Channel morphology and sedimentation in the Kakanui and Kauru Rivers, North Otago

October 2010

Foreword

Understanding the channel morphology and sedimentation characteristics of Otago's rivers enables their effective management. Increasing growth throughout the Otago region has implications for management of river systems, primarily with regard to the extraction of gravel and the effect on flood hazard.

The Otago Regional Council (ORC) undertakes scheduled cross-section surveys of selected rivers as part of the natural hazards programme. This information is utilised to understand the dynamic fluvial processes of each river and general state of the gravel resource.

This report explores how the morphology and sedimentation of the Kakanui River and one of its tributaries, the Kauru River, has changed over the surveyed periods, while providing a synthesis of the study's results to guide river management into the future.

Executive summary

An analysis of channel morphology and sedimentation in surveyed reaches of the Kakanui River and Kauru River has been undertaken using aerial photography, cross-section surveys and relevant documentation. This information can be used to support assessment of community vulnerability and river management.

The Kakanui River has a catchment area of 894km^2 and is located in North Otago. The main tributaries of the Kakanui River are Kauru River, Island Stream, and Waiareka Creek. The Kauru River has a catchment area of 143km^2 and is an important tributary of the Kakanui River as a source of water and gravel to the main catchment.

Gravel extraction is focused on the Kakanui River, between the Kauru River confluence and Gemmells Crossing, and in the lower reaches of the Kauru River. Gravel in these rivers has historically been a viable commercial resource and consented gravel extraction has occurred to utilise this resource and also, in some instances, as a river management tool for maintaining channel capacity. Gravel extraction activities and past flood events have notably contributed to both localised erosion and aggradation in both rivers. River management techniques in both rivers have included channel re-alignment and willow planting where bank erosion has impacted on adjacent land.

At present, the Kakanui River changes between a single-thread meandering form and a braided form. Aerial photograph analysis of the Kakanui River (dating back to 1955) shows that the river has shifted within its banks in some reaches with small changes to the meander pattern in other reaches. The bed of the river has lowered overall, and steepened in some sections. Change in the mean bed level of the cross-section sites ranges from 1m of degradation to 1.2m aggradation; 15 of the 24 cross-section sites have experienced net degradation while seven of the 24 sites have experienced net aggradation.

Aerial photograph analysis of the Kauru River (between 1955 and 2006) has revealed some changes to the channel location as a result of natural migration of the semi-braided river system, as well as greater exposure of gravel in the channel below Kininmont Ford due to a previous period of intensive gravel extraction activities. The bed profile has slightly steepened with more significant bed lowering occurring in the lowermost reach of the river. Change in the mean bed level of some parts of the cross-section lines ranges from 1m degradation to 0.35m aggradation. In the last survey period (2005 to 2008), some sites that were previously degrading have experienced small amounts of aggradation.

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1 Introduction

This document provides a background into morphological change and sedimentation in the Kakanui River Catchment and the Kauru River Catchment, North Otago. Aerial photography, cross-section analyses and anecdotal information is collated and interpreted, to provide a comprehensive review of change over surveyed periods. This information can be used to support assessment of community vulnerability and river management.

In 2005, a similar report was written for the Kauru River entitled "Kauru River Gravel Resource Assessment", which analysed cross-section surveys from 1978 to 2001 in the broader context of gravel management. There have been no similar reports relating to the Kakanui River published by the ORC. The 2005 Kauru River report is superseded by this report which includes further bed level analysis utilising the latest 2009 survey results, as well as a more extensive desktop investigation into the nature and dynamics of the Kakanui and Kauru River systems.

The most recent cross-section surveys were undertaken on the Kakanui River and Kauru River in the same period. As the Kauru River is a major tributary of the Kakanui, and contributes a significant proportion of sediment to the Kakanui system, the analysis of channel morphology and sedimentation trends, following completion of the latest cross-section surveys, have been synthesised into this report.

2 Catchment description

The Kakanui River Catchment has an area of 894km^2 and is bound in the south and west by the Kakanui Mountains and Pisgah Spur; Mt Pisgah is the highest point of this catchment with an elevation of 1634m (Figure 2.1). In the north, the catchment is separated from the Waitaki catchment by rolling hill country. The main tributaries of Kakanui River are the Kauru River (catchment size of 143km^2), Island Stream (122km^2), and Waiareka Creek (213km^2).

The Kauru River catchment comprises 16% of the total catchment area of the Kakanui River. The Kauru River lies between the catchment of the main branch of the Kakanui and Island Stream catchment and is bound in the south by the Kakanui Mountains (Figure 2.1). Hector's Stream is the main tributary of the Kauru River and the catchment rises to an elevation of 1286m at Siberia Hill.

Initial settlement in the Kakanui Catchment (including Kauru River Catchment) began in the 1850s when pastoral runs were made available on a "licence to occupy" basis (ORC, 1991). Kakanui basin developed quickly due to the highly fertile soils and transport links to Dunedin and the Central Otago goldfields, and in the 1890s farming became more intensive as estates were subdivided into farms. Today the Kakanui downlands, which includes the lower Kauru River, continue to be intensively farmed and small forestry plantations have been established on areas less suited to other uses. Crop cultivation occurs on the gentler slopes with deeper topsoils and horticulture (market gardens) is especially prominent in the Totara district.

Both the Kakanui River and Kauru River have a long history of flooding and the known record of flood events extends back to 1868 when flooding in the Kakanui and Waiareka catchments caused widespread damage and loss of life (ORC, 1991). Over 50 significant floods of the Kakanui River have been recorded between 1868 and 1987 including June 1968, June 1980, and March 1986 (OCB, 1987). Recent significant flood events occurred in December 1993, July 1995, April 2006, July 2007 and May 2010. The distribution of rainfall in the catchment as well as the occurrence of localised thunderstorms has, in the past, caused varying degrees of flooding across the relatively small spatial extent of the catchment.

Channel improvement works and the construction of flood banks have occurred in the Kakanui River Catchment (OCB, 1988). The channel improvement works have included willow spraying and clearing, closing off secondary flow paths, and excavation and training of channels. Works in the Island Stream catchment have been limited to willow clearing but some realignment works were carried out in the upper catchment in the late 1970s.

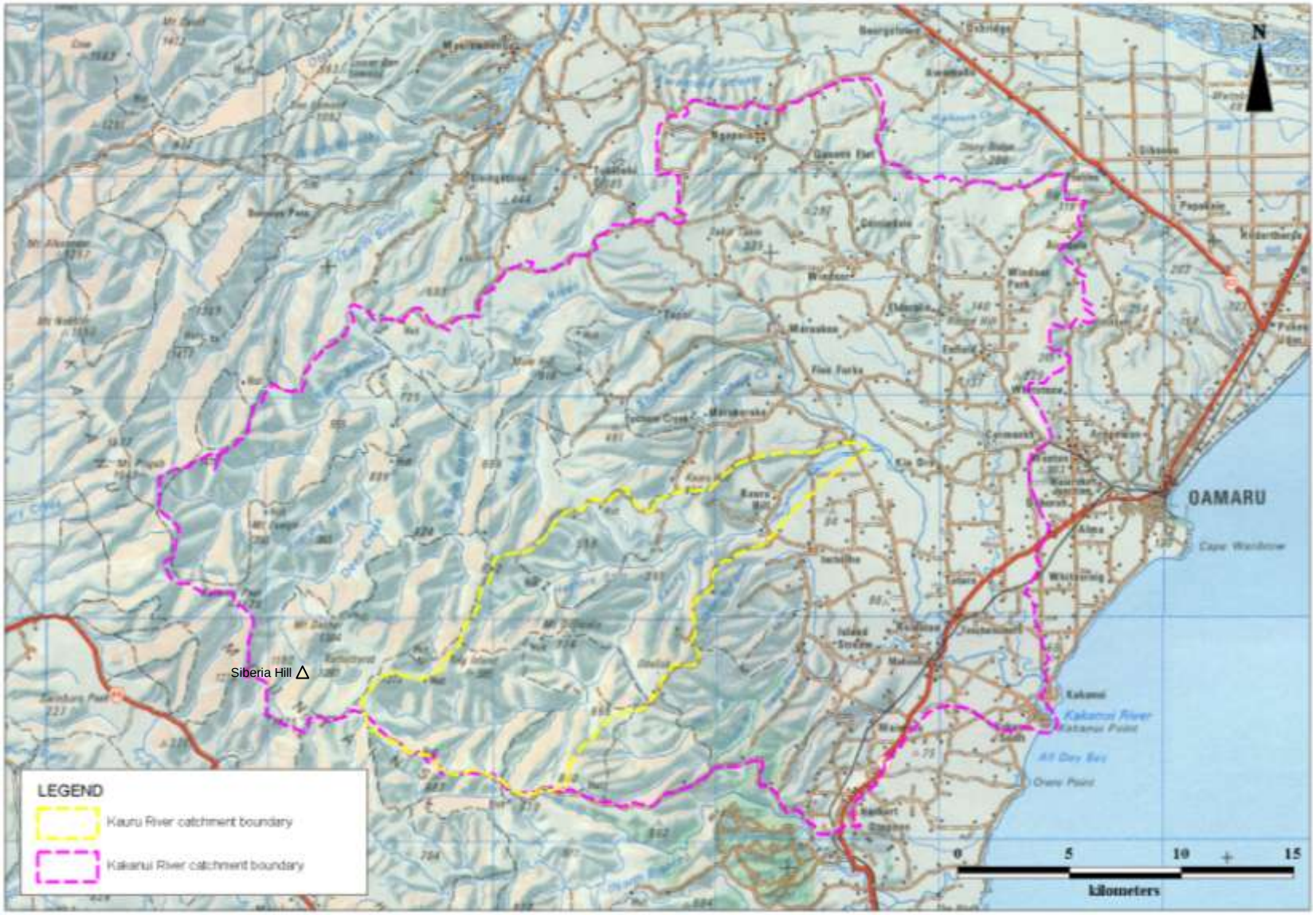

Figure 2.1 Kakanui River and Kauru River Catchment locality map.

2.1 Geology

The geology of the entire Kakanui Catchment varies from the mountainous region of the upper catchment to the downlands and floodplains of the watercourses in this catchment. The mountainous terrain in the upper Kakanui, Kauru and Island Stream catchments comprises varying grades of quartzofeldspathic sandstone interbedded with mudstone (greywacke) and semi-schist, plus non-marine sedimentary rock (Forsyth, 2001). Deborah Volcanics and the younger Dunedin Volcanic Group basalts cap the peaks of the Kakanui Mountains. Rock strength decreases with weathering in the sedimentary and volcanic rock, and stronger foliation in the schistose sandstone will also reduce rock strength. This weathered material is delivered to the channel of the river through mass movement on exposed scarps (Figure 2.2).

The rolling hill country and downlands of the Kakanui Catchment (including the entire Waiareka River catchment) comprises marine sedimentary rock as well as the Deborah Volcanics at higher elevations (Forsyth, 2001).

The historic and present floodplains of the Kakanui River and its tributaries comprise Pleistocene weathered gravel and sand in alluvial terraces with loess cover (Forsyth, 2001). The current floodplain areas comprise recent transported gravels from the upper reaches of the rivers as well as reworked alluvium from the banks.

Figure 2.2 An upper catchment hillside showing exposed, mobile weathered material above the incised river channel. Taken January 2008

2.2 Geomorphology

2.2.1 Geomorphological description

The upper reaches of the Kakanui River catchment (west of Five Forks, Kauru Hill and Island Stream settlements) are mountainous, rising to a peak elevation of 1643m at Mt Pisgah. River channels are single threaded and meandering, passing through native and indigenous forest and tussock land.

The lower reaches of the catchment comprise rolling hill country and floodplain, where gentler gradients result in localised braiding and lateral migration of river channels and active transport and deposition of sediment. Between Five Forks and the coast, the main channel of the Kakanui River and the lower reaches of the Kauru River follow a meandering path through old river terraces. Gravel deposition is common in the lower reaches of Kauru River and between its confluence and Gemmells Crossing on the Kakanui River, particularly during flood events.

Between the Kauru River confluence and Maheno the river has a history of breaking out of the main channel and crossing farmland. River breakout during flood events has also occurred in the lower reaches of the Kauru River. The channel gradient of the Kakanui is approximately 1:400 upstream of Maheno and 1:800 downstream. Kauru River has a relatively steep gradient for this catchment and in the lower reaches the river flows in a fairly direct path through the floodplain at a gradient of 1:150. Island Stream and Waiareka Creek have relatively flat gradients; ponding is a common result of flooding particularly on the Waiareka Creek floodplain (OCB, 1987).

The upper Kauru catchment consists of an incised gorge up to 300m deep with steep convex slopes above the gorge (Figure 2.3A). This geomorphological form is representative of the mountainous, upper reaches of the Kakanui Catchment. The gorge slopes are very steep at low elevations and decrease in gradient with increasing altitude. The hillslope form is controlled by the presence of a cap-rock resistant to weathering (volcanics) on the mountain summits above an altitude of approximately 620m, together with the high angle of foliation of the schist on the lower slopes.

The lower catchment of Kauru River is a terraced alluvial fan with its apex at the mouth of the gorge leading to the confluence with Kakanui River (Figure 2.3B). The lower Kauru alluvial fan has several terraces with scarps of between 2 and 15m.

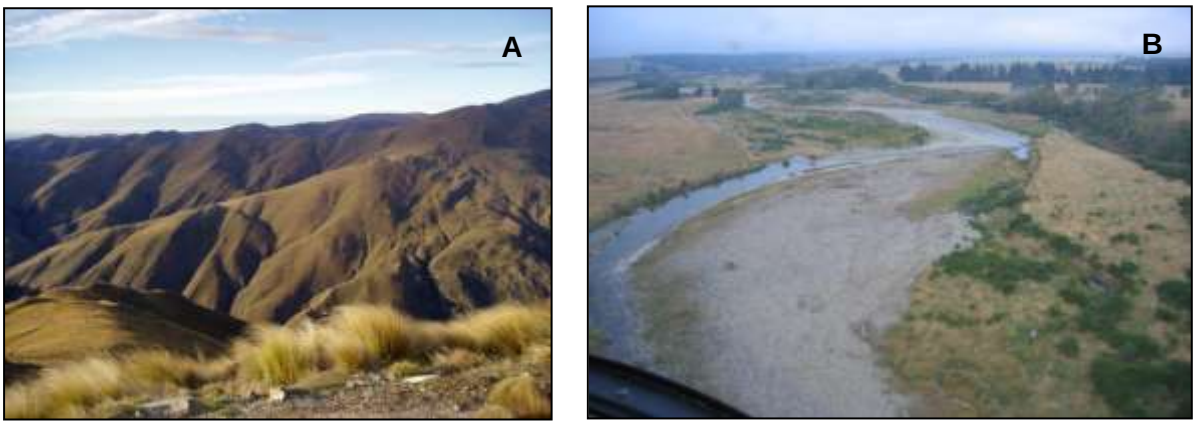

Figure 2.3 Examples of the geomorphology of the upper (A) and lower (B) catchment

2.2.2 Aerial photograph analysis of river morphology

Analysis of aerial photographs dating back to 1955 has illustrated some morphological change in the Kakanui River system over time (Figure 2.4 A-E).

From the river mouth up to Reidston (refer Figure 2.1) the Kakanui River is a single-thread channel with a few localised point and lateral bars[1] on both sides of the river (Figure 2.4A and 2.4B). Some of the bars have reduced in size or migrated slightly over the past decades.

Between Reidston and approximately 3km upstream of Gemmells Crossing the river becomes semi-braided (Figure 2.4B to Figure 2.4D). There is evidence of more significant morphological change in this reach of the river with the channel migrating laterally between its banks in some locations, and change in the gravel islands and bars over time. In some locations, braids have become cut off and previously exposed gravel is now vegetated. Upstream of Gemmells Crossing, the river has straightened between its banks and the sinuosity of the channel has reduced.

Between Gemmells Crossing and the Kauru River confluence the channel widens with more gravel deposited in the channel of this reach (Figure 2.4D). The river is braided in some parts and, over time, the channel has migrated laterally over the channel between its banks. The river has reduced in sinuosity since earliest aerial photographs. The mouth of the Kauru River has widened on the true right causing a change in morphology at the confluence.

Upstream of the confluence the channel narrows and the amount of gravel deposited in this reach is less (Figure 2.4E). Some localised morphological change has occurred in this reach with relatively small amounts of aggradation and degradation of some bars. The meanders of this reach appear to have migrated slightly over time.

[1] Point and lateral bars are accumulations of sediment within the active channel margins of a river. Point bars are formed on the convex side of channel meanders by the lateral accretion of sediment. Conversely, lateral bars are formed by the accumulation of sediment as the river shifts laterally within the active channel margin. Observations of the spatial distribution of these features can provide insight into the dynamics of the river's sediment supply.

Figure 2.4A Aerial photographs of Kakanui River in 1955, 1996 and 2006 from the river mouth upstream approximately 7km

Figure 2.4B Aerial photographs of Kakanui River in 1955, 1996 and 2006 between 7 and 12km upstream of the river mouth

Figure 2.4C Aerial photographs of Kakanui River in 1955, 1996 and 2006 from 12 to 19km upstream of the river mouth.

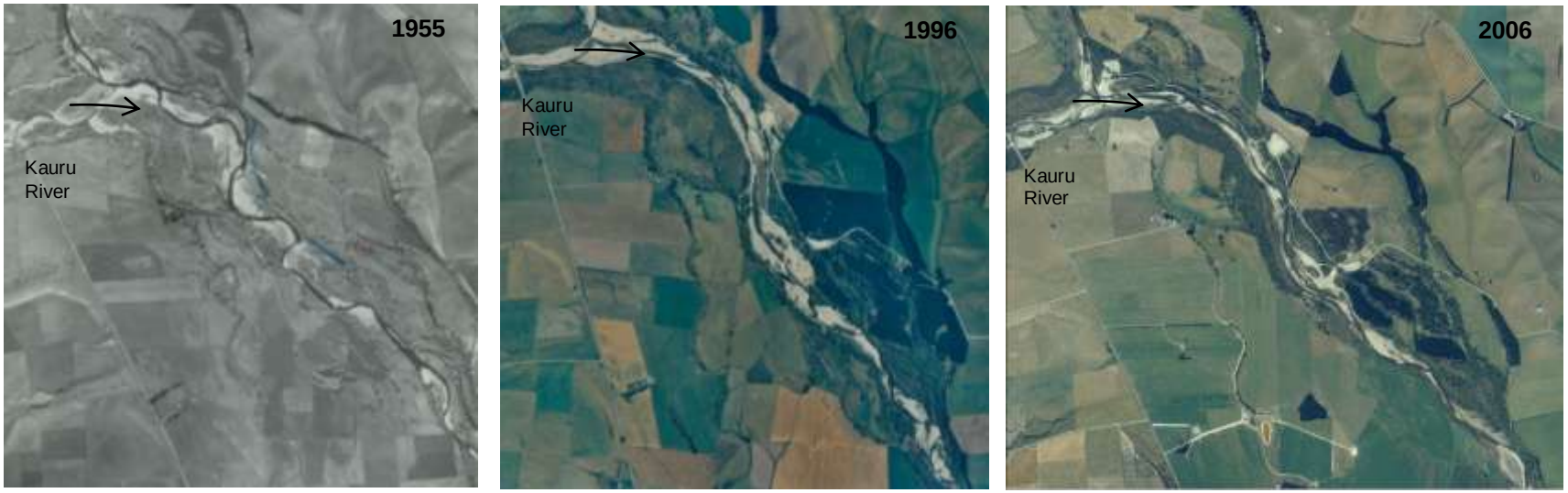

Figure 2.4D Aerial photographs of Kakanui River in 1955, 1996 and 2006 from 19 to 23km upstream of the river mouth.

Figure 2.4E Aerial photographs of Kakanui River in 1955, 1996 and 2006 from 23 to 29km upstream of the river mouth.

Analysis of aerial photographs dating back to 1955 have also illustrated some morphological change in the Kauru River system over time (Figure 2.5 A and B).

Between the confluence with Kakanui River and Kininmont Ford the semi-braided channel has migrated laterally between its banks such that areas of gravel exposure and vegetation, and localised morphology of some islands and bars, have changed over time (Figure 2.5A). Gravel extraction has been common in this reach of the river in the past so some of the morphological change can be attributed to this activity.

Between Kininmont Ford and Kauru Hill Road there has been less obvious morphological change than the lowermost reaches of the river, although the main channel has still migrated laterally between its banks (Figure 2.5B). The active channel in the vicinity of the Ford has widened between 1955 and 1996 and appears to have become braided; in 2006 the channel was still a similar width to 1996 but had reverted to a meandering river form. Downstream of Kauru Hill Road the river appears to have increased in sinuosity and, where it was evident as a single-threaded channel down to about 1km below Kauru Hill Road in the 1955 aerial, it is now partially braided similarly to the rest of the river downstream. Changes to both sediment supply rates and gradient of the river bed can induce such changes in river form.

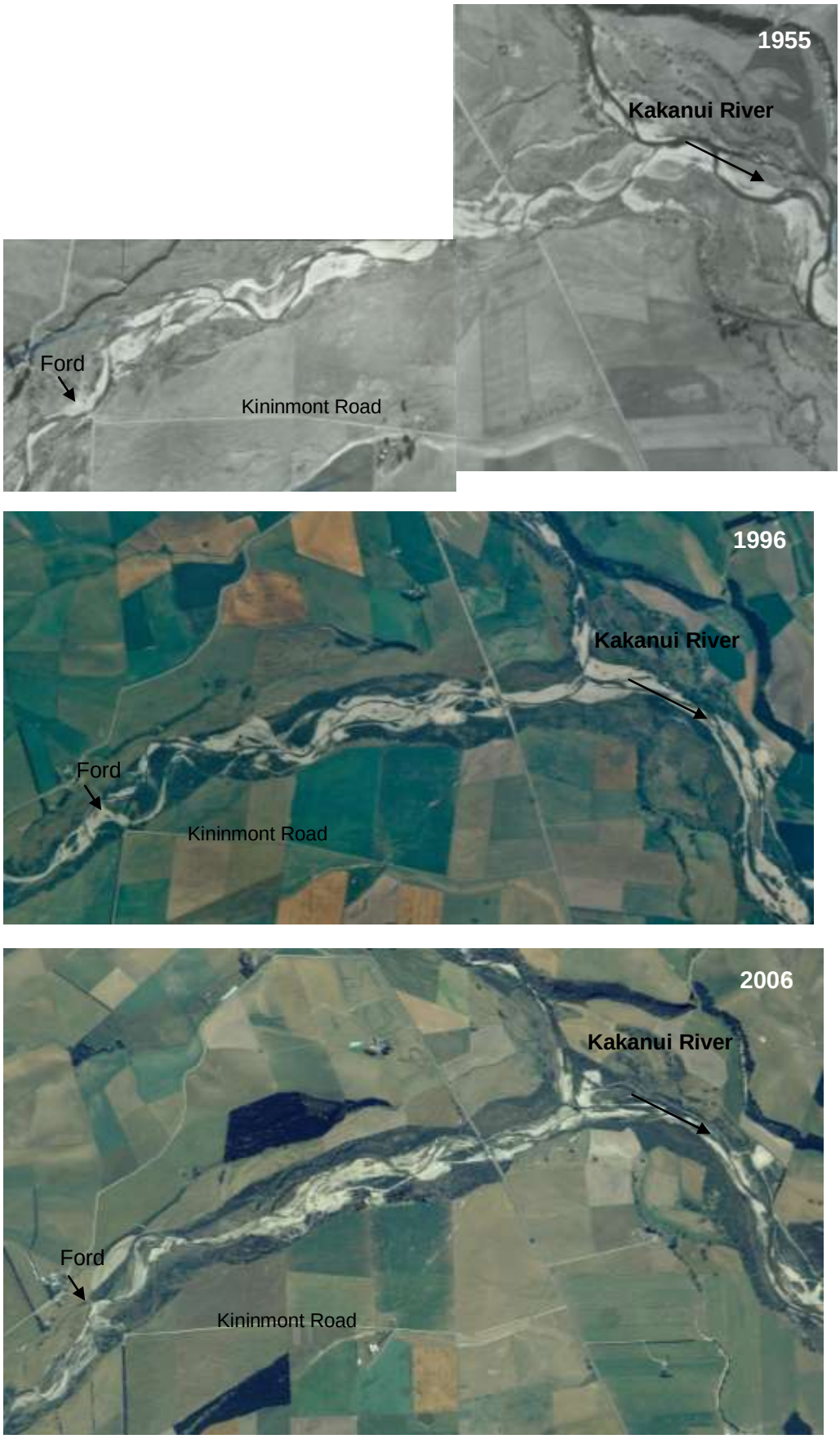

Figure 2.5A Aerial photographs of Kauru River from the confluence with Kakanui River up to Kininmont Ford.

