


River-cross-section data from the Wakapuaka and Whangamoa rivers: analysis of data 2007–2012 and implications for managing gravel extraction

Envirolink Medium Advice Grant 1272-NLCC69





Landcare Research
Manaaki Whenua

River-cross-section data from the Wakapuaka and Whangamoa rivers: analysis of data 2007–2012 and implications for managing gravel extraction (Envirolink Medium Advice Grant 1272-NLCC-69)

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Contents

Summary

Project and Client

- Nelson City Council (NCC) asked Landcare Research to undertake an analysis of river-cross-section data collected from the Wakapuaka and Whangamoa rivers between 2007 and 2102 and to provide advice about the implications for gravel management.
- The work was completed between February and May 2013.

Objectives

- Analyse all available information including NCC annual bed-level surveys, historical orthophoto coverage, consented gravel extraction, any other historical information and hydrological records.
- Map changes in morphology of the Wakapuaka and Whangamoa rivers to identify areas of gravel aggradation and erosion.
- Interpret this information to underpin development of a gravel management plan.

Methods

- All available river cross section data was compiled from data supplied by NCC.
- Changes in mean bed levels (MBL) and gravel volume (using the end-area method) were calculated in Hilltop Reach software and manually in a spreadsheet.
- Areas of gravel beaches were mapped from digital orthophotos (2009 and 2012 for the Wakapuaka River, 2009 for the Whangamoa River) supplied by NCC.
- Data on gravel extraction was compiled from information in NCC's Regional Resource Consents spreadsheet and NCS database.

Results

- There remain some errors in data compilation for some cross sections, which need to be corrected before Hilltop Software will generate reliable estimates of MBL and gravel volume changes. The manual calculations provide the most reliable estimates of MBL and gravel volume changes at present.
- The network of cross sections provides a good coverage of the gravel beaches within both rivers and the data is a good basis for understanding their aggradational and degradational behaviour, although the spacing of cross sections is very wide compared with channel width (especially on the Whangamoa River).
- The gravel beaches are persistent features of river morphology rather than migrating features, over the short term (5–10 years), but the magnitude of observed bank erosion and channel avulsion suggests there will be a longer-term (multi-decadal) evolution of the channel involving meander migration and avulsion.

- All cross sections have fluctuated between aggradation and degradation with none showing a consistent trend across all survey dates, reflecting the episodic movement of gravel through these river systems.
- Over the 5-year survey period mean bed levels have been declining overall in both rivers: −0.045 m in the Wakapuaka and −0.035 m in the Whangamoa, a trend that is also occurring in other rivers throughout the Nelson-Tasman region.
- Between 2007 and 2012 there was a net loss of 21 927 m^3 of gravel in the Wakapuaka River and 4878 m^3 in the Whangamoa River. The Wakapuaka River had a net loss of gravel from 2007 to 2011 (29673 m^3) and a net gain only between 2011 and 2012 (7746 m^3). By contrast the Whangamoa River had a net gain of gravel from 2007 to 2008 (4399 m^3) and a net loss from 2008 to 2012 (9277 m^3). The differences between the Wakapuaka and Whangamoa rivers may be a result of the wider cross-section spacing in the Whamgamoa as it is expected that the gravel load in the Whangamoa would be higher than in the Wakapuaka.
- Some cross sections have had severe bank erosion (c. 5–10 m of bank retreat within a year) but the timing has varied from location to location. At these sites there is little evidence that build-up of gravel has put pressure on the opposite bank and caused the erosion.

Conclusions

- The present network of cross sections provides a good basis for understanding bed-level and river dynamics, although they may be more widely spaced than is desirable in the Whangamoa.
- Hilltop Software provides a very efficient platform for storing and analysing river-cross-section data but some basic requirements for archiving and quality assurance need to be met to ensure reliable results.
- Over the 5-year survey period mean bed levels have been declining overall in both rivers, suggesting a cautious approach to gravel extraction is needed. Areas of net aggradation have been identified in both rivers that would be more suitable for gravel extraction than others. The annual and net changes in gravel volumes are quite small suggesting only small volumes should be extracted.

Recommendations

- The procedure for archiving and analysis of river-cross-section data in Hilltop Software should be improved to retain all information from raw survey data to final analysis. Some training in the use of Hilltop Reach would assist in this.
- Annual surveys should be continued to build a longer-term understanding of river and channel dynamics, and the surveys should be tied to a common datum to underpin analysis in Hilltop Software.
- Recording of the location, timing and amounts of gravel extracted under resource consents should be improved.

1 Introduction

In 2007 Nelson City Council (NCC) asked Landcare Research to design a practical, low-cost method for monitoring bed-level trends in Nelson rivers (Basher 2007). Twenty-two cross sections were established in the Wakapuaka River between the coast and Hira, and 10 cross sections in the Whangamoa River between the coast and State Highway 6 (Figures 1 and 2). Details of the data collection and compilation methodology are described in Basher (2007, 2012). The cross sections have been surveyed annually since 2007 by NCC staff, and data are compiled into Hilltop Software for archiving and analysis.

In December 2011 a severe storm affected parts of the Nelson Region, causing large floods in the Wakapuaka and Whangamoa rivers. At the Wakapuaka-at-Hira gauging site the flood recurrence interval was only 6.3 years; however, much of the rain was concentrated near the coast and in the lower reaches of the river the flood was probably much larger – 370 mm of rain was recorded in 2 days at Hira. The effects of the storm included localised extensive landsliding, flooding, gravel deposition and changes in river morphology.

NCC have sought advice from Landcare Research on the operation of the river-cross-section network to provide guidance for future gravel extraction, river and flood control measures to protect infrastructure. Some advice was provided under a small Envirolink grant (Basher 2012), which included a recommendation to complete an analysis of the 2012 survey data and review results of all previous surveys for errors, to underpin decisions about the need for gravel extraction. Funding was received from the Ministry of Business, Innovation and Employment under an Envirolink Medium Advice Grant (1272-NLC-C69) to complete an analysis of all the river-cross-section survey data and other information relevant to understanding river dynamics and the potential impacts of gravel extraction. The work was completed between February and May 2013.

2 Background

Many regional councils maintain river-cross-section monitoring networks that are used to inform both flood management and gravel extraction management (Basher 2006a). Until 2007 NCC undertook no quantitative bed-level monitoring in any of the local rivers and relied on expert judgement to assess how much gravel could be extracted. At the time the council was concerned that resource consents were being issued for gravel extraction without an adequate understanding of the available gravel resource, and there was uncertainty about the amounts of gravel being extracted (Basher 2007).

Extraction of gravel from riverbeds is used both to source aggregate for roading and construction and to improve the flood carrying capacity of rivers by reducing the build-up of gravel within the flood channel. Overextraction of gravel can destabilise channels and banks and affect the ecological functioning of rivers, particularly if undertaken at the wrong time, or in the wrong place, or in a way that damages the riverbed or margins. Similarly, underextraction, in areas of long-term gravel build-up, can also destabilise channels and worsen flooding problems. For these reasons regional councils exercise controls on the amounts and the process of extraction, to avoid or reduce adverse effects.

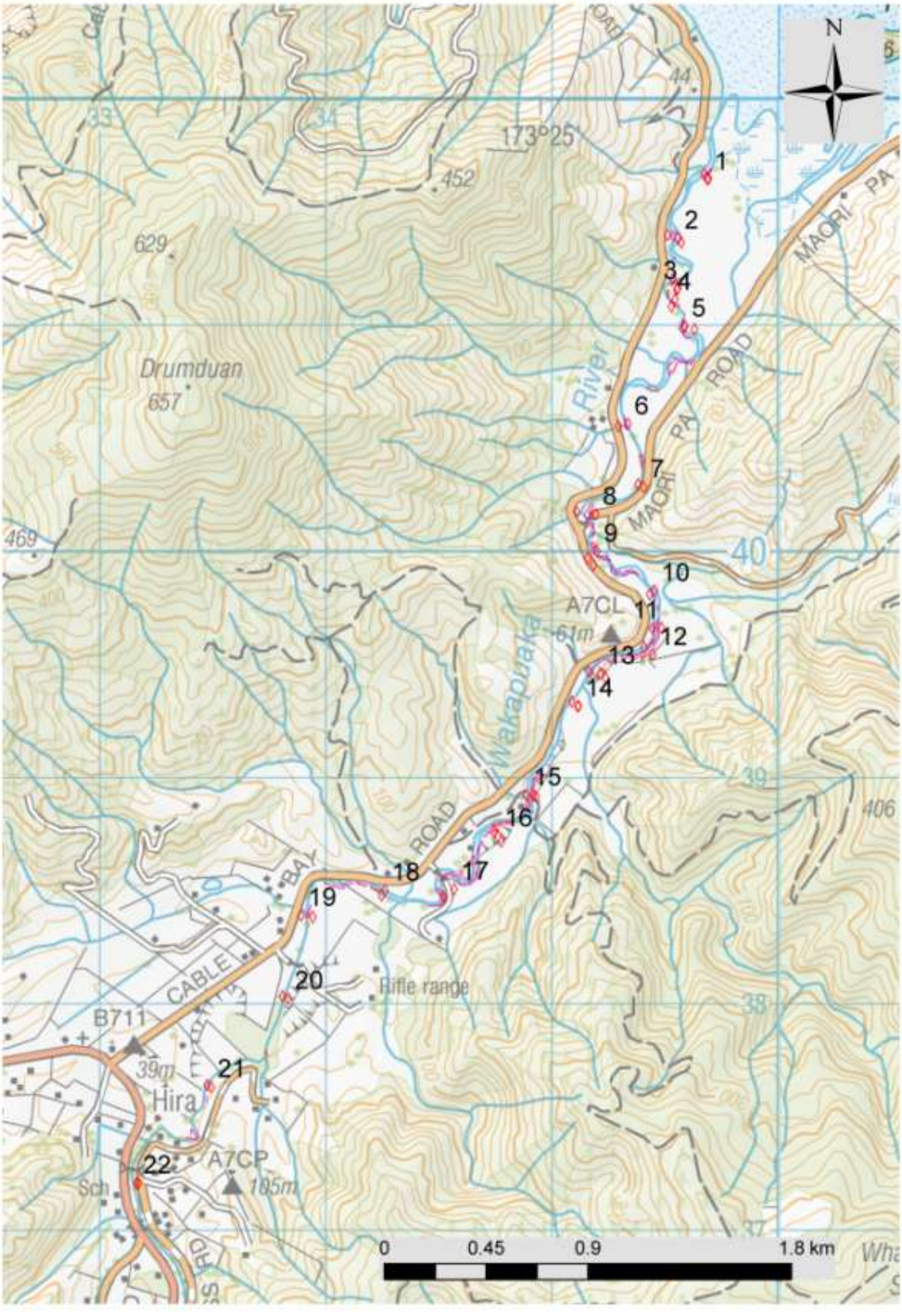


Figure 1 Location of surveyed river cross sections in the Wakapuaka River, Nelson region.

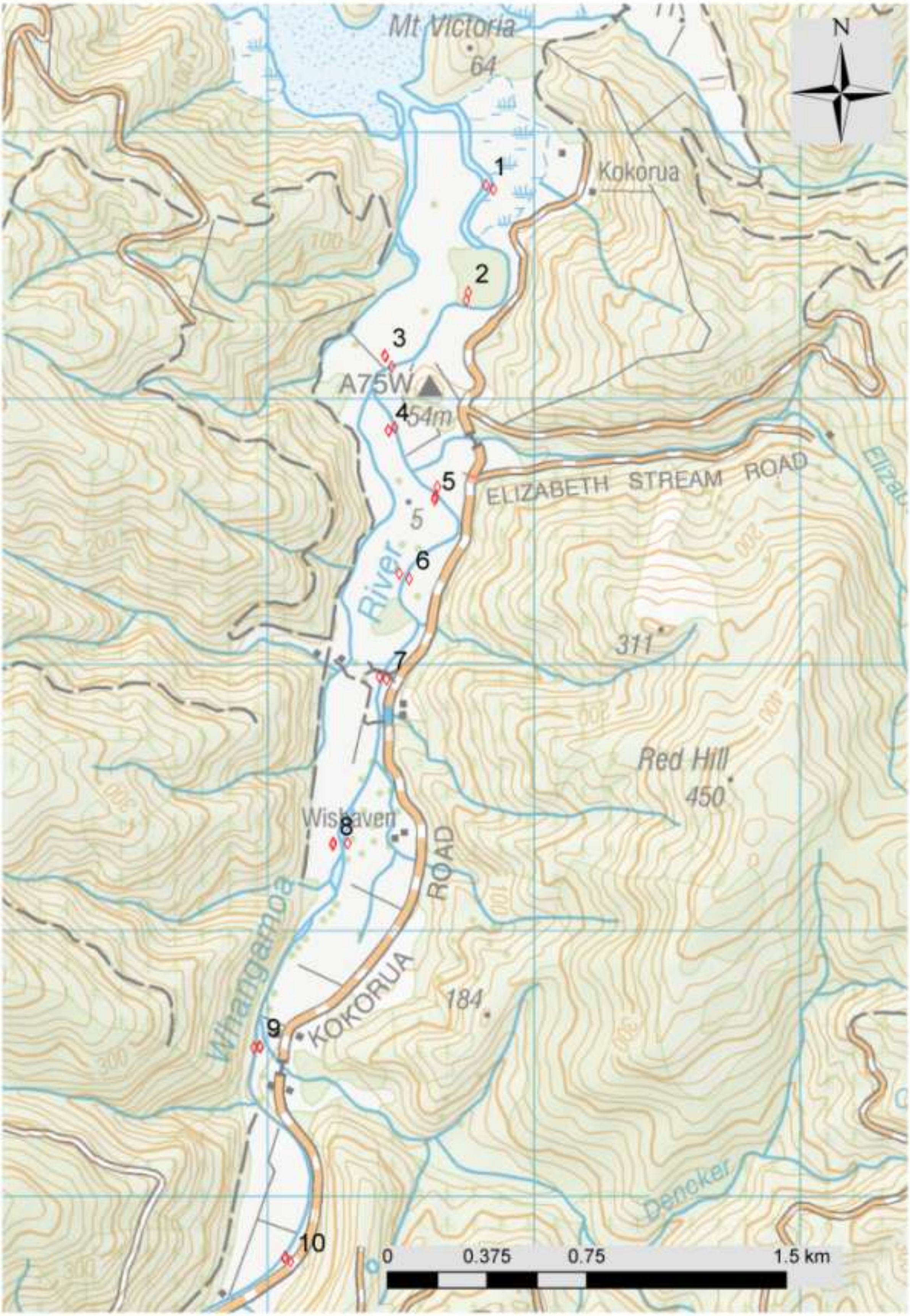


Figure 2 Location of surveyed river cross sections in Whangamoa River, Nelson region.

River-cross-section surveys are the primary tool used by most regional councils to monitor riverbed levels and to help set gravel extraction limits. Knowing the gravel transport rate is fundamental to setting gravel extraction limits, whether it is applied to estimating aggradation rates in natural long-term deposition zones or assessing the proportion of gravel transport rate that can be sustainably harvested without causing significant downstream effects. While river-cross-section surveys provide direct data on trends in mean bed levels, they do have limitations for calculating changes in gravel storage in the river and gravel transport rate (Basher 2006a). Calculation of gravel storage changes from cross-section data typically only gives a minimum estimate of the gravel transport rate, particularly when derived from relatively infrequent cross-section surveys (Fuller et al. 2003).

In a 2002 report for NCC Stocker recommended that gravel extraction be permitted on the basis of threshold for availability rather than an annual volume, and forestry operations be controlled to minimise delivery of gravel to rivers. He also identified the location of gravel beaches considered suitable for gravel extraction. Average gravel yield for Nelson rivers was estimated by Basher (2006b) as a proportion of suspended sediment yield. Assuming a gravel yield of 25% of the suspended sediment yield gave supply rates to the coast of about 1000 and 1500 m^3 for the Wakapuaka and Whangamoa rivers, respectively. These figures appeared to be of a similar magnitude to consented extractions, and there appeared to be no demonstrable evidence of overextraction (e.g. undermining of bridges or stopbanks), suggesting that current extraction rates were probably not excessively high. However, the amount of gravel extraction undertaken each year in Nelson City is poorly known, and the ability of NCC staff to source this information is poor because there is no system for consistently recording and retrieving it.

3 Objectives

- Analyse all information available, including NCC annual bed-level surveys, historical orthophoto coverage, consented gravel extraction and flood control works, any other historical information and hydrological records.
- Map changes in morphology of the Wakapuaka and Whangamoa rivers from historical aerial photography and ground surveys to identify areas of gravel aggradation and erosion.
- Interpret this information to underpin development of a gravel management plan that will guide and prioritise future resource decisions and assist landowners, gravel extractors and NCC to sustainably manage the gravel resource to help mitigate erosion and flooding.

4 Methods

All available river-cross-section data were compiled from data supplied by NCC, checked for errors (where benchmarks (BM) had been lost, surveyed length of cross sections had changed, or the orientation of survey lines had changed), and changes in mean bed levels (MBL) and gravel volume calculated in the Reach module of Hilltop Software (using the end-area method). Manual checks were also undertaken to compare with the Hilltop Software calculations to derive recommendations for the use of Hilltop. The results presented in Section 5 are derived from the manual calculations and the reasons for this are outlined in Section 5.3.

NCC supplied orthorectified aerial photographs of the Wakapuaka for 1999, 2001, 2009, 2010 and 2012 and the Whangamoa in 1999 and 2009. Only the 2009 orthophotos covered the entire study reaches in both rivers and these were used to map all gravel beaches in ArcGIS. The 2012 orthophotos also covered the study reach in the Wakapuaka River and were used to map all beaches in 2012 and to assess changes in beach location and extent. The 1999 and 2001 orthophotos of the Wakapuaka were partial coverages but combined could be used for analysis of the whole reach. Similarly the 1999 orthophotos covered the Whangamoa Reach and were used to assess changes in beach location and extent. Mapping was completed at a scale of 1:500 to 1:1000 depending on the resolution of the orthophotos.

Data on gravel extraction were compiled from information supplied by NCC from their Regional Resource Consents spreadsheet and NCS database (Carl Jenkins, Paul Fisher pers. comm., April 2013). Gravel extraction returns are stored as comments in the Resource Consent file held in the NCS database and summary details of active and expired consents are listed on a Regional Resource Consent spreadsheet.

5 Results

Topographic plots for all cross sections are compiled in Appendix 1. Mean bed levels for each year for all cross sections are compiled in Appendices 2 and 3 and summarised in Tables 1 and 2. Trends in MBL and gravel volume changes through time are illustrated in Figures 3 to 6. Most cross sections have had relatively small changes in MBL and have fluctuated between aggradation and degradation. A small number of cross sections have changed little in the 5 years of monitoring.

There are a number of cross sections for which the data have been adjusted either because of (a) bank erosion and loss of BMs or (b) the development of deep pools that cannot be surveyed leading to errors in MBL calculation:

- Wakapuaka Cross Section 2: There was severe bank erosion between 2007 and 2008 resulting in loss of the left BM and considerable lengthening of the surveyed cross section. Earlier offsets have been adjusted using the location of the right BM.
- Wakapuaka Cross Section 3: There was severe bank erosion between 2010 and 2011 resulting in loss of the left BM and considerable lengthening of the surveyed cross section. Earlier offsets have been adjusted using the location of the right BM.

- Wakapuaka Cross Section 5: This cross section has not been measured full width since 2009 and it is unusable for MBL and gravel volume calculations since then. An alternative location should be surveyed.
- Wakapuaka Cross Section 15: The 2009 data overestimates MBL as there was a deep pool that could not be completely surveyed.
- Wakapuaka Cross Section 17: There was severe bank erosion between 2009 and 2010 resulting in loss of the left BM, channel avulsion and the subsequent surveys may have a slightly different orientation to the previous surveys. Earlier offsets have been adjusted using the location of the right BM.
- Wakapuaka Cross Section 22: There has been considerable aggradation on the right bank with burial of the BM with the result that MBLs are probably underestimated. A BM should be established higher on the right bank to avoid this problem.
- Whangamoa Cross Section 2: There has been severe bank erosion between 2011 and 2012 resulting in loss of the left BM, formation of a deep pool that was only partially surveyed (i.e. the MBL is lower than estimated) and lengthening of the surveyed cross section. Earlier offsets have been adjusted using the location of the right BM.

5.1 Mean bed level and gravel volume changes

5.1.1 Wakapuaka

Over the 5-year period MBL change over all cross sections averaged −0.045 m (Table 1). Average MBLs over the whole reach degraded in 2007–08 (−0.071 m), 2009–10 (−0.003 m) and 2010–11 (−0.023 m) and aggraded in 2008–09 (+0.004 m) and 2011–12 (+0.032 m). The largest change over all cross sections was in 2007–08 when the average MBL change was −0.071 m. Most of the change occurred at Cross Sections 2 and 5, which degraded by 0.8 and 0.4 m respectively caused by severe erosion of the left bank at Cross Section 2 (c. 10 m) and erosion of a beach on the right bank at Cross Section 5 (Figure 3). The greatest aggradation occurred between 2011 and 2012 with an average MBL increase of 0.032 m, probably caused by delivery of significant quantities of gravel in the December 2011 storm.

Table 1 Summary of bed level and gravel volume changes, Wakapuaka River

		2007–08	2008–09	2009–10	2010–11	2011–12	Net 2007–12
MBL (m)	Mean	−0.071	0.004	−0.003	−0.023	0.032	−0.045
	Max	0.031	0.196	0.378	0.108	0.264	0.407
	Min	−0.782	−0.202	−0.102	−0.244	−0.127	−0.826
Change in gravel volume (m^3)		−23 388	−139	−3999	−2148	7746	−21 927

All cross sections have fluctuated between aggradation and degradation with none showing a consistent trend across all survey dates (Figure 3). The sections that have had the greatest changes in MBL are Cross Sections 2 (net change of −0.826 m), 8 (net change of +0.407 m) and 17 (net change of −0.214 m). Many sections have had rather small changes (17 out of 22 cross sections <±0.15 m). Most of the change to Cross Section 2 occurred between 2007 and 2008 when >10 m of the left bank eroded and the wetted channel degraded by about 1 m. Similarly Cross Section 17 has had severe erosion of the left bank (c. 10 m), deepening of the channel (by about 1.5 m) and avulsion as the channel cut through a meander bend and straightened (between 2009 and 2010). There was also severe bank erosion (c. 5 m of the left bank) at Cross Section 3 between 2010 and 2011. By contrast Cross Section 8 has aggraded on a beach on the right bank with significant aggradation occuring on both banks between 2008 and 2009 and then further aggradation on the right bank in both 201011 and 2011–12.

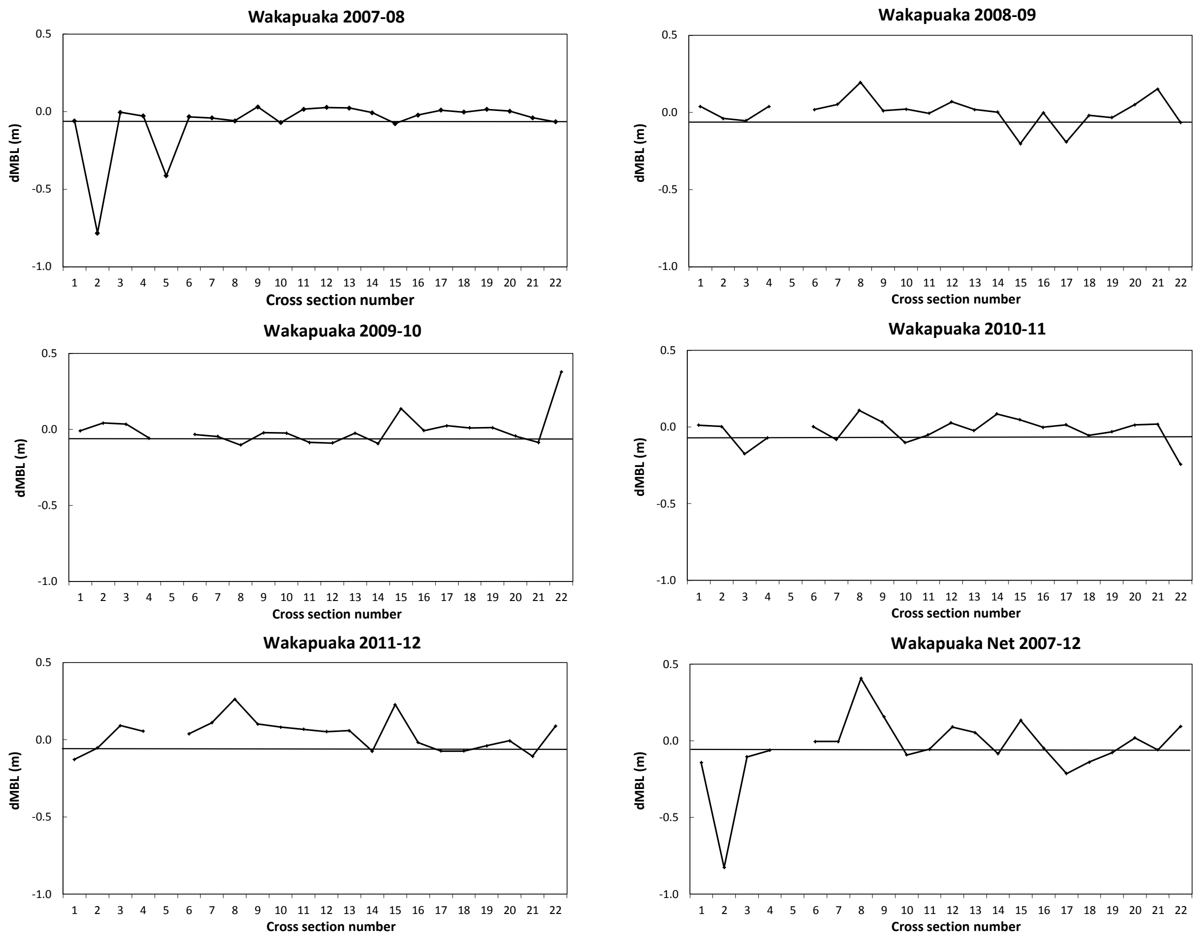


Figure 3 Plot of annual bed level change between 2007 and 2012 and net change 2007–12, Wakapuaka River.

