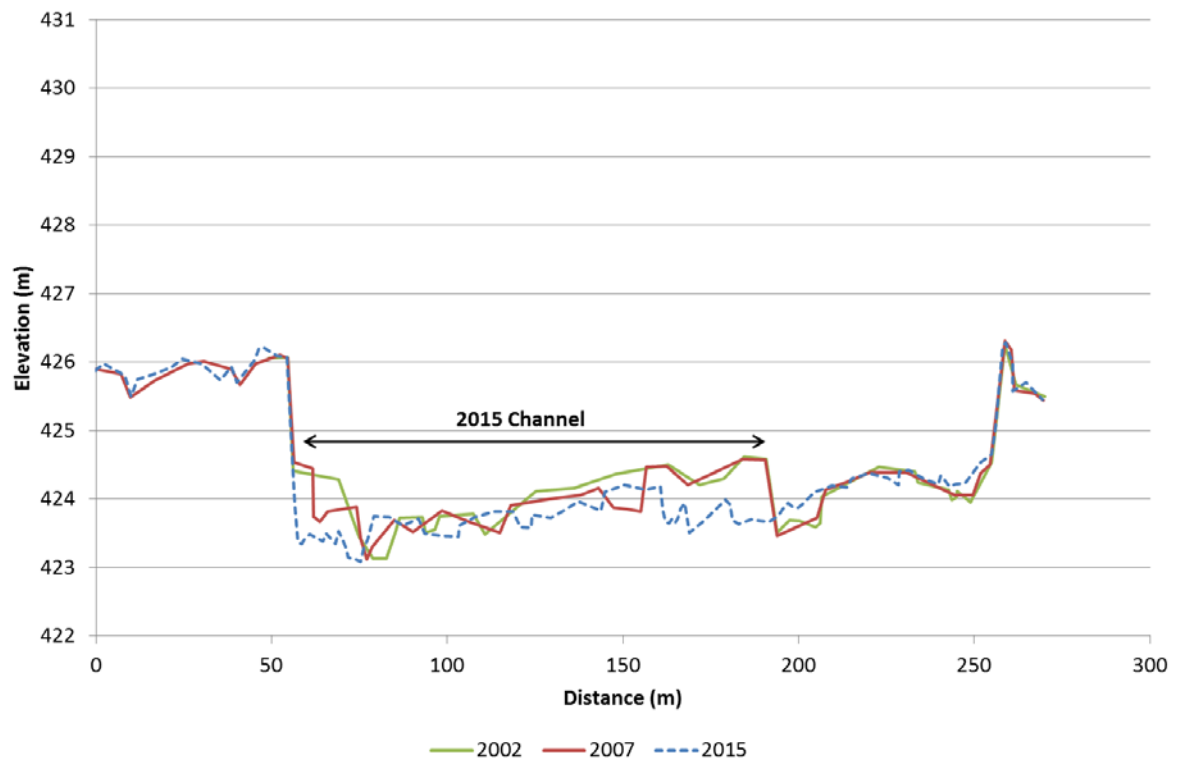


Figure 101. Cardrona River cross-section CR39-1, looking downstream refer to Figure 4 for location



Figure 102. Cardrona River cross-section CR39-1, looking upstream, November 2015

Cross-section CR39-1 is located 6.5 km upstream of the confluence with the Clutha River/Mata-Au. The active fairway has experienced mostly degradation between 2007 and 2015. Erosion of the true left bank of the active fairway has occurred between 2002 and 2015. The wider floodplain has remained similar between 2007 and 2015.