Figure 2.5B Aerial photographs of Kauru River from Kininmont Ford up to Kauru Hill Road.

3 Cross-section and mean bed level analysis

The ORC undertakes scheduled cross-section surveys for selected rivers. The cross-section programme enables changes in river morphology to be monitored and supports assessments of potential affects on communities. Mean bed level is the average elevation of the river bed across the active channel and is used to determine overall bed lowering (degradation) or aggradation at a specific site between survey periods.

The mean bed level of the active channel in each cross-section has been calculated using the X-Sect cross-section database[2]. Mean bed level calculations at each cross-section and for each year surveyed are presented, as well as the values of net change in mean bed level between survey periods. While results are expressed to two decimal places, these are mean values and may therefore have an error margin which exceeds this level of specificity. Some historical surveys have been completed over relatively short widths of the channel and do not encompass the current active channel width at that cross-section site. In this instance, mean bed levels have been calculated over these shorter distances in order to assess change over the entire survey period but are not directly comparable to the wider active channel results.

3.1 Kakanui River

Twenty-four cross-section locations have been surveyed on the Kakanui River (Figure 3.1A-B) between 1985 and 2009. Table 3.1 shows each year surveyed and the respective mean bed level calculation for each cross-section. The net change in mean bed level over the different survey periods is then presented in Table 3.2.

Annotated plots of each cross-section for all surveyed years are included in Section 8 – Appendices. A commentary is provided for each cross-section noting observed mean bed level, morphological and geomorphic changes.

[2] The X-Sect database compiles a list of widths and their associated elevations for each cross-section and survey period. X-Sect calculates all output information (minimum, maximum and mean bed levels) from the respective widths and elevations.

Figure 3.1A Location of surveyed cross-sections for the upper Kakanui River superimposed on 2006 aerial photograph.

Figure 3.1B Location of surveyed cross-sections for the lower Kakanui River superimposed on 2006 aerial photograph.

Table 3.1 Mean bed level results[3] (2 d.p.) for surveyed cross-sections of the Kakanui River. A blank space indicates the cross-section was not surveyed for that year.

Cross-section	Channel Width (m)	Mean bed level (m)									
		Mar-Aug 1985	Oct 1985	Aug 1987	Oct 1987	Dec 1987	Jun 1990	Jul 1990	Jul-Aug 2000	Mar 2006	Feb 2009
100	150.36					99.92			99.95	99.34	99.14
101	43.82					109.88			109.86	109.97	109.58
2/1	34.20		110.31		110.54					110.68	110.66
3/1	26.70		111.25		111.18					110.94	110.72
4/1	25.00		112.30		112.38					111.78	111.69
5/1	32.30		112.66							112.39	112.30
KA34	68.06								117.17	117.34	117.41
KA31	49.94					119.85			120.37	120.48	120.48
KA28	29.36					122.68			123.33	123.80	123.79
KA26	46.30					126.50			126.83	125.98	125.83
KA1	54.40	129.00			128.89		129.12			129.20	128.90
KA2	64.50	132.13			132.14				132.13	131.83	131.72
KA5	66.61								134.46	134.26	134.12
KA6	98.71								139.33	139.15	138.88
KA7	41.30	140.84			140.73		140.65		140.50	140.15	139.85
KA8	176.23									143.06	143.17
KA9	110.53								145.88	145.72	145.56
KA10	98.70	150.18							149.18	149.29	149.36
KA11	265.00	153.09								152.27	152.36
KA14	121.07								156.42	156.17	156.14
KA15	39.75					162.04			161.84	161.83	161.91
KA36	68.56								167.68	167.61	167.73
KA102	60.37								172.37	172.37	172.39
KA37	142.38								177.78	177.74	177.84
Cross-section mean bed level calculations undertaken for widths that do not cover the current active channel											
5/1	24.60		112.41		111.97					112.05	111.94
KA5	52.30	134.43			134.28				134.08	134.06	133.87
KA6	37.30	138.80			138.10		137.97		139.92	140.21	140.01
KA8	68.20	143.61			143.95			143.22	143.12	143.51	143.45
KA9	50.00	146.98		146.32				145.84	145.54	145.85	145.97
KA10	52.20	149.64		149.31	149.34			149.32	148.42	148.43	148.55
KA11	115.70	152.11			151.95			151.54	152.04	151.86	151.92
KA14	40.67					155.34		155.60	156.24	155.33	155.13

[3] Mean bed levels are expressed in the Otago Datum which lies 100 metres below the Dunedin Vertical Datum 1958.

Table 3.2 Net change in mean bed level (2 d.p.) for each respective survey period.

Cross-section	Width (m)	1985-1987	Aug 1987-Oct1987	1987-1990	1990-2000	2000-2006	2006-2009	Net change
100	150.36			+0.03		-0.61	-0.20	-0.78
101	43.82			-0.02		+0.11	-0.39	-0.30
2/1	34.20	+0.23		+0.14			-0.02	+0.35
3/1	26.70	-0.07		-0.24			-0.22	-0.53
4/1	25.00	+0.08		-0.60			-0.09	-0.61
5/1	32.30	-0.27					-0.09	-0.36
KA34	68.06					+0.17	+0.07	+0.24
KA31	49.94			+0.52		+0.11	0.00	+0.63
KA28	29.36			+0.65		+0.47	-0.01	+1.11
KA26	46.30			+0.33		-0.85	-0.15	-0.67
KA1	54.40	-0.11		+0.23	+0.08		-0.30	-0.10
KA2	64.50	+0.01		-0.01		-0.30	-0.11	-0.41
KA5	66.61					-0.20	-0.14	-0.34
KA6	98.71					-0.18	_0.27	-0.45
KA7	41.30	-0.11		-0.08	-0.15	-0.35	-0.30	-0.99
KA8	152.70						+0.11	+0.11
KA9	110.53					-0.16	-0.16	-0.32
KA10	98.70	-1.00				+0.11	+0.07	-0.82
KA11	265.00	-0.82					+0.09	-0.73
KA14	121.07					-0.25	-0.03	-0.28
KA15	39.75			-0.20		-0.01	+0.08	-0.13
KA36	68.56					-0.07	+0.12	+0.05
KA102	60.37					0.00	+0.02	+0.02
KA37	142.38					-0.04	+0.10	+0.06
Cross-section mean bed level calculations undertaken for widths that do not cover the current active channel								
5/1	24.60	-0.44		+0.08			-0.11	-0.47
KA5	52.30	-0.15		-0.20		-0.02	-0.19	-0.56
KA6	37.30	-0.70		-0.13	+1.95	+0.29	-0.20	+1.21
KA8	68.20	+0.34		-0.73	-0.1	+0.39	-0.06	-0.16
KA9	50.00	-0.66		-0.48	-0.30	+0.31	+0.12	-1.01
KA10	52.20	-0.33	+0.03	-0.02	-0.90	+0.01	+0.12	-1.09
KA11	115.70	-0.16		-0.41	+0.5	-0.18	+0.06	-0.19
KA14	40.67			+0.26	+0.64	-0.91	-0.20	-0.21

Figure 3.2 shows a graphical representation of the net change in mean bed levels for each cross-section on Kakanui River over the entire survey period (noting that the net survey period varies between cross-section sites), and also between the two most recent surveys. Over the entire survey period (long-term), net aggradation has occurred at eight out of 24 sites and the spatial distribution of net aggradation appears to be quite varied i.e. is in localised areas over the entire surveyed reach. The majority of sites experienced net degradation over the entire survey period. Between 2006 and 2009 (short-term), the majority of sites again experienced net degradation of the bed level. Upstream of cross-section KA8 there has been an overall trend of aggradation in the last survey period (2006 to 2009).

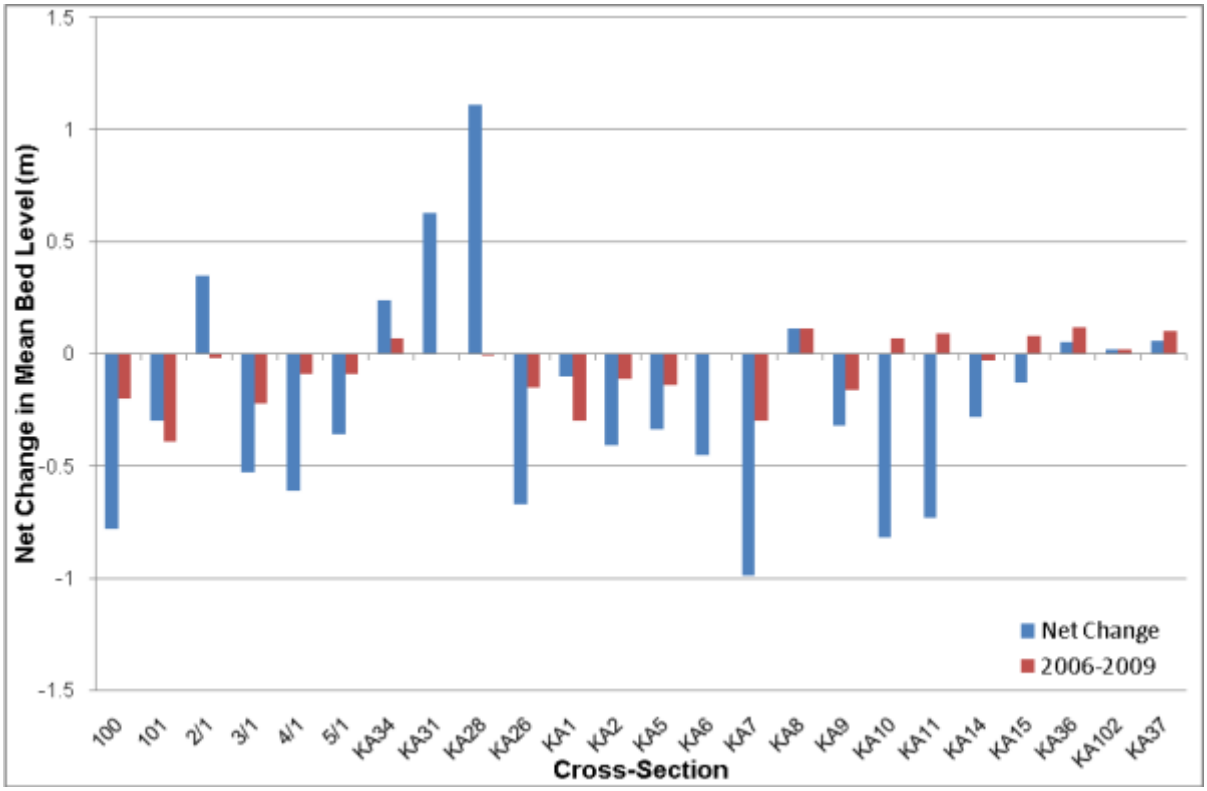

Figure 3.2 Graph showing net change in mean bed level across all survey periods and between the last two surveys (2006 and 2009) for each cross-section.

3.2 Kauru River

Seventeen cross-section locations have been surveyed on the Kauru River (Figure 3.3) between 1978 and 2008. Four new cross-sections were established during the latest survey (K6B, K6A, K7A, and K20) but will not be analysed in this report. Table 3.3 shows each year surveyed and the respective mean bed level calculation for each cross-section. The net change in mean bed level over the different survey periods is then presented in Table 3.4.

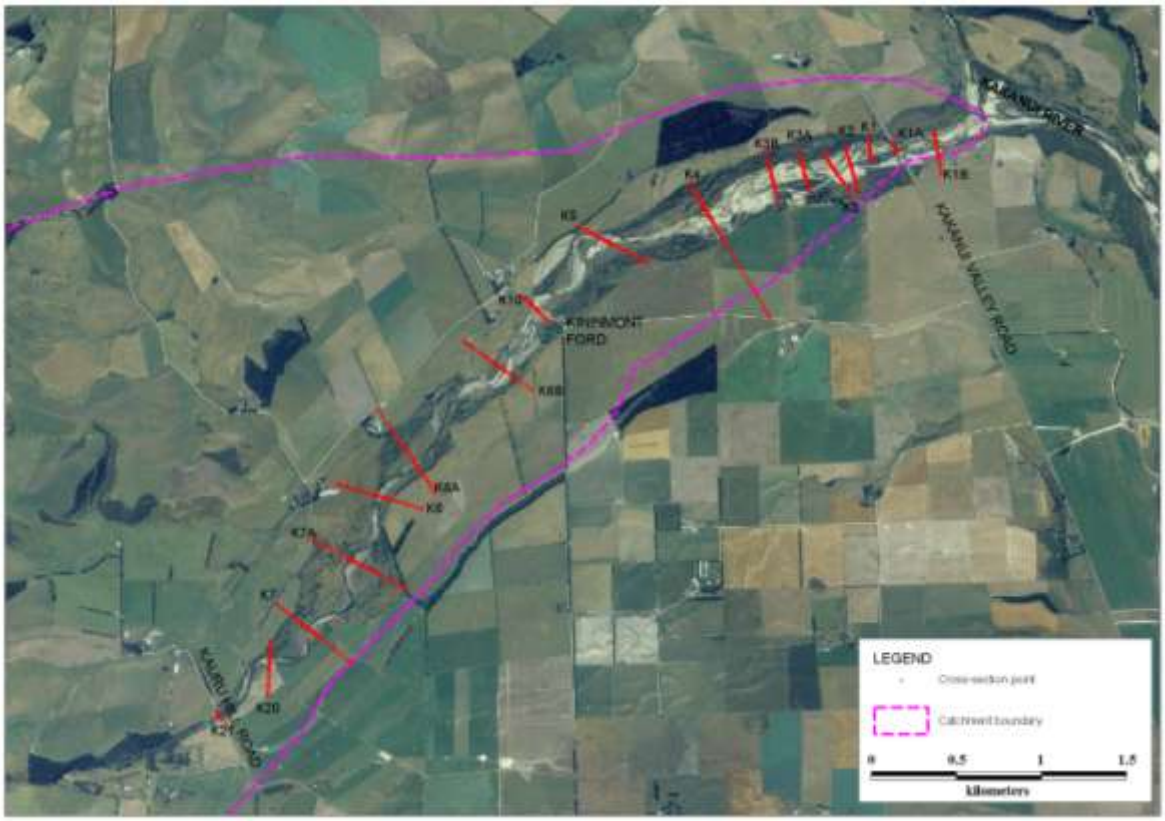

Figure 3.3 Location of surveyed cross-sections for the Kauru River superimposed on 2006 aerial photograph.

Table 3.3 Mean bed level results (2 d.p.) for surveyed cross-sections of the Kauru River. A blank space indicates the cross-section was not surveyed for that year.

Cross-section	Width (m)	Mean bed level (m)						
		May 1978	Sep 1987	Jun 1990	Jan 2001	Jan 2002	Dec 2005	Dec 2008
K1B	135.62						154.60	154.57
K1A	60.23		156.26				155.33	155.43
K1	99.21				156.73		156.53	156.77
K2	116.40				157.72		157.87	157.87
K3	144.05						158.56	158.57
K3A	122.64			160.51			159.68	159.59
K3B	109.26						160.60	160.95
K4	218.41						165.06	164.70
K5	158.51						168.78	169.05
K10A	73.61				173.18		173.26	173.26
K6	74.77						183.78	183.80
K7	113.03						191.76	191.51
K21	40.15				196.35		196.52	196.32
Cross-section mean bed level calculations undertaken for widths that do not cover the current active channel								
K1B	104.06				154.79		154.29	154.15
K1A	53.16		156.31	155.90	155.68	155.30	155.27	155.50
K1	66.50	157.61	157.16	157.18	156.49		156.48	156.78
K2	77.00	158.50	158.60	158.39	157.19		157.46	157.71
K3	131.00	159.78	159.36	159.18	158.33		158.74	158.81
K3A	92.30	161.03	160.66	160.66	159.66		159.44	159.40
K3B	43.50	162.86	161.85		161.39		161.34	161.41

Table 3.4 Net change in mean bed level (2 d.p.) for each respective survey period.

Cross-section	Width (m)	1978-1987	1987-1990	1990-2001	2001-2002	2002-2005	2005-2008	Net change
K1B	135.62						-0.03	-0.03
K1A	60.23		-0.93				+0.10	-0.83
K1	99.21				-0.20		+0.24	+0.04
K2	116.40				+0.15		0.00	+0.15
K3	144.05						+0.01	+0.01
K3A	122.64			-0.83			-0.09	-0.92
K3B	109.26						+0.35	+0.35
K4	218.41						-0.36	-0.36
K5	158.51						+0.27	+0.27
K10A	73.61				+0.08		0.00	+0.08
K6	74.77						+0.02	+0.02
K7	113.03						-0.25	-0.25
K21	40.15				+0.17		-0.20	-0.03
Cross-section mean bed level calculations undertaken for widths that do not cover the current active channel								
K1B	104.06				-0.50		-0.14	-0.64
K1A	53.16		-0.41	-0.22	-0.38	-0.03	+0.23	-0.81
K1	66.50	-0.45	+0.02	-0.69	-0.01		+0.30	-0.83
K2	77.00	+0.10	-0.21	-1.20	+0.27		+0.25	-0.79
K3	131.00	-0.42	-0.18	-0.85	+0.41		+0.07	-0.97
K3A	92.30	-0.37	0.00	-1.00	-0.22		-0.04	-1.63
K3B	43.50	-1.01	-0.46		-0.05		+0.07	-1.45

Figure 3.4 shows a graphical representation of the net change in mean bed levels for each cross-section on Kauru River over the entire survey period (noting that the net survey period varies between cross-section sites), and also between the two most recent surveys. Six of the thirteen cross-section sites have experienced net degradation; in two locations (K1A and K3A) the mean bed level has lowered by more than 0.8m. Seven of the thirteen sites have experienced net aggradation, but in relatively smaller amounts than where degradation has occurred (i.e. less than 0.4m). In the last survey period (2005 to 2008) both aggradation and degradation of the mean bed level occurred at different sites. Significant flood events in 2006 and 2007 may account for the variation in bed level change along the surveyed length of the river as high flows have the tendency to relocate sediment from the bars and channel, and alter the active channel profile.

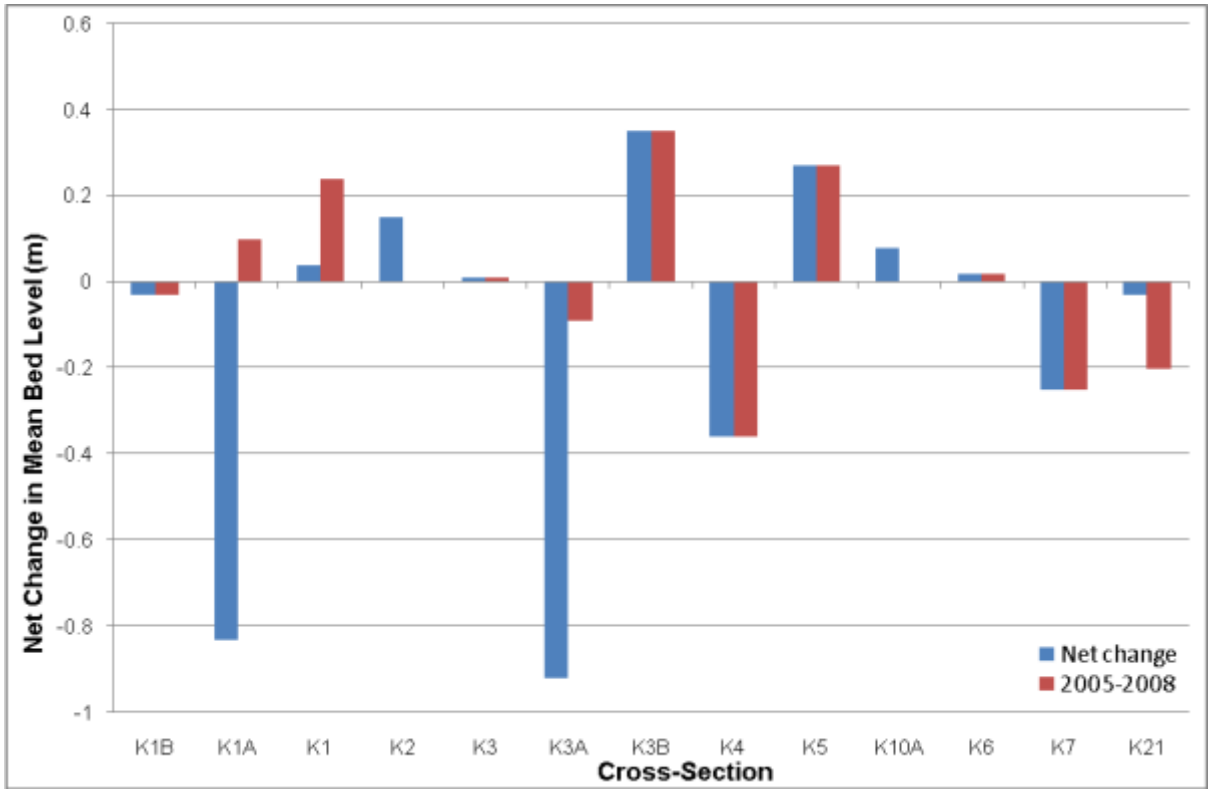

Figure 3.4 Graph showing net change in mean bed level across all survey periods and between the last two surveys (2005 and 2008) for each cross-section.

4 Longitudinal Profile Analysis

4.1 Longitudinal profile of Kakanui River

A longitudinal profile of Kakanui River has been produced from the minimum bed level (thalweg[4]) values of all the cross-section locations over their respective survey periods (Figure 4.1). Analysis of changes to the longitudinal profile of a river over time can indicate where the gradient of the river bed has changed as a result of movement of sediment (aggradation and degradation) and migration of the channel. A change in river gradient is synonymous with a change in sediment supply so can be used to determine broader scale variation in a river system compared to site specific cross-section locations.

At the downstream end of Kakanui River (between the mouth and 9km upstream) the river bed increased in gradient up to 2006, but since this time the gradient has become flatter again. The greatest lowering of the bed level has occurred at the river mouth. Between cross-sections 101 and 5/1 the gradient of the bed has fluctuated and is stepped in profile. In this reach of the river the channel has remained within its banks but has migrated across the bed as episodes of aggradation and degradation have occurred.

Between KA34 and KA11 (at the Kauru River confluence) the gradient of the river bed is slightly stepped. The river bed has significantly aggraded at KA28 and has conversely degraded at KA26. Upstream of KA26 the bed level has lowered overall from earliest surveys in 1985. Localised change in gradient (for instance, over <10km distance) can result from the river altering its local base level as bed morphology changes, as pulses of sediment move through the system, or as bedrock is exposed in the river bed. The change through this reach is likely to be a result of frequent migration of the channel and movement of sediment through this wider section during flood events. The profile through this reach is slightly more concave (to the sky) than the reaches upstream and downstream and aerial photographs show that it is a wider channel with more gravel exposure. It appears that this reach acts like a sink for gravel, with lesser sediment being transported downstream toward the mouth than is inputted. A reduction in the replenishment rate of gravel to this reach would result in the river stabilising itself with increased channel incision and armouring of the bed and banks. Flood events could rework the sediment within this reach. If significant aggradation occurred within this reach, channel capacity could be reduced, thereby increasing the breakout and flood hazard risk.