Cross sections where beaches have *aggraded* are Cross Sections 1 (left bank), 2 (right bank), 8 (right bank plus some aggradation on the left bank), 9 (right bank), 12 (left bank), 13 (right bank), 15 (right bank). Beaches have *degraded* at Cross Sections 3 (right bank), 4 (right bank), 19 (right bank). A number of cross sections have shown *little change* – Cross Sections 6, 7, 10, 14, 16, 18, 20, 21, 22; most of these are transport reaches with straight narrow channel planform. Cross sections classified as beaches have had an average net change of -0.060 m, whereas transport reaches have had little change on average (0.004 m).

The changes in MBL convert to a loss of gravel from 2007 to 2011 (with the greatest loss between 2007 and 2008 amounting to −23 388 m^3), but an overall gain between 2011 and 2012 of 7746 m^3 (Figure 4). Between 2007 and 2012 there was a net loss of 21 927 m^3. While most parts of the river have fluctuated between aggradation and degradation, there are areas where the river has more consistently degraded (between Cross Sections 1 and 3, and between Cross Sections 16 and 20) and areas where it has aggraded (between Cross Sections 7 and 9 net aggradation of 10 715 m^3 of gravel). The latter area (the beaches above and below the Maori Pa Road bridge) is likely to be the most suitable for gravel extraction as it has aggraded in four out of the five survey periods. However, overall the entire reach has experienced a net loss of gravel, despite the significant input of gravel in the December 2011 storm, and a cautious approach needs to be taken to gravel extraction. At the cross sections that have experienced the most bank erosion (Cross Sections 2 and 17) there is little evidence that build-up of gravel has put pressure on the opposite bank and caused the erosion.

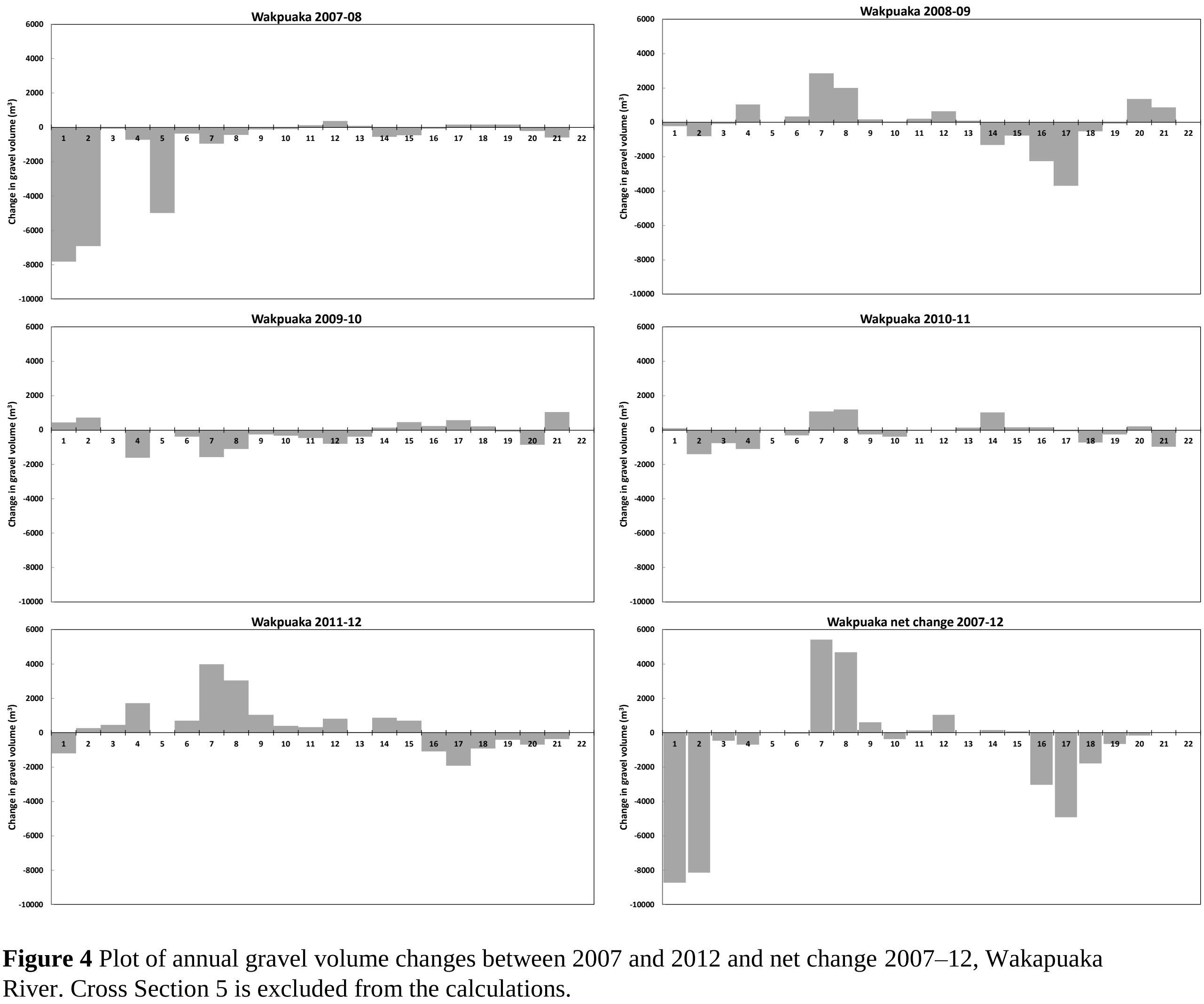


Figure 4 Plot of annual gravel volume changes between 2007 and 2012 and net change 2007–12, Wakapuaka River. Cross Section 5 is excluded from the calculations.

5.1.2 Whangamoa

Average MBL change over the period 2007–2012 was −0.035 m (Table 2). Average MBLs over the whole reach aggraded slightly from 2007 to 2009 (by +0.016 m) but have degraded between 2009 and 2012 (by −0.052 m). The largest average change occurred between 2009 and 2010 when the average MBL decreased by 0.032 m and all but one cross section (2) degraded, although the amount of change was relatively small at all sections (maximum of -0.144 m). The reach did not aggrade between 2011 and 2012 when half the sections did aggrade but this was offset by much larger degradation particularly at Cross Sections 2 and 4.

As in the Wakapuaka all cross sections have fluctuated between aggradation and degradation with none showing a consistent trend across all survey dates (Figure 5). The magnitude of bed level change tends to be smaller than in the Wakapuaka. The sections with the greatest change in MBL have all degraded (Cross Sections 2, 5 and 10 with MBL changes of −0.178, −0.093, and −0.076 m respectively). The major change to Cross Section 2 occurred between 2011 and 2012 with c. 5 m of erosion of the left bank.

Cross sections where beaches have *aggraded* are Cross Sections 1 (left bank) and 8 (centre of channel) while beaches have *degraded* at Cross Sections 2 (right bank) and 3 (left bank). Many cross sections have shown relatively *small changes* in MBL (Cross Sections 1, 3, 4, 6, 7,8, 9). Cross sections classified as beaches have had an average net change of −0.055 m, whereas transport reaches have had little change on average (−0.005 m).

Table 2 Summary of bed level and gravel volume changes, Whangamoa River

		2007–08	2008–09	2009–10	2010–11	2011–12	Net 2007–12
MBL (m)	Mean	0.015	0.001	−0.032	−0.007	−0.013	−0.035
	Max	0.073	0.093	0.064	0.147	0.069	0.061
	Min	−0.069	−0.051	−0.144	−0.123	−0.166	−0.178
Change in gravel volume (m^3)		4399	−357	−4724	−3430	−765	−4878

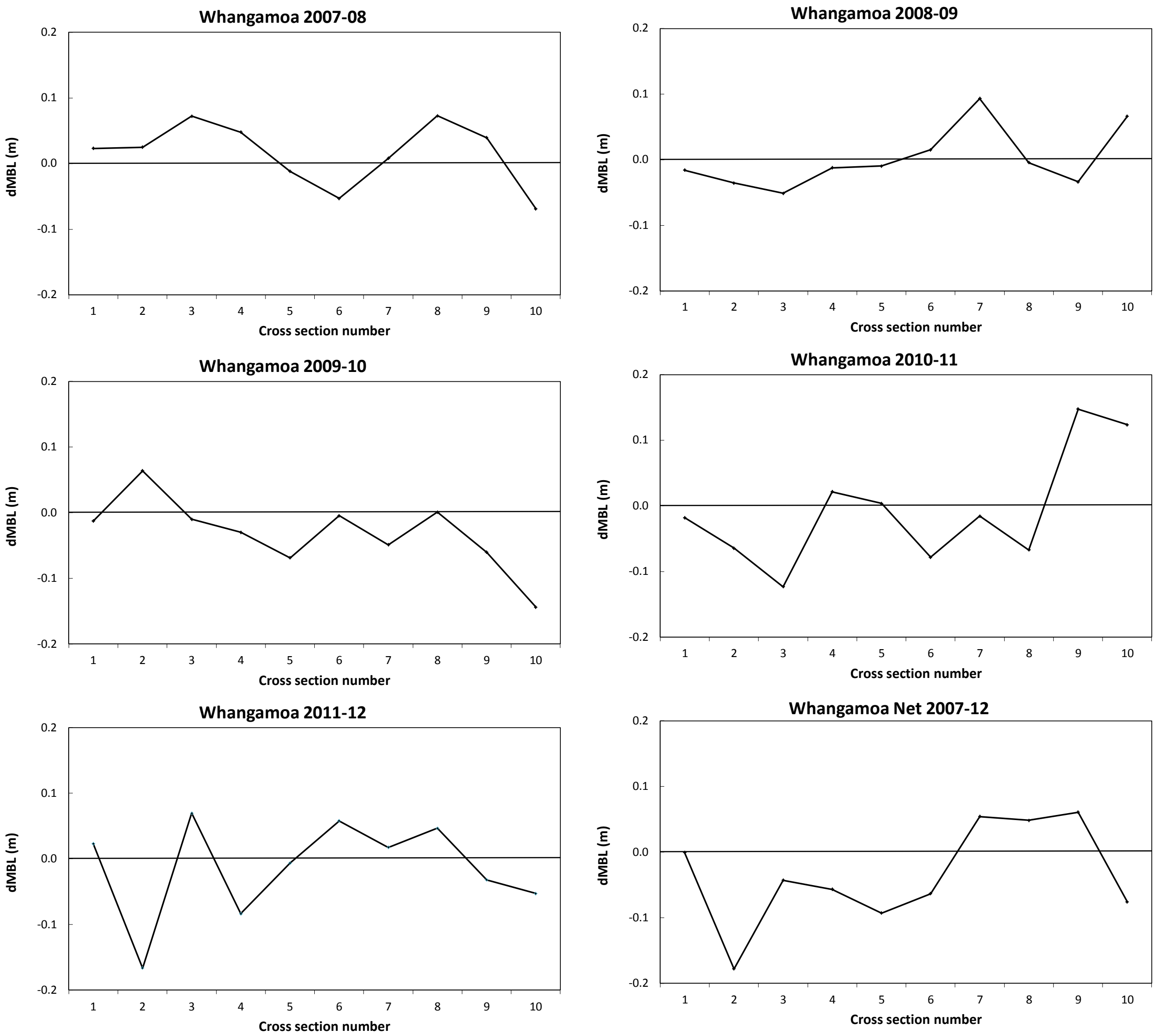


Figure 5 Plot of annual bed level change between 2007 and 2012 and net change 2007–12, Whangamoa River.

The changes in mean bed level convert to a gain of gravel from 2007 to 2008 (4399 m^3), and a loss from 2008 to 2012 (9277 m^3) (Figure 6). Between 2007 and 2012 the net change was −4875 m^3. The only part of the reach that had net aggradation over the 5-year period was between Cross Sections 7 and 9 (a total of 3226 m^3). Each of these cross sections had relatively small net changes in MBL but all had aggraded. *This area is the most suitable for gravel extraction, with the biggest beaches being located upstream and downstream of Cross Section 8.*

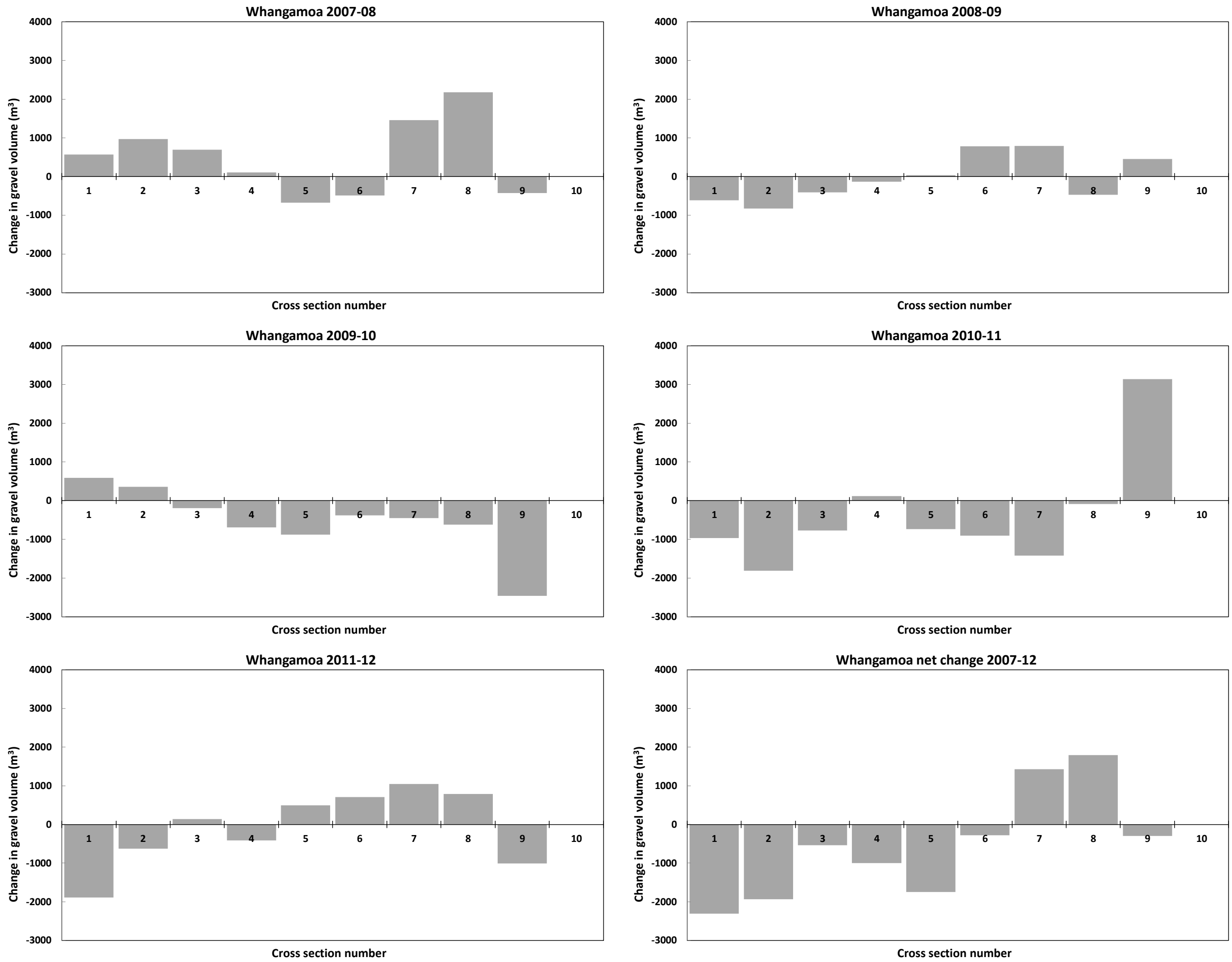


Figure 6 Plot of annual gravel volume changes between 2007 and 2012 and net change 2007–12, Whangamoa River.

5.2 River morphology, gravel beach extent and location

Both rivers are meandering single-thread rivers characterised (within the study reaches) by:

- An upstream segment that is relatively narrow and straight and often with relatively high banks (upstream of about Cross Section 18 in the Wakapuaka and Cross Section 8 in the Whangamoa)
- A downstream segment where the river meanders more and alternates between depositional reaches and straighter transport reaches between the meander bends. Within this zone gravel beaches have typically been deposited on the inside of the meander bends and bank erosion is active on the outside of the bends
- Downstream fining of the channel bed sediment and transition from a gravel-bed river to a silt-bed river just before entering the estuaries

The location of gravel beaches in the Wakapuaka River in 1999/2001, 2009 and 2012 is shown in Figure 7. This shows that gravel beaches are present on the inside of most meander bends especially below Cross Section 18. Above there the river tends to become narrower, straighter and more incised. The same beaches that are present on the 2009 photography are mostly present in 2012 and 1999/2001, suggesting they are persistent features of the river morphology rather than migrating features. However, the magnitude of observed bank erosion and channel avulsion suggests there will be a longer-term evolution of the channel involving meander migration and avulsion. The mapped area of beaches was 3.83 ha in 1999/2001, 2.91 ha in 2009 and 2.87 ha in 2012. Any differences in extent or number of mapped beaches (41 in 1999/2001, 37 in 2009 and 34 in 2012) are likely to largely reflect the differences in flow on the dates of photography (11 Feb. 1999 – 0.63 m^3 $s^{–1}$, 31 Dec. 2001 – 1.35 m^3 $s^{–1}$, 23 Jan. 2009 – 0.627 m^3 $s^{–1}$, 5 Jan. 2012 – 2.069 m^3 $s^{–1}$). Similarly a large number of the beaches mapped on the 2009 and 2012 photography were also identified by Stocker (2002) as gravel beaches at that time.

Similarly in the Whangamoa River, gravel beaches are present on the inside of most meander bends especially below Cross Section 8 (Figure 8). There are few gravel beaches above there, again because the river tends to become narrower, straighter and more incised. The mapped area of gravel beaches was 2.05 ha in 2009 and 2.65 ha in 1999. Most of the beaches mapped on the 1999 photography are also present in 2009, although the mapped location often shows a significant offset. This is probably due to slight differences in actual location and misregistration of the aerial photographs – the average offset of 20 Ground Control Points mapped on the 1999 and 2009 imagery was 11.4 m (compared with 1.1 m for the 2009 and 2012 imagery). Some of the beaches mapped on the 2009 and 2012 photography were also identified by Stocker (2002) as gravel beaches at that time, although he identified a considerably smaller number of beaches.

The location of all gravel beaches is listed in Appendix 4. This identifies which beaches were present in each mapping period and which were also identified by Stocker (2002).

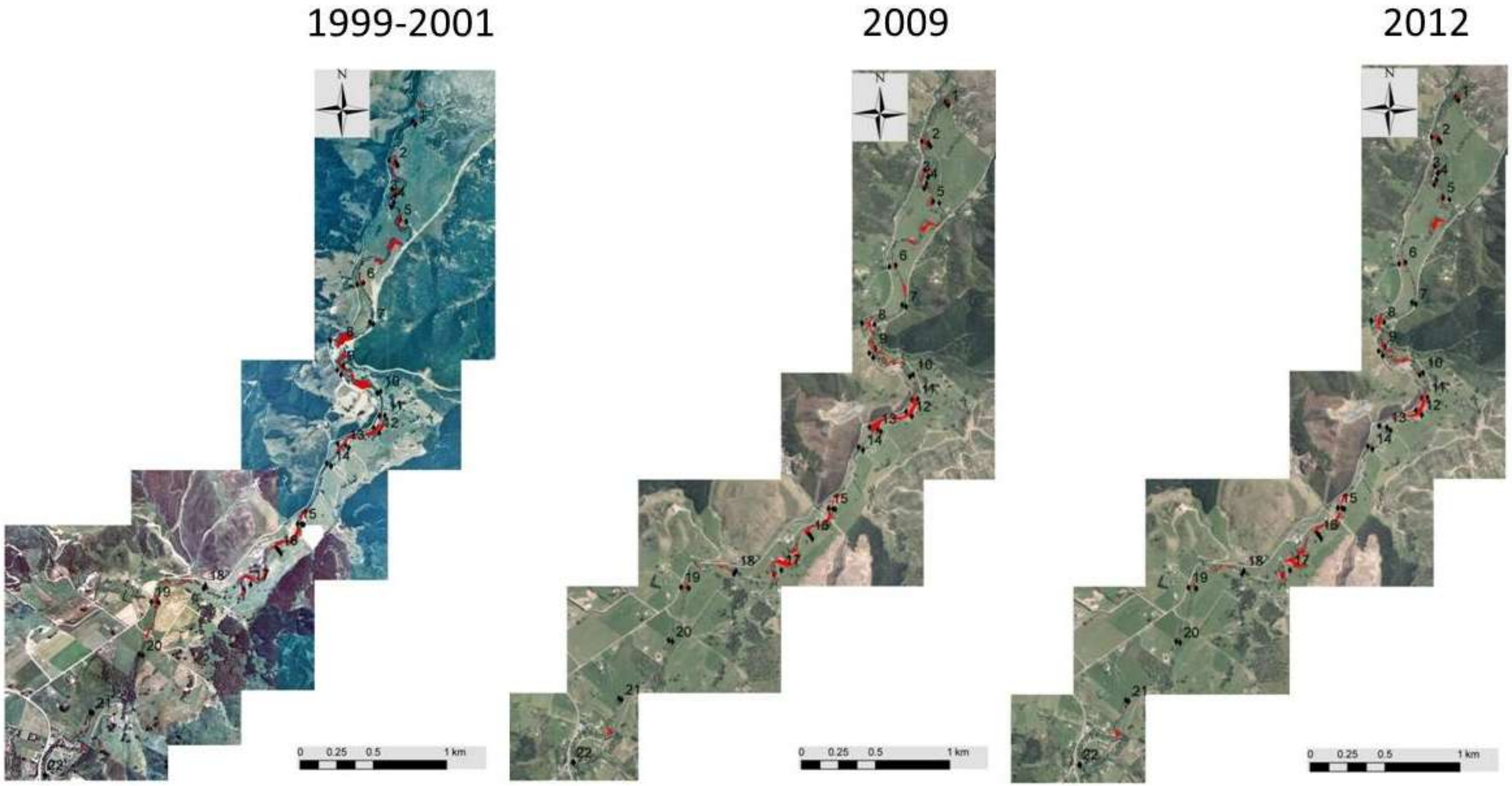
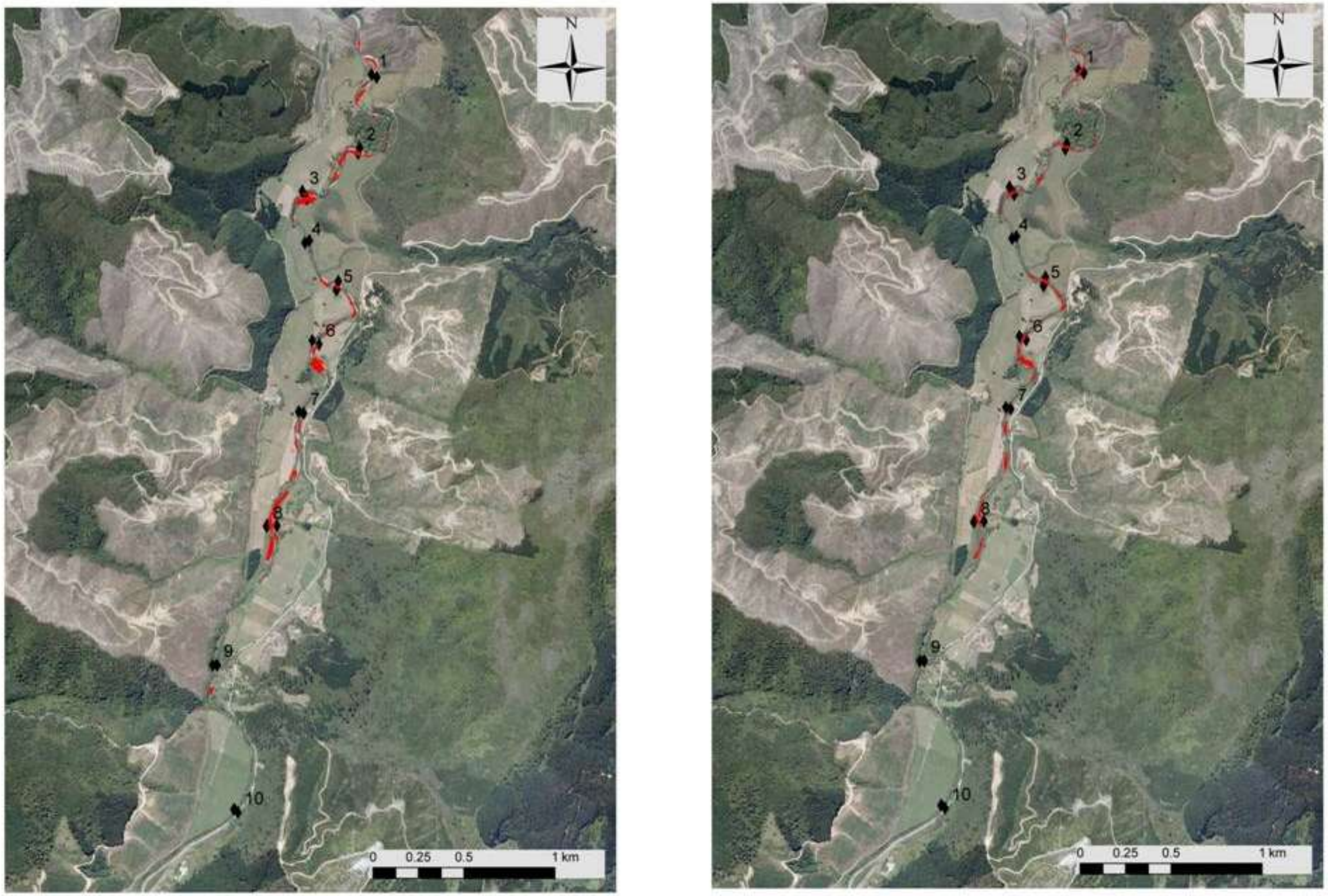


Figure 7 Location of gravel beaches in Wakapuaka River in 1999/2001, 2009 and 2012 overlain on the imagery for that date. Locations of cross sections also shown.