Cardrona River cross-section CR40-1

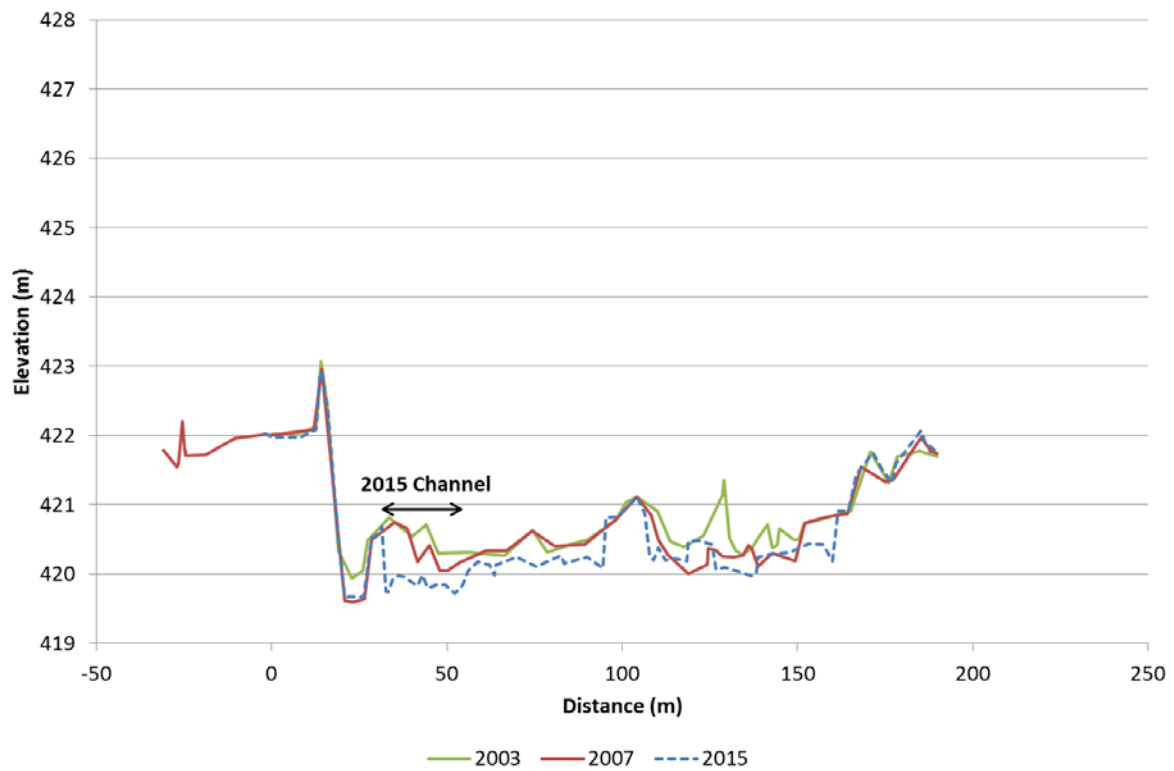


Figure 103. Cardrona River cross-section CR40-1, looking downstream refer to Figure 4 for location



Figure 104. Cardrona River cross-section CR40-1, looking downstream, November 2015

Cross-section CR40-1 is located 6 km upstream of the confluence with the Clutha River/Mata-Au. The active fairway has experienced mostly degradation between 2007 and 2015. There has been minimal change of the wider floodplain between 2007 and 2015.

Cardrona River cross-section CR41

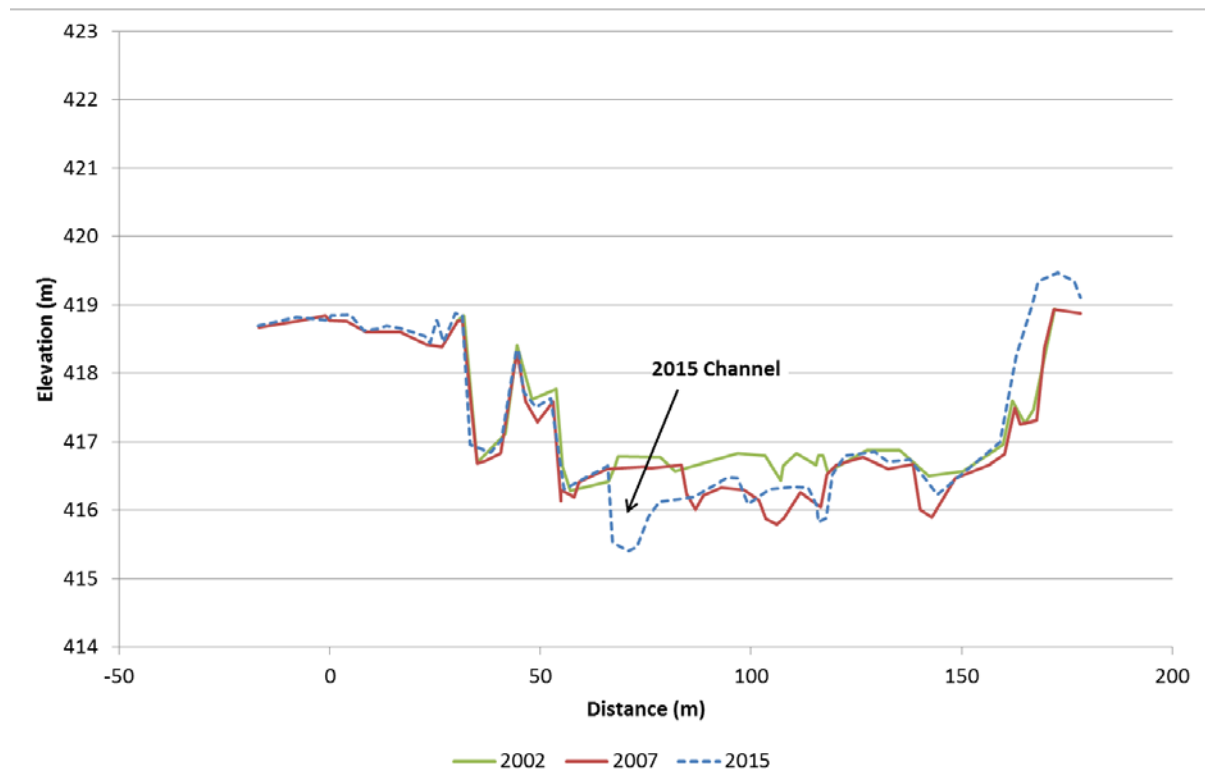


Figure 105. Cardrona River cross-section CR41, looking downstream refer to Figure 4 for location



Figure 106. Cardrona River cross-section CR41, looking upstream, November 2015

Cross-section CR41 is located 5.6 km upstream of the confluence with the Clutha River/Mata-Au. The main channel has switched from the centre of the active fairway in 2007 to the true left side in 2015. The true right bank has experienced aggradation between 2007 and 2015.