Upstream of the Kauru River confluence (KA15 to KA37) there has been little change in the gradient of the river. The cross-section profiles also highlight the stability of this reach, although the last three cross-sections at this end of the river have only been surveyed since 2000. Between cross-section 102 and KA37 the gradient of the river becomes considerably steeper than the general profile downstream. At cross-section KA37 there is a zone of natural deposition as the river comes out of the steeper upper catchment onto the flatter slopes of the lower catchment before steepening again toward Fuschia Creek Road (102).

[4] The thalweg is the lowest point of the cross-section i.e. the deepest part of the channel.

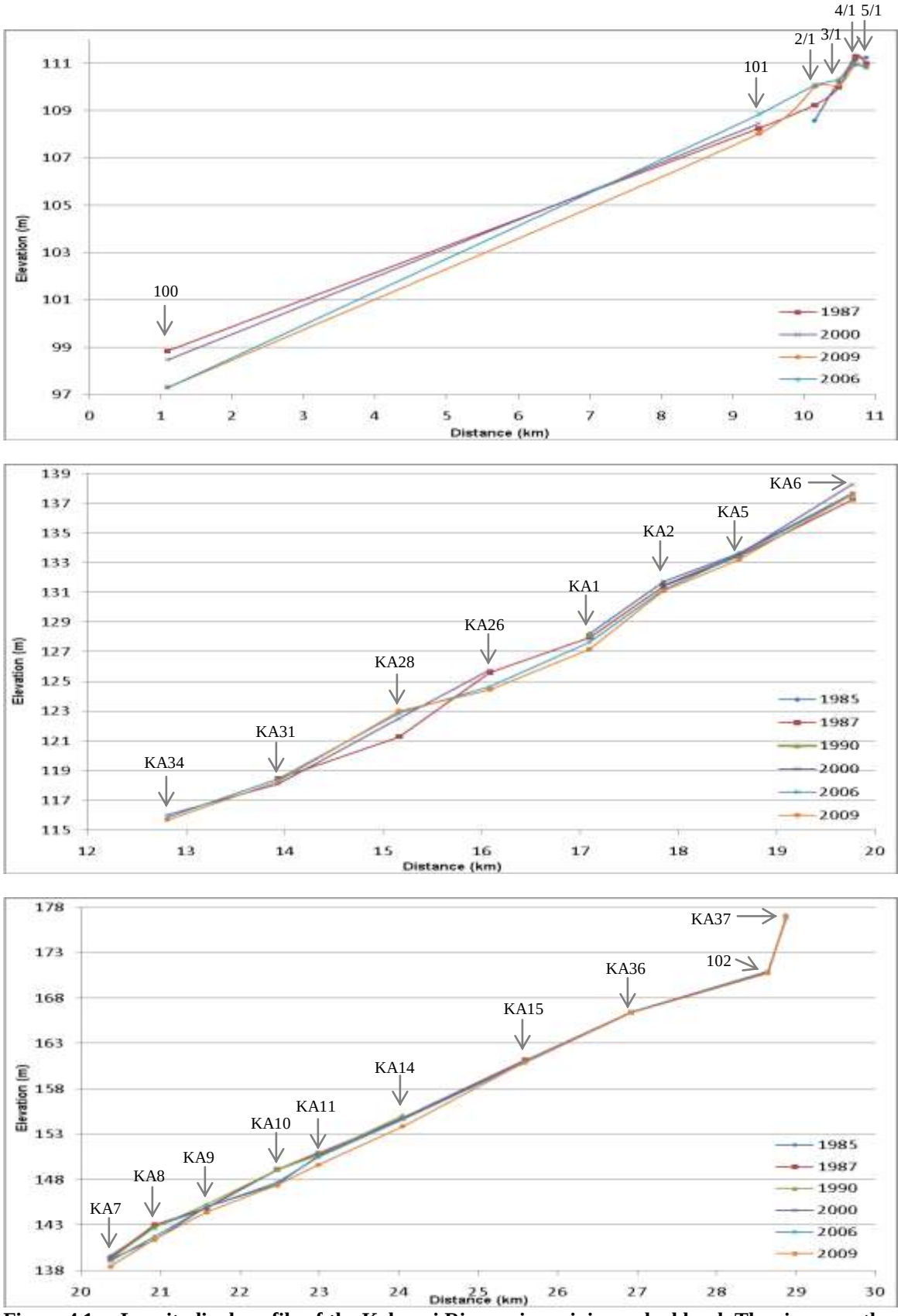

Figure 4.1 Longitudinal profile of the Kakanui River using minimum bed level. The river mouth is at 0km distance.

4.2 Longitudinal profile of Kauru River

A longitudinal profile of Kauru River has been produced from the minimum bed level (thalweg) values of all the cross-section locations over their respective survey periods (Figure 4.2). The lower reach of the river (downstream of cross-section K3B) has been surveyed over a longer period of time than the upper cross-section locations, therefore a more detailed analysis of change in bed profile could be undertaken.

From the river mouth up to cross-section K3B the bed of the river has a fairly stepped profile. The bed has overall lowered compared to earliest surveys in 1978 but there have been localised areas of aggradation (from 1987 to 1990 and 2001 to 2008) and degradation (from 1978 to 1987 and at cross-section K1A between 2001 and 2005). This reach of the river has previously been subject to fairly intensive gravel extraction which will artificially change the bed profile of the whole channel. The reach is also relatively wide and flat so is a site of considerable gravel movement during flood events. Degradation of the bed may have implications on bank erosion and bed instability.

Upstream of cross-section K4 the river takes on a more uniform gradient. Overall the bed level has increased from earlier surveys and the gradient has also become slightly steeper. The active channel is narrower through this reach than below Kininmont Ford and so significant aggradation of the bed may act to reduce the channel capacity of the river, thereby increasing the breakout or flood hazard risk. Between cross-sections K6A and K21 the bed profile appears to have become more stepped; however, the 2008 survey includes new cross-section sites (K6A, K6B, K7A, K20) which have simply resulted in an improved spatial accuracy of the longitudinal profile.

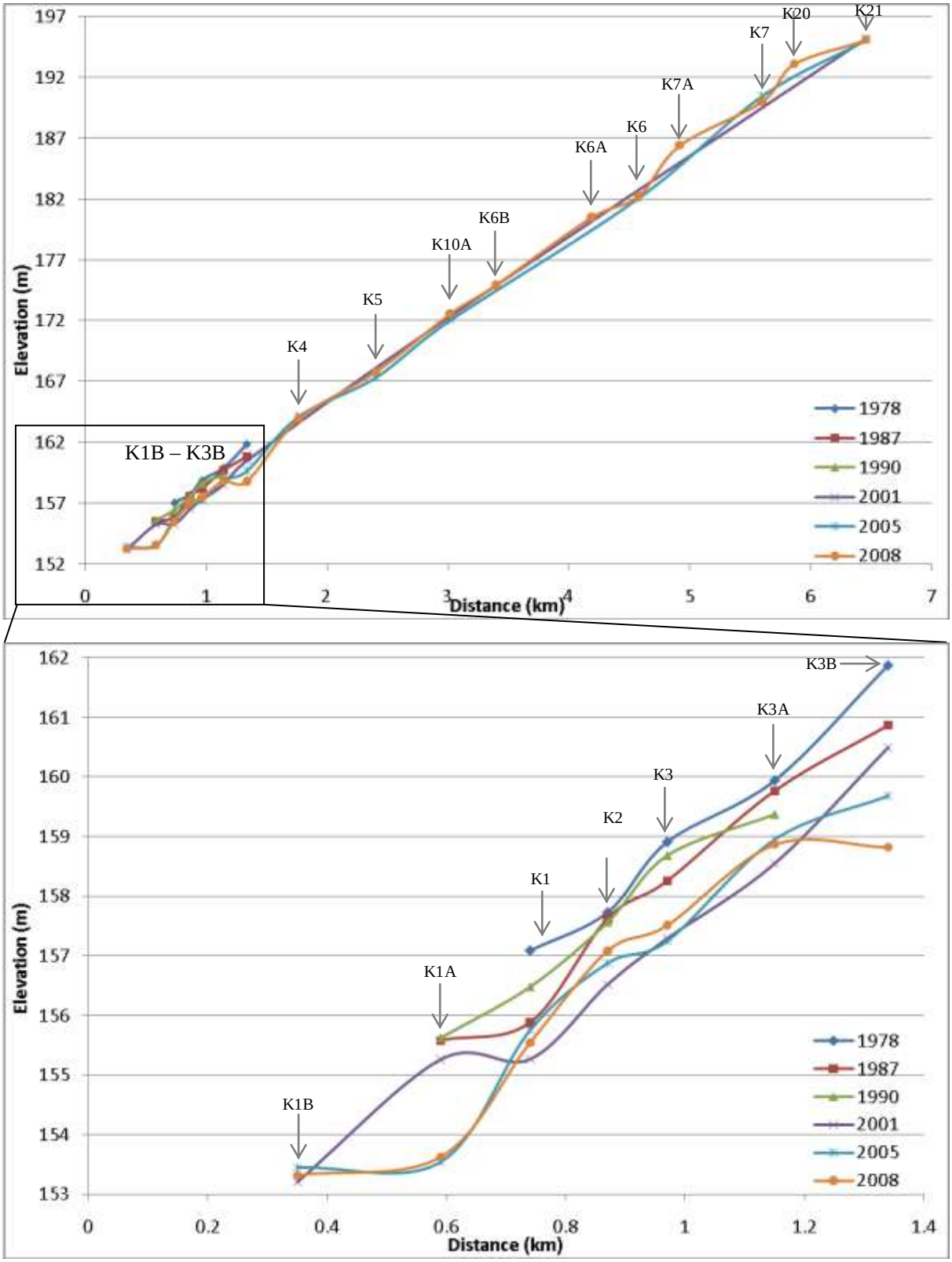

Figure 4.2 Longitudinal profile of the Kauru River, using minimum bed level. The river mouth is at 0km distance.

5 Discussion

Analysis of aerial photographs, cross-section profiles, mean bed level values and longitudinal profiles have allowed an assessment of the general channel morphology and sedimentation trends of the lower reaches of the Kakanui and Kauru Rivers. The nature of both of the river systems is for the channel to migrate laterally over time across the floodplain, which tends to be bound by older terraces. Flood events, resulting from intense or extended periods of rainfall will allow the transportation of gravel from the upper catchment, and while some areas of the rivers will experience scour and bank erosion during such flood events, fresh gravel will be deposited in the flatter reaches of the rivers where flow velocities slow down. As various meanders of the rivers migrate downstream some bank erosion will occur. Commonly, bank erosion occurs within the active channel margins of the river, rather than into the wider floodplain margins. However, the floodplains of the Kakanui and Kauru are commonly used for stock grazing so continued bank erosion can impact upon this arable land.

In the Kakanui River, the reach which experiences the most morphological and sedimentation change is between the confluence with Kauru River downstream to about Gemmell's Crossing. This reach has the widest active channel and is a zone of prominent and mobile gravel islands and bars. Gravel appears to be deposited mostly in this reach, with lesser amounts being transported to the lower reaches and mouth of the river. Consented gravel extraction activities have previously occurred in this reach and will also have contributed to the observed morphological change. This study indicates that the surveyed reach of the Kakanui River is in an overall state of degradation, with considerable bed level lowering and steepening of the entire surveyed reach, as well as straightening of the channel in the most dynamic reach of the river. If sediment replenishment rates and exposed gravel deposits are diminished in the most active zone of the river (Kauru confluence to Gemmell's Crossing), the channel will continue to incise. Alternatively, if significant aggradation occurs in this reach, channel capacity may be reduced thereby increasing the risk of breakout and flooding.

In the Kauru River the reach which has experienced the most morphological and sedimentation change is between Kininmont Ford and the confluence with Kakanui River. Similarly to the most dynamic reach of the Kakanui, this reach is relatively wide and mobile. Previous gravel extraction activities have also been focussed in this reach. This study indicates that the surveyed reach of the Kauru River is a sensitive system, prone to localised aggradation and degradation, commonly influenced by flood events and also gravel extraction. The Kauru River has a relatively small natural gravel replenishment rate and so river form will be easily adversely affected by any change to the morphology of the channel through sediment movement or removal.

The 2005 Gravel Resource Assessment of the Kauru River (ORC, 2005) highlighted that there has been considerable channel degradation and bank erosion in the Kauru River as a result of significant gravel extraction in a supply-limited river system. Following recent studies of this river, it is currently understood that the Kauru does have a relatively low replenishment rate of gravel, that gravel is sourced from the upper mountainous catchment as well as from some reworking of the banks, and is deposited in the channel mostly during flood events. Current river management practices are tailored toward maintaining the flood-carrying capacity of the channel and avoiding over-allocation of the gravel resource (ORC, 2008; ORC, 2009).

6 Conclusions

A review of channel morphology and sedimentation in the Kakanui River and Kauru River has revealed that the most significant change to these systems has occurred in those wider, flatter and gravel-rich reaches where lateral migration of the channel and movement of sediment are a common result of high-flow and flood events. The remainder of both river systems has shown little morphological change other than small adjustments of localised bars or gradual migration of some meander bends. The bed profile of the Kakanui River has steepened overall, with the most bed degradation occurring in the lower 10km of the river. The bed profile of the Kauru River has also steepened overall with some aggradation occurring in the last survey period where degradation had previously been occurring. If sediment replenishment rates and exposed gravel deposits are diminished in the most dynamic reaches of both rivers the channel will continue to incise with potential overall bed degradation and bank erosion resulting. Alternatively, if significant aggradation occurs in these reaches, channel capacity may be reduced thereby increasing the risk of breakout and flooding.

7 References

Forsyth, P.J. (compiler), 2001: Geology of the Waitaki Area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 19. Institute of Geological and Nuclear Sciences, Lower Hutt.

Otago Catchment Board, 1987: A Chronology of Flooding on the Kakanui 1868-1987. Otago Catchment Board, Dunedin.

Otago Catchment Board, 1988: Floodplain Management Report for the Kakanui Catchment. Otago Catchment Board, Dunedin.

Otago Regional Council, 1991: Report on Floodplains within the Part of Waitaki District within the Otago Region. Otago Regional Council, Dunedin.

Otago Regional Council, 2005: Kauru River Gravel Resource Assessment. Otago Regional Council, Dunedin.

Otago Regional Council, 2008: Sustainable Options for Kauru River Management. Council Report 2008/191.

Otago Regional Council, 2009: Update – Kauru River Gravel Management. Council Report 2009/068.

8 Appendix

8.1 Cross-section 100

Cross-section 100 is located approximately 1.10km upstream of the Kakanui River mouth at the Waianakarua Road Bridge. Figure 8.1 shows a plot of cross-section 100 for the 1987, 2000, 2006 and 2009 surveys.

The active channel is located across the full extent of the cross-section and has a width of 150m. Mean bed level analysis shows that this location has experienced net degradation of 0.78m between 1987 and 2009 (refer Table 3.2). Since 2000 the bed level has lowered and the channel has established itself on the true left. There has been little morphological change in this reach since the 1950s (Figure 2.4A).

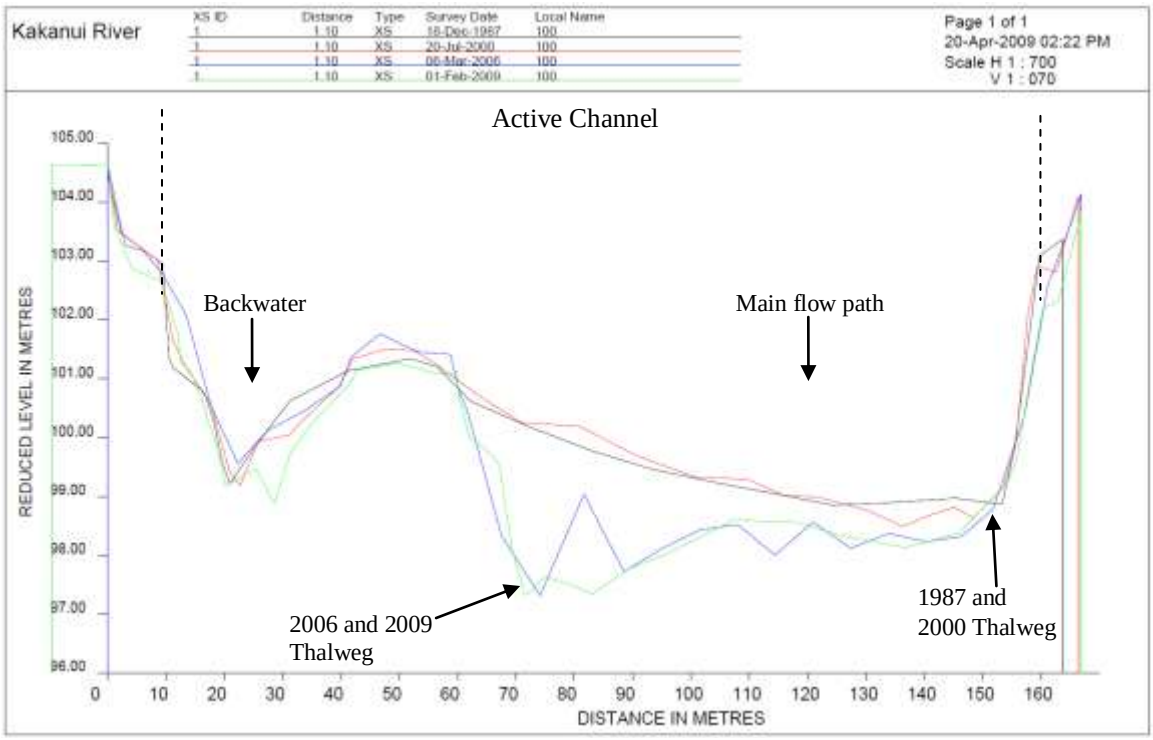

Figure 8.1 Cross-section 100, looking downstream.

8.2 Cross-section 101

Cross-section 101 is located approximately 9.36km upstream of the Kakanui River mouth at the State Highway 1 Bridge. Figure 8.2 shows a plot of cross-section 101 for the 1987, 2000, 2006 and 2009 surveys.

The active channel is located on the true left of the cross-section and has a width of 44m. Mean bed level analysis shows that this location has experienced net degradation of 0.30m between 1987 and 2009 (refer Table 3.2). The true left bank has remained relatively stable but the true right bank has eroded back by about 10m since 1987. This appears to be a result of the way the river is forced around the true left beach just upstream of the bridge (Figure 2.4B). The active channel has widened as a result of the bank movement and the river is currently concentrated on the true right of the active channel.

Channel morphology has changed in this area since the 1950s whereby the Kakanui previously intercepted Waimotu Creek about 300m upstream of the current confluence.

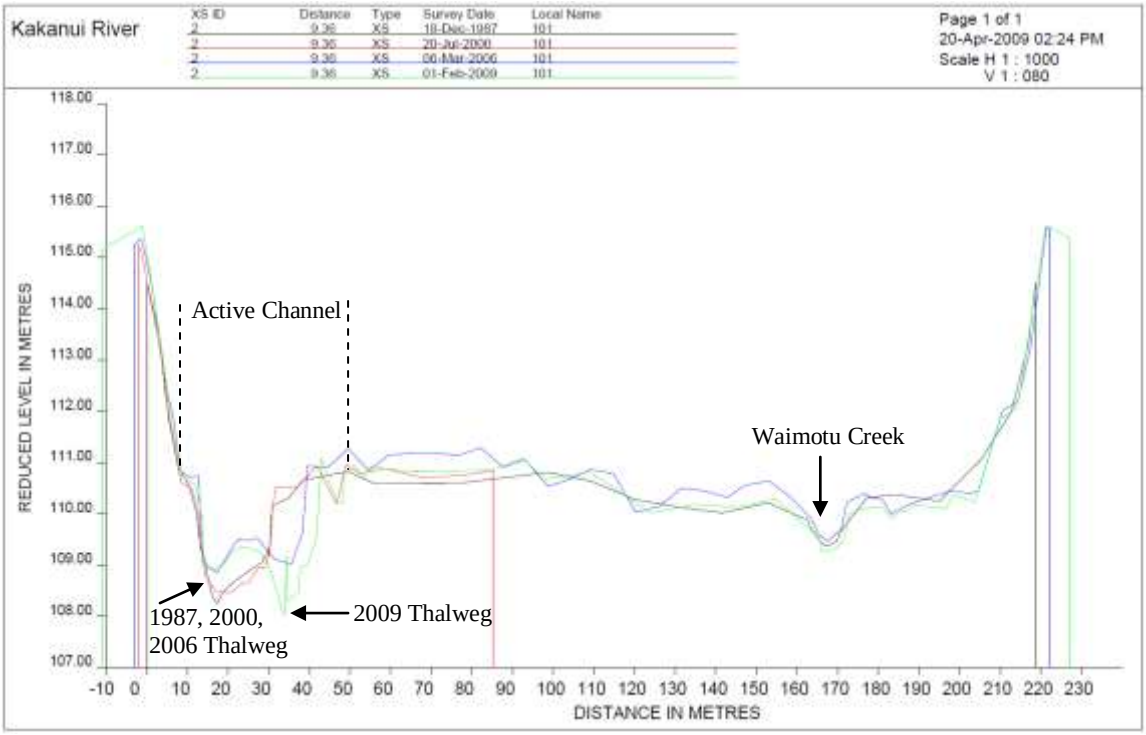

Figure 8.2 Cross-section 101, looking downstream.

8.3 Cross-section 2/1

Cross-section 2/1 is located approximately 10.14km upstream of the Kakanui River mouth. Figure 8.3 shows a plot of cross-section 2/1 for the 1985, 1987, 2006 and 2009 surveys.

The active channel is located toward the true right of the cross-section and has a width of 34m. Mean bed level analysis shows that this location has experienced net aggradation of 0.35m between 1985 and 2009 (refer Table 3.2). The bed of the active channel has been aggrading and flattening since 1985. Significant aggradation (0.23m) occurred between 1985 and 1987, probably as a result of the 1986 flood event. The banks of this section have remained relatively stable.

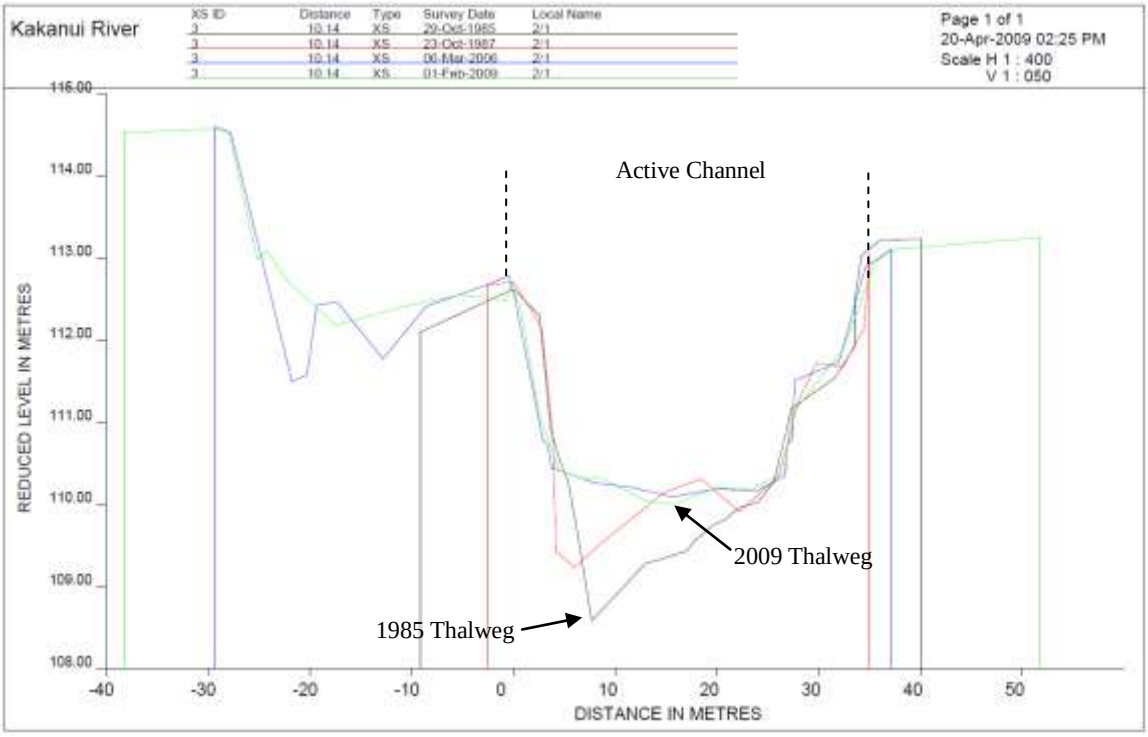

Figure 8.3 Cross-section 2/1, looking downstream.