1999 2009

Figure 8 Location of gravel beaches in Whangamoa River in 1999 and 2009 overlain on the imagery for that date. Locations of cross sections also shown.

5.3 Use of Hilltop Software for archiving and analysis of river cross section data

At present the recording and archiving of data from the cross section surveys is somewhat unsatisfactory. The following steps appear to occur but are not well documented anywhere:

1. Cross sections are surveyed in the field; the origin can be the left bank or right bank BM, depending on which is more convenient or which is still present if bank erosion has occurred. An offset (Draw) is measured from the origin and relative level (RLraw) is measured locally.

2. The field data is entered into an Excel spreadsheet.

3. The offset is converted to distance from the left bank(Dlb), if not surveyed from the left bank, and RL (RLraw) is converted to elevation above the right BM (RLRadj , with the elevation of the right BM defined as 0).

4. The RL is further adjusted by defining the left BM as 10 m (BMadjL10).

5. Data is read into Hilltop as csv files for analysis of MBL using the Sections Over Time command, and gravel volumes are calculated using the Volume and Volume Over Time commands. The volume calculations can use either the end-area method (equivalent to the manual calculation) or the RICODA triangles method and provide the gravel volume between each cross section, total volume of bed material in the reach, and change in volume over time.

6. Further transformations (steps 2 and 3) may occur as BMs are lost and the length of surveyed section changes.

This procedure is not particularly clear or transparent and makes it difficult to keep track of changes to offsets and RLs as they occur. It would be preferable if all data is stored in Hilltop as collected in the field – as a raw data file. Any transformations and adjustments (offset changes from left bank or right bank, change in cross-section length, RLs adjusted to RB or to 10 m) should be made in Hilltop Manager as working files (with the same site name) and the final corrected data stored as an archive file to keep the quality assurance trail from survey data to final data underpinning calculations.

The changes to BMs should also be reflected in the Sites table and Facecards (in which BMs are referred to as pin positions) associated with each cross section. Facecards should be stored for each site and each survey otherwise Hilltop assumes the widest distance measured along any section is used to calculate MBL (this may be one reason why MBL calculated manually is different from that calculated by Hilltop). This allows for changes in pin (or BM) positions through time. Note that pins are recorded as an easting, northing and RL. The left pin defines the zero offset and right pin defines the orientation of the cross section.

To use gravel calculations in Hilltop all sections need to be surveyed to a common datum as gravel volume is calculated above a datum (assumed as the lowest RL in a reach if not otherwise specified). If this is not done then the calculations of gravel volume above the datum will be inaccurate since the present procedure of defining the left BM as 10 m has the effect of flattening a sloping riverbed. It is unclear whether this would affect calculation of gravel volume changes over time. In the absence of a common survey datum it is probably better to manually calculate gravel volume. Similarly only the end-area method should be used for gravel volume calculations– the RICODA triangles method should only be used if adjacent sections have the same number of survey points, implying all sections in a reach would need the same number of survey points (Mark Rodgers, pers. comm., March 2013).

Hilltop Reach calculates gravel volume in an upstream direction – there is no real reason for this (Mark Rodgers, pers comm., March 2013). In theory it should be calculated in a downstream direction because gravel moves downstream. It should not make any difference to net gravel change in a reach (discussed later in this section) but it does affect the gravel volume changes associated with each cross section and hence the interpretation of location of gravel loss or gain. *It is recommended that gravel volume calculations in Hilltop Reach use the end-area method applied in a downstream direction.*

A comparison of MBLs and gravel volumes calculated by Hilltop Software with those calculated manually indicates there remain some issues with data compilation. The comparison of MBLs for the Wakapuaka cross sections (Figure 9) shows most calculations are comparable but there are significant differences for some cross sections:

- 2007–08 Cross Sections 5, 6, 16, 17, 18, 20, 21
- 2008–09 Cross Sections 5, 6, 8, 17, 18, 20, 21
- 2009–10 Cross Sections 5, 8, 11, 17
- 2010–11 Cross Sections 2, 3, 5, 11, 17
- 2011–12 Cross Sections 2, 5, 8, 15, 21

The biggest differences relate to errors in offsets input into Hilltop, while the minor differences are probably related to the way the internal calculations within Hilltop use pin positions in the Facecards and Sites Table to calculate MBL. The overall result is some large differences in the net MBL change 2007–2012 (Figure 9) calculated by the two approaches.

Similarly there are differences for the Whangamoa River cross sections (Figure 10). The manual MBL calculations and the Hilltop calculations are quite similar for 2007–08 and 2008–09, but there are some large differences in subsequent years:

- 2009–10 Cross Sections 3, 6, 7, 10
- 2010–11 Cross Sections 2, 3, 6, 10
- 2011–12 Cross Sections 6–9

The overall result is a difference in the net MBL change 2007–2012 at most cross sections (Figure 10), and a large difference estimated by the two approaches for Cross Sections 7-9.

The differences in MBL translate into some very significant differences in gravel volume calculations. Figures 11 and 12 show the comparison between Hilltop and manually calculated gravel volume changes for the Wakapuaka and Whangamoa rivers (calculated using the same method, i.e. end-area method applied in a downstream direction). Part of these differences is due to errors in the data compiled in Hilltop, but even where there are no errors (e.g. Whangamoa Cross Sections 3–10) there are some big differences. For the Whangamoa these differences appear to have resulted from discrepancies in MBL calculation, and there may also be an influence of the lack of a common datum for the gravel volume calculations in Hilltop. It is notable that the gravel volume changes calculated by Hilltop are commonly much larger than the manually calculated values.

Table 3 summarises the reach gravel volumes calculated using different methods. The net change (2007–12) in gravel volume using the recommended approach (i.e. end-area method applied in a downstream direction) calculated manually (−21 927 m^3 for the Wakapuaka and −4878 m^3 for the Whangamoa) is very different to that calculated in Hilltop Reach (−62 669 m^3 for the Wakapuaka and 42 786 m^3 for the Whangamoa). Similarly in Hilltop the end-area and RICODA triangle methods produce significantly different results, and application of these methods in a downstream or upstream direction also produces very different estimates of net gravel balance (Table 3). For the Wakapuaka the Hilltop end-area method produces a net (2007–12) loss of gravel although the annual estimates of gravel loss and gain are inconsistent (e.g. in 2011–12 manual calculations suggest a gain of 7746 m^3, whereas Hilltop suggest a loss of 22 102 m^3). However, Hilltop suggests a net gain of gravel for the Whangamoa (42 786 m^3) whereas the manual calculations suggest a small net loss (4878 m^3). This is largely a result of the differences in MBL estimated for Cross Sections 7, 8 and 9, especially for 2011–12 (Figure 10).

These results imply that Hilltop Reach needs to be used with care to produce accurate results. The results of the manual calculations presented here provide a cross-check that NCC can use to ensure that when all errors in the compiled survey data are corrected then estimates of gravel volume changes using Hilltop Reach should be similar to the manually calculated values. Gravel volume calculations in Hilltop Reach should be with respect to the downstream direction to reflect the downstream transport of gravel and use the end-area method.

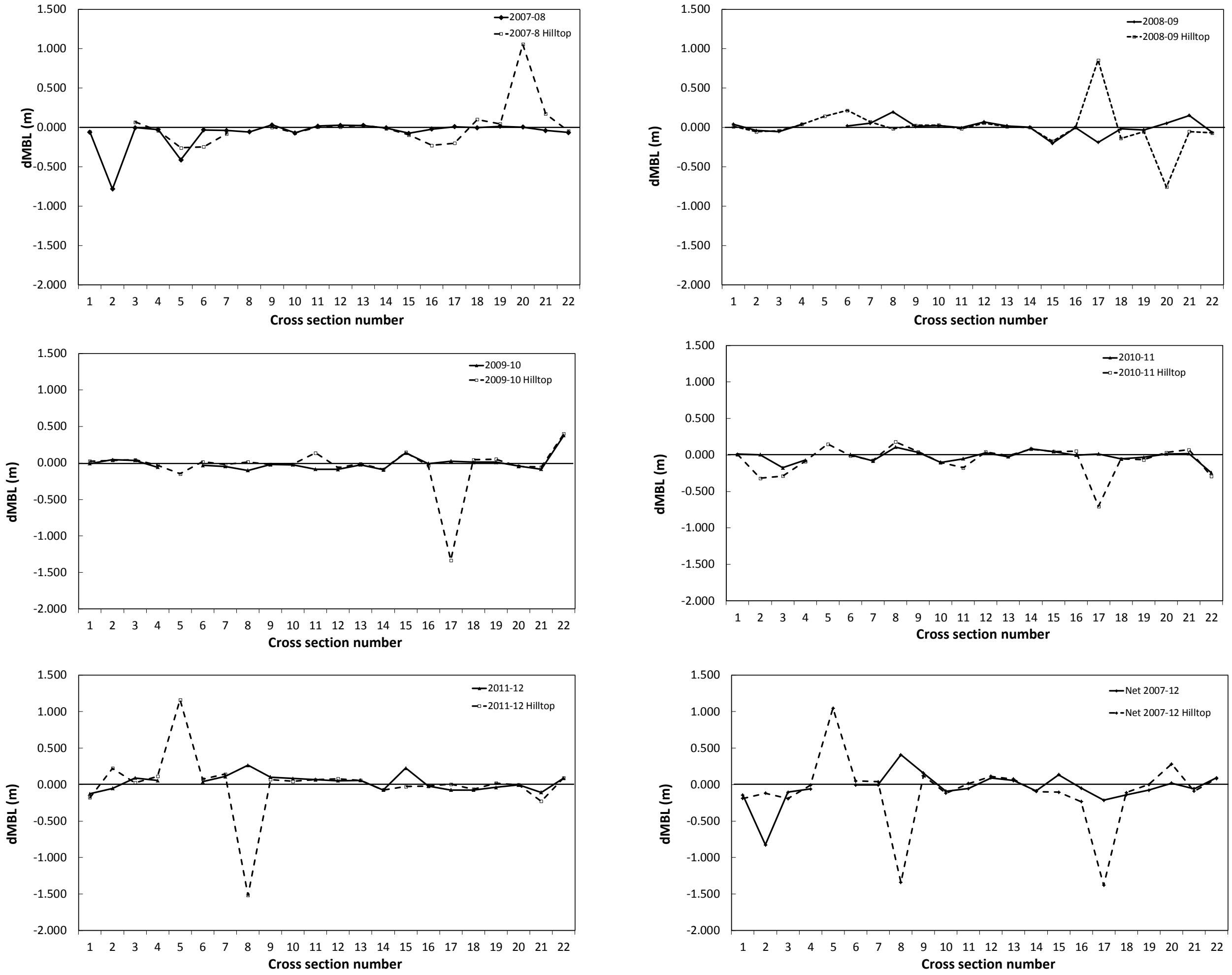


Figure 9 Comparison of Hilltop-calculated MBLs and manually calculated MBLs for the Wakapuaka River cross sections.

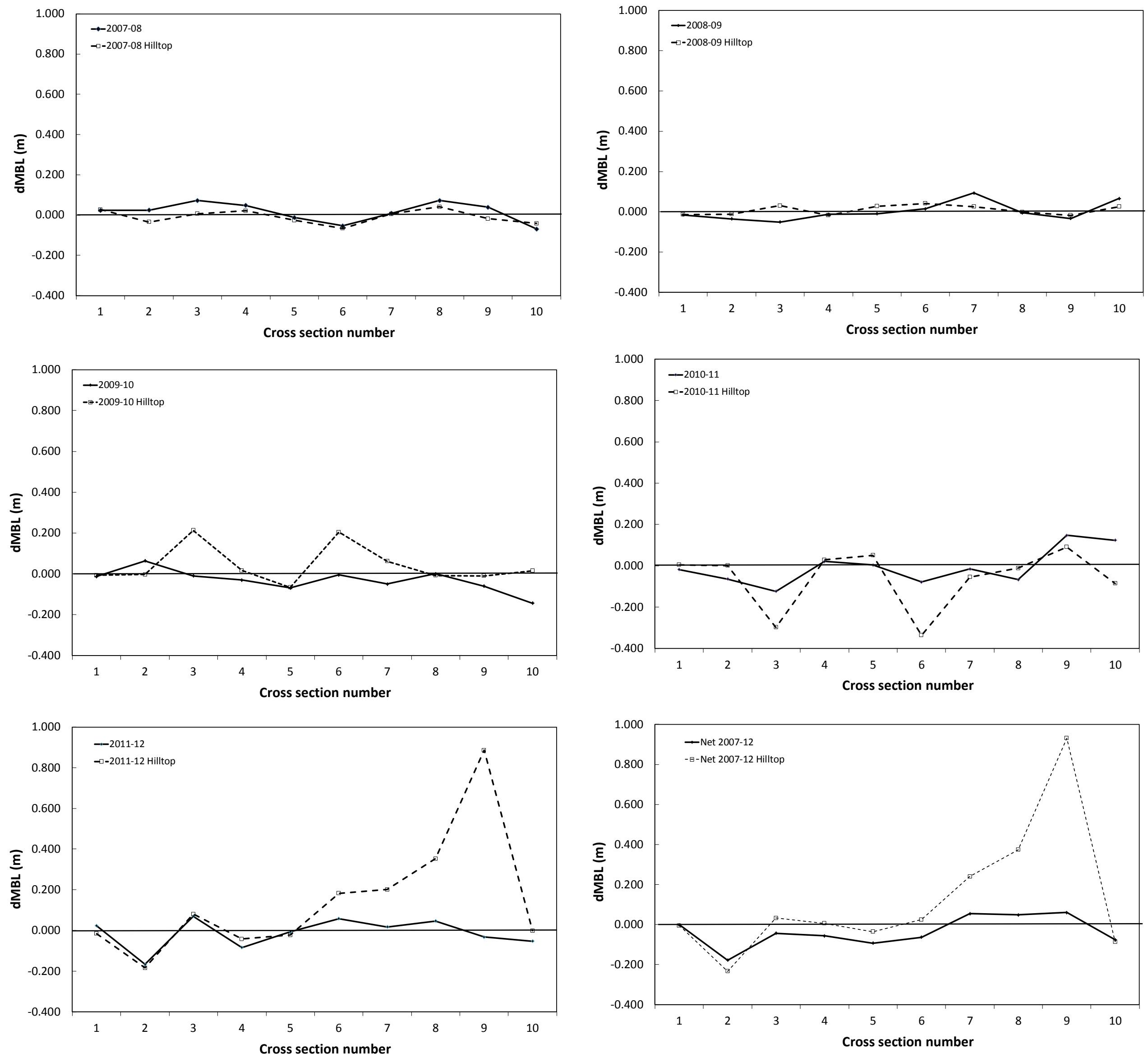


Figure 10 Comparison of Hilltop-calculated MBLs and manually calculated MBLs for the Whangamoa River.

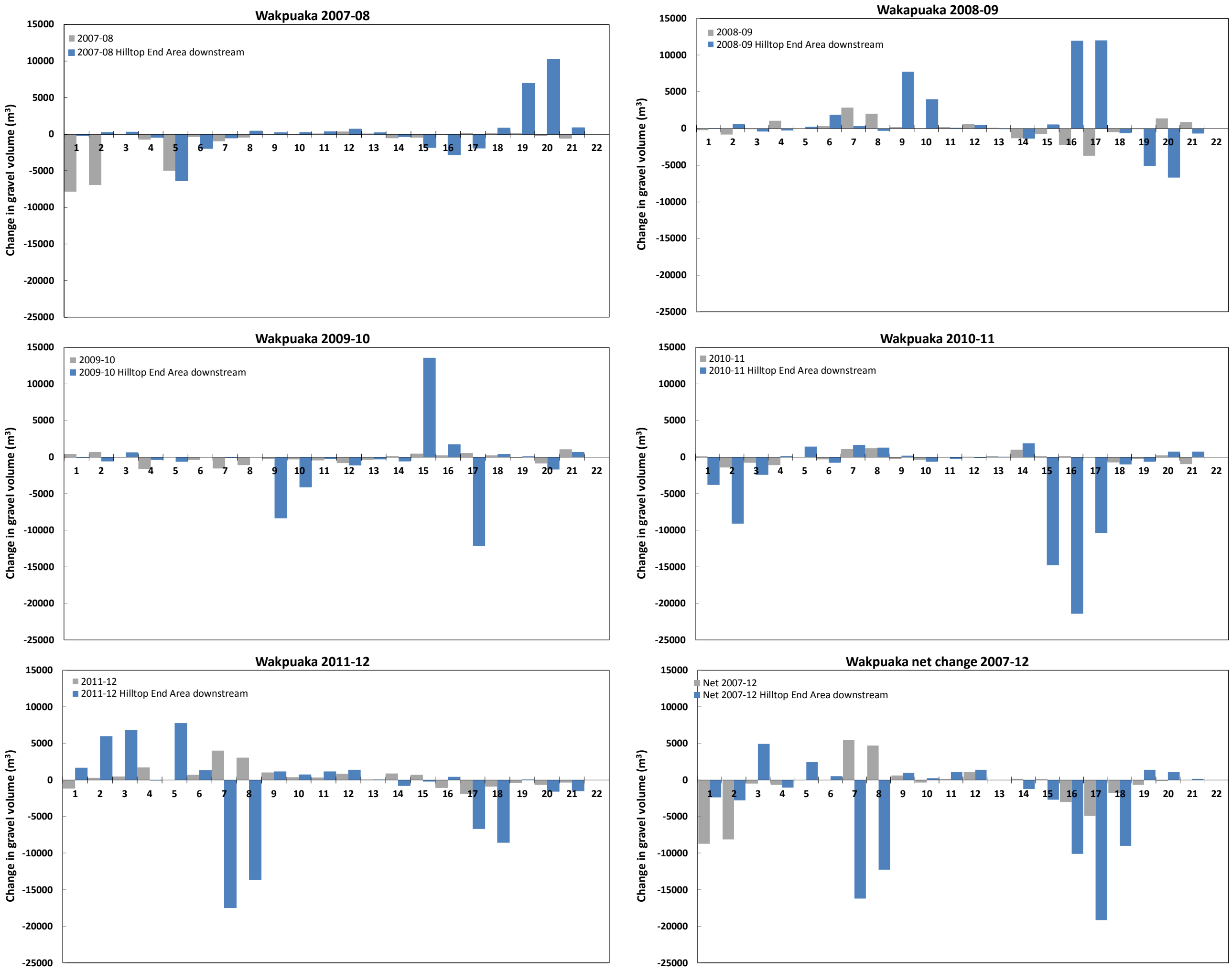


Figure 11 Comparison of Hilltop-calculated gravel volume changes between cross sections (calculated in downstream direction using the end-area method) and manually calculated gravel volume changes for the Wakapuaka River.

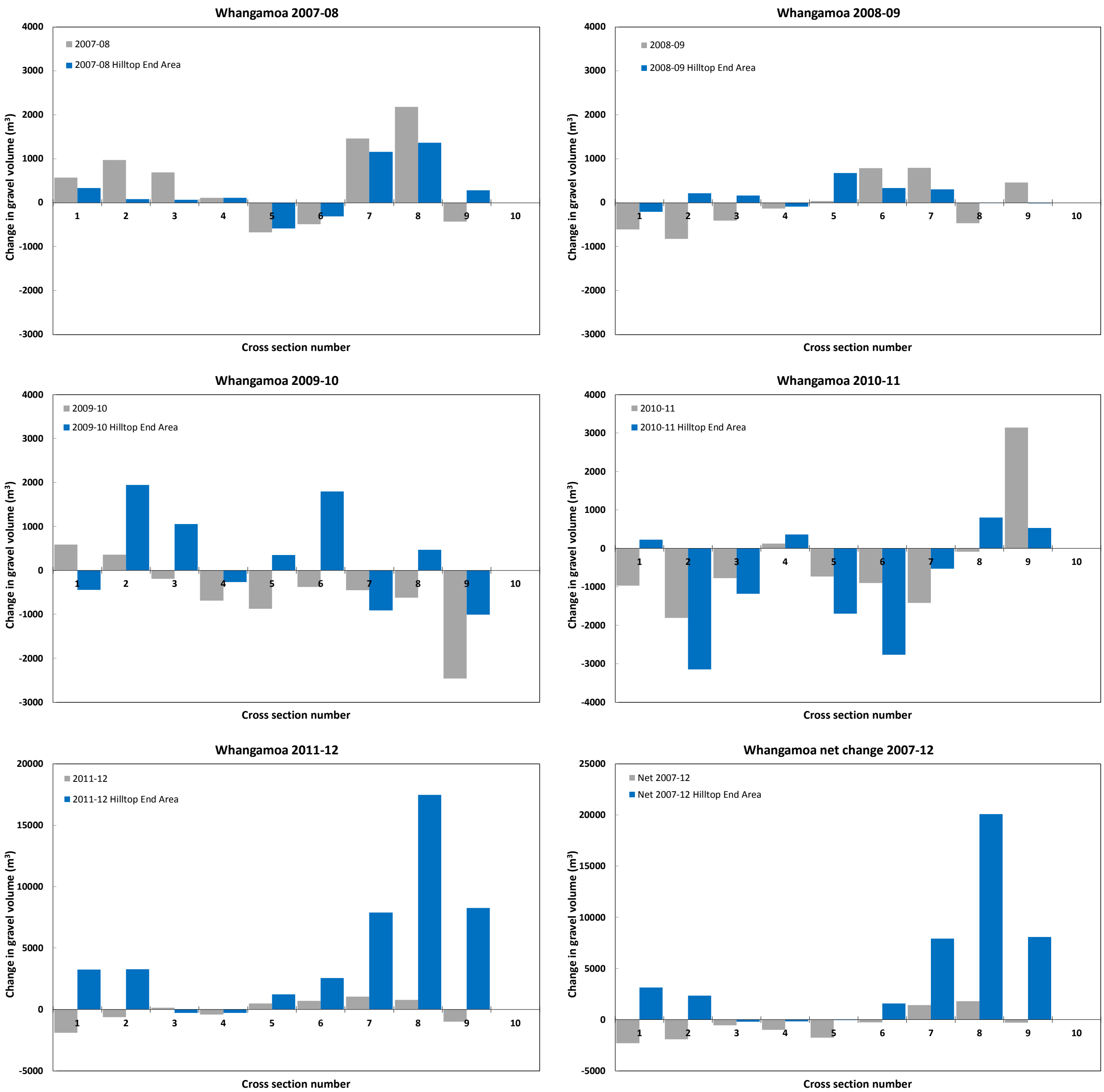


Figure 12 Comparison of Hilltop-calculated gravel volume changes between cross sections (calculated in downstream direction using the end-area method) and manually calculated gravel volume changes for the Whangamoa River.