Cardrona River cross-section CR42

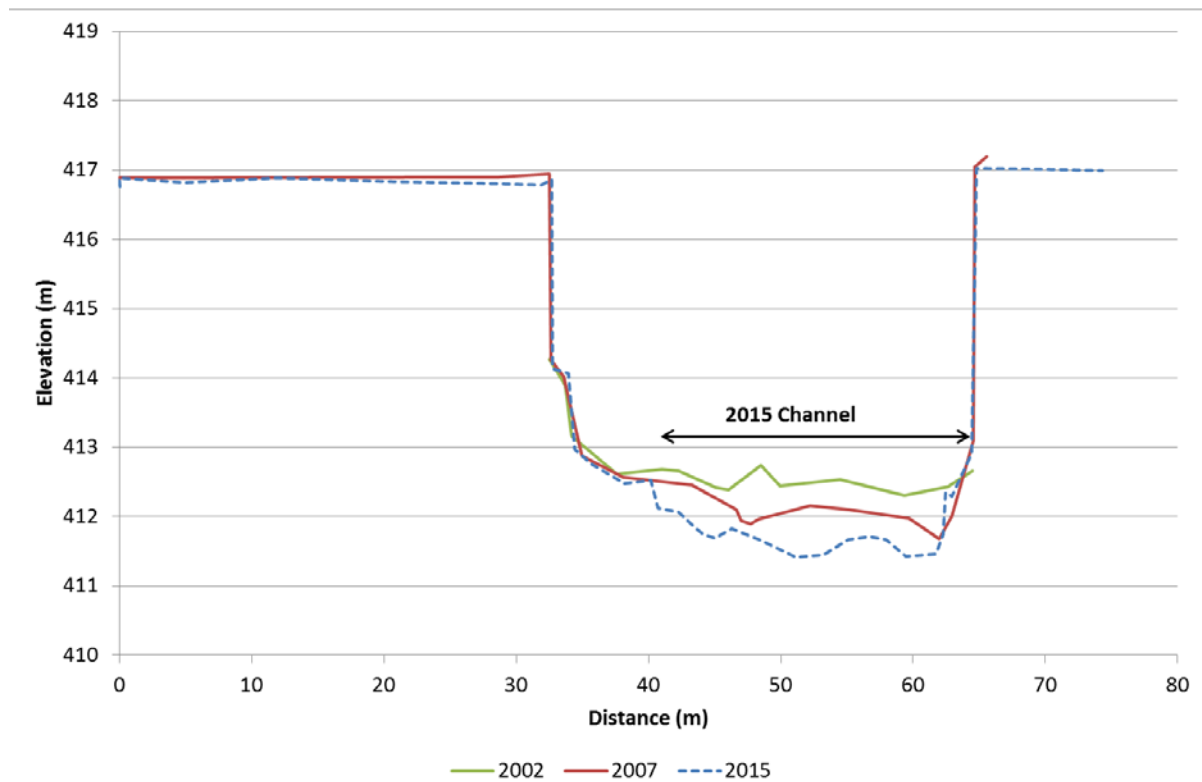


Figure 107. Cardrona River cross-section CR42, looking downstream refer to Figure 4 for location



Figure 108. Cardrona River cross-section, looking upstream, November 2015

Cross-section CR42 is located 5.1 km upstream of the confluence with the Clutha River/Mata-Au at the Ballantyne Road bridge. The active channel at this location is confined by the presence of the bridge and has continued to degrade between 2002 and 2015.

Cardrona River cross-section CR44

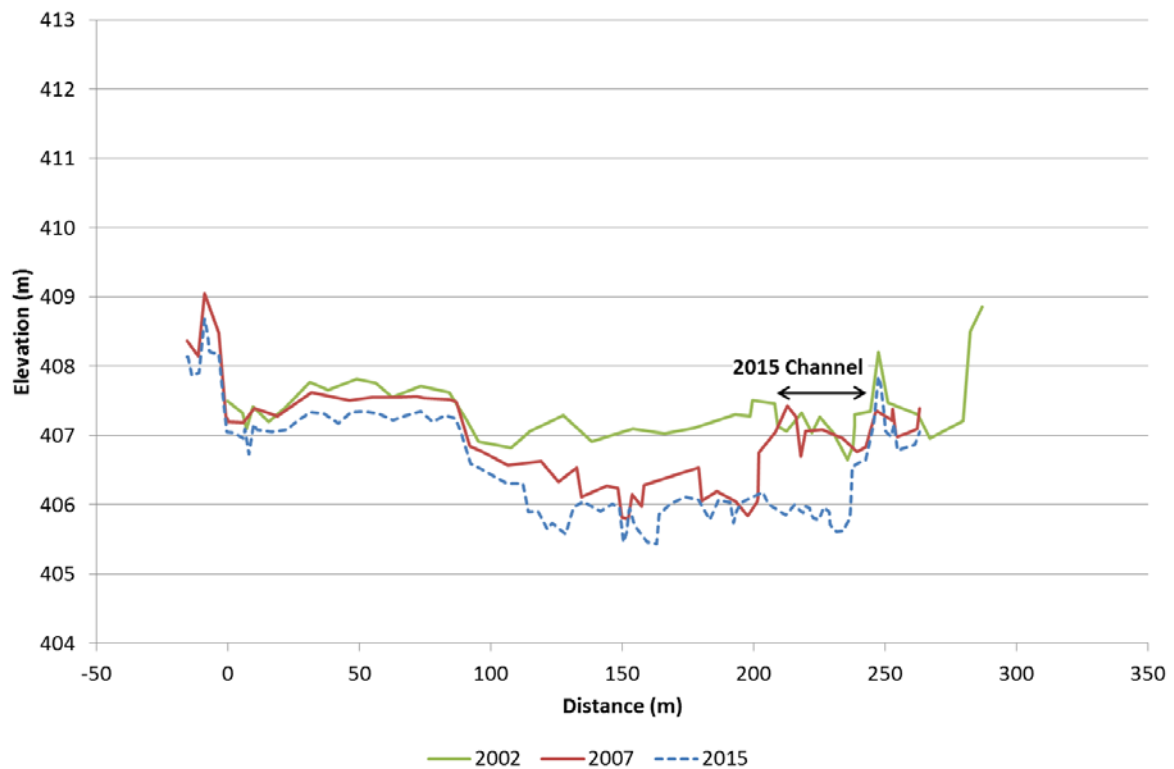


Figure 109. Cardrona River cross-section CR44, looking downstream refer to Figure 4 for location



Figure 110. Cardrona River cross-section CR44, looking downstream, November 2015

Cross-section CR44 is located 4.3 km upstream of the confluence with the Clutha River/Mata-Au. The active fairway has degraded between 2002 and 2015. Degradation of the true left bank floodplain has occurred between 2002 and 2015.