Between cross-section 2/1 and cross-section 5/1 there has been some morphological change, with localised aggradation and degradation occurring as the meanders of the river migrate.

8.4 Cross-section 3/1

Cross-section 3/1 is located approximately 10.48km upstream of the Kakanui River mouth. Figure 8.4 shows a plot of cross-section 3/1 for the 1985, 1987, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 27m. Mean bed level analysis shows that this location has experienced net degradation of 0.53m between 1985 and 2009 (refer Table 3.2). The bed has degraded on the true left and the bed profile has flattened, but there have been only small changes to the depth of the thalweg.

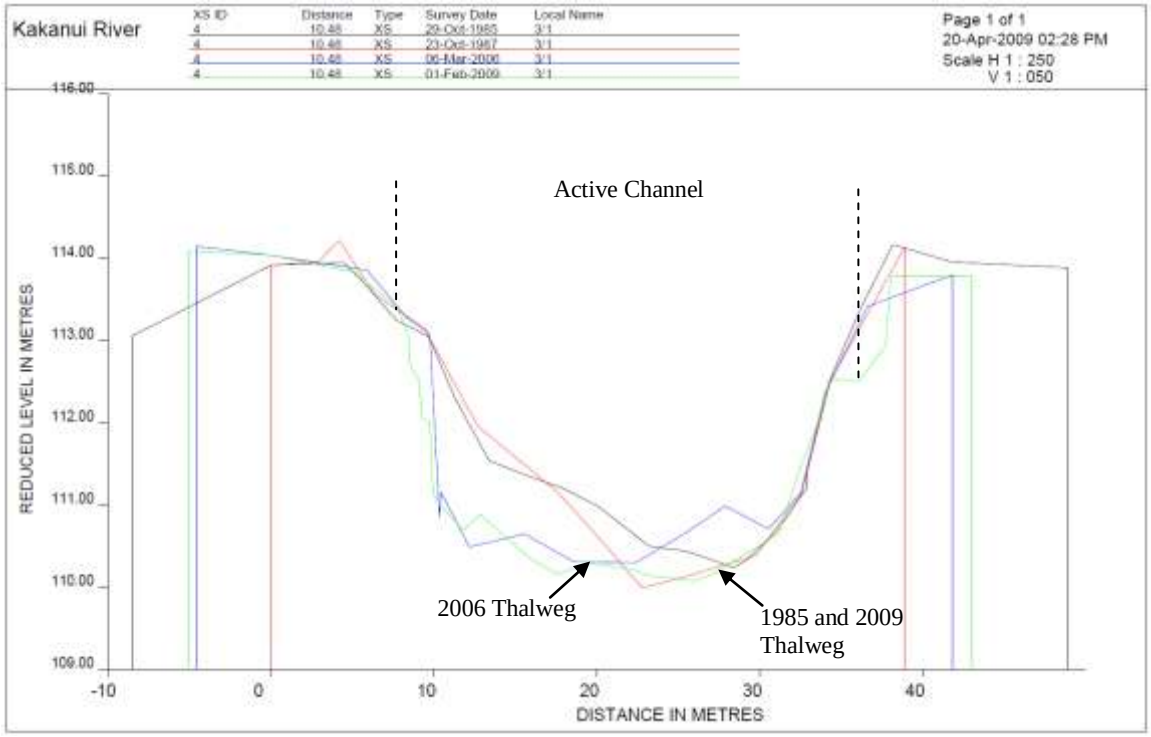

Figure 8.4 Cross-section 3/1, looking downstream.

8.5 Cross-section 4/1

Cross-section 4/1 is located approximately 10.71km upstream of the Kakanui River mouth. Figure 8.5 shows a plot of cross-section 4/1 for the 1985, 1987, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 25m. Mean bed level analysis shows that this location has experienced net degradation of 0.61m between 1985 and 2009 (refer Table 3.2). The bed has degraded on the true left and the bed profile has flattened. The true right bank has become steeper as a result of some bank erosion.

Through this reach the river has taken different paths across the floodplain in the past. This is evidenced in the 2006 survey of this cross-section; this channel is now a secondary flow path for the river and may be re-established following a high-flow or flood event.

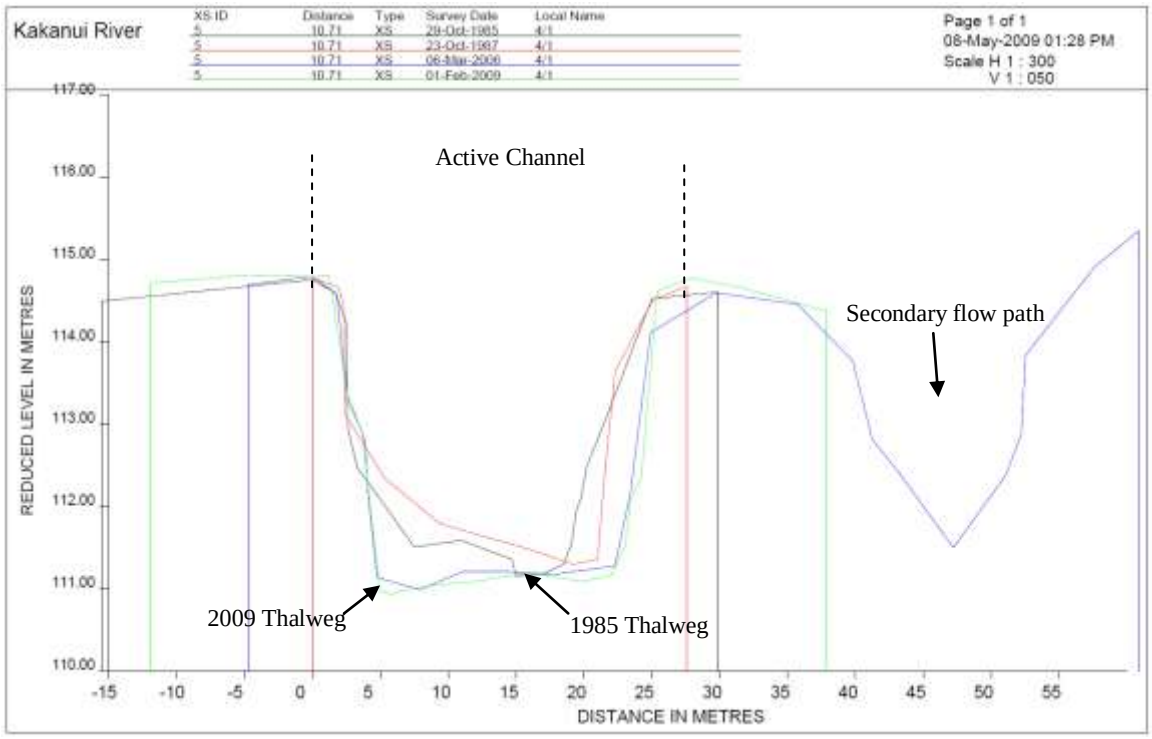

Figure 8.5 Cross-section 4/1, looking downstream.

8.6 Cross-section 5/1

Cross-section 5/1 is located approximately 10.86km upstream of the Kakanui River mouth. Figure 8.6 shows a plot of cross-section 5/1 for the 1985, 1987, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 32m. Mean bed level analysis shows that this location has experienced net degradation of 0.36m between 1985 and 2009 (refer Table 3.2) over the current active channel extent; this is excluding the 1987 cross-section which was surveyed at a shorter extent. Between 1985 and 1987 there was a significant amount of bed degradation, probably as a result of the 1986 flood event. The bed profile has remained comparatively similar with the channel concentrated on the true left side.

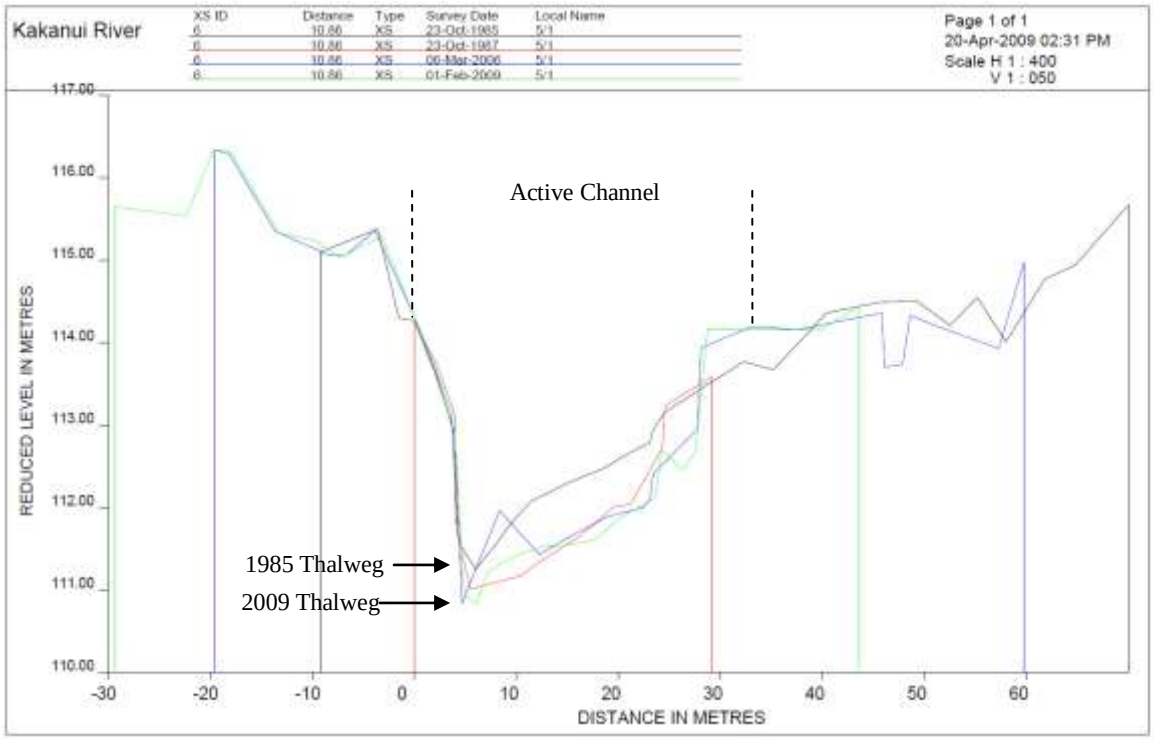

Figure 8.6 Cross-section 5/1, looking downstream.

8.7 Cross-section KA34

Cross-section KA34 is located approximately 12.81km upstream of the Kakanui River mouth. Figure 8.7 shows a plot of cross-section KA34 for the 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 68m. Mean bed level analysis shows that this location has experienced net aggradation of 0.24m between 2000 and 2009 (refer Table 3.2). This net aggradation value is accounted for by the aggradation that has occurred in the ephemeral channel on the true left. The main channel has experienced small amounts of degradation as the channel has deepened on the true right.

Some morphological change has occurred in this reach since the 1950's with localised aggradation and degradation, and subsequent lateral migration, of the channel.

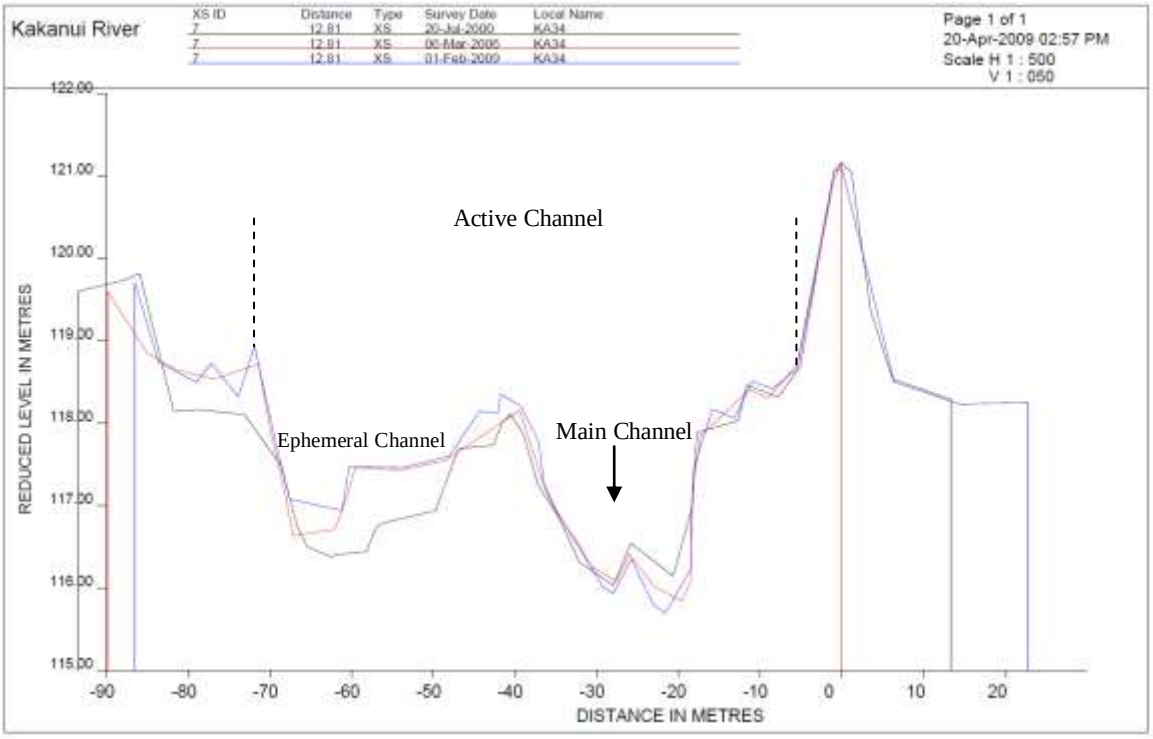

Figure 8.7 Cross-section KA34, looking downstream.

8.8 Cross-section KA31

Cross-section KA31 is located approximately 13.93km upstream of the Kakanui River mouth. Figure 8.8 shows a plot of cross-section KA34 for the 1987, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 50m. Mean bed level analysis shows that this location has experienced net aggradation of 0.63m between 1987 and 2009 (refer Table 3.2). The most significant aggradation occurred between 1987 and 2001 where a beach has developed and aggraded on the true right of the channel. The main flow path has established itself on the true left and this has aggraded slightly since 2000.

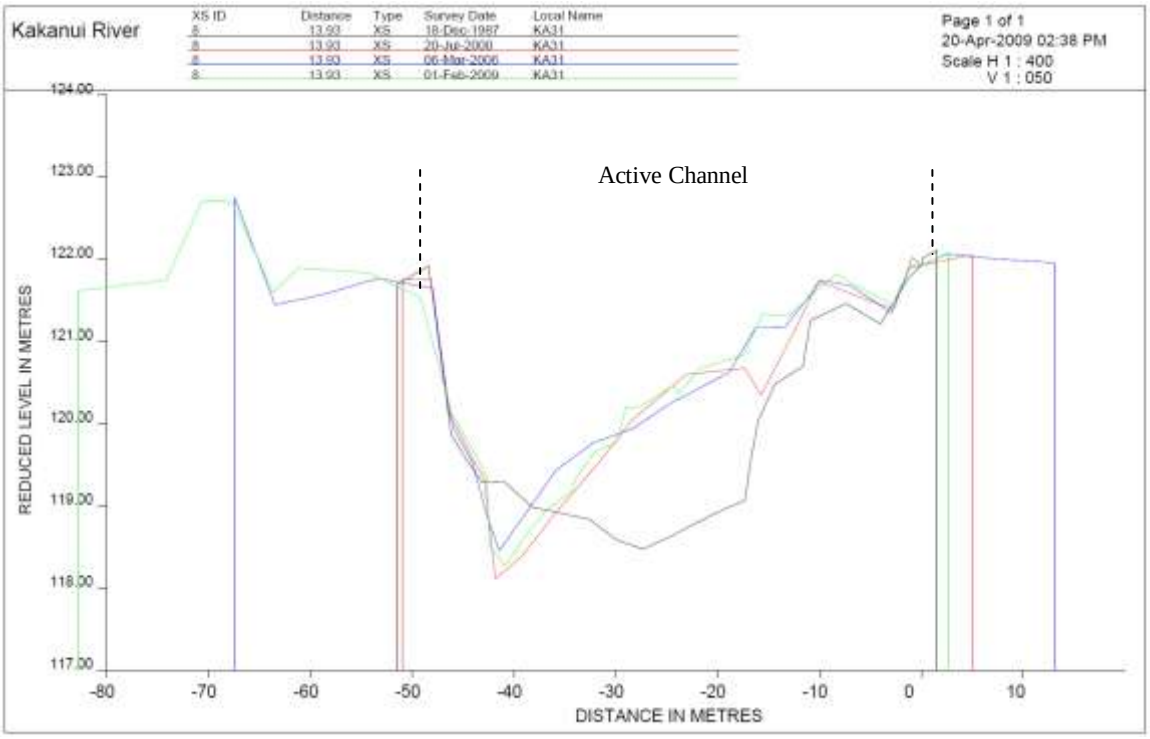

Figure 8.8 Cross-section KA31, looking downstream.

8.9 Cross-section KA28

Cross-section KA28 is located approximately 15.16km upstream of the Kakanui River mouth. Figure 8.9 shows a plot of cross-section KA28 for the 1987, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 29m. Mean bed level analysis shows that this location has experienced net aggradation of 1.11m between 1987 and 2009 (refer Table 3.2). Significant aggradation in this reach has raised the bed of the channel and narrowed the active channel margins. The bed has been relatively stable since 2006.

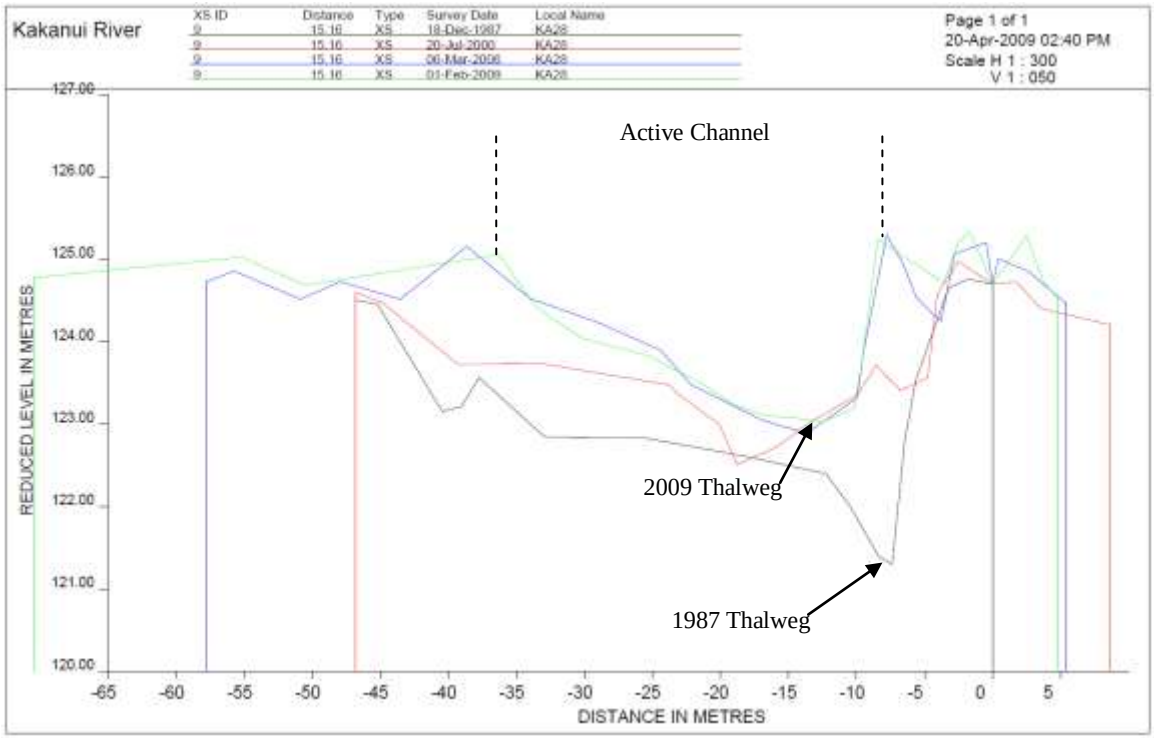

Figure 8.9 Cross-section KA28, looking downstream.

8.10 Cross-section KA26

Cross-section KA26 is located approximately 16.08km upstream of the Kakanui River mouth. Figure 8.10 shows a plot of cross-section KA26 for the 1987, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 46m. Mean bed level analysis shows that this location has experienced net degradation of 0.67m between 1987 and 2009 (refer Table 3.2). The mean bed level of the channel increased between 1987 and 2000 by 0.33m, but significantly reduced between 2000 and 2006 by 0.85m. Further degradation of the bed has occurred since 2006, particularly on the true left. The banks of the channel have remained relatively stable.

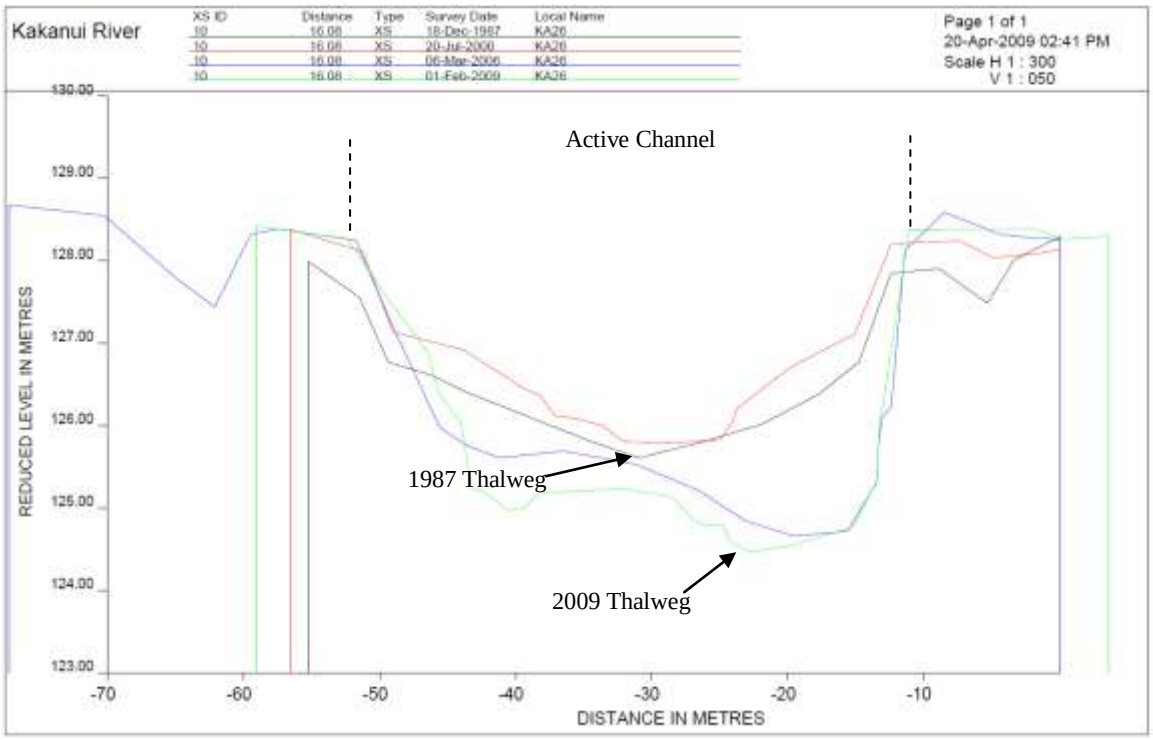

Figure 8.10 Cross-section KA26, looking downstream.