Table 3 Differences in net gravel volume change (m3) for Wakapuaka and Whangamoa reaches determined using different calculation methods

	Downstream calculation			Upstream calculation	
	Manual end-area	Hilltop end-area	Hilltop Ricoda triangles	Hilltop end-area	Hilltop Ricoda triangles
Wakapuaka					
2007–08	−23 388	5507	11436	−1927	9502
2008–09	−139	24448	5719	24142	10800
2009–10	−3999	−13447	−2083	36518	34212
2010–11	−2418	−57075	−43230	−58165	−38013
2011–12	7746	−22102	−30716	−37694	−41130
Net change 2007–12	−21 927	−62 669	−58874	−37126	−24629
Whangamoa					
2007–08	4399	2507	−9441	−268	−10307
2008–09	−357	1384	−1986	1471	−1046
2009–10	−4724	2988	9809	7003	10146
2010–11	−3430	−7407	−1116	−11089	−9336
2011–12	−765	43 314	33731	53392	33987
Net change 2007–12	−4878	42 786	20997	50509	23354

6 Discussion

There remain some errors in data compilation for some cross sections, which need to be corrected before Hilltop Software will generate reliable estimates of MBL and gravel volume changes. This applies particularly to Cross Sections 2, 3, 5 (unusable after 2008), and 17 in the Wakapuaka (Figure 9). Some of the Whangamoa cross sections also need to be re-examined to resolve differences in MBL estimates (Cross Sections 3 and 6 in 2009–10 and 2010–11, cross sections 6, 7, 8, 9 in 2011–12 – see Figure 10). It is suggested that the manual calculations provide the most reliable estimates of MBL and gravel volume changes.

It is recommended that for future use of Hilltop Software that:

- All data be stored in Hilltop Software including raw field data, working files recording any changes to offsets and RLs, and final working files that are used for data analysis
- Only the end-area method is used for calculation of gravel volumes
- All calculations are completed with the sections aligned in a downstream direction

It also appears that it might be necessary to survey all cross sections to a common datum since Hilltop calculates volumes under the bed of a river with respect to a common datum. If no datum is entered Hilltop chooses the lowest point across all sections in a reach. The present NCC approach of using 10 m as the datum for all left-bank BMs has the effect of flattening a sloping riverbed – the sections extend from near sea level to c. 30 m in the Wakapuaka and c. 20 m in the Whangamoa. This will have a significant effect on the calculation of volumes under the riverbed, although it is unclear whether it would affect the calculated changes in volume. It would be a relatively small task to tie all sections in each river to a common surveyed datum – this would only have to be completed once to accurately establish locations and elevations of all BMs.

The mapping shows that the present network of cross sections provides a good coverage of the gravel beaches within both rivers and the data are a good basis for understanding their aggradational and degradational behaviour. However, it should be noted that the spacing of cross sections is very large (average of 346 and 546 m in the Wakapuaka and Whangamoa rivers respectively) compared with channel width (typically 10–20 m), and gravel beaches occupy a fairly limited extent of the channel planform (Figures 7 and 8). While the estimates of MBL change at the cross sections are reliable, the estimates of gravel volume change are limited by the ability of the network to represent within-channel morphological variability. This could only be improved by multi-temporal LIDAR or GPS surveys of riverbed morphology (e.g. Basher 2006a; Fuller et al. in review). Previous studies have found that estimates of gravel volume changes derived from cross section surveys typically underestimate the volumetric changes (Fuller et al. 2003).

The gravel beaches are persistent features of the river that probably reflect changes in river gradient, curvature and width. In the Wakapuaka 15 out of 22 sections are across beaches, and in the Whangamoa 6 out of 10 are across beaches. It also provides valuable data on channel dynamics and bank erosion, which at some sections has been very severe (Cross Sections 2, 3, 5, 17 in the Wakapuaka and Cross Section 2 in the Whangamoa). While bank erosion is likely to be triggered by high-flow events, the timing of observed severe bank erosion (5–10 m of bank retreat) has varied considerably. In the Wakapuaka River it occurred at Cross Section 2 between 2007 and 2008, Cross Section 3 between 2010 and 2011, Cross Section 5 between 2008 and 2009, and Cross Section 17 between 2009 and 2010. In the Whangamoa it occurred at Cross Section 2 between 2011 and 12. This probably suggests that bank erosion is being triggered by local conditions rather than a reach-wide trigger. It is surprising that more bank erosion was not observed between 2011 and 2012 as a response to the December 2011 flood, although many Wakapuaka cross sections (2, 3, 13, 15, 17) had minor (<c. 1 m) bank erosion during this period.

Gravel transport is linked to the frequency and duration of flood discharge above the critical discharge at which particle movement is initiated (e.g. Fergusson 2005). Quantitatively estimating this requires information on stream slope and sediment size as well as discharge and is not possible at this time. However, inspection of the discharge and flood record (Figure 13 and Table 4) shows that: the 2007–08 survey period had the least high-flow events and the greatest loss of gravel in the Wakapuaka; the 2009–10 survey period also had few high-flow events and had the second largest loss of gravel; years with large numbers of flood events or large flood events were characterised by minor loss of gravel (2008–09, 2010–11) or aggradation (2011–12).

Table 4 Summary of flood hydrology (maximum discharge and number of days the daily maximum discharge exceeded 1-year, mean annual flood, 5- and 10-year floods.

Period	Maximum discharge	No. of days maximum flow			
(dd/m/yy)		>1 yr	>2.33 yr (MAF)	>5 yr	>10 yr
11/5/07 – 11/6/08	69.0 (2.7*)	8	1		
12/6/08 – 7/7/09	116.2 (8.2)	19		1	
8/7/09 – 6/8/10	46.9 (1.7)	14			
7/8/10 – 16/9/11	124.5 (10.2)	28	2		1
17/9/11 – 14/9/12	105.9 (6.3)	22	1	2	

* return period (yr)

The data show quite clearly that over the 5-year survey period MBLs have been declining overall in both rivers: −0.045 m in the Wakapuaka and −0.035 m. This is a trend that has been occuring in rivers throughout the Nelson-Tasman region (see Sriboonlue & Basher 2003; Rosser & Basher 2009; Fuller et al. in review) and suggests a cautious approach to gravel extraction is needed. The measured gravel volume changes in the Whangamoa are far smaller than in the Wakapuaka, which is surprising since both catchments are a similar size (113 and 114 km^2 respectively) and would be expected to generate and transport similar volumes of gravel. Basher (2006b) suggests the Whangamoa would be expected to have about 50% higher gravel load than the Wakapuaka. This may be a result of a greater number and closer spacing of cross sections in the Wakapuaka rather than a real difference – the Wakapuaka has 22 cross sections over 7.6 km of river (average spacing 346 m) compared with 10 cross sections over 5.5 km in the Whangamoa River (average spacing 546 m).

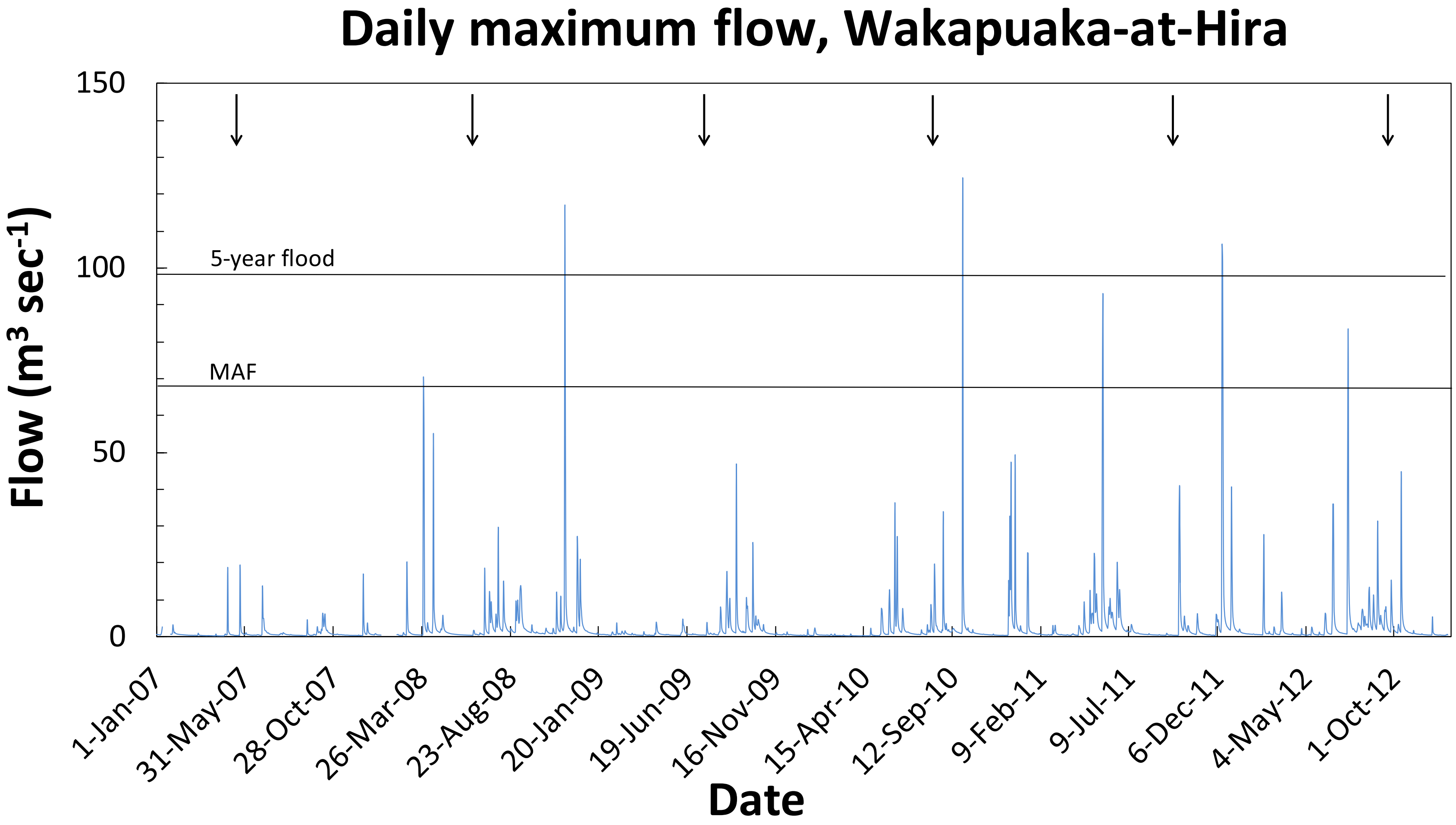


Figure 13 Plot of daily maximum discharge at Wakapuaka-at-Hira gauging site (MAF = mean annual flood, arrows show timing of cross section surveys)

The analysis suggests that part of the Wakapuaka River has been aggrading in the last 5 years (between Cross Sections 7 and 9) and this would be the most suitable location for gravel extraction – this is the area upstream and downstream of the Maori Pa Road bridge where there is quite a large area of gravel beaches. Similarly in the Wakapuaka the effect of the December 2011 storm has been very pronounced with aggradation at almost all sections below Cross Section 15 and a net increase in MBL of 0.032 m between the 2011 and 2012 surveys. Quite a number of beaches aggraded by up to c. 0.5 m (at Cross Sections 2, 3, 8, 9, 11, 12, 15). By contrast the Whangamoa did not aggrade at all between 2011 and 2012. However, despite the degradational trend in the Whangamoa Reach, as a whole there has been net aggradation between Cross Sections 7 and 9 and some extraction might be considered here. In both rivers the bed sediment characteristics suggest that gravel is not transported to the coast, as sediment in the beds of both rivers fines downstream and becomes non-gravelly before entering the estuaries. This indicates that gravel entering these river systems is broken down (abraded) within the river system. The annual and net changes in gravel volumes are quite small suggesting only small volumes should be extracted. It is also noteworthy that the net trends in the Wakapuaka gravel volumes are dominated by large annual changes – in the Wakapuaka the net loss of 21 927 m^3 was largely caused by a loss of 23 388 m^3 between 2007 and 2008, while in other years the change in gravel volume was quite small (<4000 m^3). In the Whangamoa there was greater change on an annual basis (as a proportion of the net change), although as commented earlier this may reflect the wider cross-section spacing providing a poorer estimate of changes in gravel volume.

Ideally these changes in gravel volume would be compared with quantities of gravel extracted from each river. Unfortunately it appears that this information is difficult to access and it seems unclear exactly how much gravel has been extracted and the locations of extraction. Table 5 lists the data provided by NCC (Carl Jenkins, Paul Fisher, pers.comm., March 2013) on gravel extraction between 2007 and 2012. Table 5 shows that:

- Not all consents have accurate locations (grid references).
- Many don’t show the consented volume and/or the extracted volume.
- Where records of gravel extraction are available only small volumes have been extracted suggesting extraction would have had little influence on the observed bed-level changes.
- Recording of gravel extraction activities remains poor (in terms of the location of extraction, consented and extracted volumes).

It seems unlikely that gravel extraction has influenced the the net loss of gravel from both rivers and that it is a natural feature of river behaviour.

Table 5 Active and expired resource consents in the Wakapuaka and Whangamoa rivers (source NCC)

Consent number	Consent status	Easting	Northing	Expiry (dd/mm/yy)	Location	Consented volume (m^3 yr^{-1})	Actual volume
RM075423	Expired			14/03/2010	407 Kokorua Rd, Whangamoa		Nil taken
RM 085034	Expired			5/03/2009	Whangamoa River	50	
RM985366	Expired			14/09/2008	Wakapuaka Riverbed	100	
RM105036	Active	1645514	5447373	19/08/2012	Site 1 - 413 Kokorua Road		Nil taken
		1645450	5448186		Site 2 - 413 Kokorua Road		Nil taken
		1645693	5448406		Site 3 - 413 Kokorua Road		Nil taken
		1645737	5448649		Site 4 - 413 Kokorua Road		Nil taken
RM055409	Active	1635882	5441538	31/10/2015	Wakapuaka River, Paremata Flats		
RM055682	Active	1645443	5448132	3/05/2016	Whangamoa River		
RM125023	Active	global	global	30/04/2013	Many		
RM125108	Active			9/10/2023		2000	
RM085034	Expired			5/03/2009	Kokorua Rd, Whangamoa		50
RM075423	Expired			14/03/2010	Kokorua Rd, Whangamoa		0
RM055682	Active			3/05/2016	Kokorua Rd, Whangamoa	750	0
RM055409	Active			31/10/15	Maori Pa Road, Wakapuaka		54

7 Conclusions

The present network of cross sections provides a good basis for understanding bed-level and river dynamics, although they may be more widely spaced than is desirable in the Whangamoa River. Hilltop Software (Reach) provides a very efficient platform for storing and analysing river-cross-section data but some basic requirements for archiving and quality assurance need to be met to ensure reliable results. Over the 5-year survey period MBLs have been declining overall in both rivers suggesting a cautious approach to gravel extraction is needed. Areas of net aggradation have been identified in both rivers that would be more suitable for gravel extraction than others. The annual and net changes in gravel volumes are quite small suggesting only small volumes should be extracted.

8 Recommendations

- The procedure for archiving and analysis of river-cross-section data in Hilltop Software should be improved to retain all information from raw survey data to final analysis. Some training in the use of Hilltop Reach would assist in this.
- Annual surveys should be continued to build a longer-term understanding of river and channel dynamics, and the surveys should be tied to a common datum to underpin analysis in Hilltop Software.
- Recording of the location, timing and amounts of gravel extracted under resource consents should be improved.

9 Acknowledgements

Our thanks to Paul Sheldon for initiating the surveys, assisting with field data collection and reviewing a draft of this report. Mark Rodgers discussed the intricacies of data archiving and analysis procedures within Hilltop Software. Ian Lynn and Christine Bezar commented on earlier drafts of the manuscript. The Ministry of Business, Innovation and Employment provided funding under Envirolink Medium Advice Grant 1272-NLC-C69.

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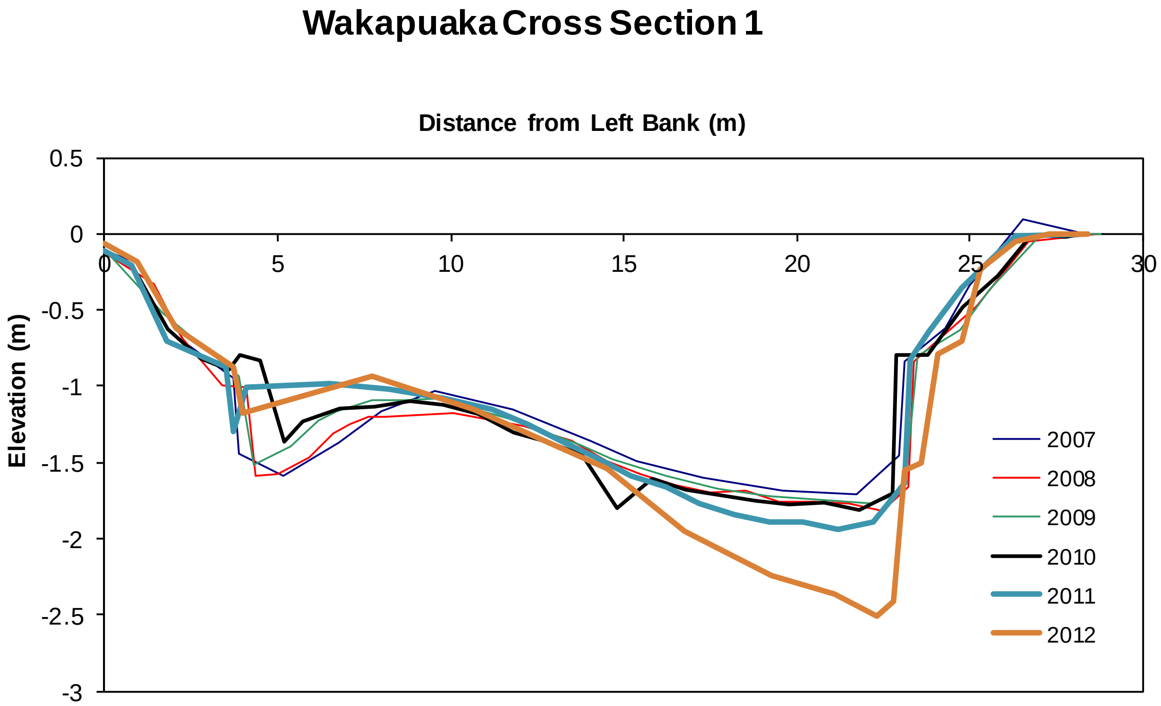
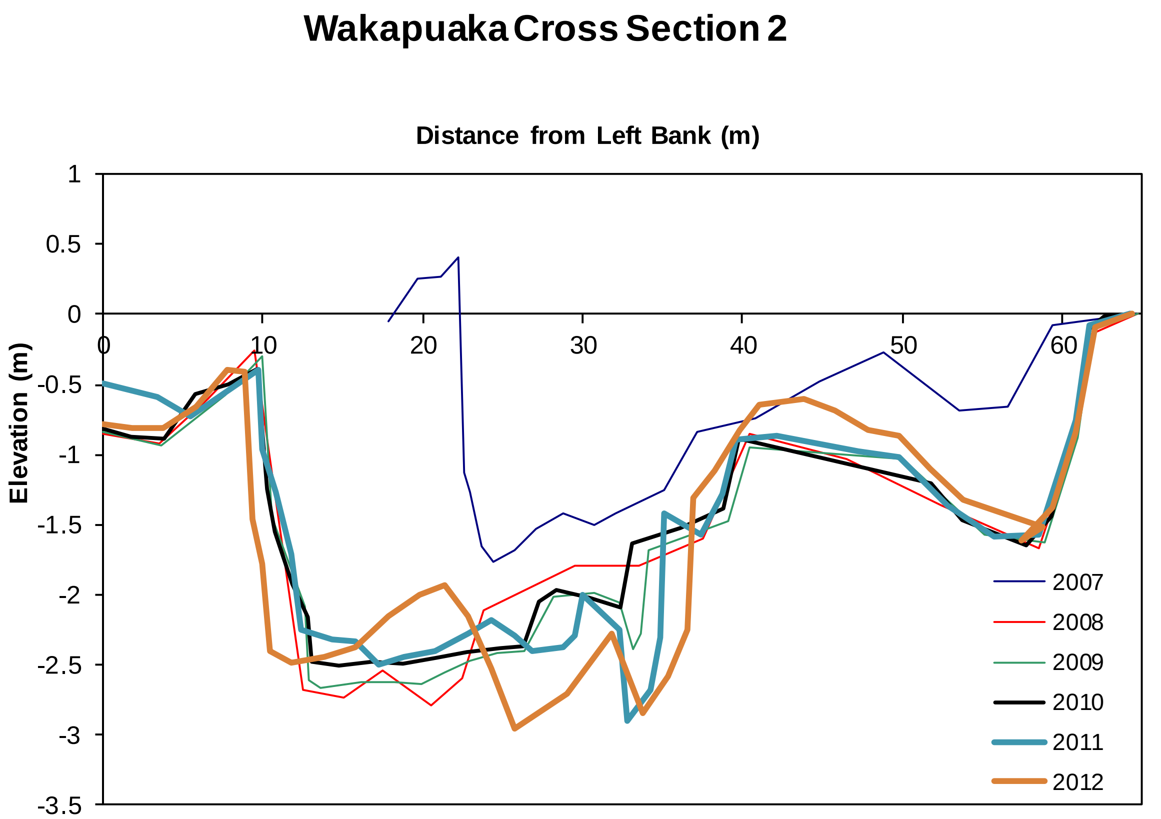
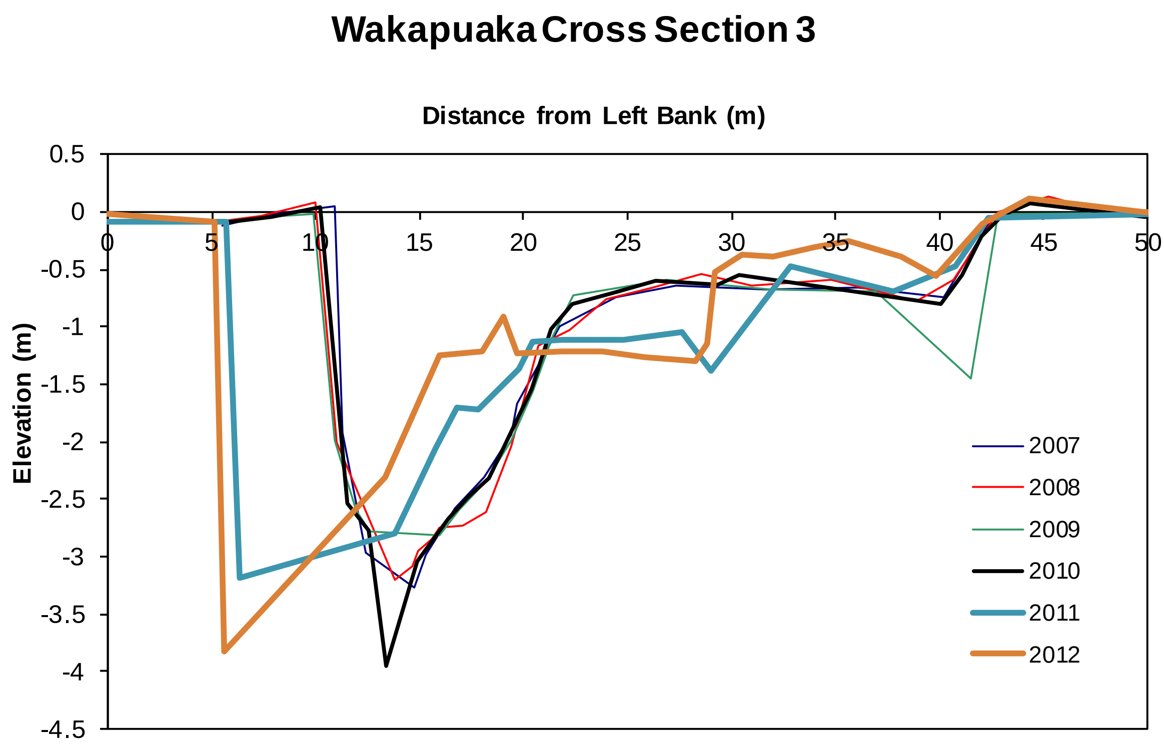
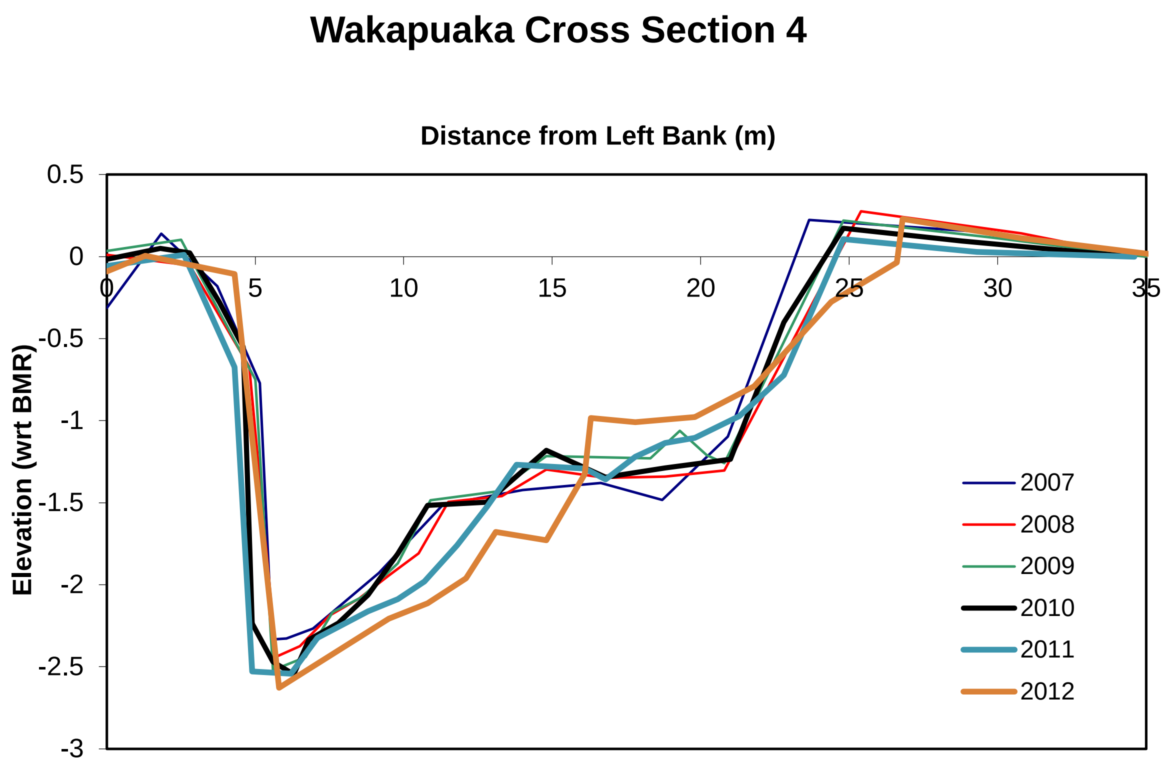
Appendix 1 – Plots of survey data for each cross section