Cardrona River cross-section CR44-1

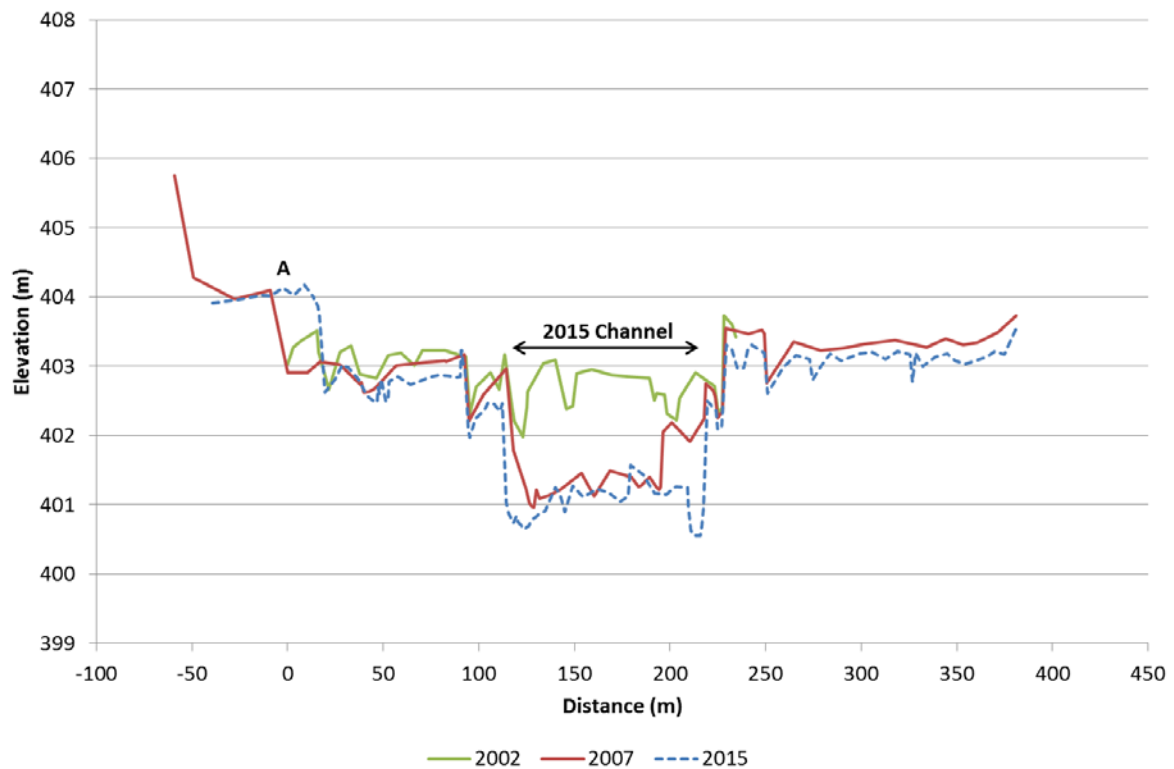


Figure 111. Cardrona River cross-section CR44-1, looking downstream refer to Figure 4 for location



Figure 112. Cardrona River cross-section CR44-1, looking downstream, November 2015

Cross-section CR44-1 is located 3.8 km upstream of the confluence with the Clutha River/Mata-Au. The active fairway and the true left and right bank floodplain have degraded between 2007 and 2015. The true left bank terrace has aggraded (at the point labelled A).