8.11 Cross-section KA1

Cross-section KA1 is located approximately 17.09km upstream of the Kakanui River mouth at Gemmells Crossing. Figure 8.11 shows a plot of cross-section KA1 for the 1985, 1987, 2000, 2006 and 2009 surveys.

The active channel is located across the full extent of the cross-section and has a width of 54m. Mean bed level analysis shows that this location has experienced net degradation of 0.10m between 1985 and 2009 (refer Table 3.2). Over this period, the bed profile has changed from being relatively flat with the channel established on the true left (1985) and the true right (1990) to greater deepening of the channel on the true left (2009).

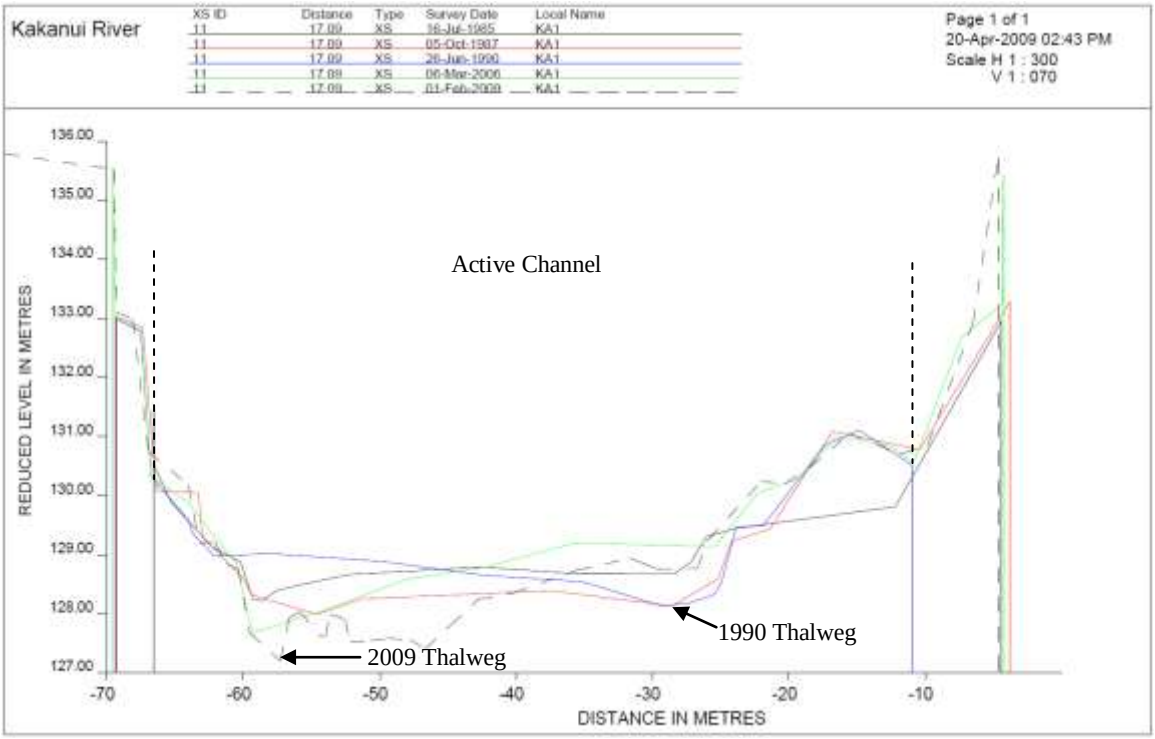

Figure 8.11 Cross-section KA1, looking downstream.

8.12 Cross-section KA2

Cross-section KA2 is located approximately 17.84km upstream of the Kakanui River mouth. Figure 8.12 shows a plot of cross-section KA2 for the 1985, 1987, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 65m. Mean bed level analysis shows that this location has experienced net degradation of 0.41m between 1985 and 2009 (refer Table 3.2). The bed of the active channel has continually degraded over the survey period, with aggradation of an island between the active channel and ephemeral channel between 1985 and 2006.

The channel in this reach of the river has become more defined, with the current vegetated floodplain having been an exposed gravel beach on both sides of the channel in the past.

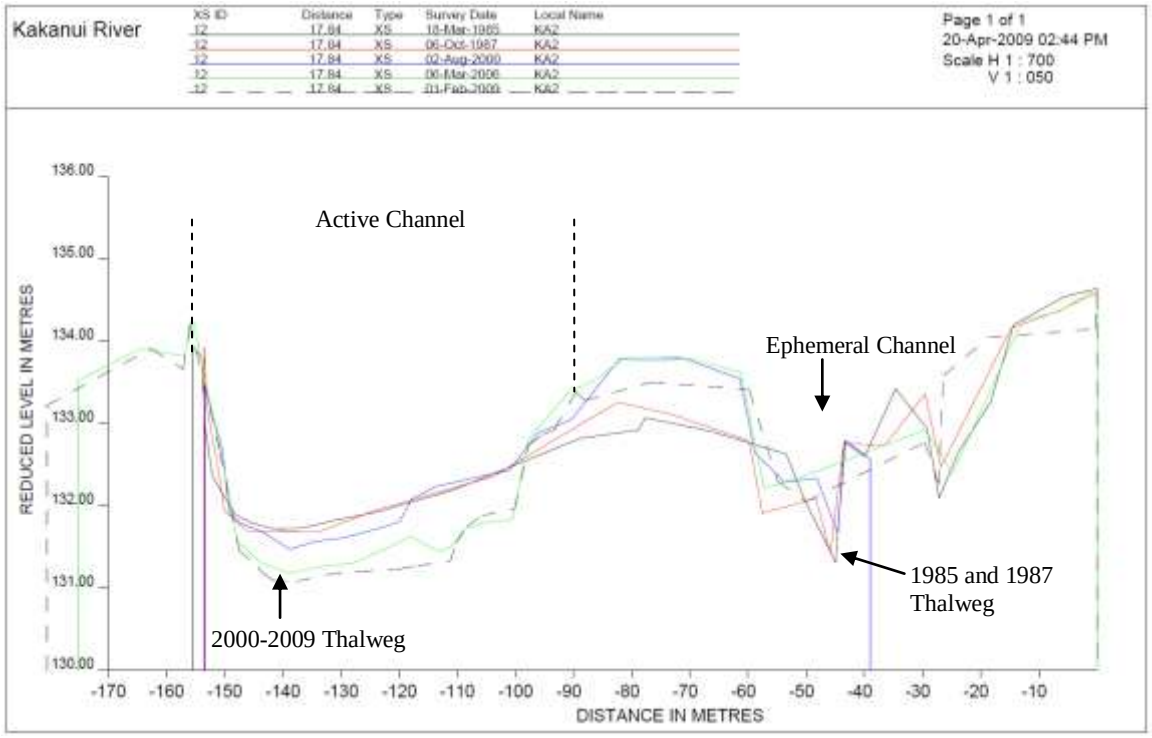

Figure 8.12 Cross-section KA2, looking downstream.

8.13 Cross-section KA5

Cross-section KA5 is located approximately 18.61km upstream of the Kakanui River mouth. Figure 8.13 shows a plot of cross-section KA5 for the 1985, 1987, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 66m. Mean bed level analysis shows that this location has experienced net degradation of 0.34m between 2000 and 2009 (refer Table 3.2). Some bank erosion has occurred, particularly on the true right. Over a shorter section of the channel, mean bed level analysis of all the previous surveys shows net degradation of 0.56m between 1985 and 2009.

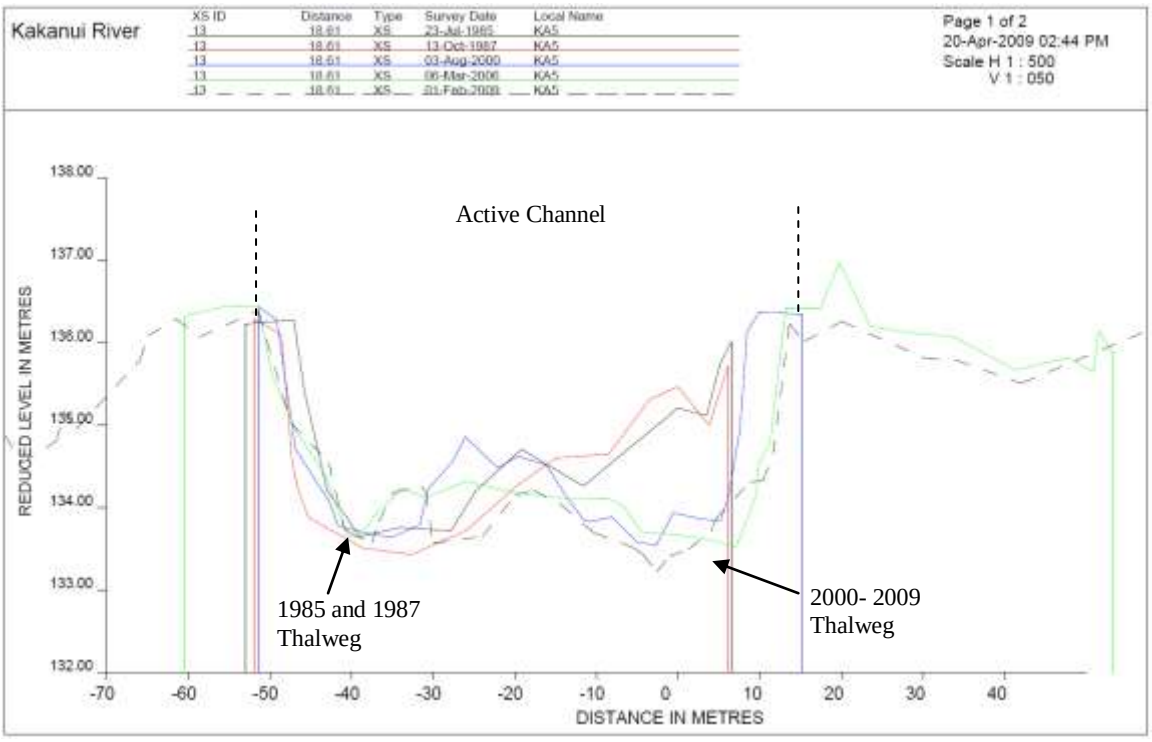

Figure 8.13 Cross-section KA5, looking downstream.

8.14 Cross-section KA6

Cross-section KA6 is located approximately 19.76km upstream of the Kakanui River mouth. Figure 8.14 shows a plot of cross-section KA6 for the 1985, 1987, 1990, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 99m. Mean bed level analysis shows that this location has experienced net degradation of 0.45m between 2000 and 2009 (refer Table 3.2). During this period the true left beach has degraded as the channel has established itself on this side, and some aggradation has occurred on the true right. In the 1980's the active channel was located toward the true right of the current vegetated floodplain.

Analysis of aerial photographs dating back to the 1950's reveals that this reach was previously a braided river system with vegetated islands between well-established channels; at present the active channel is relatively wider and is single-threaded and meandering.

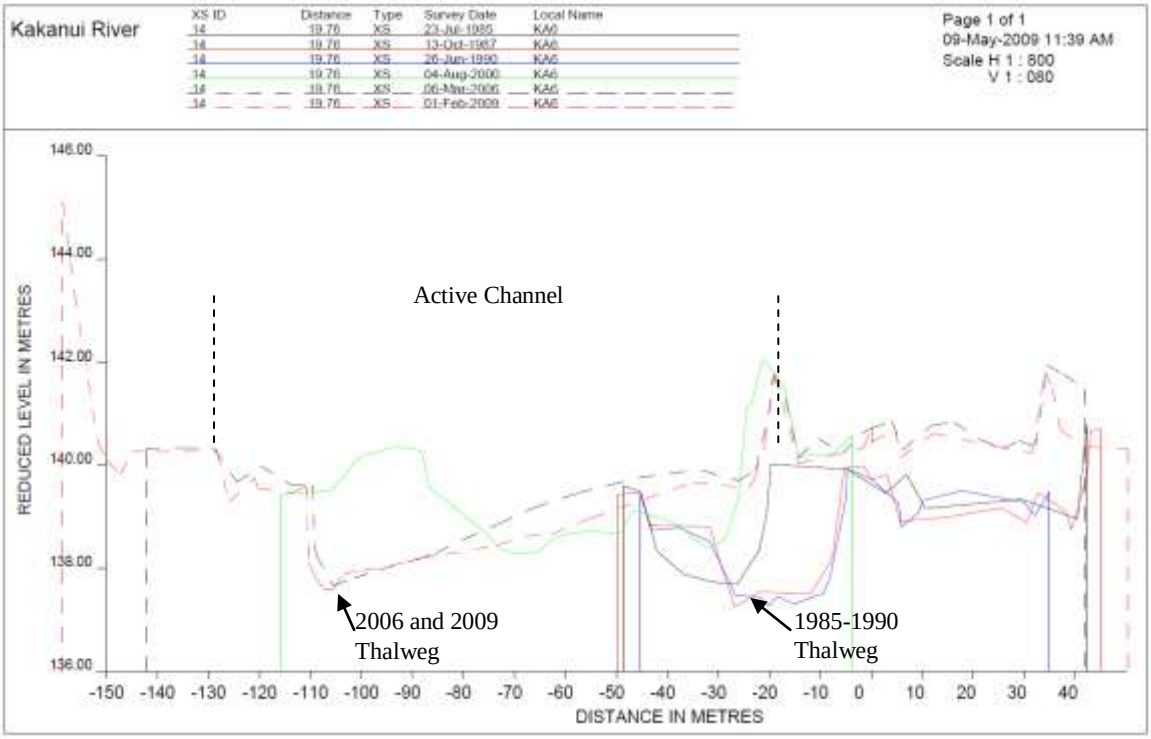

Figure 8.14 Cross-section KA6, looking downstream.

8.15 Cross-section KA7

Cross-section KA7 is located approximately 20.36km upstream of the Kakanui River mouth. Figure 8.15 shows a plot of cross-section KA7 for the 1985, 1987, 1990, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 41m. Mean bed level analysis shows that this location has experienced net degradation of 0.99m between 1985 and 2009 (refer Table 3.2). Over this survey period the bed has continually degraded with the deepest part of the channel now moving toward the centre of the active channel, away from the true left.

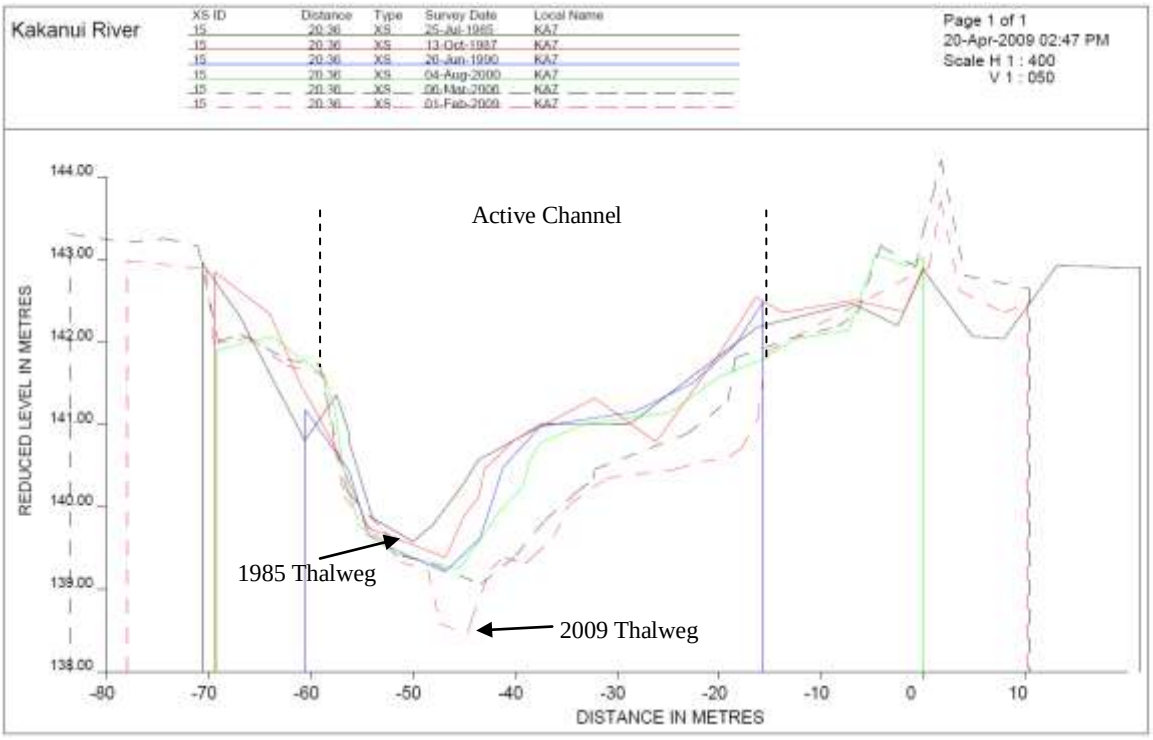

Figure 8.15 Cross-section KA7, looking downstream.

8.16 Cross-section KA8

Cross-section KA8 is located approximately 20.91km upstream of the Kakanui River mouth. Figure 8.16 shows a plot of cross-section KA8 for the 1985, 1987, 1990, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 176m. Mean bed level analysis shows that this location has experienced net aggradation of 0.11m between 2006 and 2009 (refer Table 3.2); further bank erosion on the true left has occurred however aggradation of the bed has also occurred which accounts for the increase in mean bed level over this period.

Over the entire survey period, since 1985, the channel has changed significantly with erosion of the left and right banks and shifting of the river across the channel.

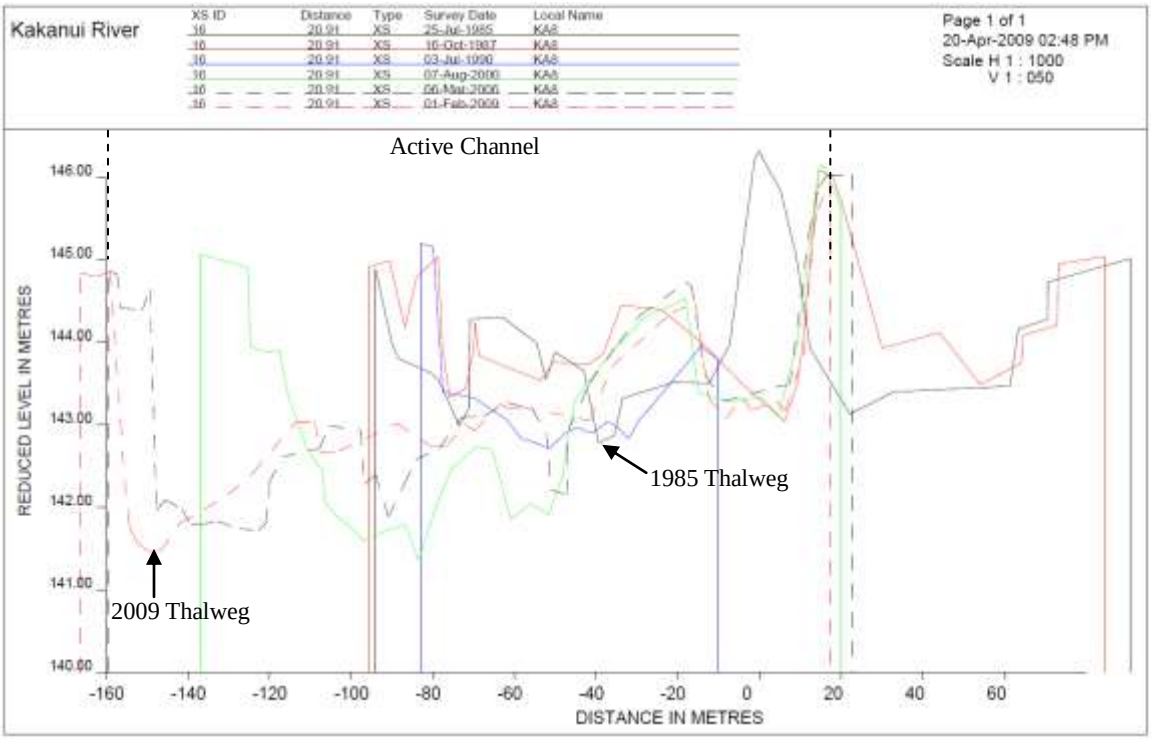

Figure 8.16 Cross-section KA8, looking downstream.

8.17 Cross-section KA9

Cross-section KA9 is located approximately 21.57km upstream of the Kakanui River mouth. Figure 8.17 shows a plot of cross-section KA9 for the 1985, 1987, 1990, 2000, 2006 and 2009 surveys.

The active channel is located toward the true left of the cross-section and has a width of 110m. Mean bed level analysis shows that this location has experienced net degradation of 0.32m between 2000 and 2009 (refer Table 3.2).

Over a short section of the channel mean bed level analysis of all the previous surveys shows net degradation of 1.01m between 1985 and 2009 with movement of the channel from the true right to the true left. Over the entire survey period, since 1985, the channel has changed significantly with erosion of the left and right banks and shifting of the river across the channel.

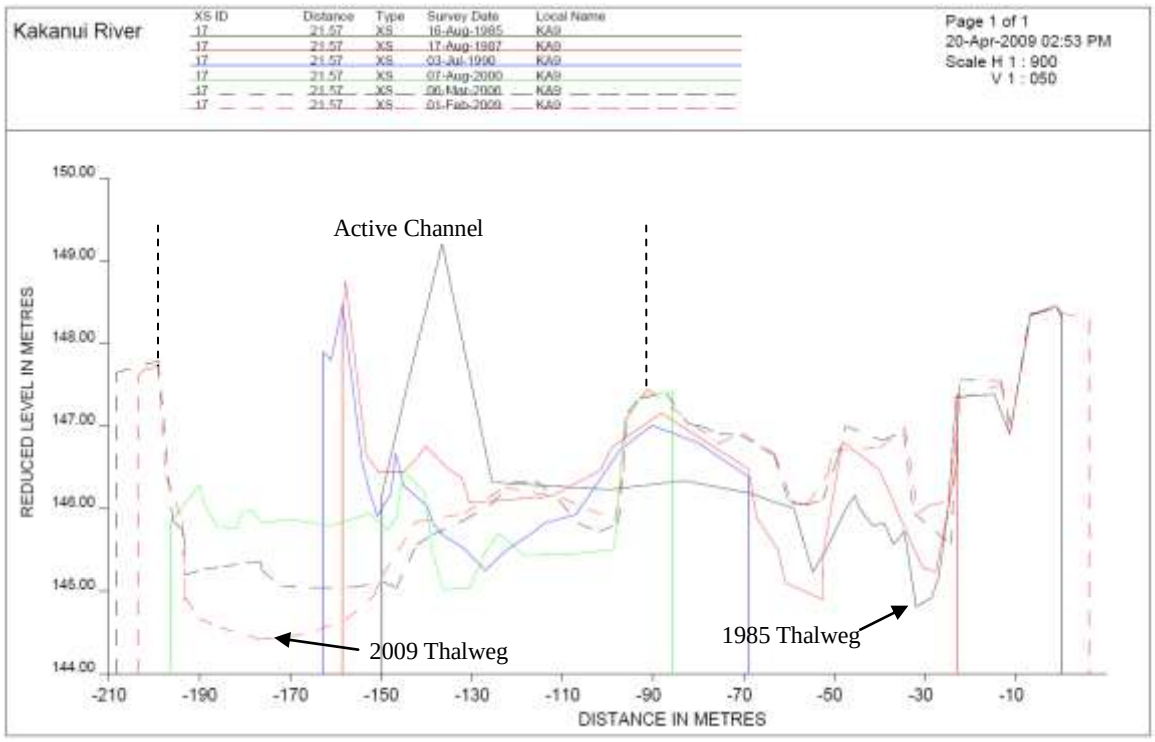

Figure 8.17 Cross-section KA9, looking downstream.