Wakapuaka






Wakapuaka Cross Section 3
Distance from Left Bank (m)
Elevation (m)
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
0
5
10
15
20
25
30
35
40
45
50
2007
2008
2009
2010
2011
2012


Wakapuaka Cross Section 4
Distance from Left Bank (m)
Elevation (wrt BMR)
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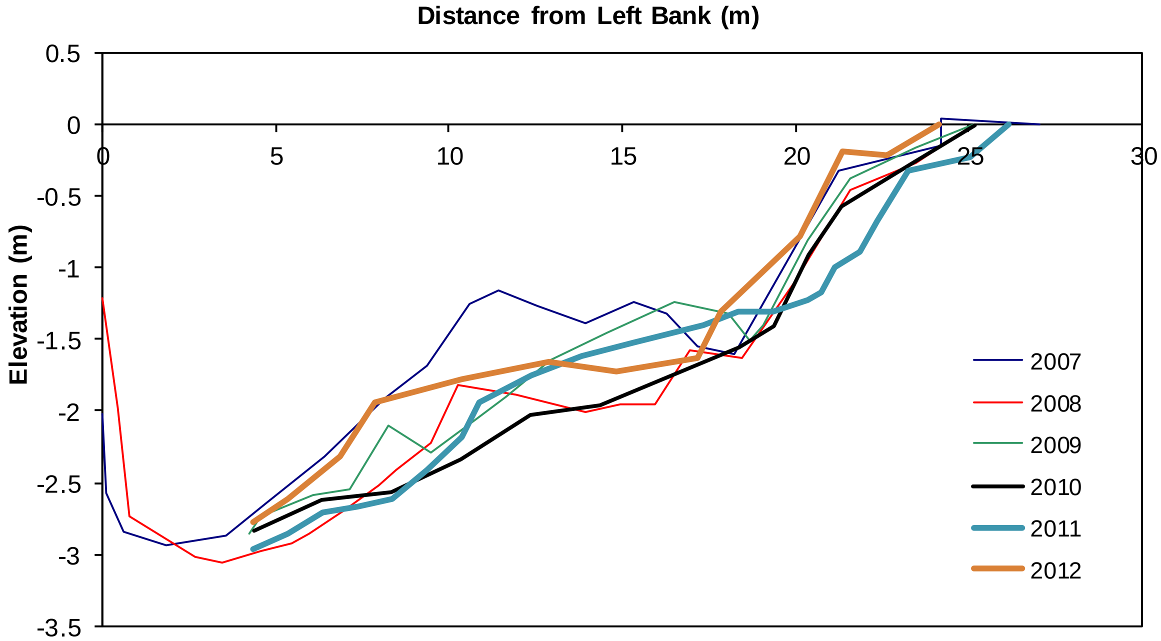
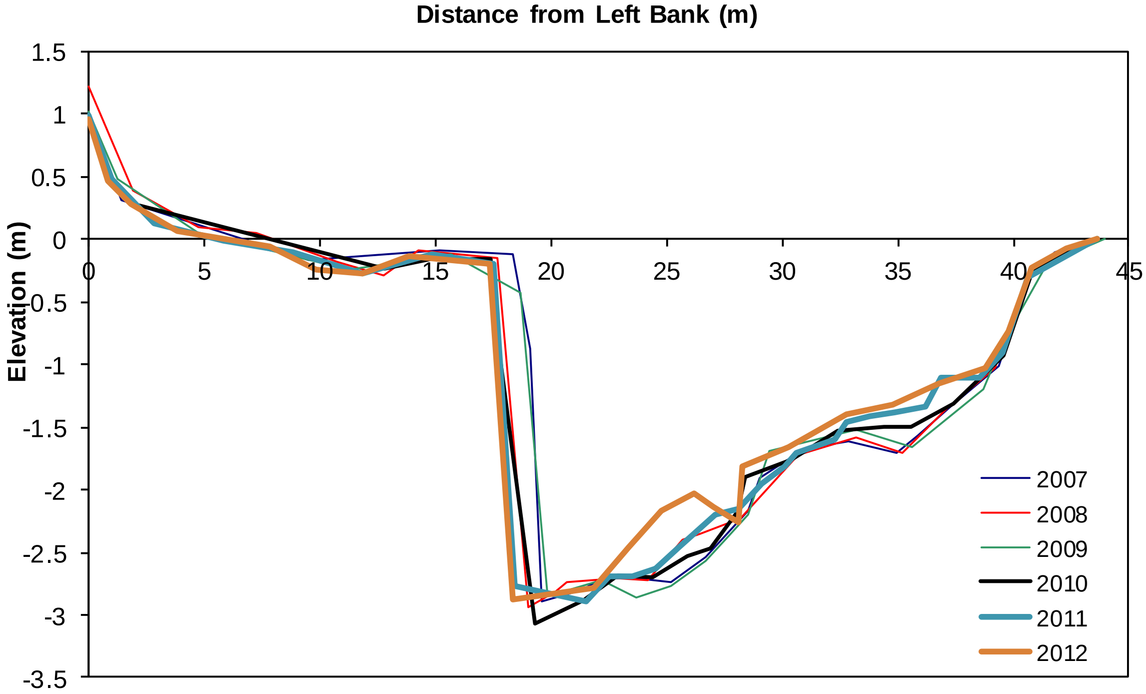
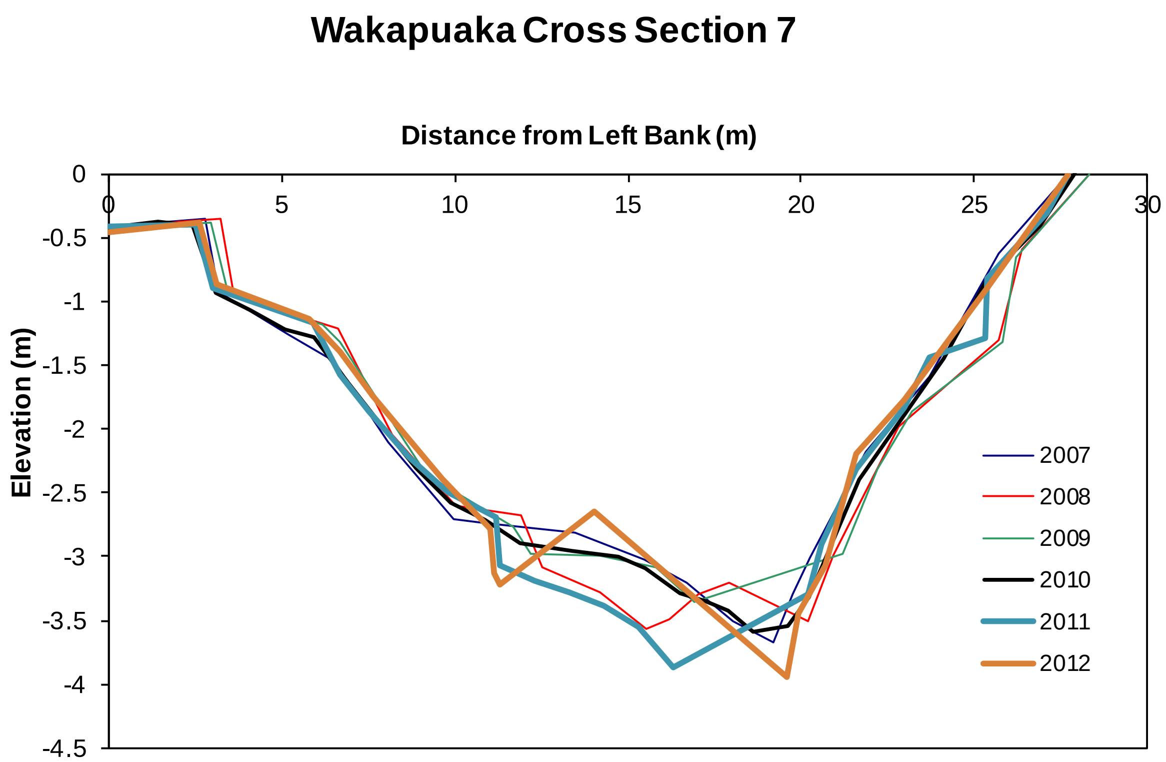
0
-0.5
-1
-1.5
-2
-2.5
-3
0
5
10
15
20
25
30
35
2007
2008
2009
2010
2011
2012

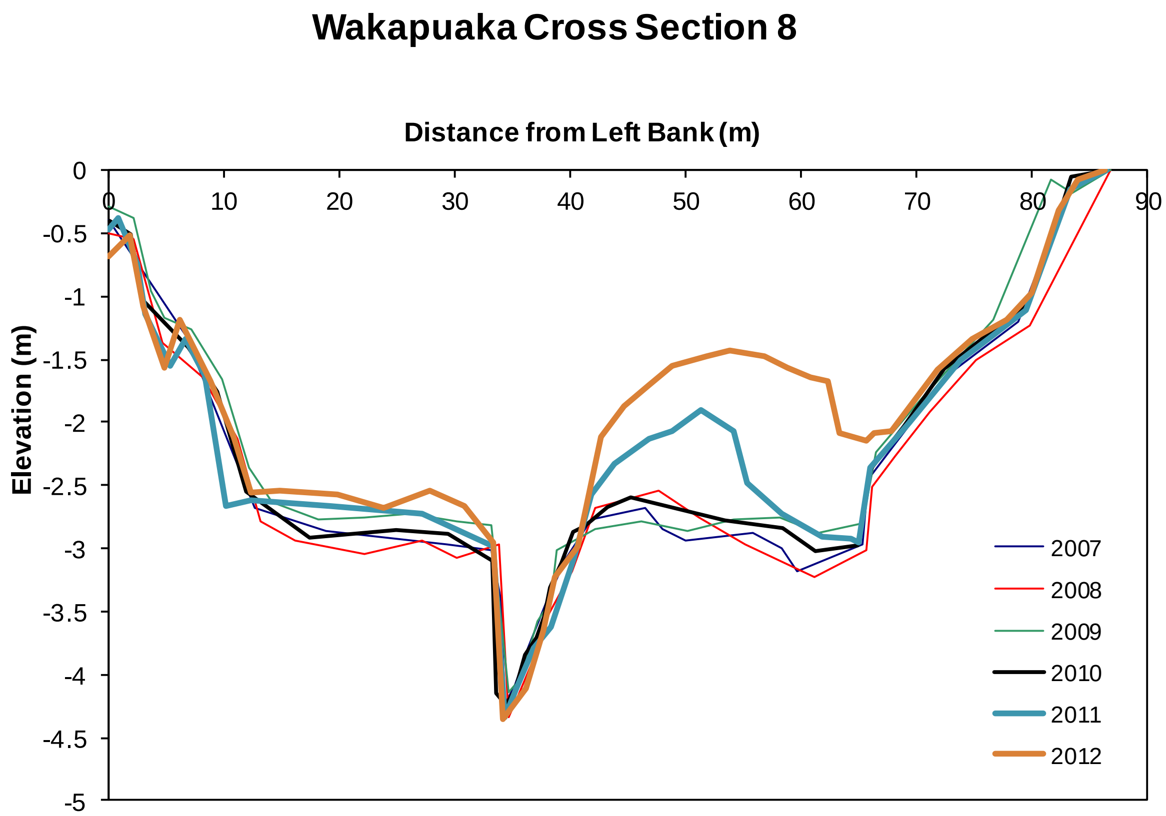
Wakapuaka Cross Section 5



Wakapuaka Cross Section 6




Wakapuaka Cross Section 7
Distance from Left Bank (m)
Elevation (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
0
5
10
15
20
25
30
2007
2008
2009
2010
2011
2012


Wakapuaka Cross Section 8
Distance from Left Bank (m)
Elevation (m)
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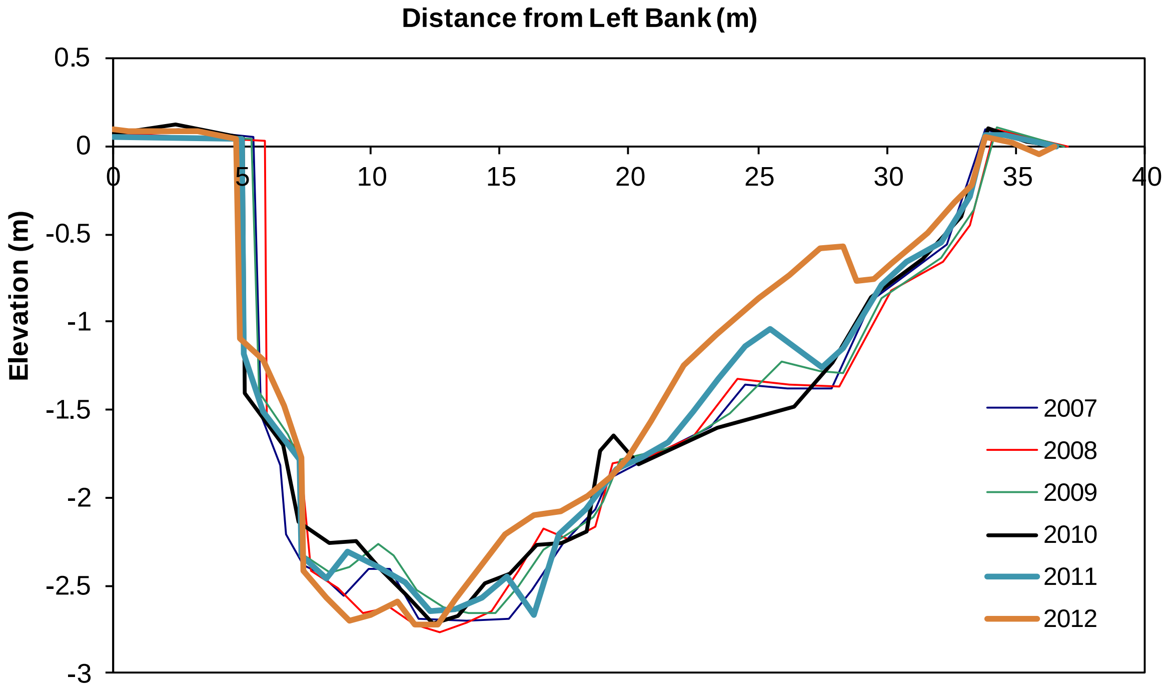
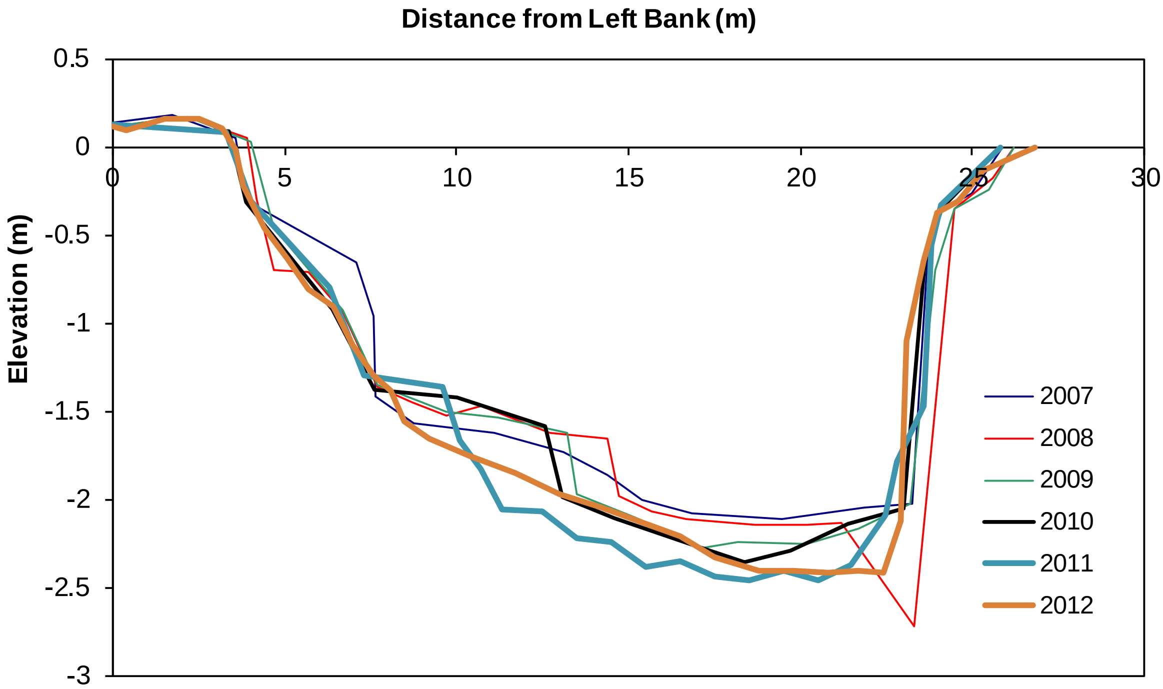
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
0
10
20
30
40
50
60
70
80
90
2007
2008
2009
2010
2011
2012