Cardrona River cross-section CR46

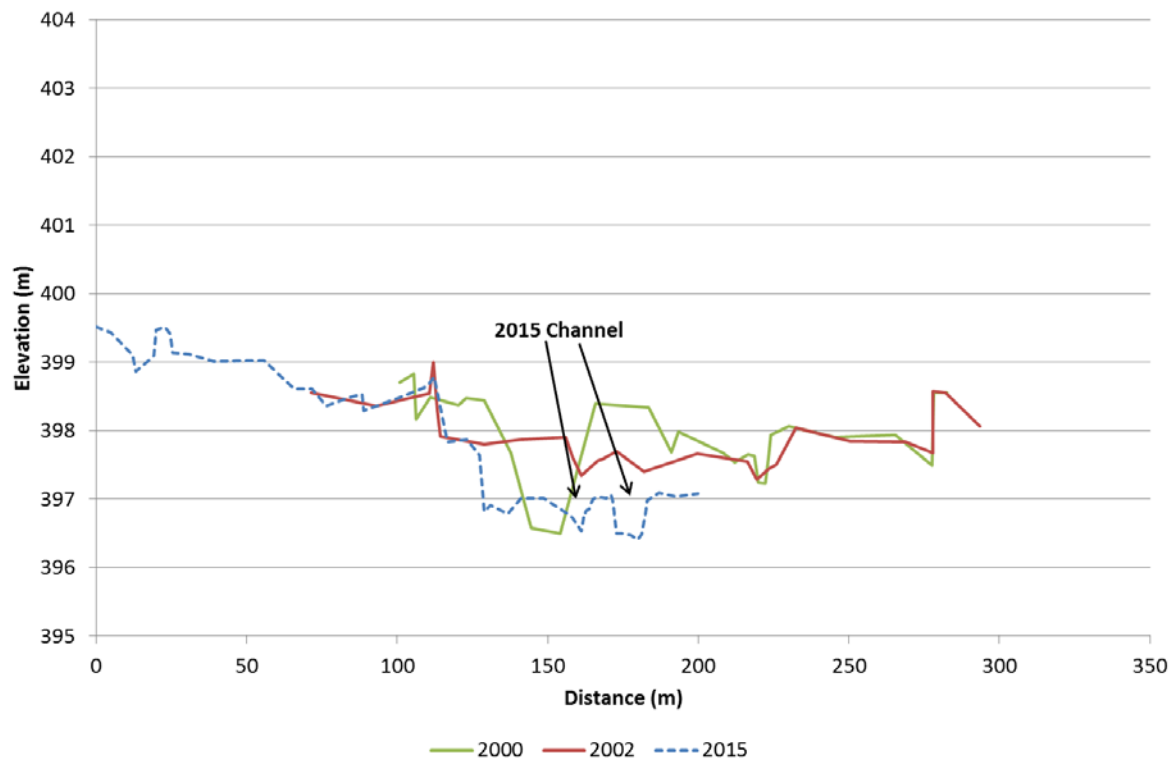


Figure 113. Cardrona River cross-section CR46, looking downstream refer to Figure 4 for location



Figure 114. Cardrona River cross-section CR46, looking upstream, November 2015

Cross-section CR46 is located 3.3 km upstream of the confluence with the Clutha River/Mata-Au. The active fairway has degraded between 2002 and 2015. The 2015 survey does not extend sufficiently onto the true right floodplain to allow a comparison to be made.

Cardrona River cross-section CR46-1

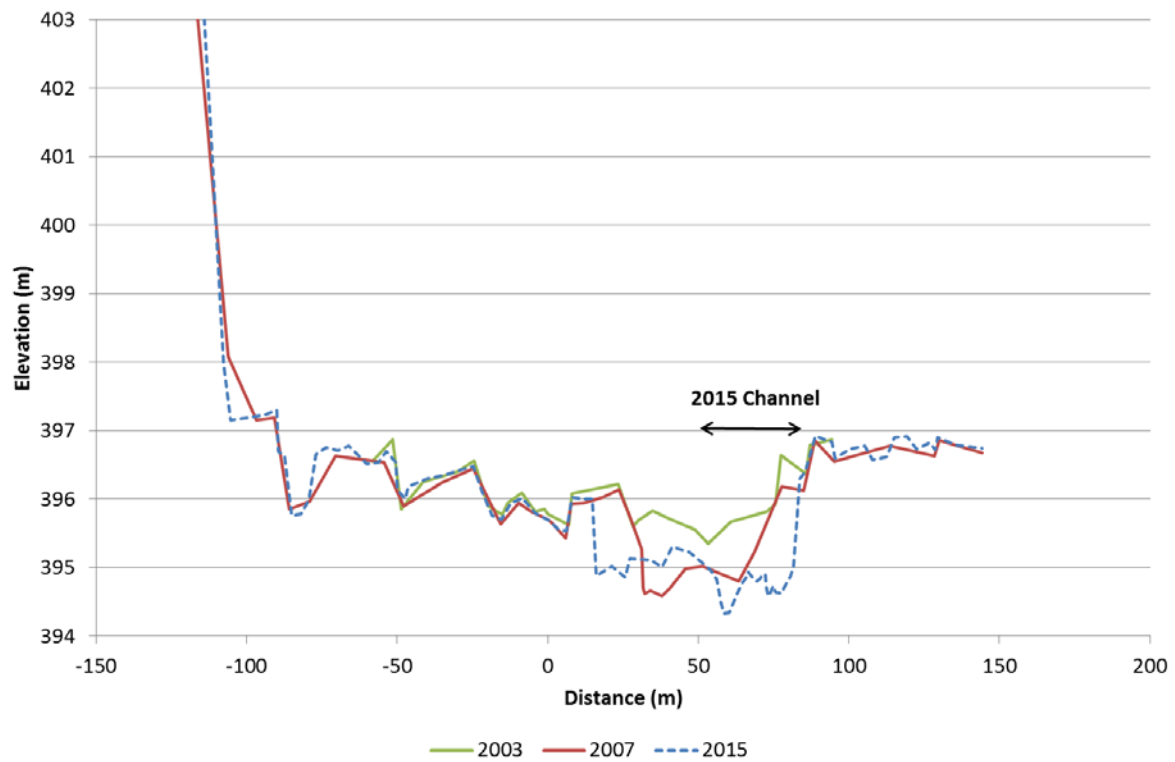


Figure 115. Cardrona River cross-section CR46-1, looking downstream refer to Figure 4 for location



Figure 116. Cardrona River cross-section CR46-1, looking upstream, November 2015

Cross-section CR46-1 is located 3 km upstream of the confluence with the Clutha River/Mata-Au. Between 2007 and 2015 the active fairway has both aggraded and degraded with erosion occurring on the true left and right banks. The wider floodplain has remained similar between 2007 and 2015.