8.18 Cross-section KA10

Cross-section KA10 is located approximately 22.46km upstream of the Kakanui River mouth. Figure 8.18 shows a plot of cross-section KA10 for the 1985, 1987 (August and October), 1990, 2000, 2006 and 2009 surveys.

The active channel is located toward the true left of the cross-section and has a width of 99m. Mean bed level analysis shows that this location has experienced net degradation of 0.82m between 1985 and 2009 (refer Table 3.2). The active channel has widened and deepened over this period, with the most significant change occurring between 1990 and 2000 with degradation of the mean bed level of 0.90m.

Analysis of aerial photographs, dating back to the 1950's, show that the channel has straightened through this reach with the establishment of more vegetation.

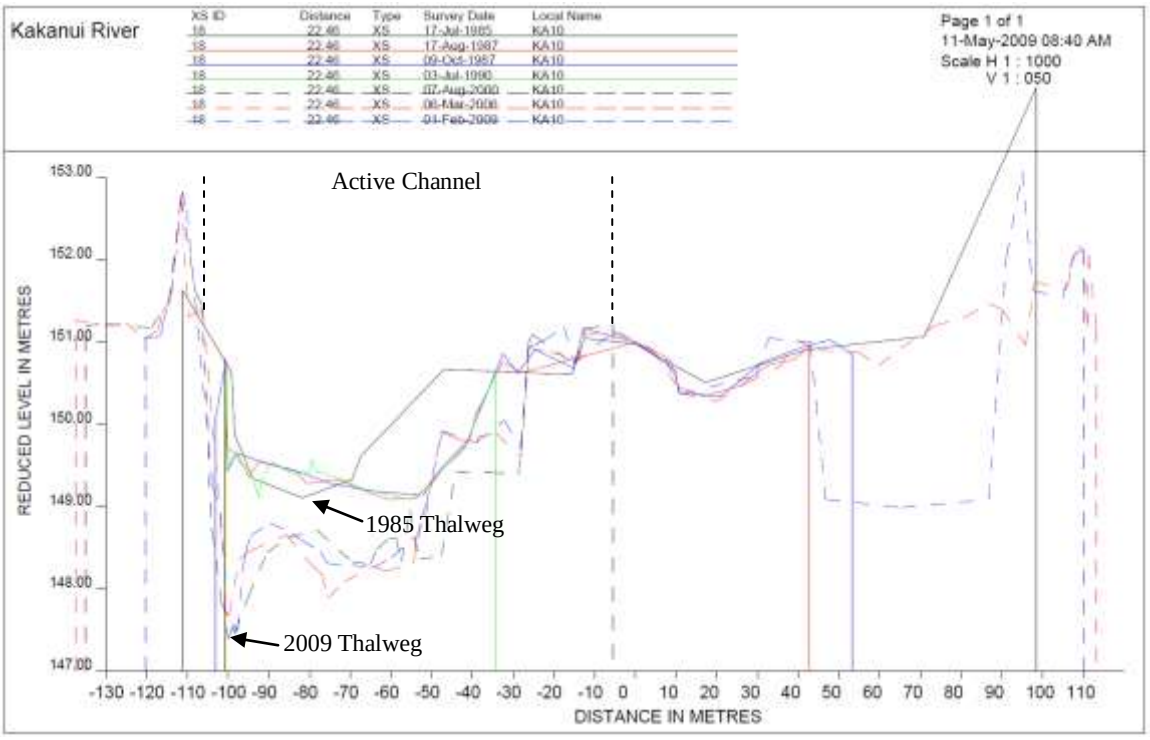

Figure 8.18 Cross-section KA10, looking downstream.

8.19 Cross-section KA11

Cross-section KA11 is located approximately 22.98km upstream of the Kakanui River mouth at the confluence with Kauru River. Figure 8.19 shows a plot of cross-section KA11 for the 1985, 1987, 1990, 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 265m. Mean bed level analysis shows that this location has experienced net degradation of 0.73m between 1985 and 2009 (refer Table 3.2). The most significant change at this location has been erosion of the true right bank as a result of the Kauru River entering the Kakanui.

Between 1985 and 1990 the channel was concentrated on the true left but shifted toward the true right between 1990 and 2000. The bed has lowered over the entire survey period.

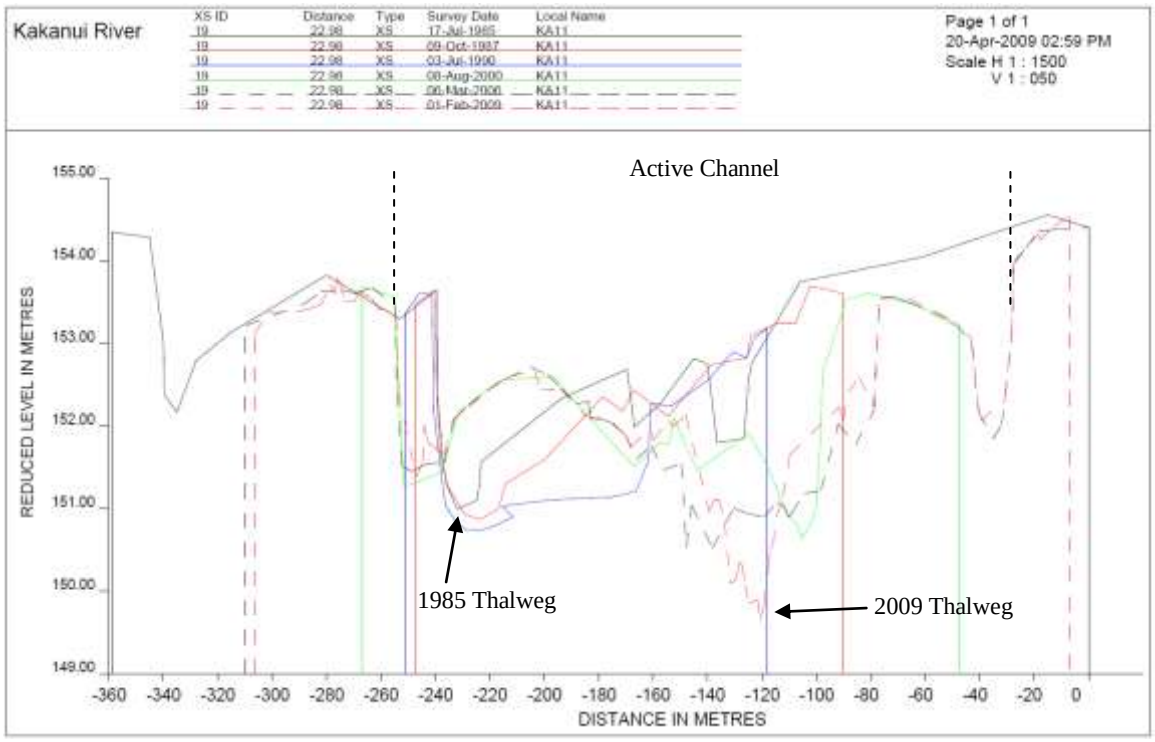

Figure 8.19 Cross-section KA11, looking downstream.

8.20 Cross-section KA14

Cross-section KA14 is located approximately 24.04km upstream of the Kakanui River mouth. Figure 8.20 shows a plot of cross-section KA14 for the 1987, 1990, 2000, 2006 and 2009 surveys.

The active channel is located across the full extent of the cross-section and has a width of 121m. Mean bed level analysis shows that this location has experienced net degradation of 0.28m between 1985 and 2009 (refer Table 3.2). The active channel has widened over this period with erosion of the true right bank.

In 2000, two channels existed on either side of a gravel island. The true right channel has since aggraded and the main flow path has established itself on the true left.

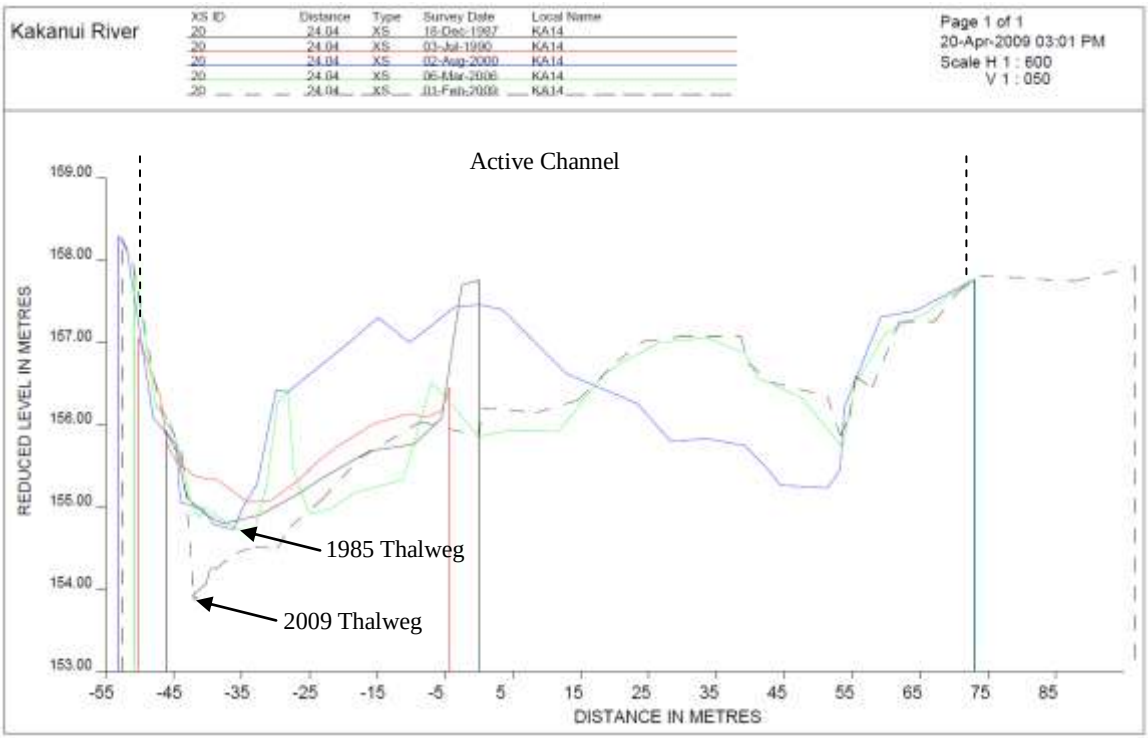

Figure 8.20 Cross-section KA14, looking downstream.

8.21 Cross-section KA15

Cross-section KA15 is located approximately 25.58km upstream of the Kakanui River mouth. Figure 8.21 shows a plot of cross-section KA15 for the 1987, 2000, 2006 and 2009 surveys.

The active channel is located toward the true left of the cross-section and has a width of 40m. Mean bed level analysis shows that this location has experienced net degradation of 0.13m between 1987 and 2009 (refer Table 3.2). The river is a single thread channel through this reach and the banks have remained relatively stable with small deepening of the channel on the true right.

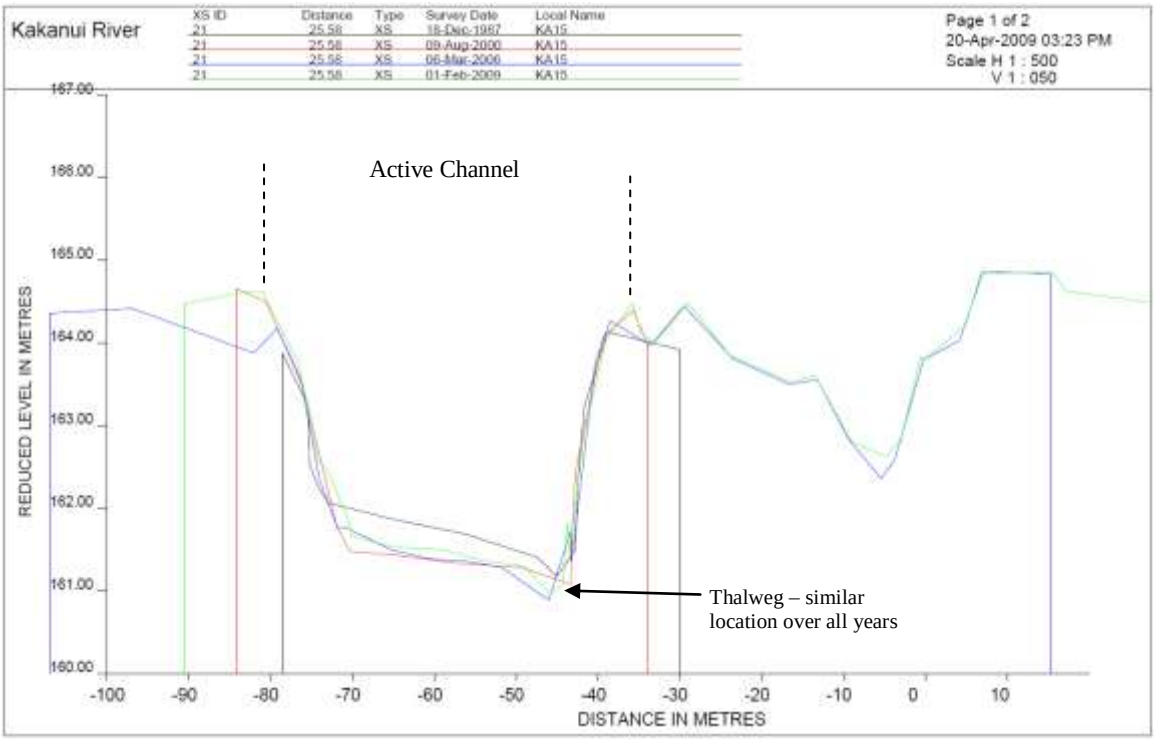

Figure 8.21 Cross-section KA15, looking downstream.

8.22 Cross-section KA36

Cross-section KA36 is located approximately 26.92km upstream of the Kakanui River mouth. Figure 8.22 shows a plot of cross-section KA36 for the 2000, 2006 and 2009 surveys.

The active channel is located across the full extent of the cross-section and has a width of 69m. Mean bed level analysis shows that this location has experienced net aggradation of 0.05m between 2000 and 2009 (refer Table 3.2). The banks of this reach and the bed have remained relatively stable over the survey period.

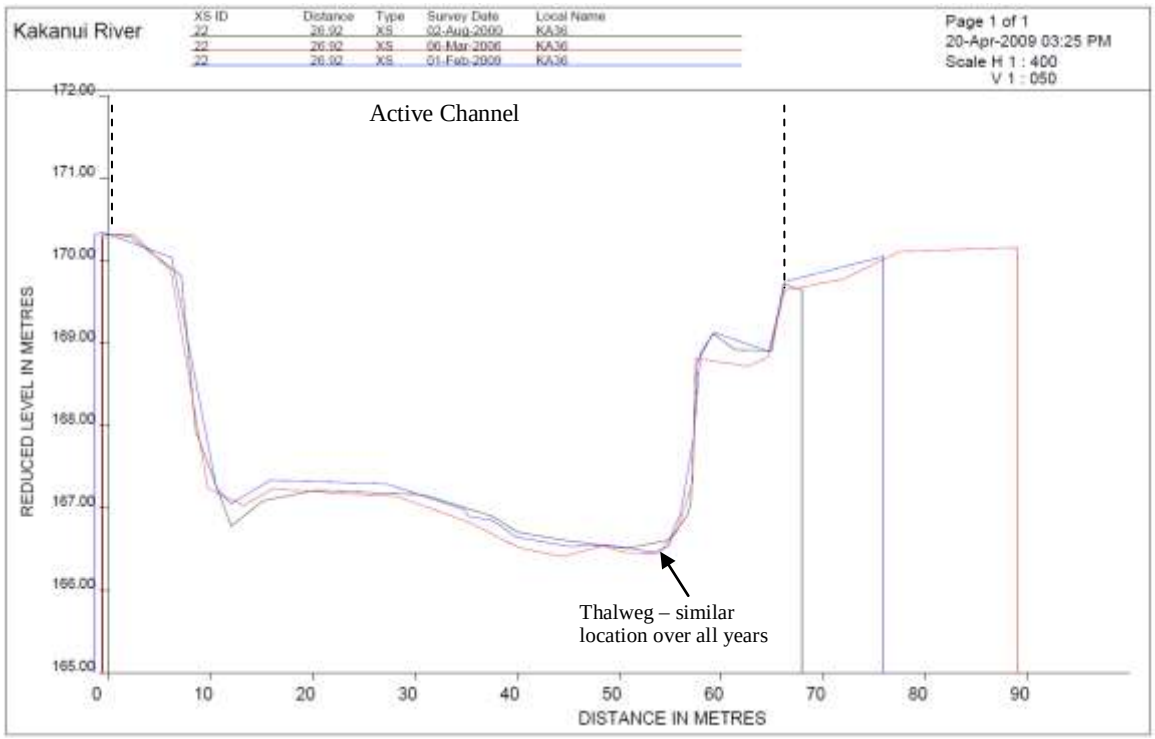

Figure 8.22 Cross-section KA36, looking downstream.

8.23 Cross-section KA102

Cross-section KA102 is located approximately 28.64km upstream of the Kakanui River mouth at Fuschia Creek Road Bridge. Figure 8.23 shows a plot of cross-section KA102 for the 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 60m. Mean bed level analysis shows that this location has experienced net aggradation of 0.02m between 2000 and 2009 (refer Table 3.2). The banks of this reach have remained relatively stable with small change of the bed level and profile over the survey period.

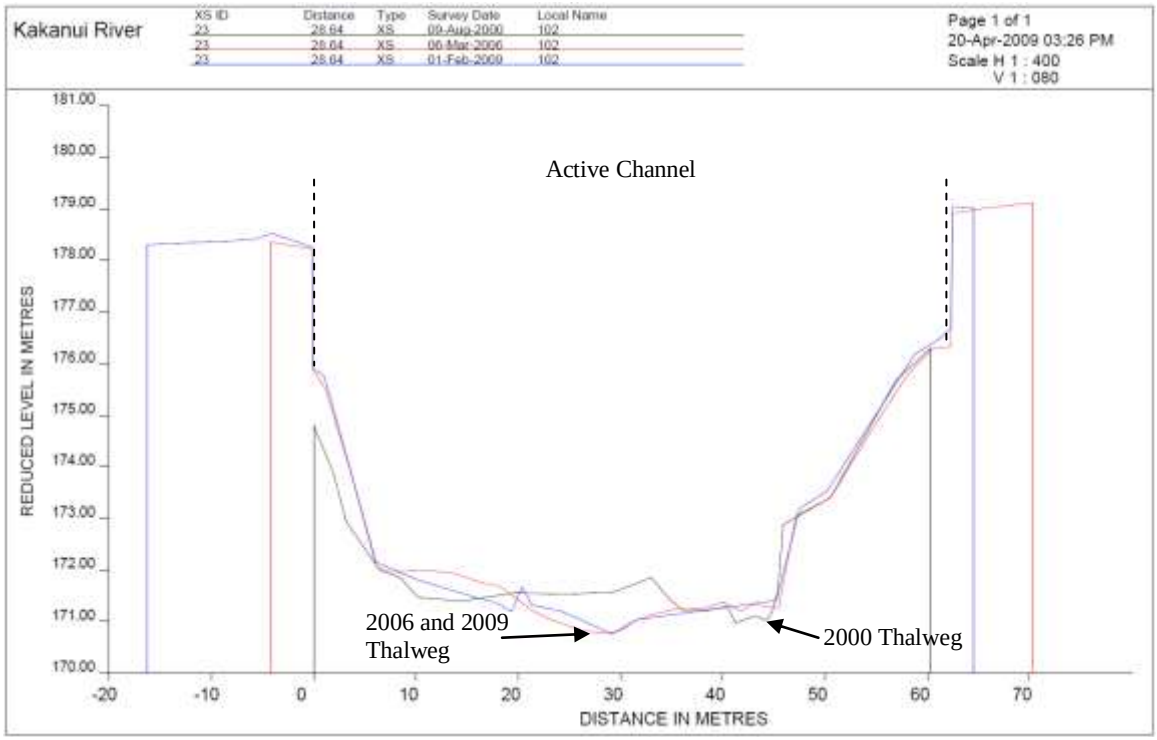

Figure 8.23 Cross-section KA102, looking downstream.

8.24 Cross-section KA37

Cross-section KA37 is located approximately 28.64km upstream of the Kakanui River mouth. Figure 8.24 shows a plot of cross-section KA37 for the 2000, 2006 and 2009 surveys.

The active channel is located in the middle of the cross-section and has a width of 60m. Mean bed level analysis shows that this location has experienced net aggradation of 0.06m between 2000 and 2009 (refer Table 3.2). The banks of this reach have remained relatively stable with small change of the bed level and profile over the survey period.

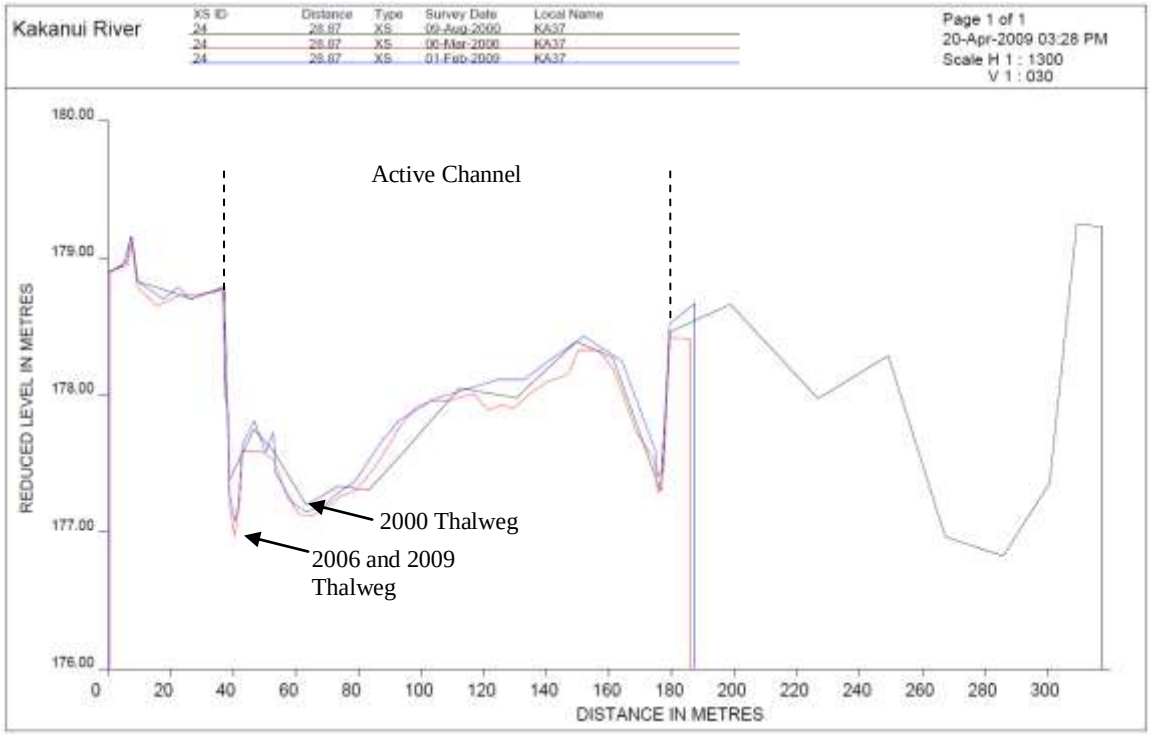

Figure 8.24 Cross-section KA37, looking downstream.