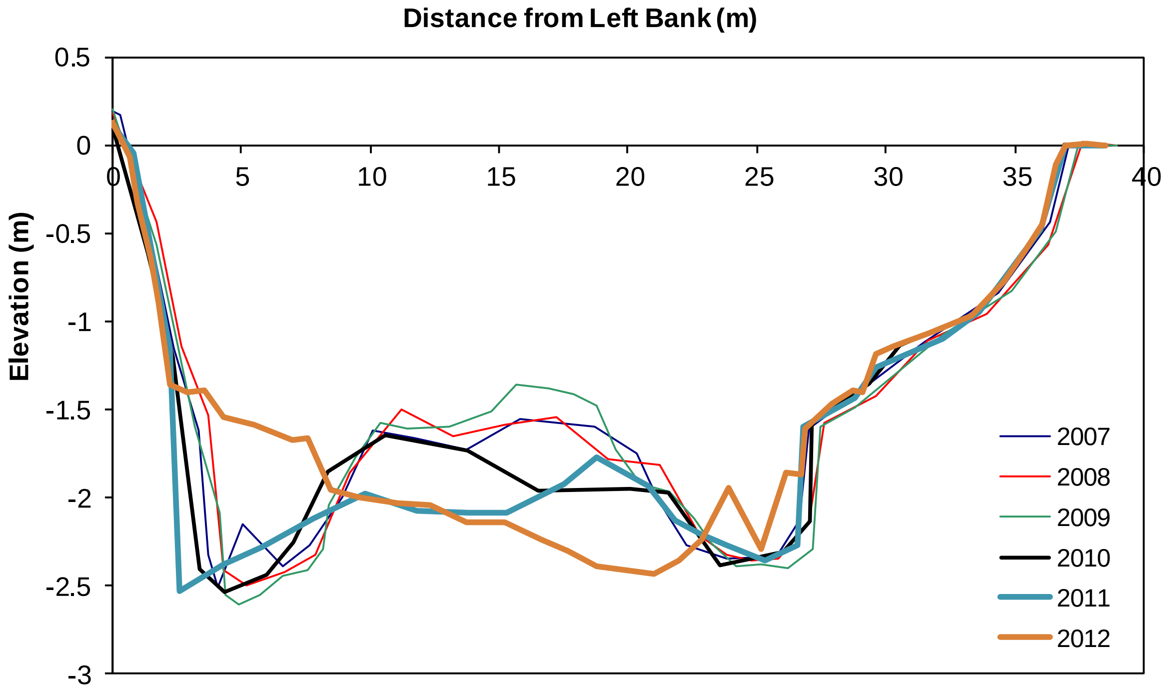
Wakapuaka Cross Section 9



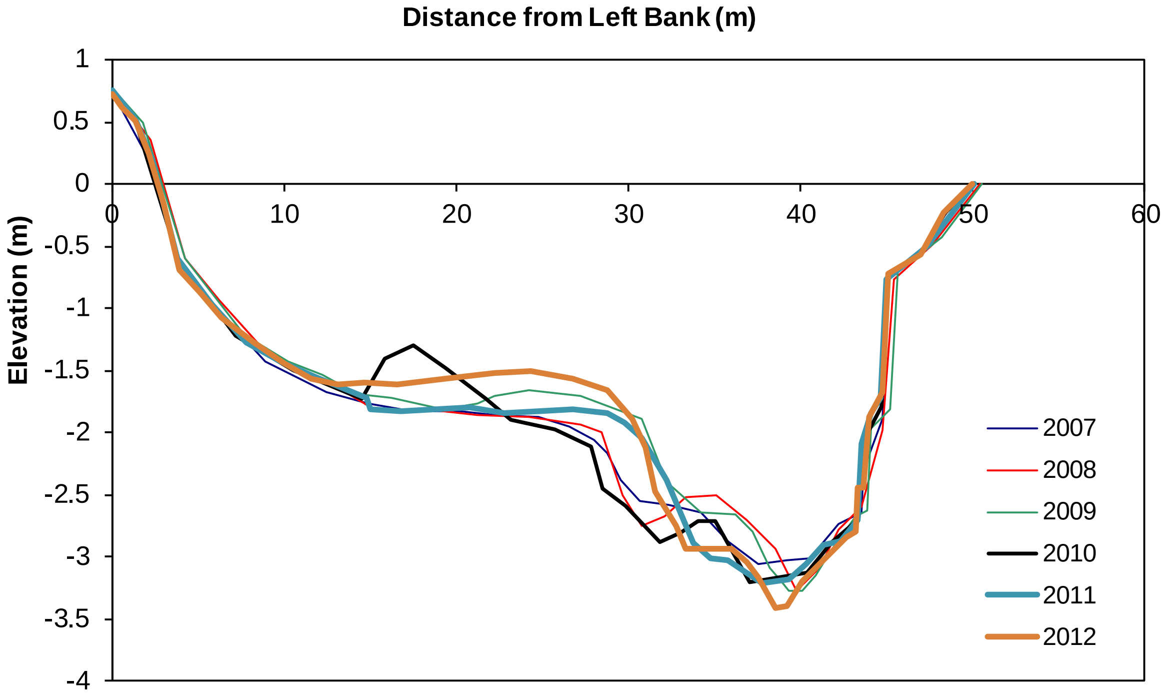
Wakapuaka Cross Section 10

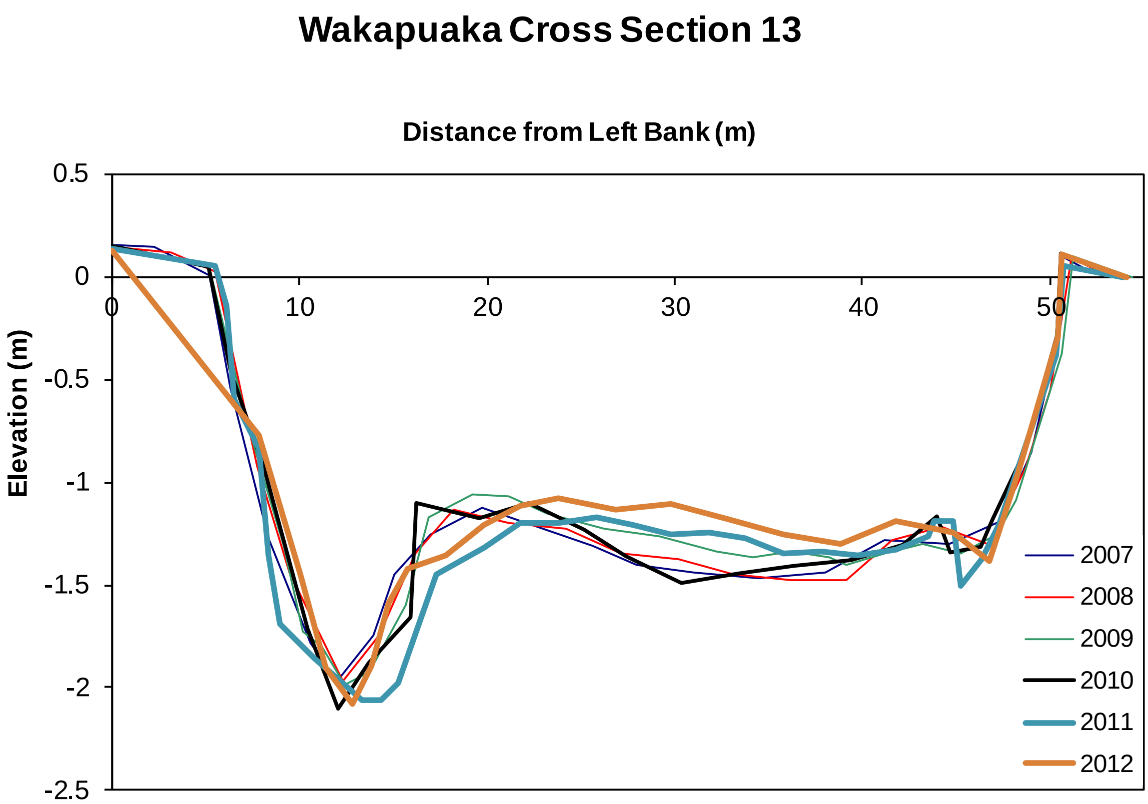


Wakapuaka Cross Section 11



Wakapuaka Cross Section 12




Wakapuaka Cross Section 13
Distance from Left Bank (m)
Elevation (m)
0.5
0
-0.5
-1
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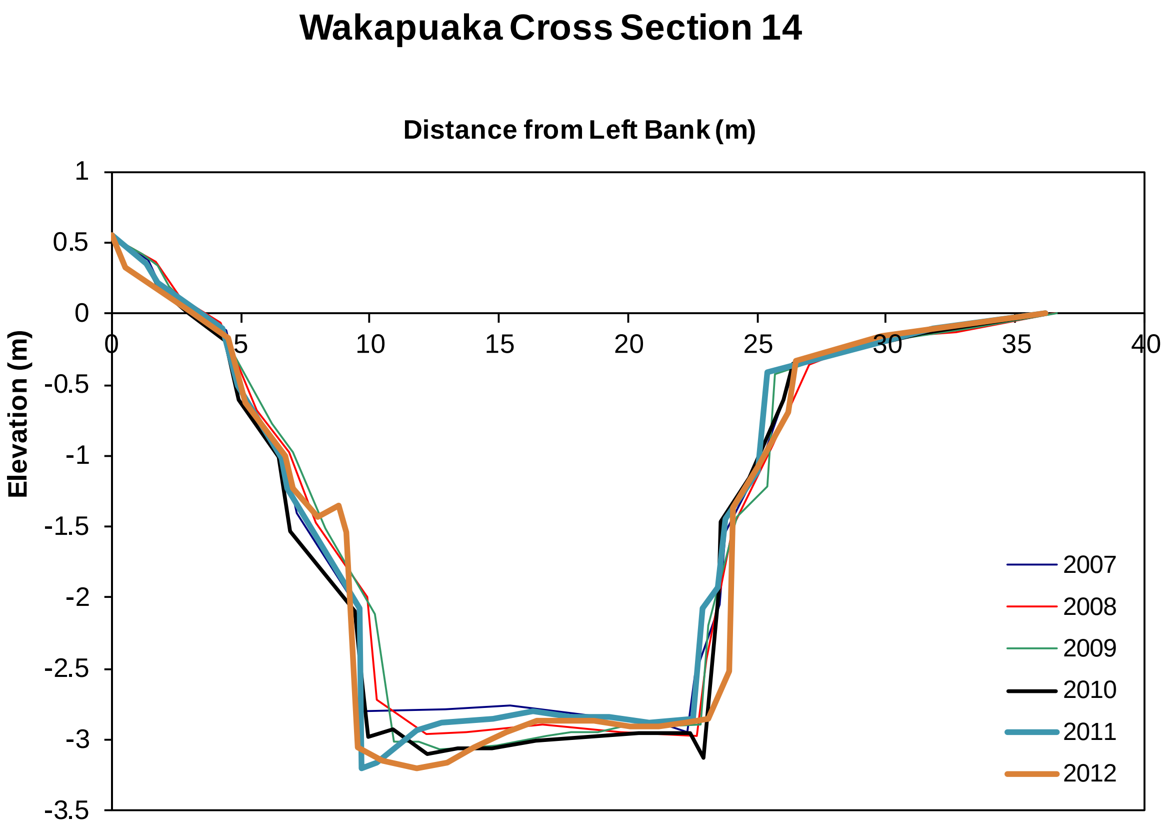
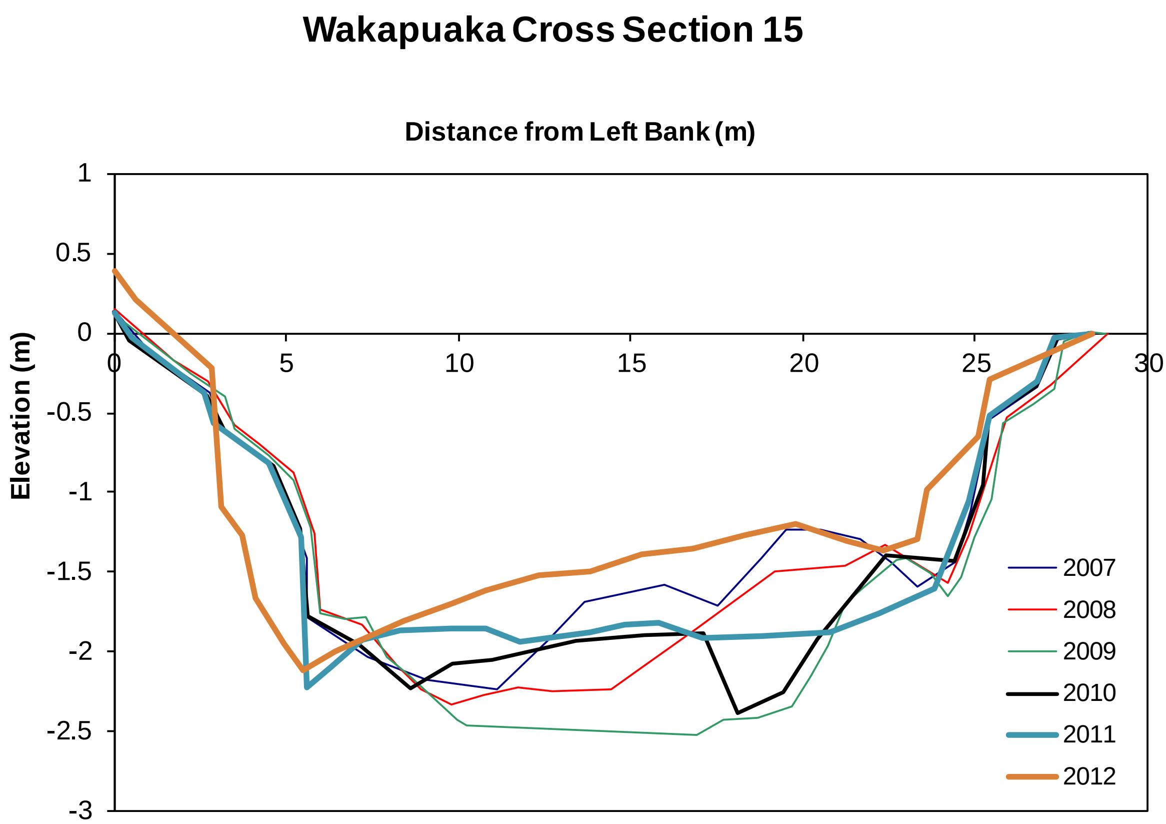
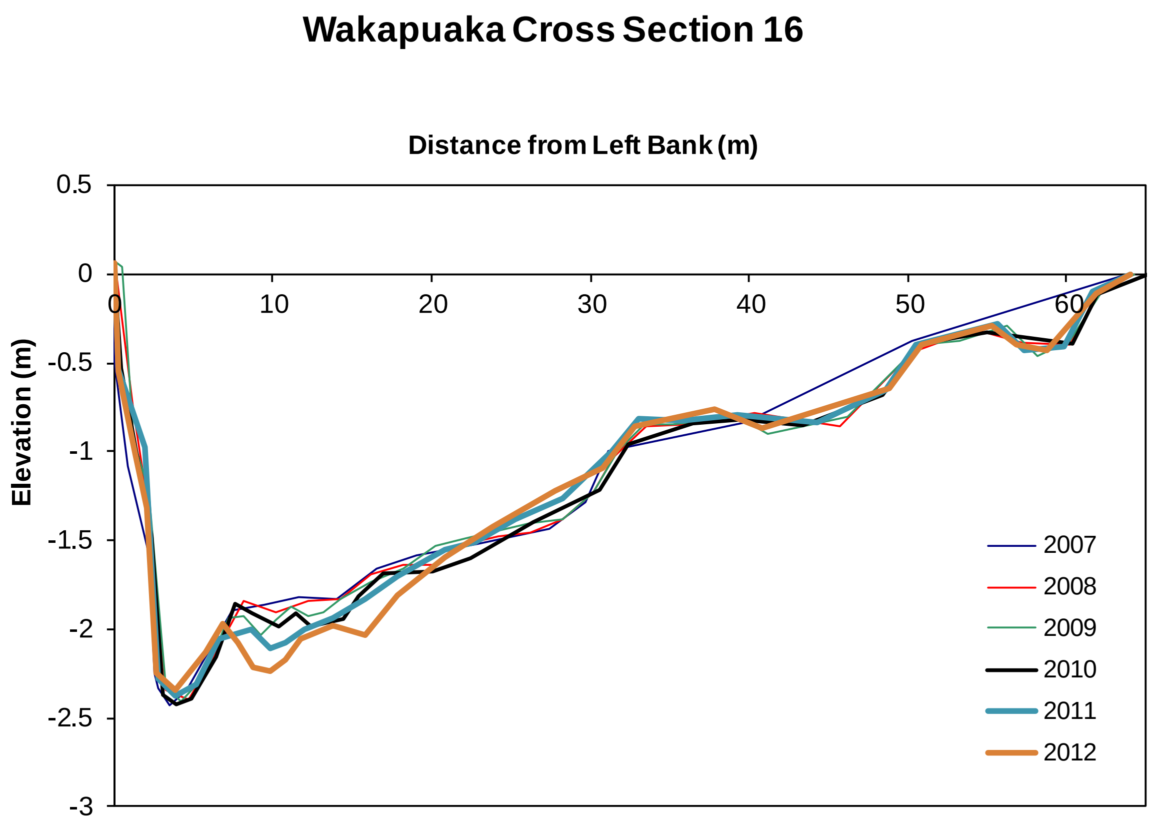
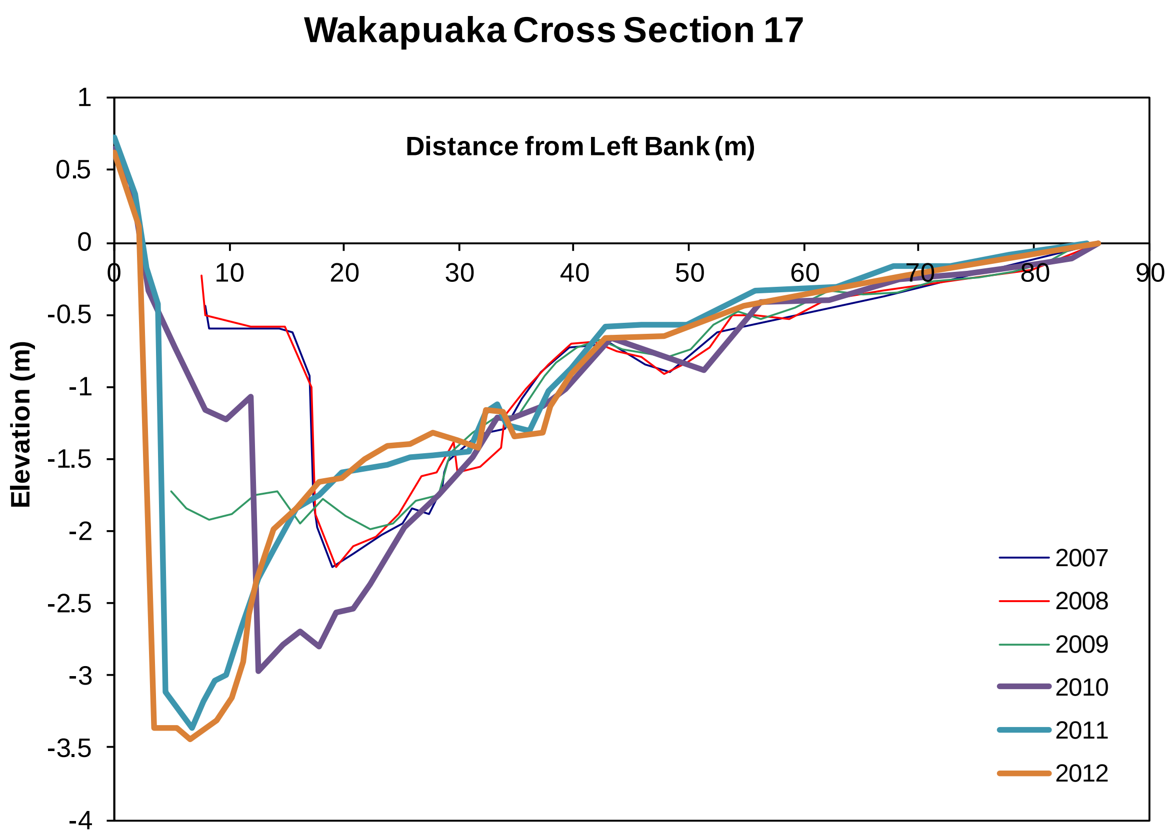
-2
-2.5
0
10
20
30
40
50
2007
2008
2009
2010
2011
2012


Wakapuaka Cross Section 14
Distance from Left Bank (m)
Elevation (m)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0
5
10
15
20
25
30
35
40
2007
2008
2009
2010
2011
2012


Wakapuaka Cross Section 15
Distance from Left Bank (m)
Elevation (m)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
5
10
15
20
25
30
2007
2008
2009
2010
2011
2012


Wakapuaka Cross Section 16
Distance from Left Bank (m)
Elevation (m)
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
10
20
30
40
50
60
2007
2008
2009
2010
2011
2012


Wakapuaka Cross Section 17
Distance from Left Bank (m)
Elevation (m)
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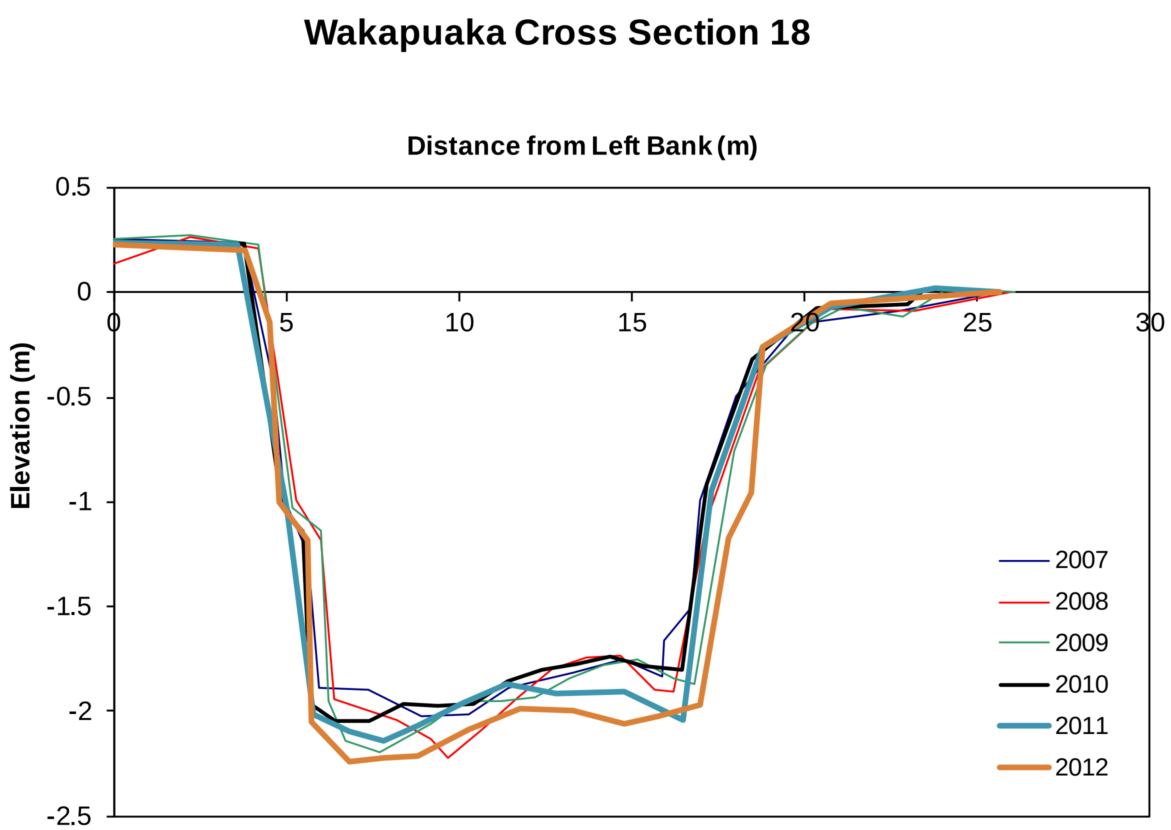
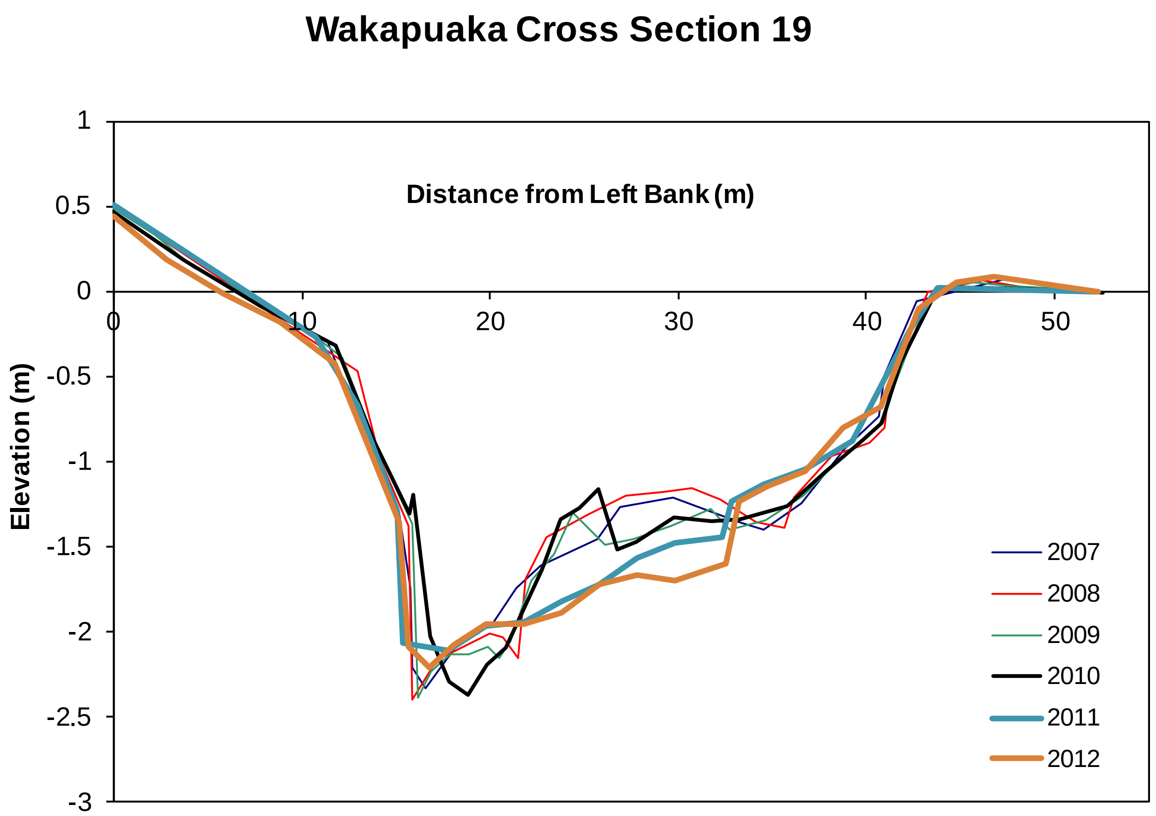
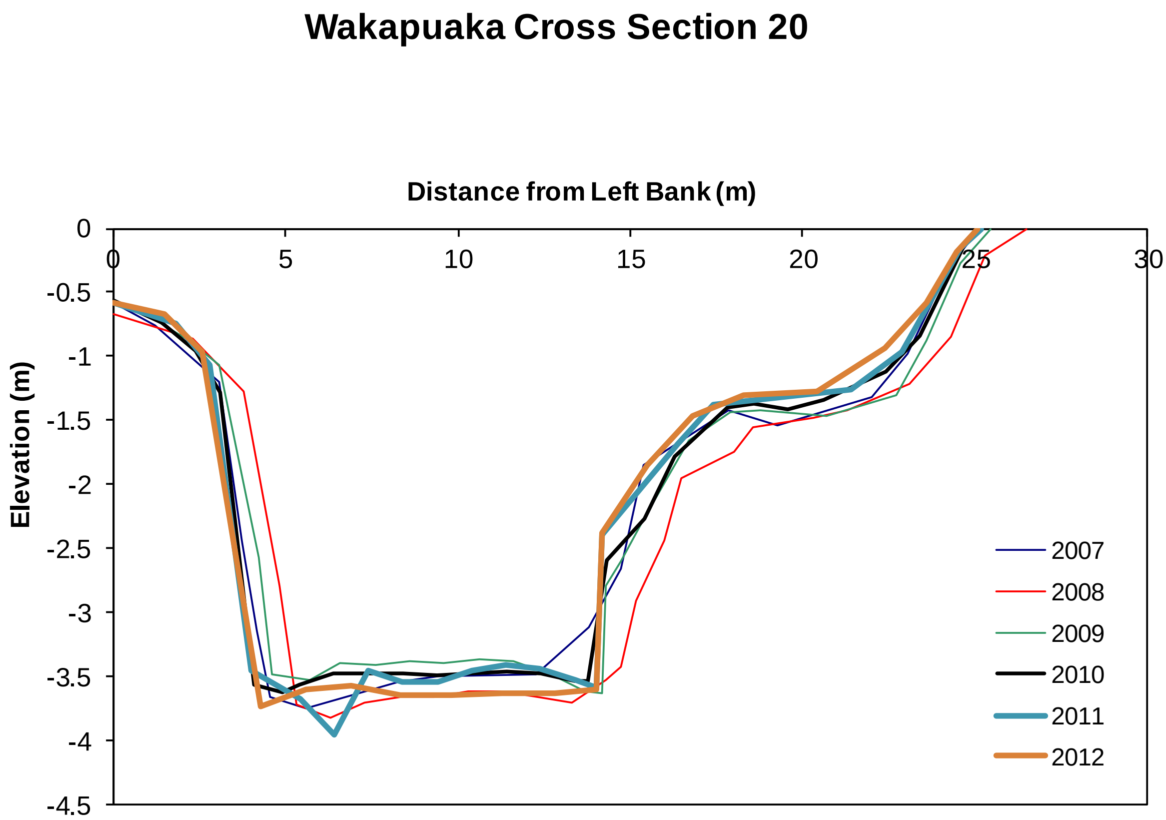
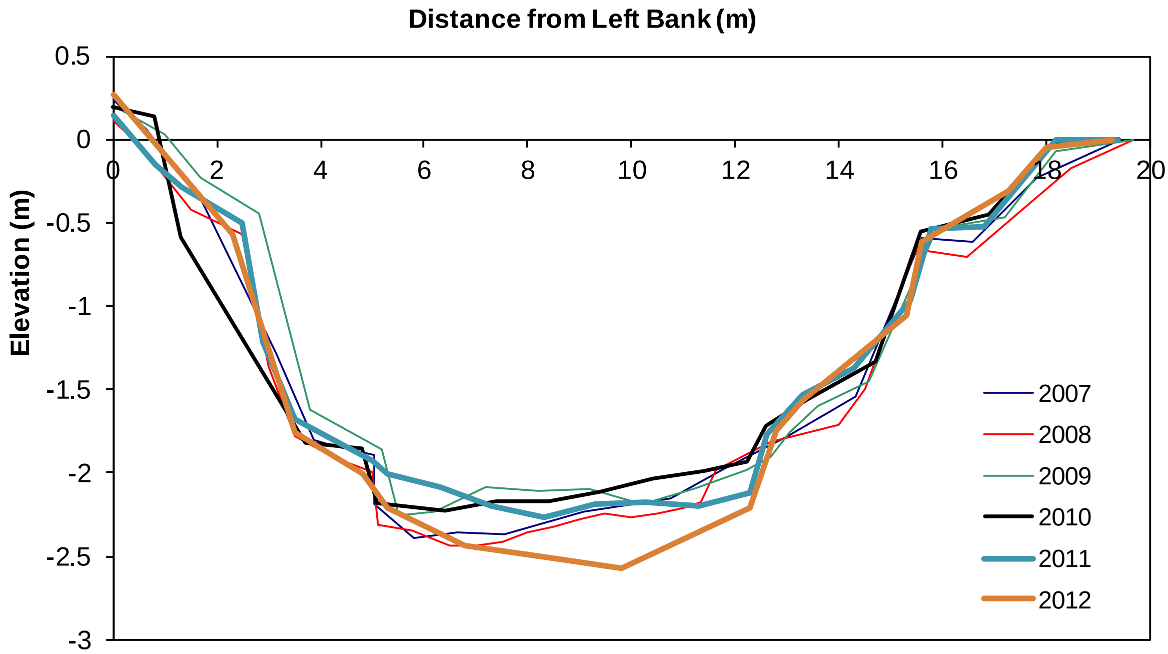
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
10
20
30
40
50
60
70
80
90
2007
2008
2009
2010
2011
2012