Cardrona River cross-section CR47-1

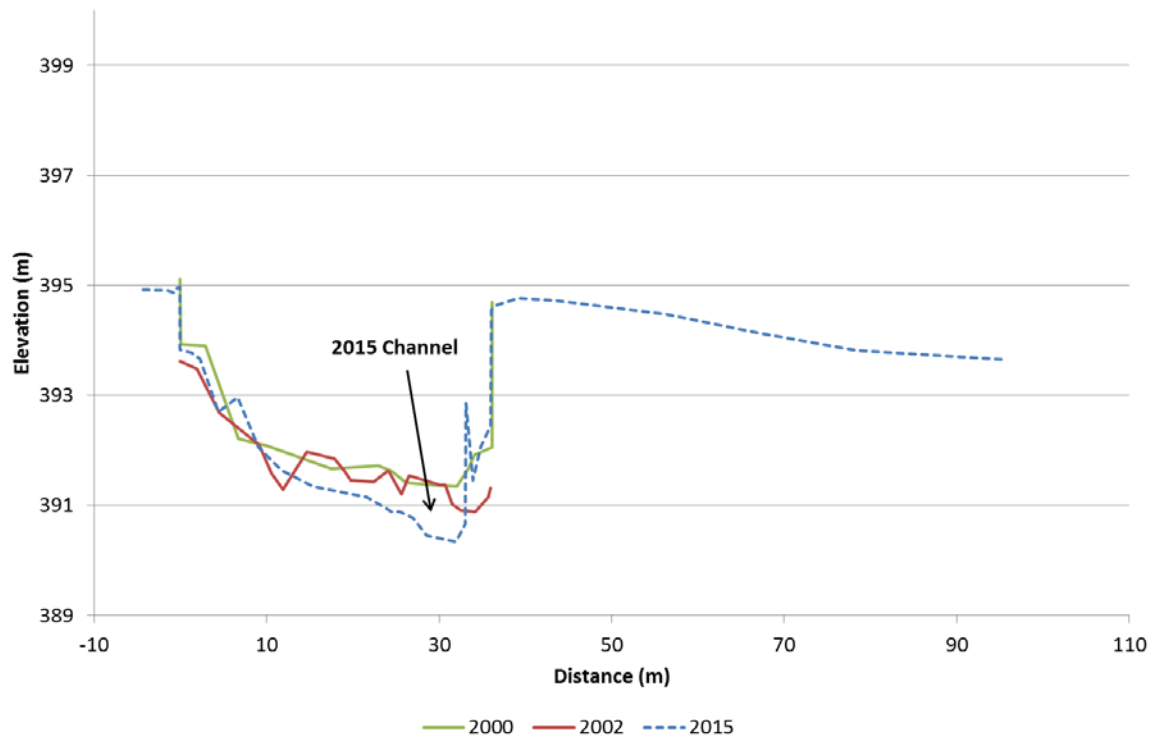


Figure 117. Cardrona River cross-section CR47-1, looking downstream refer to Figure 4 for location



Figure 118. Cardrona River cross-section CR47-1, looking upstream, November 2015

Cross-section CR47-1 is located 2.5 km upstream of the confluence with the Clutha River/Mata-Au at the SH6 bridge. This cross-section was not surveyed in 2007. Between 2000 and 2015 the main channel has degraded creating a more confined river channel.

Cardrona River cross-section CR48-1

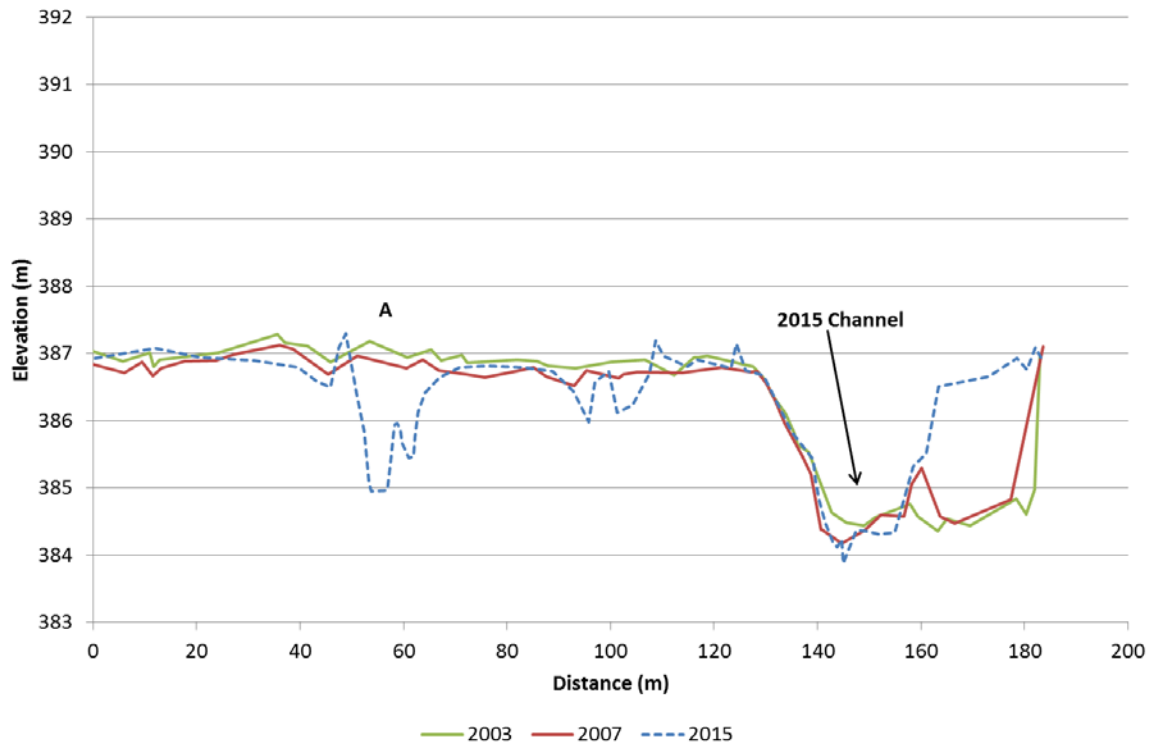


Figure 119. Cardrona River cross-section CR48-1, looking downstream refer to Figure 4 for location