8.25 Cross-section K1B

Cross-section K1B is located approximately 0.35km upstream of the Kauru River mouth. Figure 8.25 shows a plot of cross-section K1B for the 2001, 2005 and 2008 surveys.

The active channel is located toward the true left of the cross-section and has a width of 136m. Mean bed level analysis shows that this location has experienced net degradation of 0.03m between 2005 and 2008 (refer Table 3.4). However, larger changes to the bed level have occurred during this period in localised areas of the channel due to migration of the main channel. Over a shorter section of the channel, mean bed level analysis of all the previous surveys shows net degradation of 0.64m between 2001 and 2008. The largest change in bed level occurred between 2001 and 2005 which may be a result of significant flood events in January 2002 and July 2005.

This section of the river appears to have become less braided since the earliest aerials of 1955. A secondary channel use to run along the base of a terrace on the true left approximately 100m from the true left end of the current cross-section line (Figure 2.5A). This channel was evident in aerial photographs taken in 1955 but had diminished and become vegetated by the 1996 aerial photographs.

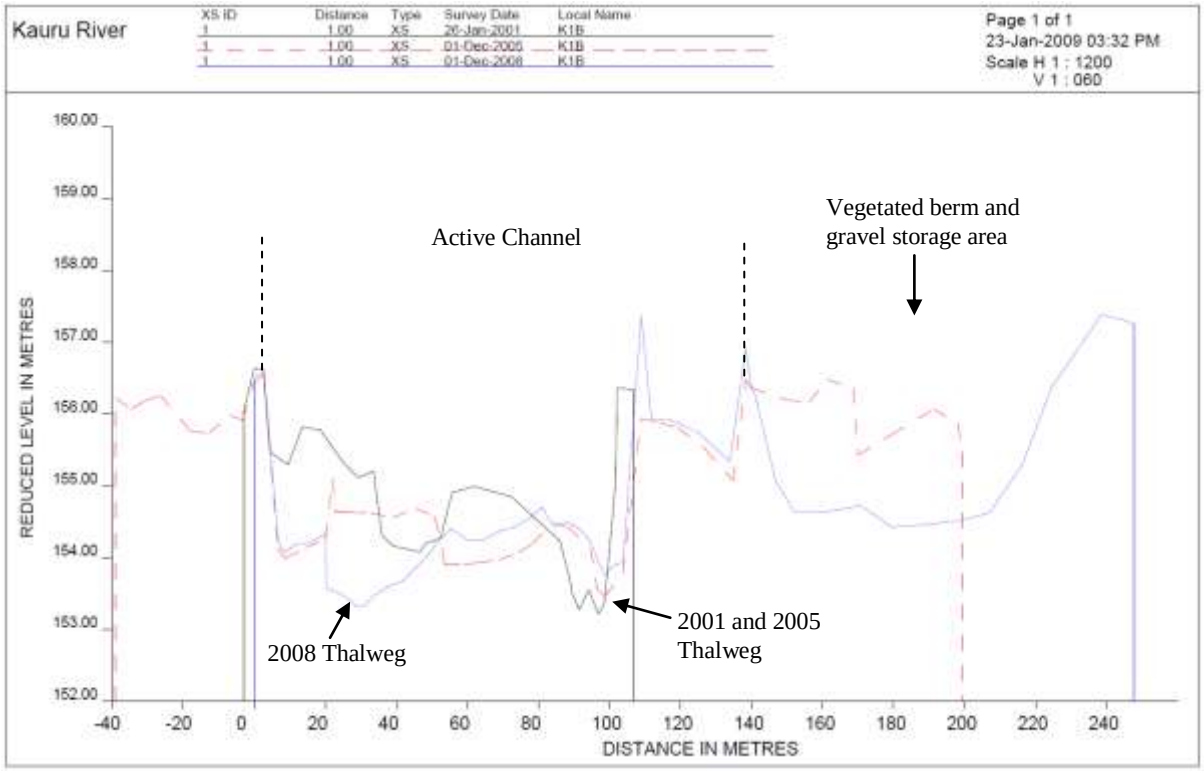

Figure 8.25 Cross-section K1B, looking downstream.

8.26 Cross-section K1A

Cross-section K1A is located approximately 0.59km upstream of the Kauru River mouth at the Kakanui Valley Road Bridge. Figure 8.26 shows a plot of cross-section K1A for the 1987, 1990, 2001, 2002, 2005 and 2008 surveys.

The active channel is located across the full extent of the cross-section and has a width of 60m. Mean bed level analysis shows that this location has experienced net degradation of 0.83m between 1987 and 2008 (refer Table 3.4). Over this period the bed has lowered and the main flow path has become established on the true right of the channel. The mean bed level has experienced net aggradation of 0.10m between 2005 and 2008. Between the 2001 and 2002 surveys a significant flood event occurred in early January 2002 flood. The bed degraded significantly between these survey periods and the channel shifted to the true right of the bed.

A comparison of earlier aerial photographs dating back to 1955 shows that the channel has narrowed underneath the bridge over time (Figure 2.5A) which may be due to past changes in bridge construction.

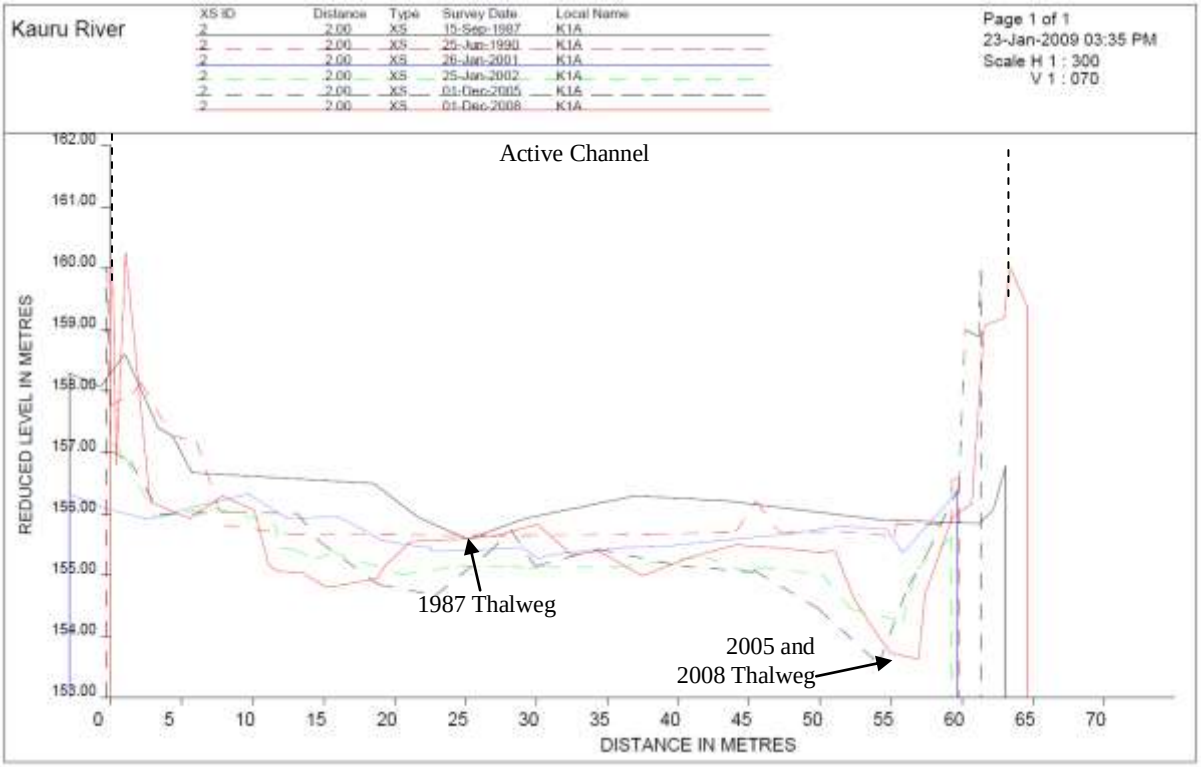

Figure 8.26 Cross-section K1A, looking downstream.

8.27 Cross-section K1

Cross-section K1 is located approximately 0.74km upstream of the Kauru River mouth. Figure 8.27 shows a plot of cross-section K1 for the 1978, 1987, 1990, 2001, 2005 and 2008 surveys.

The active channel is located in the middle of the cross-section and has a width of 99m. Mean bed level analysis shows that this location has experienced net aggradation of 0.04m between 2001 and 2008 (refer Table 3.4). Between 2001 and 2005 the net bed level degraded by 0.20 m with erosion of the true right beach and another in-stream island. Between 2005 and 2008 the channel has aggraded, resulting in an increase in net bed level of 0.24m.

Over a shorter section of the channel, mean bed level analysis of all the previous surveys shows net degradation of 0.83m between 1978 and 2008. The active channel has also widened over this period with bank erosion on the true left of about 15m since 1978, and erosion of the true right bank of about 35m since 1978.

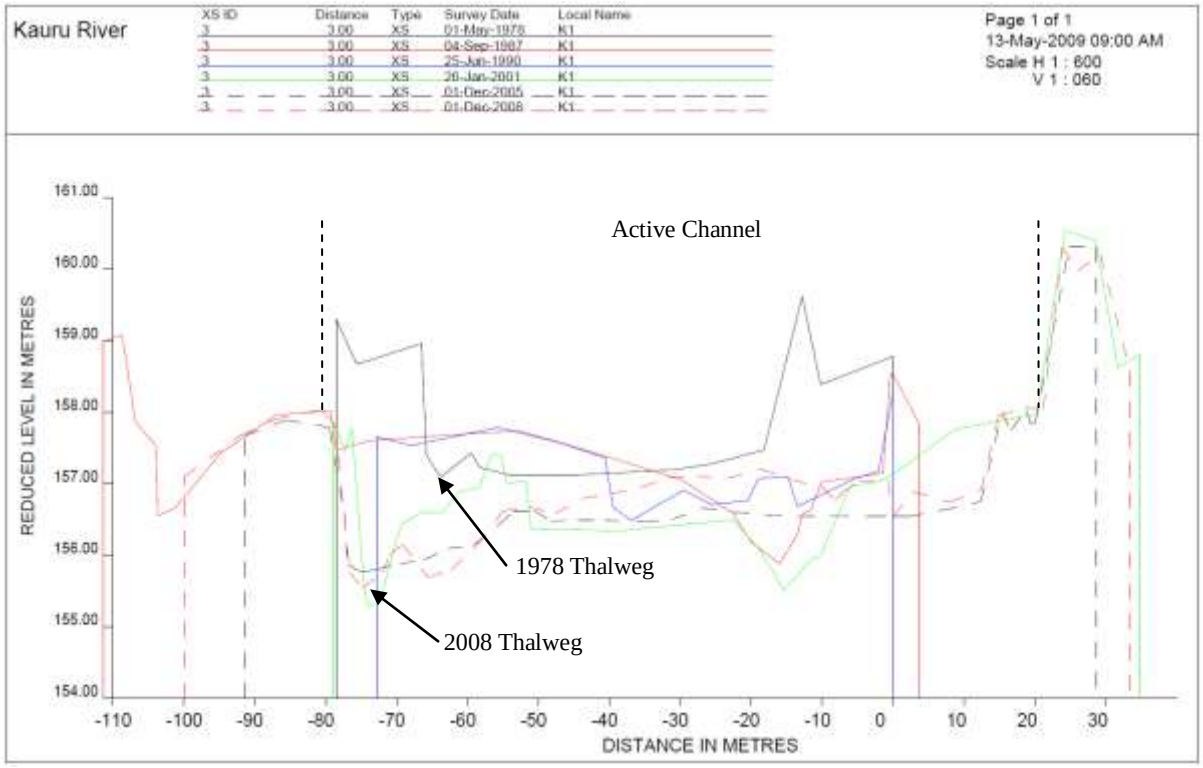

Figure 8.27 Cross-section K1, looking downstream.

8.28 Cross-section K2

Cross-section K2 is located approximately 0.87km upstream of the Kauru River mouth. Figure 8.28 shows a plot of cross-section K2 for the 1978, 1987, 1990, 2001, 2005 and 2008 surveys.

The active channel is located in the middle of the cross-section and has a width of 116m. Mean bed level analysis shows that this location has experienced net aggradation of 0.15m between 2001 and 2008 (refer Table 3.4). The section has experienced several phases of aggradation and degradation as well as lateral movement of the channel. A large episode of degradation occurred between 1990 and 2001 with the net mean bed level (of the active channel at that time) lowering by more than 1m. Since 2005 there has been significant aggradation of the bed but erosion of the true right bank by more than 10m.

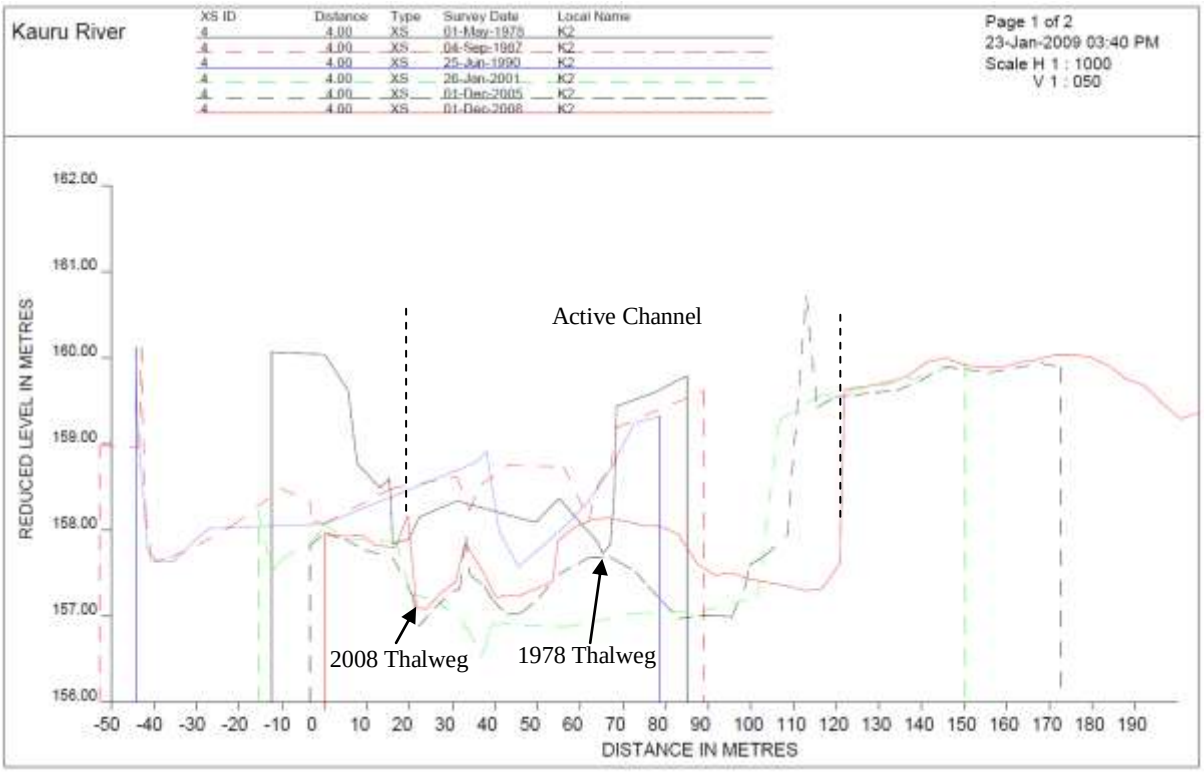

Figure 8.28 Cross-section K2, looking downstream.

8.29 Cross-section K3

Cross-section K3 is located approximately 0.97km upstream of the Kauru River mouth. Figure 8.29 shows a plot of cross-section K3 for the 1978, 1987, 1990, 2001, 2005 and 2008 surveys.

The active channel is located in the middle of the cross-section and has a width of 144m. Mean bed level analysis shows that this location has experienced net aggradation of 0.01m between 2005 and 2008 (refer Table 3.4); aggradation has occurred across the middle of the bed with deepening of the channel on the true right.

The bed of the channel was at its lowest in 2001 and has aggraded since this time. Bank erosion on the left and right has occurred as well as significant shifting of the river across the channel.

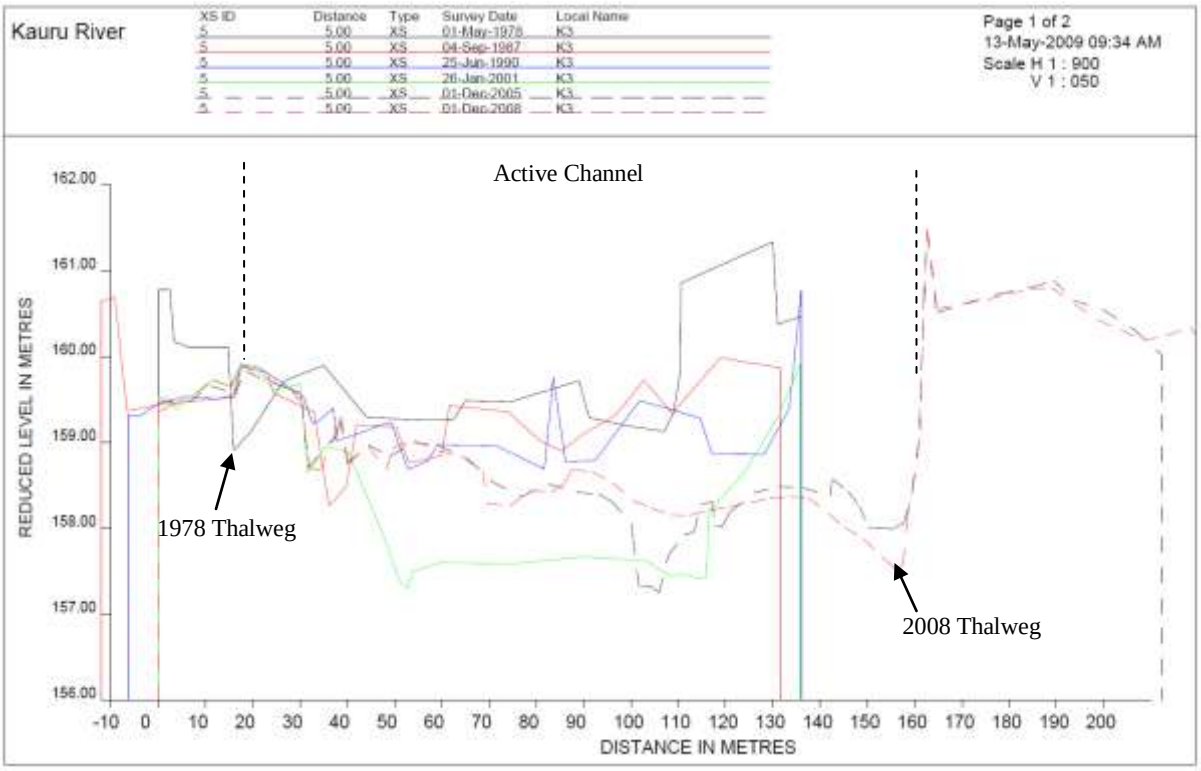

Figure 8.29 Cross-section K3, looking downstream.

8.30 Cross-section K3A

Cross-section K3A is located approximately 1.15km upstream of the Kauru River mouth. Figure 8.30 shows a plot of cross-section K3A for the 1978, 1987, 1990, 2001, 2005 and 2008 surveys.

The active channel is located toward the true left of the cross-section and has a width of 123m. Mean bed level analysis shows that this location has experienced net degradation of 0.92m between 1990 and 2008 (refer Table 3.4). Most degradation of the bed occurred between 1990 and 2001. The channel is deepening on the true right with aggradation on the beach of the current active channel.

There has been some change on the flood plain of this section since the earliest survey in 1978, probably as a result of high flows redistributing sediment across this area during flood events.

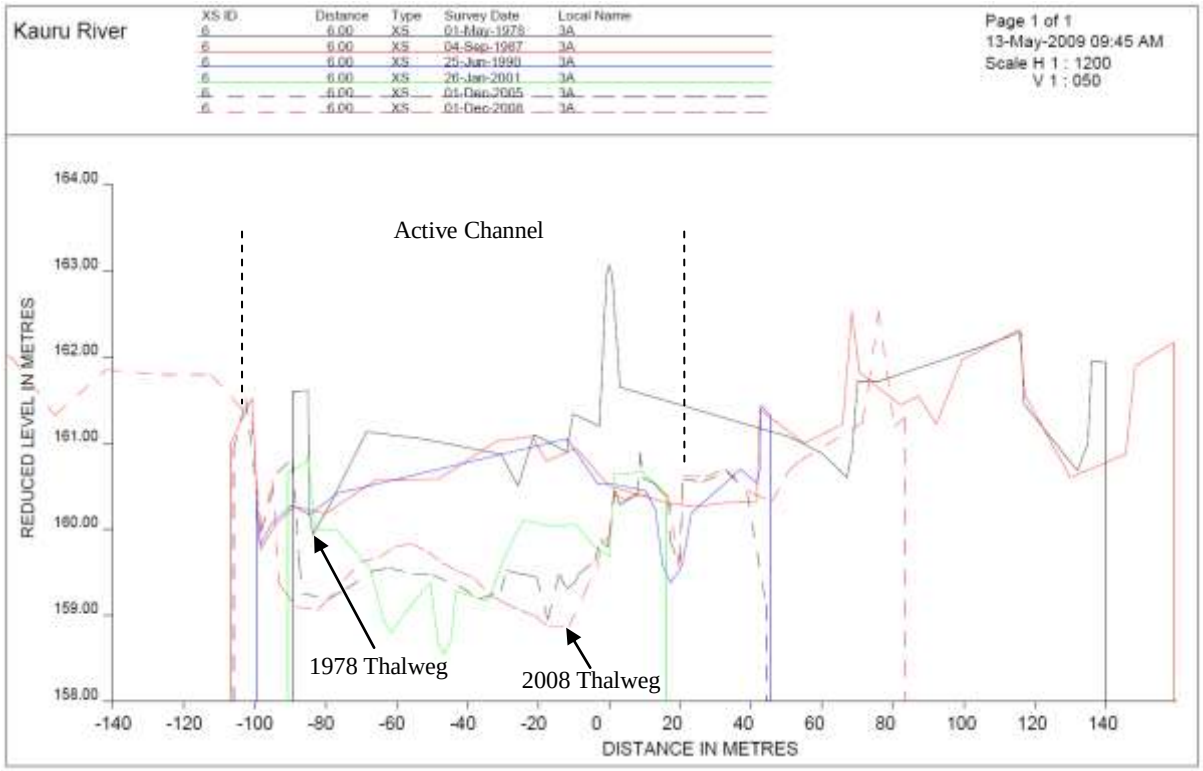

Figure 8.30 Cross-section K3A, looking downstream.

8.31 Cross-section K3B

Cross-section K3B is located approximately 1.34km upstream of the Kauru River mouth. Figure 8.31 shows a plot of cross-section K3B for the 1978, 1987, 2001, 2005 and 2008 surveys.

The active channel is located toward the true left of the cross-section and has a width of 116m. Mean bed level analysis shows that this location has experienced net aggradation of 0.35m between 2005 and 2008 (refer Table 3.4). Over the entire survey period, since 1978, the bed level has lowered significantly and migrated laterally toward the true left. As the channel has established itself on the true left some bank erosion has occurred as well as deepening of the channel on this side.

While the channel has deepened between 2005 and 2008, aggradation of a beach toward the true right has occurred which accounts for the rise in the mean bed level.