Wakapuaka Cross Section 18
Distance from Left Bank (m)
Elevation (m)
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
5
10
15
20
25
30
2007
2008
2009
2010
2011
2012

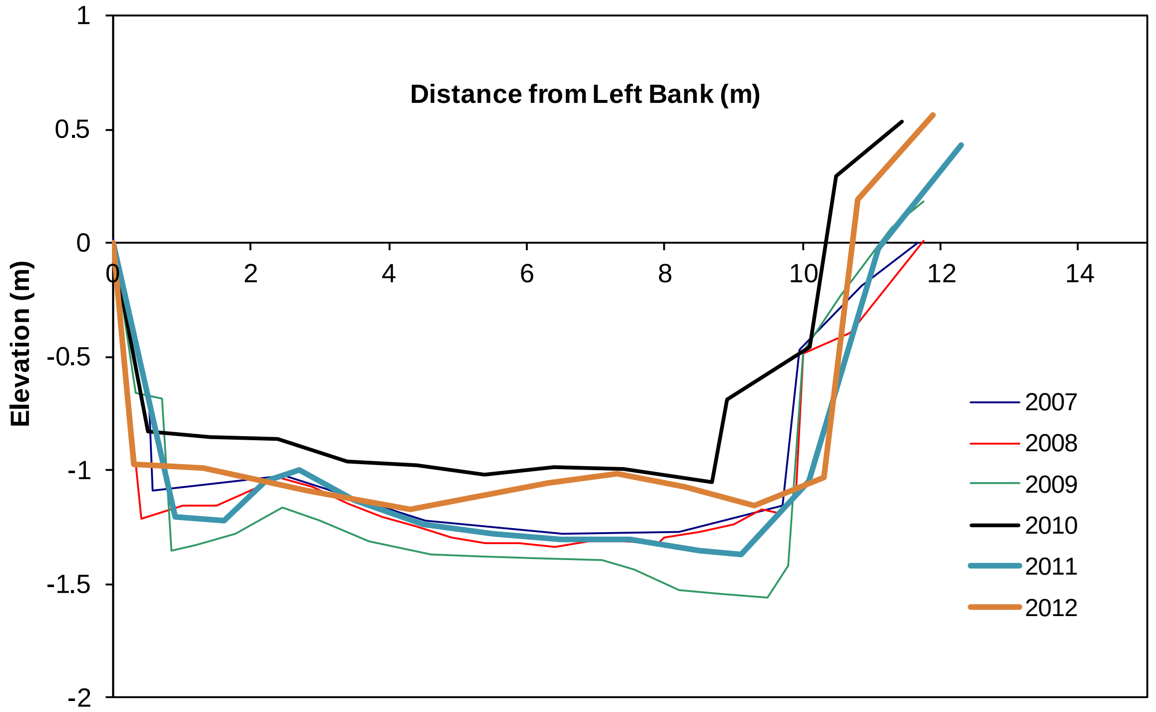

Wakapuaka Cross Section 19
Distance from Left Bank (m)
Elevation (m)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
10
20
30
40
50
2007
2008
2009
2010
2011
2012


Wakapuaka Cross Section 20
Distance from Left Bank (m)
Elevation (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
0
5
10
15
20
25
30
2007
2008
2009
2010
2011
2012

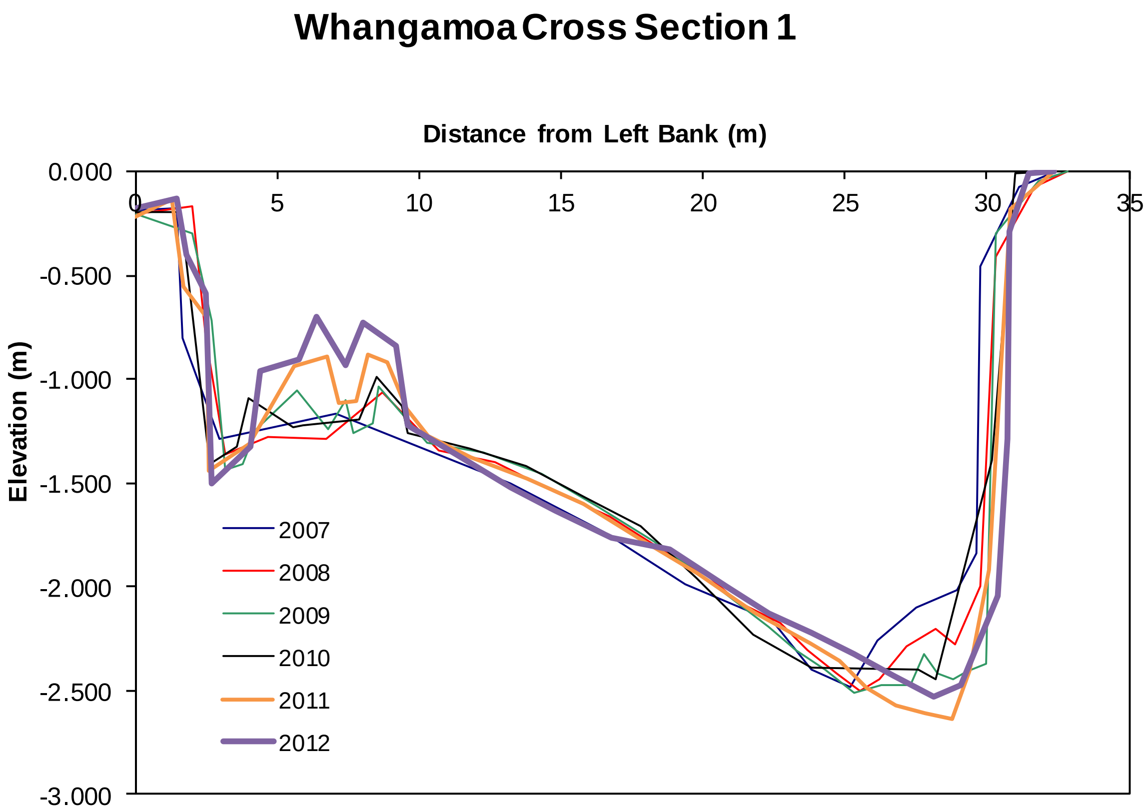
Wakapuaka Cross Section 21

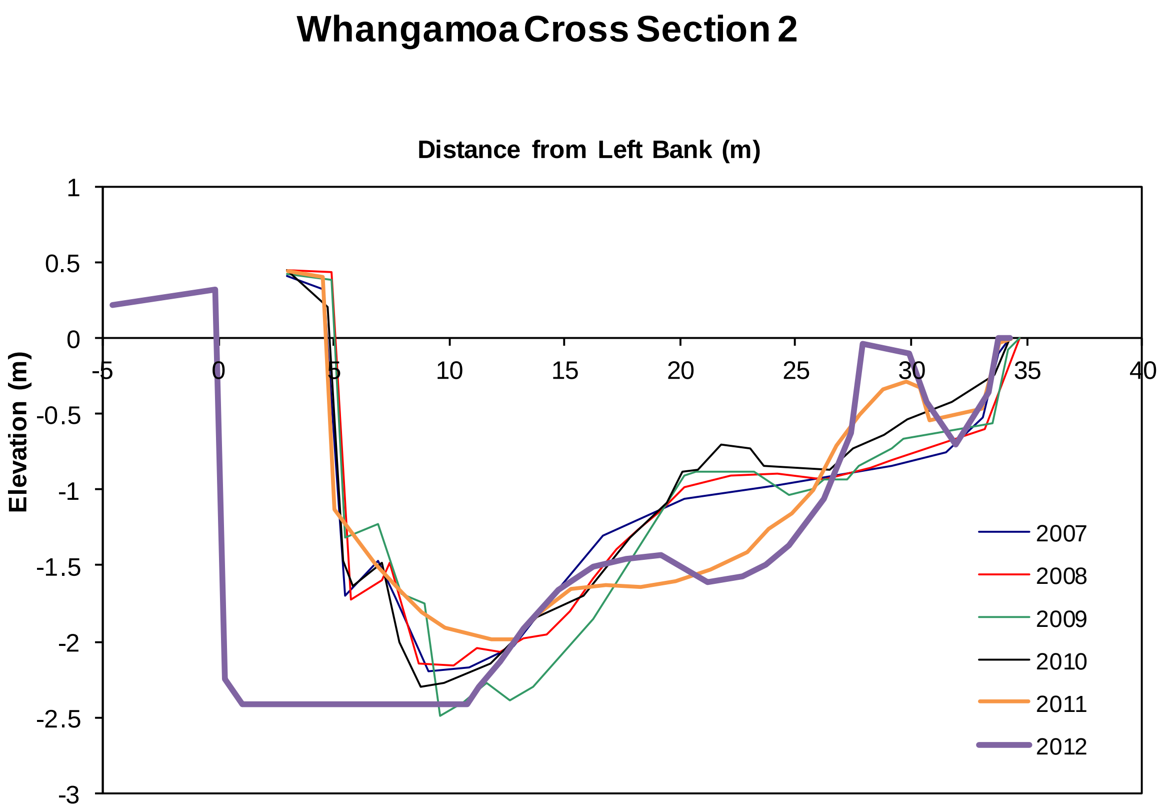


Wakapuaka Cross Section 22

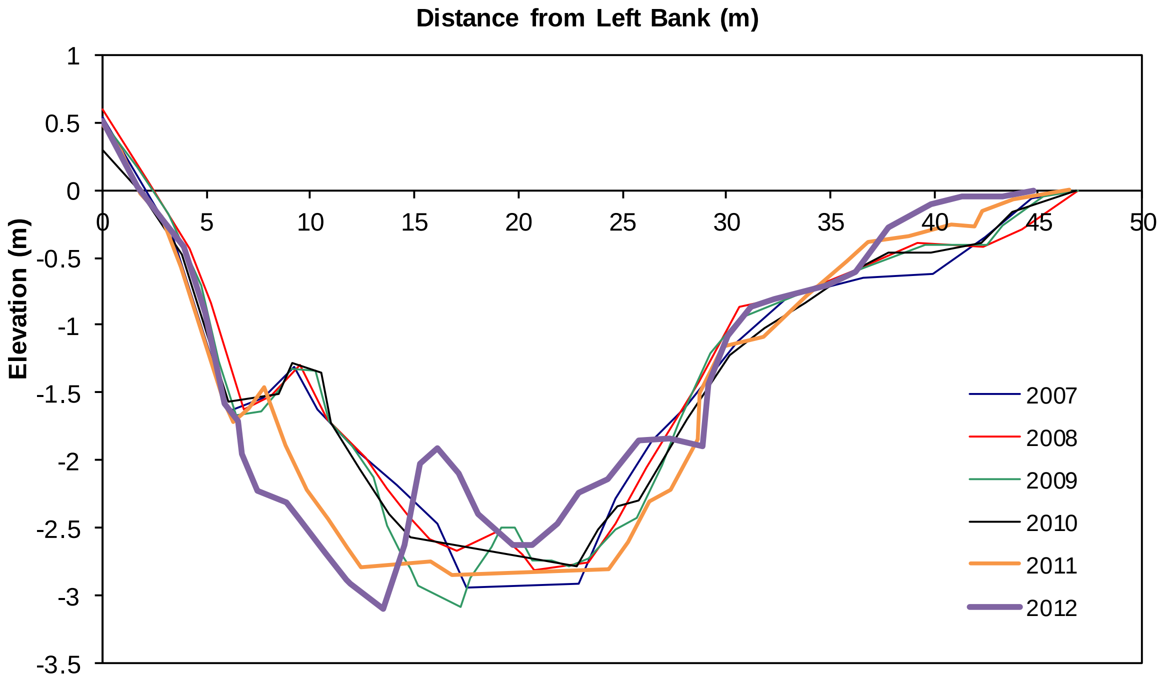


Whangamoa

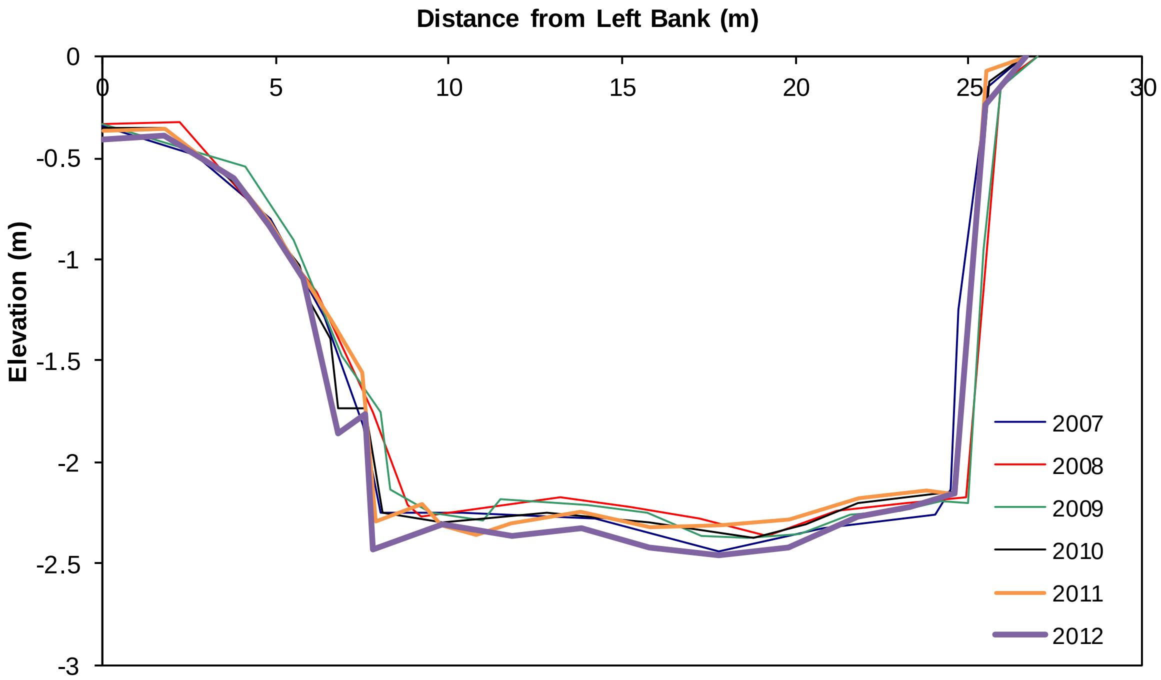

Whangamoa Cross Section 1
Distance from Left Bank (m)
Elevation (m)
0.000
-0.500
-1.000
-1.500
-2.000
-2.500
-3.000
0
5
10
15
20
25
30
35
2007
2008
2009
2010
2011
2012


Whangamoa Cross Section 2
Distance from Left Bank (m)
Elevation (m)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-5
0
5
10
15
20
25
30
35
40
2007
2008
2009
2010
2011
2012