Figure 120. Cardrona River cross-section CR48-1, looking upstream, November 2015

Cross-section CR48-1 is located 1.7 km upstream of the confluence with the Clutha River/Mata-Au. The main channel in 2015 has remained in a similar position to 2007; there has been a large quantity of aggradation of the true right bank between 2007 and 2015. A new channel that has formed on the true left floodplain (at the point labelled A) is associated with a new industrial development.

Cardrona River cross-section CRMWD1

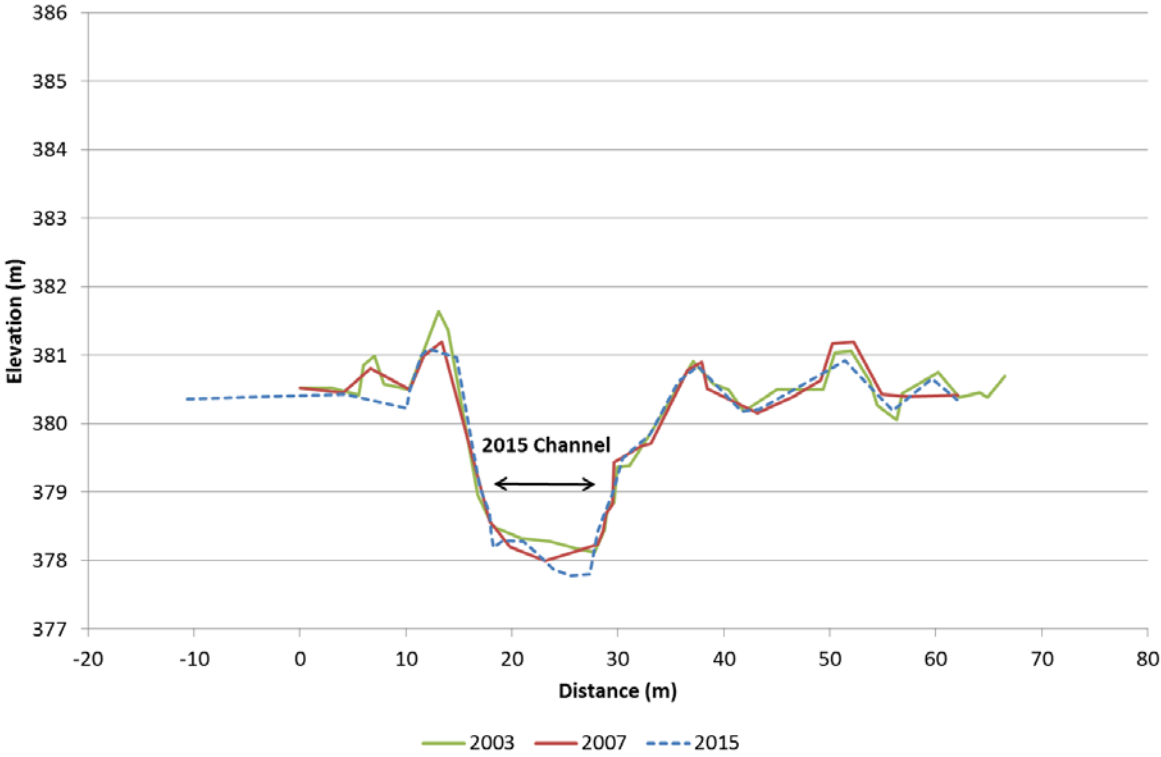


Figure 121. Cardrona River cross-section CRMWD1, looking downstream refer to Figure 4 for location

Cross-section CRMWD1 is located 0.9 km upstream of the confluence with the Clutha River/Mata-Au. Between 2007 and 2015 the main channel has degraded while the wider floodplain has remained similar.