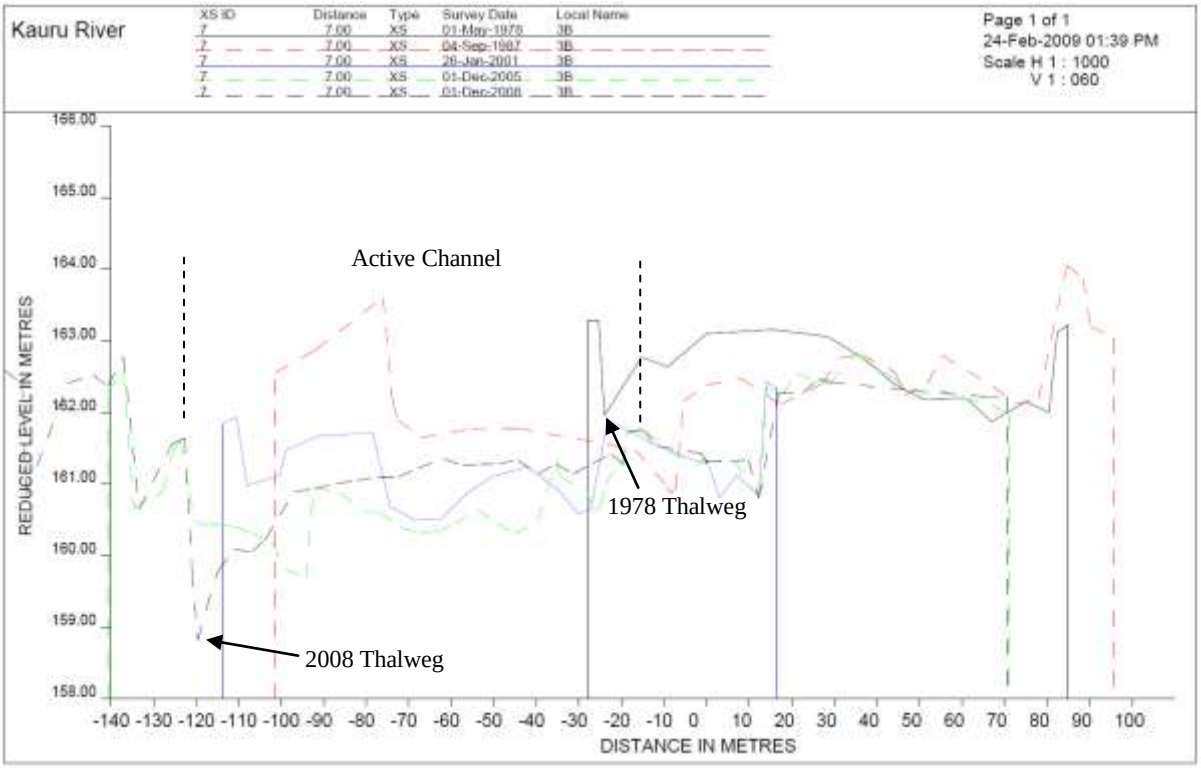

Figure 8.31 Cross-section K3B, looking downstream.

8.32 Cross-section K4

Cross-section K4 is located approximately 1.77km upstream of the Kauru River mouth. Figure 8.32 shows a plot of cross-section K4 for the 2005 and 2008 surveys.

The active channel is located in the middle of the cross-section and has a width of 218m. Mean bed level analysis shows that this location has experienced net degradation of 0.36m between 2005 and 2008 (refer Table 3.4). The net degradation is a result of erosion of a beach on the true left of the active channel; the main flow path is now concentrated on this side of the bed. The banks have remained relatively stable in this reach.

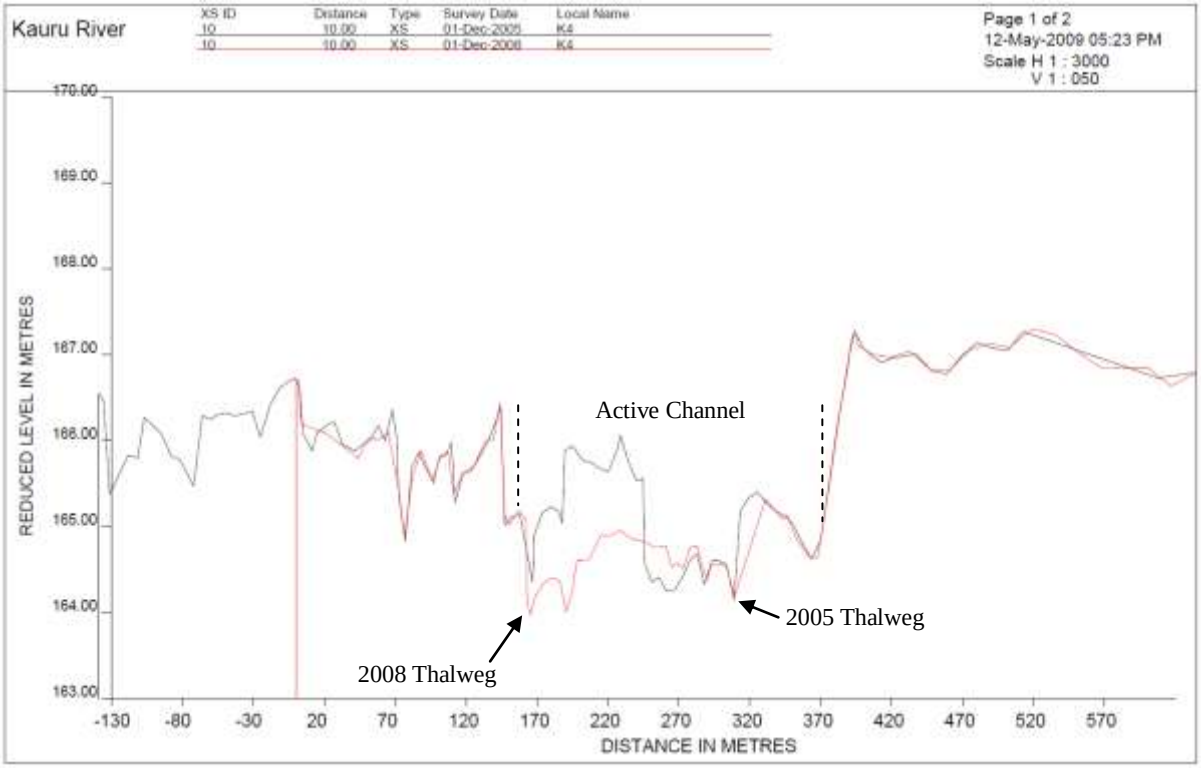

Figure 8.32 Cross-section K4, looking downstream.

8.33 Cross-section K5

Cross-section K5 is located approximately 2.41km upstream of the Kauru River mouth. Figure 8.33 shows a plot of cross-section K5 for the 2005 and 2008 surveys.

The active channel is located toward the true left of the cross-section and has a width of 159m. Mean bed level analysis shows that this location has experienced net aggradation of 0.27m between 2005 and 2008 (refer Table 3.4). The banks of the active channel have remained relatively stable with aggradation occurring on either side of a deepening channel.

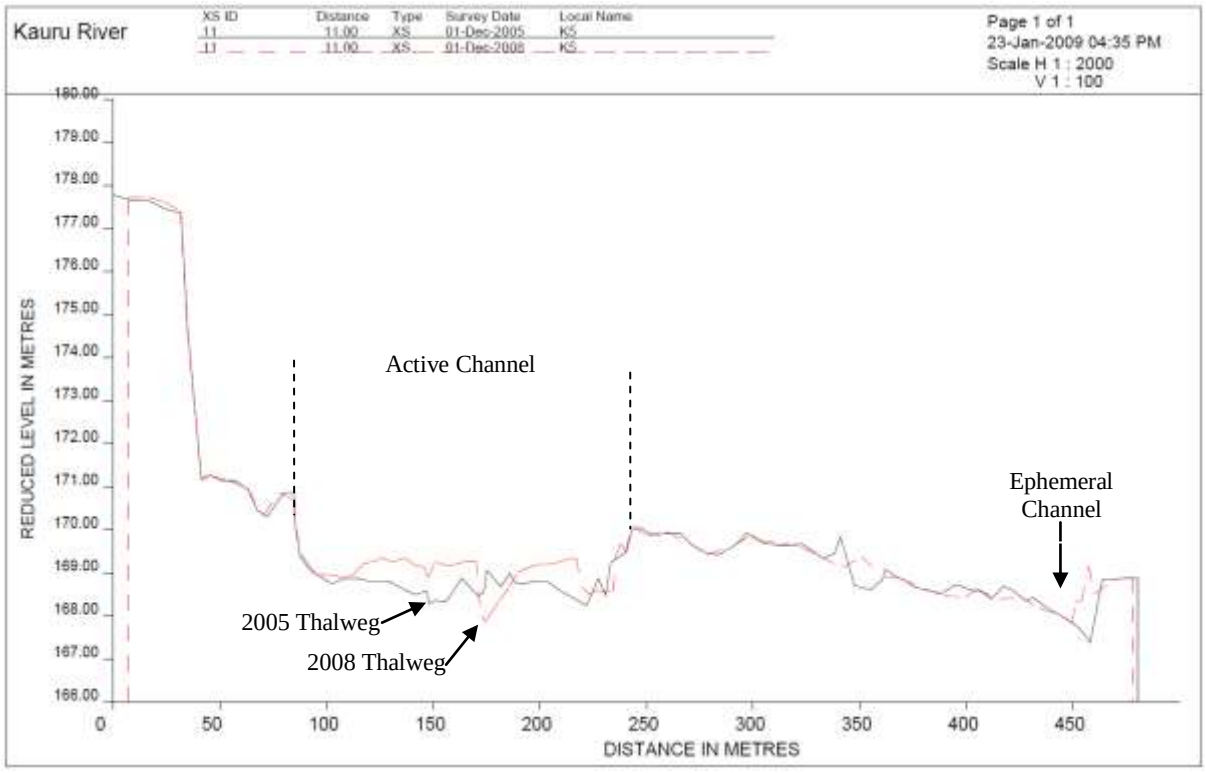

Figure 8.33 Cross-section K5, looking downstream.

8.34 Cross-section K10A

Cross-section K10A is located approximately 3.02km upstream of the Kauru River mouth at Kininmont Ford. Figure 8.34 shows a plot of cross-section K10A for the 2001, 2005 and 2008 surveys.

The active channel is located in the middle of the cross-section and has a width of 74m. Mean bed level analysis shows that this location has experienced net aggradation of 0.08m between 2001 and 2008 (refer Table 3.4). The bed profile in this reach appears to be flattening out.

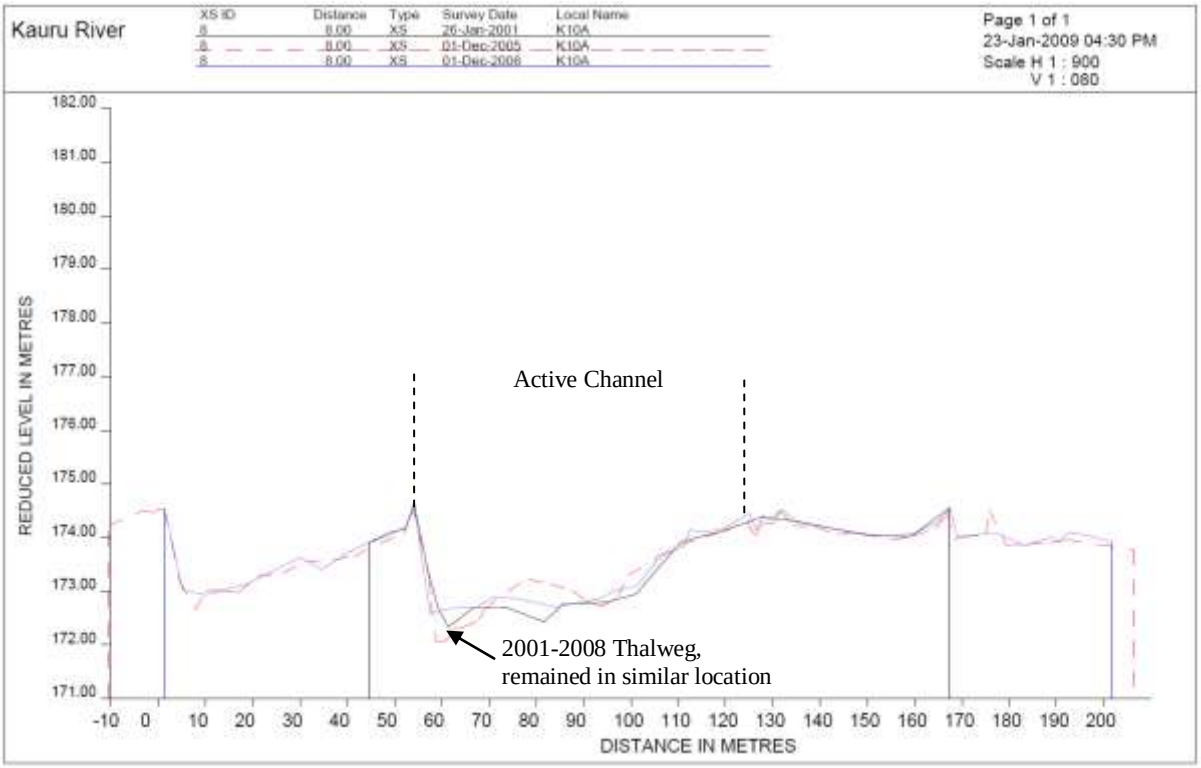

Figure 8.34 Cross-section K10A, looking downstream.

8.35 Cross-section K6

Cross-section K6 is located approximately 4.58km upstream of the Kauru River mouth. Figure 8.35 shows a plot of cross-section K6 for the 2005 and 2008 surveys.

The active channel is located in the middle of the cross-section and has a width of 75m. Mean bed level analysis shows that this location has experienced net aggradation of 0.02m between 2005 and 2008 (refer Table 3.4). While the true left bank has remained relatively stable, some degradation of the true right beach has occurred, as well as aggradation of a backwater on this side.

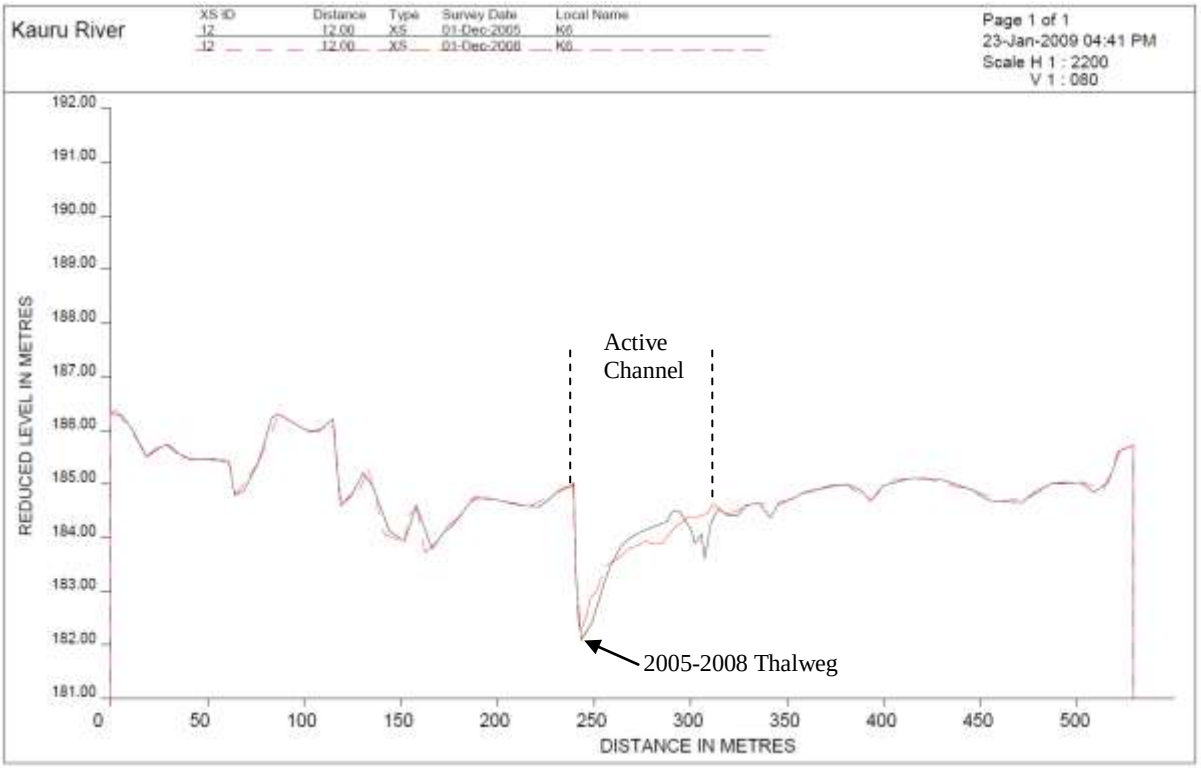

Figure 8.35 Cross-section K6, looking downstream.

8.36 Cross-section K7

Cross-section K7 is located approximately 5.60km upstream of the Kauru River mouth. Figure 8.36 shows a plot of cross-section K7 for the 2005 and 2008 surveys.

The active channel is located in the middle of the cross-section and has a width of 113m. Mean bed level analysis shows that this location has experienced net degradation of 0.25m between 2005 and 2008 (refer Table 3.4). Over the extent of the active channel the bed has lowered and the main channel has deepened slightly.

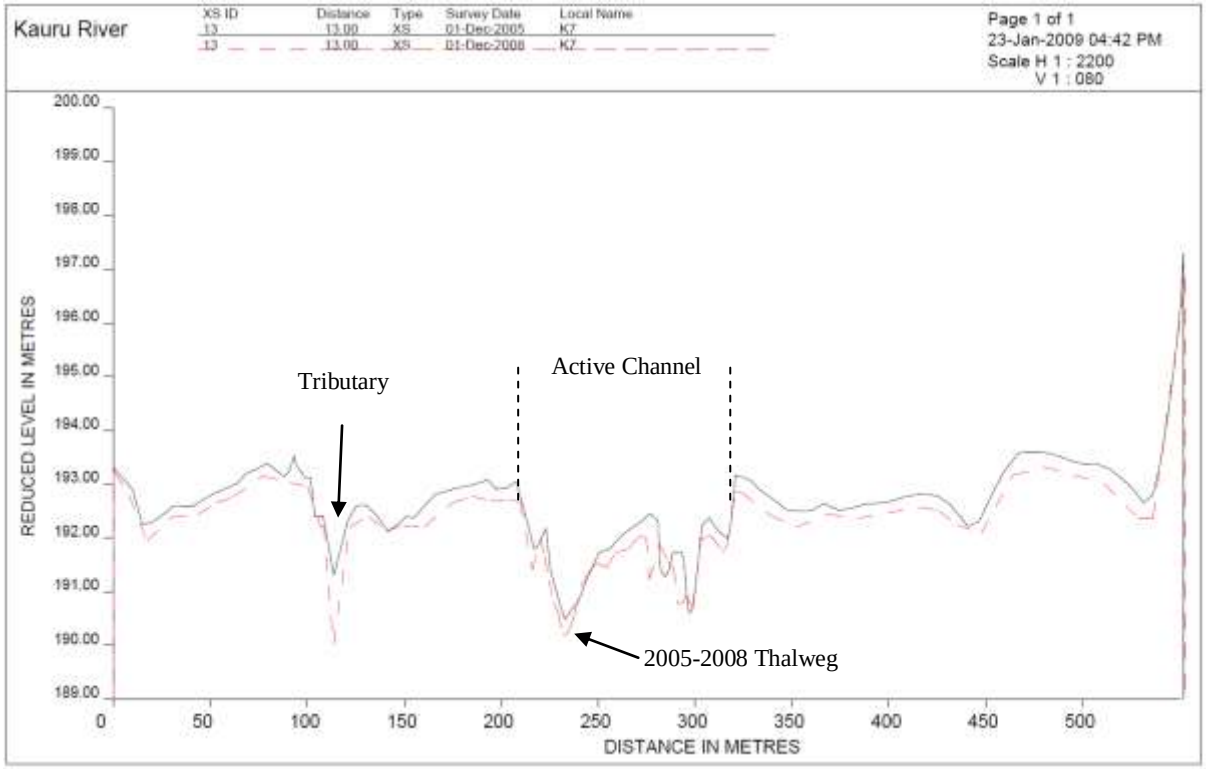

Figure 8.36 Cross-section K7, looking downstream.

8.37 Cross-section K21

Cross-section K21 is located approximately 6.46km upstream of the Kauru River mouth at Kauru Hill Road Bridge. Figure 8.37 shows a plot of cross-section K21 for the 2001, 2005 and 2008 surveys.

The active channel is located across the full extent of the cross-section and has a width of 40m. Mean bed level analysis shows that this location has experienced net degradation of 0.03m between 2001 and 2008 (refer Table 3.4). Some aggradation occurred between 2001 and 2005, with degradation of the bed occurring between 2005 and the latest survey in 2008.

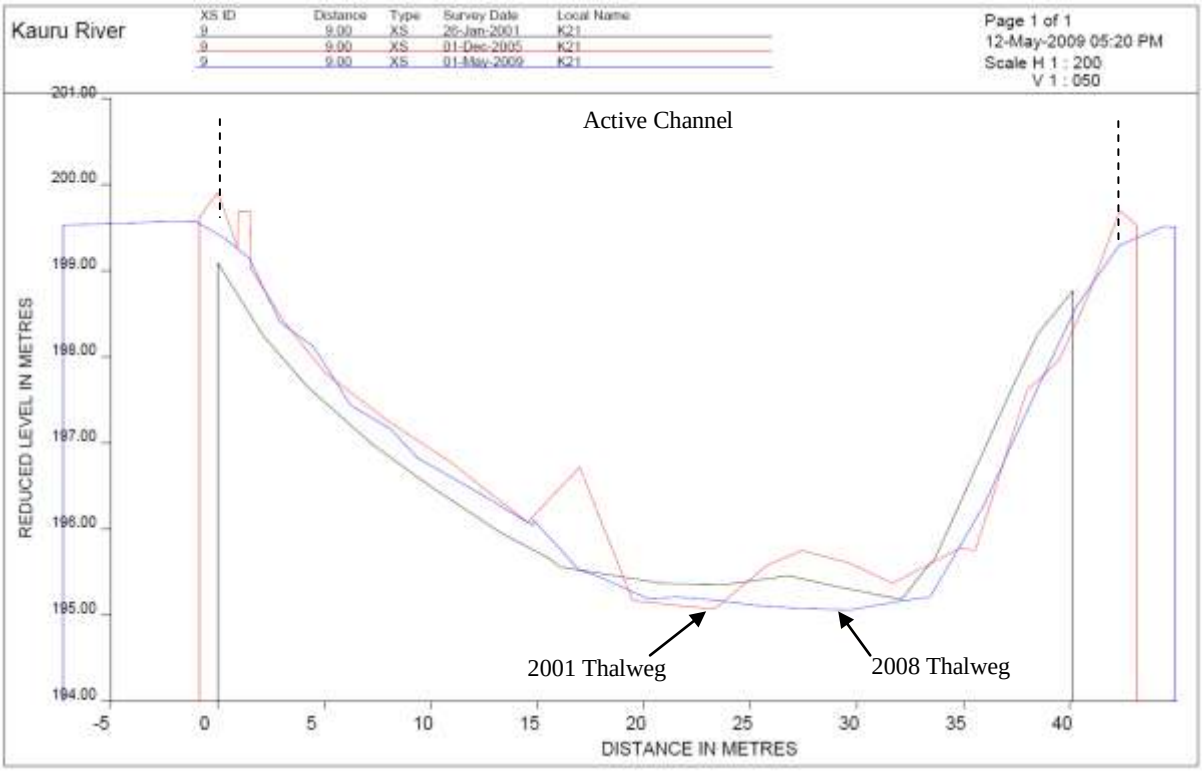

Figure 8.37 Cross-section K21, looking downstream.