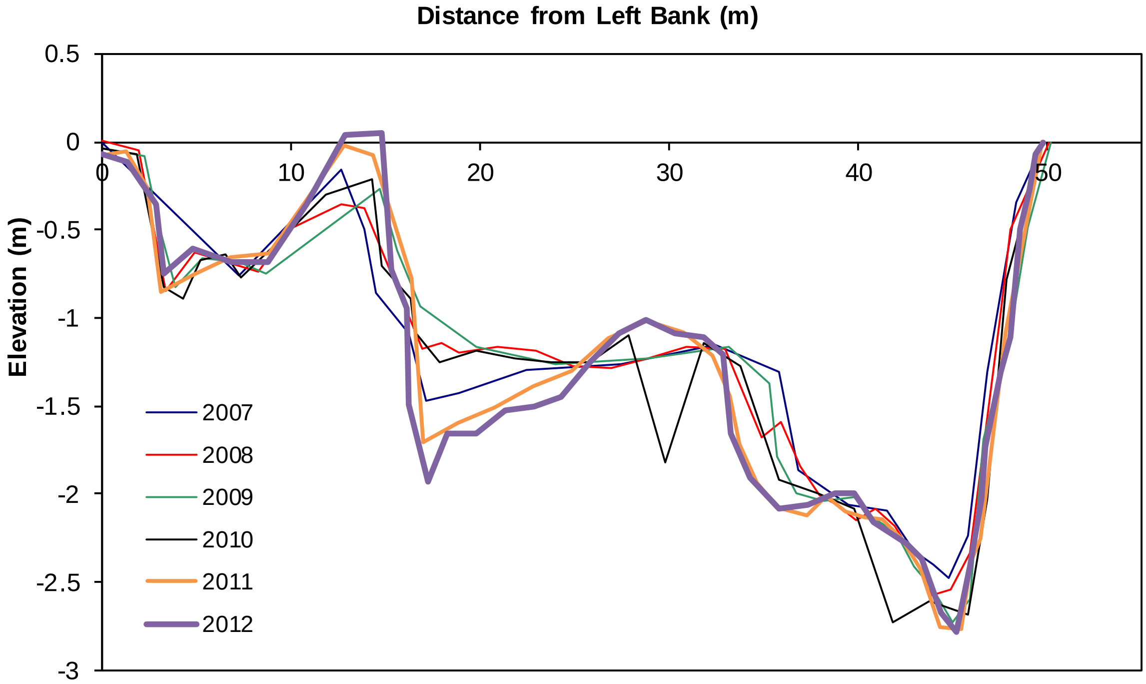
Whangamoa Cross Section 3



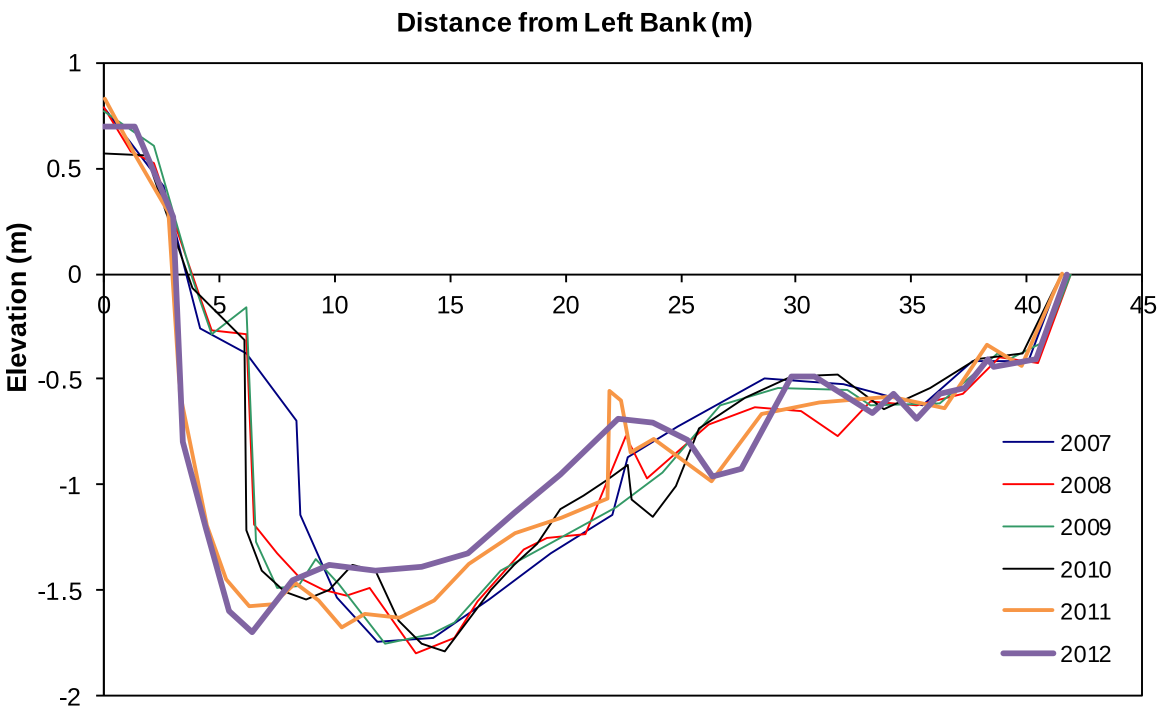
Whangamoa Cross Section 4

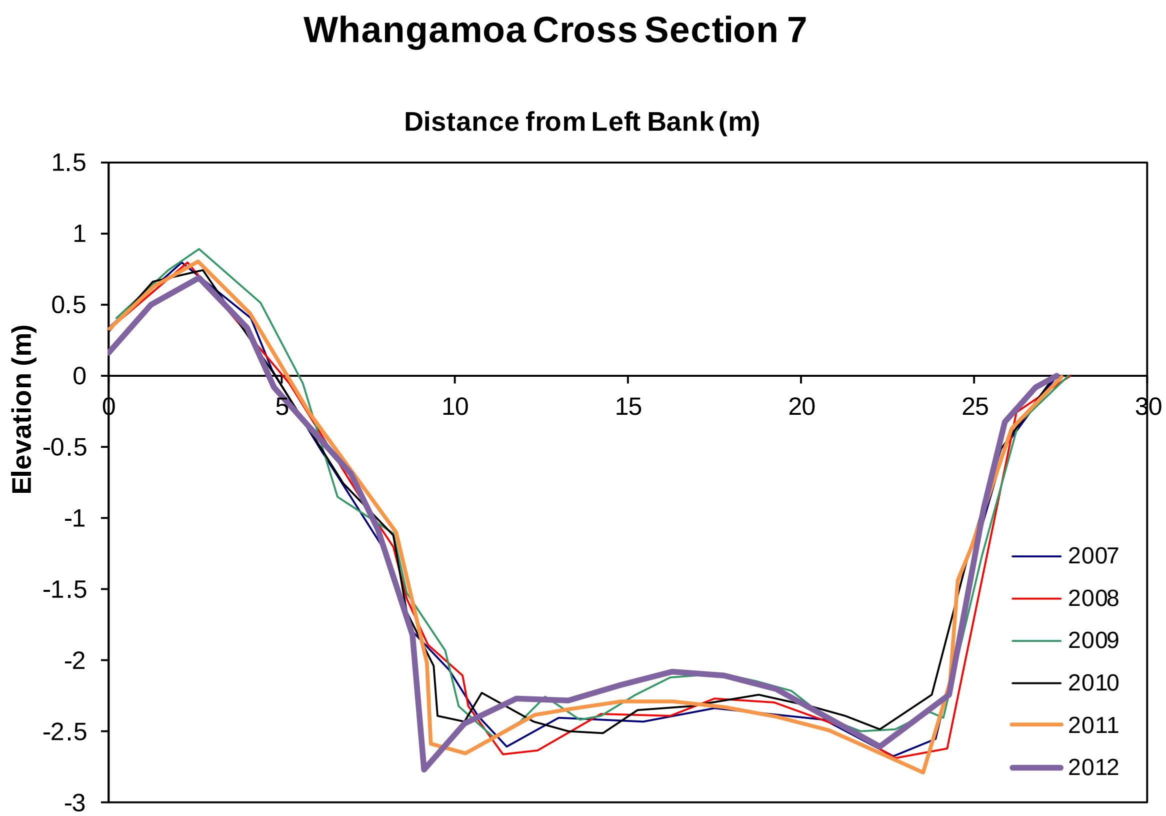


Whangamoa Cross Section 5

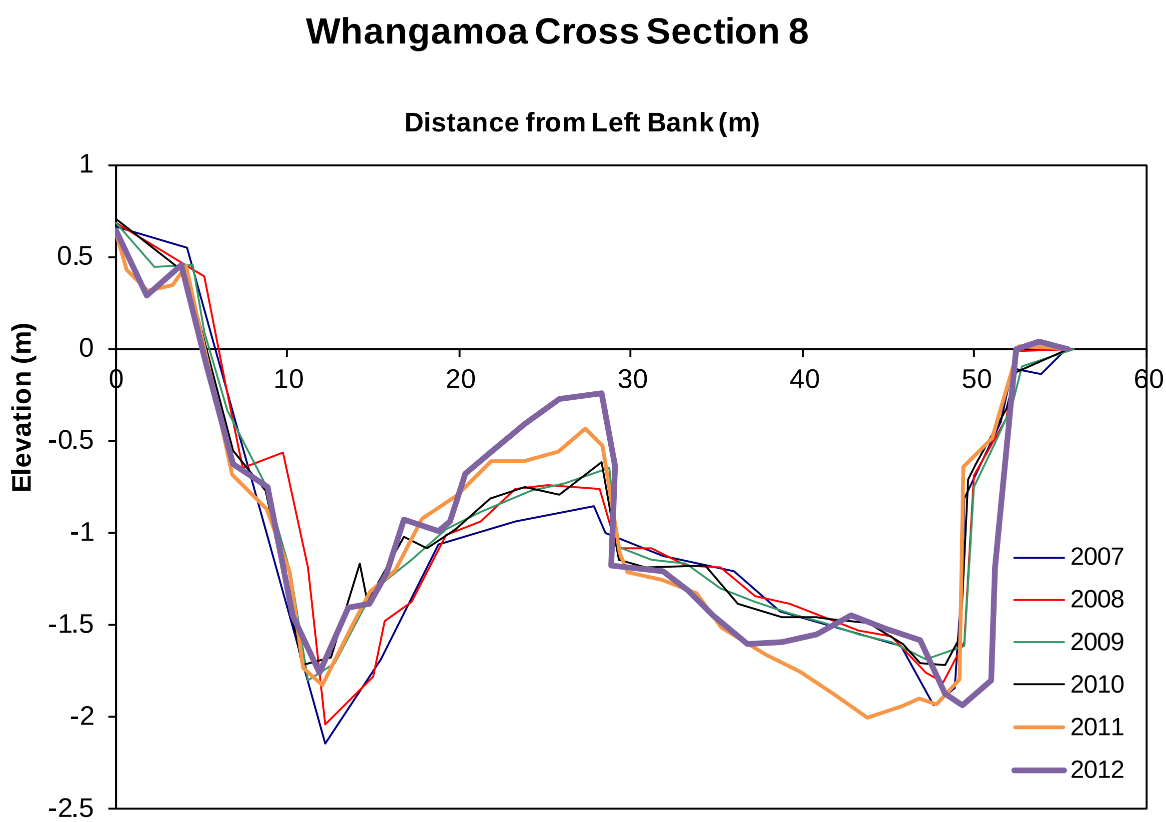


Whangamoa Cross Section 6

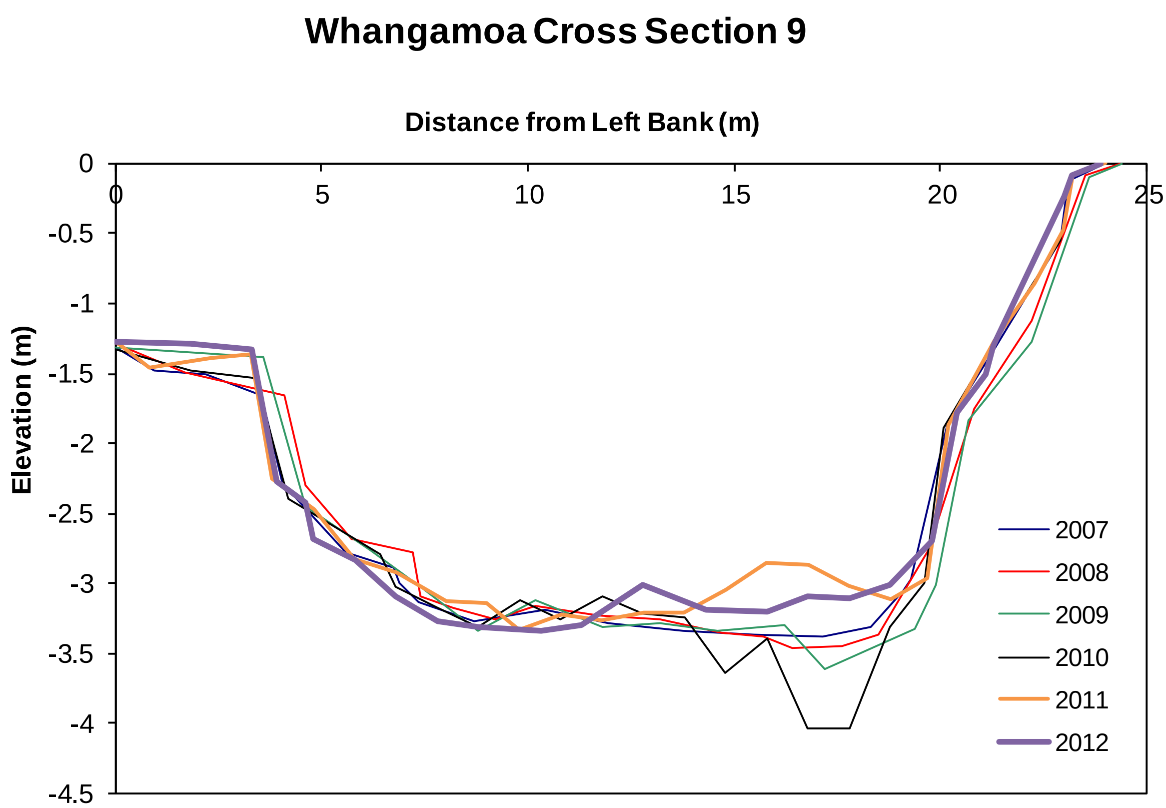


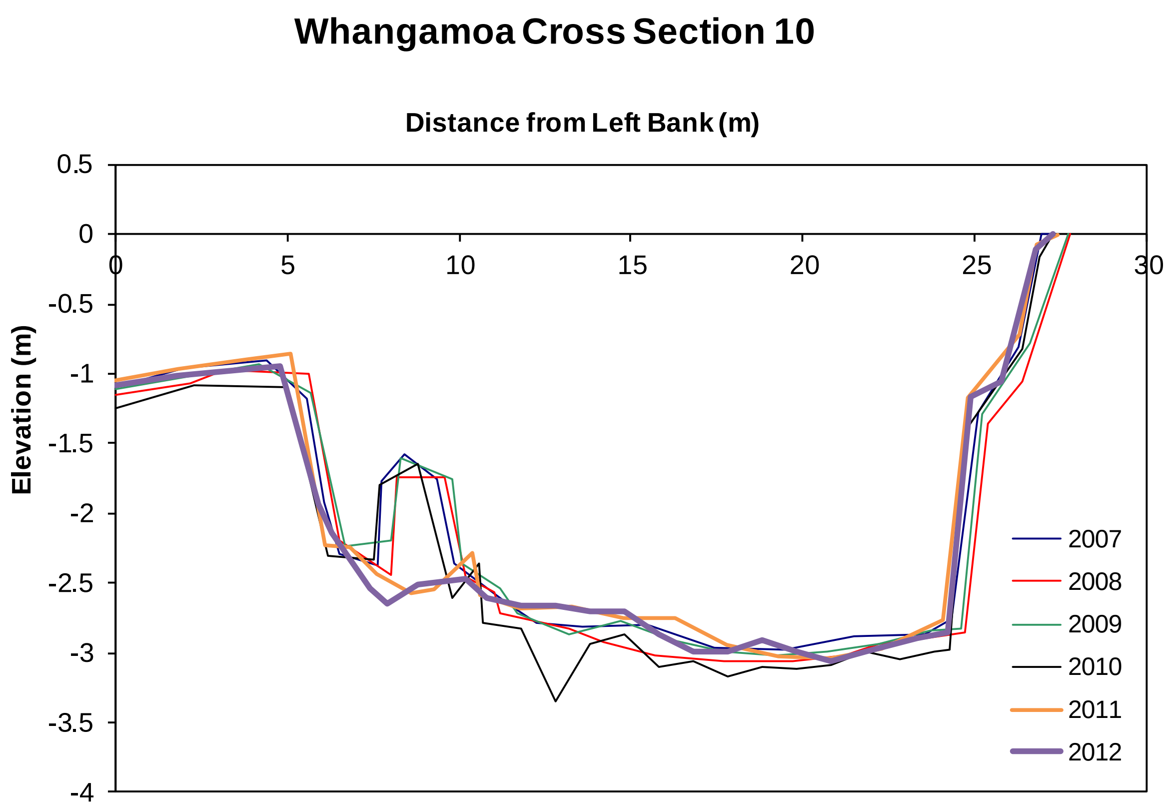


Whangamoa Cross Section 7
Distance from Left Bank (m)
Elevation (m)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
5
10
15
20
25
30
2007
2008
2009
2010
2011
2012



Whangamoa Cross Section 8
Distance from Left Bank (m)
Elevation (m)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
10
20
30
40
50
60
2007
2008
2009
2010
2011
2012


Whangamoa Cross Section 9
Distance from Left Bank (m)
Elevation (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
0
5
10
15
20
25
2007
2008
2009
2010
2011
2012


Whangamoa Cross Section 10
Distance from Left Bank (m)
Elevation (m)
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
25
30
2007
2008
2009
2010
2011
2012

Appendix 2 – Mean bed level and gravel volume data for Wakapuaka River

		Width (m)						MBL (m)						Change in MBL (m)					
Distance	ID	2007	2008	2009	2010	2011	2012	2007	2008	2009	2010	2011	2012	2007-08	2008-09	2009-10	2010-11	2011-12	Net
218	1	28.37	28.70	28.80	28.34	28.4	28.4	-1.081	-1.140	-1.101	-1.109	-1.096	-1.224	-0.059	0.039	-0.008	0.012	-0.127	-0.143
564	2	46.81	64.70	64.70	64.26	64.3	64.4	-0.688	-1.470	-1.509	-1.466	-1.462	-1.514	-0.782	-0.038	0.043	0.003	-0.052	-0.826
880	3	49.39	49.70	49.70	49.36	54.7	54.9	-0.803	-0.807	-0.860	-0.824	-0.999	-0.907	-0.004	-0.053	0.036	-0.175	0.092	-0.104
1012	4	34.36	35.00	35.00	34.57	34.6	35.85	-0.764	-0.792	-0.752	-0.810	-0.880	-0.825	-0.028	0.040	-0.057	-0.071	0.055	-0.061
1137	5	27.05	25.15					-1.440	-1.853					-0.413					
1956	6	43.58	43.55	43.95	43.55	43.6	43.6	-0.983	-1.015	-0.996	-1.029	-1.027	-0.988	-0.032	0.019	-0.032	0.002	0.039	-0.005
2247	7	27.72	28.30	28.30	27.93	27.7	27.7	-1.971	-2.012	-1.958	-2.004	-2.085	-1.975	-0.041	0.054	-0.046	-0.081	0.110	-0.004
2556	8	86.38	86.75	86.80	86.23	86.5	86.3	-2.342	-2.400	-2.204	-2.307	-2.198	-1.935	-0.058	0.196	-0.102	0.108	0.264	0.407
2785	9	36.56	37.00	36.90	36.52	36.6	36.5	-1.370	-1.339	-1.327	-1.348	-1.315	-1.213	0.031	0.012	-0.021	0.032	0.102	0.157
3139	10	25.87	26.19	26.20	25.8	25.8	26.8	-1.238	-1.308	-1.285	-1.309	-1.411	-1.329	-0.070	0.022	-0.024	-0.102	0.082	-0.092
3305	11	38.63	39.00	39.00	38.45	38.5	38.5	-1.523	-1.507	-1.511	-1.596	-1.647	1.578	0.016	-0.004	-0.085	-0.051		-0.124
3424	12	50.08	50.45	50.55	50.03	50.1	50	-1.721	-1.693	-1.623	-1.711	-1.684	-1.631	0.028	0.070	-0.089	0.027	0.053	0.090
3705	13	53.91	54.30	54.40	53.95	53.9	54.1	-1.082	-1.058	-1.039	-1.063	-1.086	-1.027	0.023	0.019	-0.023	-0.024	0.059	0.054
3870	14	36.26	36.55	36.60	36.15	36.2	36.2	-1.348	-1.354	-1.351	-1.443	-1.358	-1.432	-0.006	0.003	-0.092	0.085	-0.074	-0.084
4335	15	28.49	28.85	28.80	28.4	28.4	28.4	-1.301	-1.377	-1.578	-1.441	-1.394	-1.167	-0.076	-0.202	0.137	0.047	0.227	0.134
4599	16	63.72	64.30	64.30	65.32	64	64	-1.080	-1.101	-1.102	-1.109	-1.111	-1.128	-0.021	-0.001	-0.007	-0.001	-0.018	-0.048
4897	17	77.73	78.10	80.70	85.65	84.7	85.65	-0.798	-0.788	-0.978	-0.953	-0.939	-1.012	0.010	-0.191	0.025	0.014	-0.073	-0.214
5371	18	25.7	26.00	26.10	25.68	25.7	25.7	-0.893	-0.896	-0.915	-0.903	-0.959	-1.032	-0.003	-0.018	0.011	-0.056	-0.073	-0.139
5842	19	52.19	52.20	52.40	52.56	52.3	52.3	-0.763	-0.749	-0.782	-0.769	-0.801	-0.840	0.014	-0.033	0.013	-0.032	-0.039	-0.077
6223	20	25.11	26.50	25.45	25.1	25.2	25.1	-2.205	-2.202	-2.150	-2.193	-2.179	-2.185	0.004	0.052	-0.043	0.014	-0.006	0.020
6846	21	19.45	19.70	19.70	19.4	19.4	19.3	-1.384	-1.423	-1.270	-1.355	-1.336	-1.443	-0.039	0.153	-0.085	0.019	-0.106	-0.059
7615	22	11.67	11.77	11.77	11.45	12.3	11.9	-0.993	-1.059	-1.123	-0.744	-0.988	-0.899	-0.066	-0.064	0.378	-0.244	0.089	0.094
														Mean dMBL					
														-0.071	0.004	-0.003	-0.023	0.032	-0.045

Appendix 3 – Mean bed level and gravel volume data for Whangamoa River

		Width (m)						MBL (m)						Change in MBL (m)					
Distance	ID	2007	2008	2009	2010	2011	2012	2007	2008	2009	2010	2011	2012	2007-08	2008-09	2009-10	2010-11	2011-12	Net
190	1	32.41	32.85	32.85	32.4	32.4	32.4	-1.499	-1.476	-1.492	-1.505	-1.523	-1.500	0.023	-0.016	-0.013	-0.018	0.023	-0.001
932	2	31.26	31.70	31.70	31.25	31.3	38.9	-1.167	-1.142	-1.178	-1.114	-1.179	-1.345	0.025	-0.036	0.064	-0.065	-0.166	-0.178
1398	3	46.55	46.95	46.95	46.8	46.5	44.8	-1.363	-1.291	-1.342	-1.352	-1.475	-1.406	0.072	-0.051	-0.010	-0.123		-0.112
1696	4	26.61	27.00	27.00	26.6	26.6	26.65	-1.724	-1.676	-1.688	-1.718	-1.697	-1.781	0.048	-0.012	-0.030	0.021	-0.084	-0.057
2021	5	49.77	50.10	50.20	49.7	49.7	49.8	-1.148	-1.160	-1.169	-1.239	-1.235	-1.241	-0.012	-0.009	-0.069	0.004	-0.007	-0.093
2501	6	41.48	41.90	41.90	41.5	41.5	41.7	-0.756	-0.809	-0.794	-0.799	-0.877	-0.820	-0.053	0.015	-0.005	-0.078	0.058	-0.063
2993	7	27.39	27.75	27.50	27.35	27.5	27.4	-1.474	-1.465	-1.372	-1.421	-1.437	-1.420	0.008	0.093	-0.049	-0.016	0.017	0.054
3678	8	55.3	55.70	55.80	55.4	55.4	55.4	-0.990	-0.918	-0.922	-0.921	-0.989	-0.942	0.073	-0.004	0.001	-0.067	0.046	0.048
4551	9	23.98	24.35	24.40	23.95	24.0	23.9	-2.508	-2.468	-2.502	-2.562	-2.415	-2.447	0.040	-0.034	-0.060	0.147	-0.032	0.061
5460	10	27.34	27.80	27.70	27.3	27.4	27.3	-2.114	-2.183	-2.117	-2.261	-2.137	-2.190	-0.069	0.066	-0.144	0.124	-0.053	-0.076
														Mean dMBL					
														0.015	0.001	-0.032	-0.007	-0.013	-0.035

Appendix 4 – Location of beaches

Grid references are in NZTM projection and describe the centroid of the mapped polygon. Locations highlighted in grey were identified by Stocker (2002) as beaches.

Wakapuaka River

2009 ID	Comments	Easting	Northing	2012 ID		Easting	Northing
1	Partially obscured by trees on NW margin (LB), XS1 cuts u/s margin	1635690	5441670	1	Beach TL, NW margin partially obscured by trees, XS1 cuts through u/s margin		
2	XS2 cuts through centre of beach	1635530	5441400	2	Beach TR, XS cuts through centre		
3	Small beach	1635540	5441300				
4	Small beach TL, d/s of XS3	1635570	5441200				
5	Large beach TR, XS3 cuts through centre of beach	1635530	5441190	3	Small beach TR, XS3 cuts through centre		
6	Beach TR, u/s of XS3	1635510	5441140				
				4	Small beach TR, partially obscured by trees, river has widened a lot here, XS4 cuts through centre	1635530	5441100
7	Us of XS4, may be larger but obscured by trees	1635550	5441090				
8	Large beach TR, XS 5 cuts through centre of beach	1635570	5440990	5	Small beach TR, XS5 cuts through centre		
				6	Small beach TR on inside of bend, partially vegetated, river has widened considerably here	1635590	5440950
9	Beach TL	1635610	5440840	7	Small beach TL, inside of bend		
10	Large beach TR	1635540	5440820	8	Large beach TR, inside of bend, river has widened considerably here		
11	Partially vegetated small beach TR	1635440	5440720				

2009 ID	Comments	Easting	Northing	2012 ID		Easting	Northing
12	Small beach TR, XS6 cuts through middle	1635320	5440560	9	Beach TR, XS6 cuts through centre, river has widened		
13	Beach TR	1635390	5440410	10	Very small beach TR		
14	Beach TL, u/s extension of 13	1635390	5440380				
15	Large beach TR d/s of Maori Pa Rd, XS8 cuts through centre	1635160	5440170	11	Large beach TR on inside of bend, XS8 cuts through centre		
16	TL, spans bridge	1635170	5440120	12	Small beach TL, extends under bridge		
17	Beach TR, may be continuous with u/s beach	1635180	5440070	13	Small beach TR, may extend us to next beach		
18	Large beach TR, XS9 cuts trhough u/s margin	1635180	5440020	14	Large beach TR, XS9 cuts through centre		
19	Large beach TL, inside of bend	1635230	5439970	15	Large beach TL, inside of bend		
20	Large beach TR	1635270	5439920	16	Large beach TR, inside of bend		
21	Large beachTL, adjacent gravel processing plant	1635340	5439910	17	Large beach TL, inside of bend		
				18	Long narrow beach TL, XS10 cuts through centre	1635440	5439810
22	Small beach TL	1635460	5439750				
23	Large beach TL, may have been mapped on both sides of river	1635420	5439590	19 and 20	Beach TR, XS11 cuts u/s margin of beach; Large beach TL, inside of bend, XS11cuts d/s end & XS12 cuts centre of beach		
24	Large beach TR, XS13 cuts through near u/s margin	1635210	5439490	21	Small beach TR		
25	Large beach TR, near stream crossing	1634930	5439000	22	Large beach TR, river crosing, XS15 cuts u/s end,		
26	Large beach, at bridge	1634880	5438860	23	Large beach TL, inside of bend		
27	Large beach TR, XS16 cuts through u/s margin	1634760	5438790	24	Large beach TR, inside of bend, XS16 crosses near u/s end		
28	Small beach TR	1634670	5438680	25	Narrow beach TR		

2009 ID	Comments	Easting	Northing	2012 ID		Easting	Northing
29	Small beach TL	1634650	5438640	26	Beach TL, partially obscured by trees		
30	Large beach TR, XS 17 cuts through centre, major avulsion here	1634590	5438560	26	Large beach TR, XS17 cuts through centre, major channel change here		
31	Beach TL, inside of bend	1634510	5438480	27	Large beach TL inside of bend		
32	Small beach TR	1634220	5438510				
33	Small beach TR	1634150	5438530	28	Small beach TR, inside of bend		
				29	Small beach TR	1634100	5438530
				30	Small beach TL, partially vegetated	1634050	5438520
34	Small beach TR	1634010	5438530				
35	Small beach TR	1633920	5438410	31	Small beach TR, XS19 is slightly u/s of here		
36	Small beach TR	1633730	5437780				

Whangamoa River

1999 ID	Comments	Easting	Northing	2009 ID		Easting	Northing
1	Beach TR	1645750	5448970	1	Beach TR, tidal reach		
2	Beach TL, inside of bend	1645820	5448870	2	Beach TL, XS1 cuts u/s end		
3 and 4	Small beach TL; Beach TR, u/s end on inside of bend	1645780	5448750	3	Long narrow beach TR		
5	Small beach TL	1645830	5448580	4	Small beach TL		
				5	Small beach TL, inside of bend	1645910	5448570
6	Small beach TR	1645910	5448480				
7	Small beach TL	1645900	5448420	6	Long narrow beach TL, inside of bend		
8	Small beach TL	1645800	5448360	7	Small beach TL, inside of bend		
9	Beach TR, inside of bend, XS2 at d/s end	1645710	5448370	8	Large beach TR, inside of bend, XS 2 cuts through centre		
10	Beach TL	1645640	5448320	9	Small beach TL		
11	Beach TL	1645610	5448250	10	Small beach TL		
12	Beach TR	1645630	5448240	11	Beach TR		
13 and 14	Beach TR, inside of bend, XS3 cuts through centre; Beach TL, outside of bend	1645460	5448120	12	Beach TR, inside of bend, XS3 cuts through centre		
15	Small beach TR	1645380	5448010	13	Small beach TR		
16	Beach TR	1645560	5447660	14	Small beach TR		
17	Beach TR, outside of bend, XS5 near d/s end	1645630	5447640	15	Beach TL, inside of bend, XS5 cuts through centre		
18	Beach TR	1645700	5447560	16	Beach TR		
19	Beach TL, inside of bend	1645720	5447500	17	Beach TL, inside of bend	1645730	5447510
20	Small beach TL	1645630	5447440				

1999 ID	Comments	Easting	Northing	2009 ID		Easting	Northing
21	Beach TL	1645580	5447400	18	Beach TL		
22	Beach TR, XS6 just d/s	1645500	5447300	19	Beach TR, inside of bend, XS6 cuts through centre		
				20	Small beach TL	1645490	5447270
23	Large beach TR, inside of bend	1645520	5447210	21	Large beach TR, outside of bend, partly vegetated (avulsion?)		
				22	Beach TL, inside of bend	1645570	5447120
24	Beach TR	1645420	5446870	23	Beach TR below bridge		
25	Beach TR	1645410	5446770				
26	Beach TL	1645390	5446610	24	Large beach TL		
27	Large beach TR	1645300	5446440	26	Large beach TR, just d/s XS8		
28	Island	1645260	5446340	25	Beach TL, partly vegetated, XS8 cuts through centre		
29	Beach TR	1645290	5446270				
30	Beach TL	1645260	5446200	27	Large beach TL, fairly heavily vegetated		
31	Beach TR	1644940	5445430				