Cardrona River cross-section CR52-1

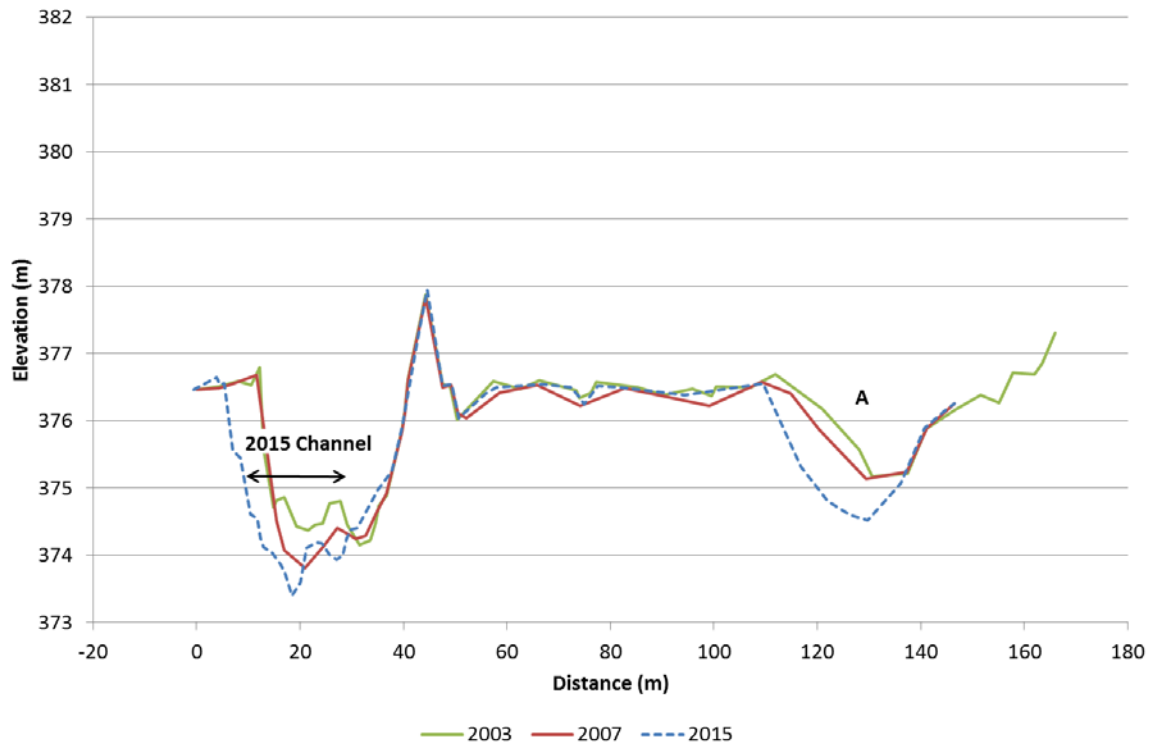


Figure 122. Cardrona River cross-section CR52-1, looking downstream refer to Figure 4 for location



Figure 123. Cardrona River cross-section CR52-1, looking upstream, November 2015

Cross-section CR52-1 is located 0.2 km upstream of the confluence with the Clutha River/Mata-Au. Between 2007 and 2015 the true left bank eroded with degradation occurring in the main channel. A secondary channel (at the point labelled A) degraded between 2007 and 2015.

Background

ORC has collected cross-section survey information on the Cardrona River from the upper reaches and the confluence with the Clutha River/Mata-Au (Figure 4 to Figure 8). The monitoring programme dates back to 1988, 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 2007. Although changes before this time are described more fully in ORC (2010), 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:

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

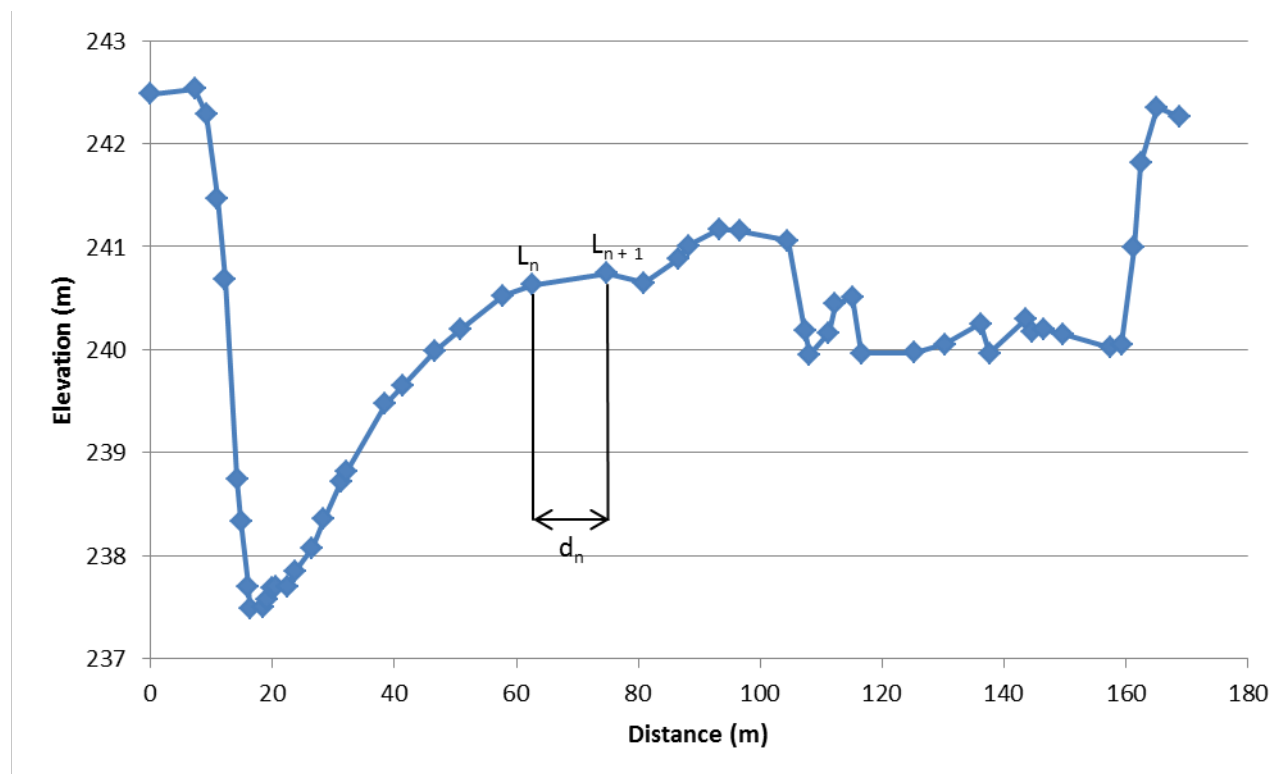


Figure 124. MBL calculation - definition of variables

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.

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 slope. This method has limitations 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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