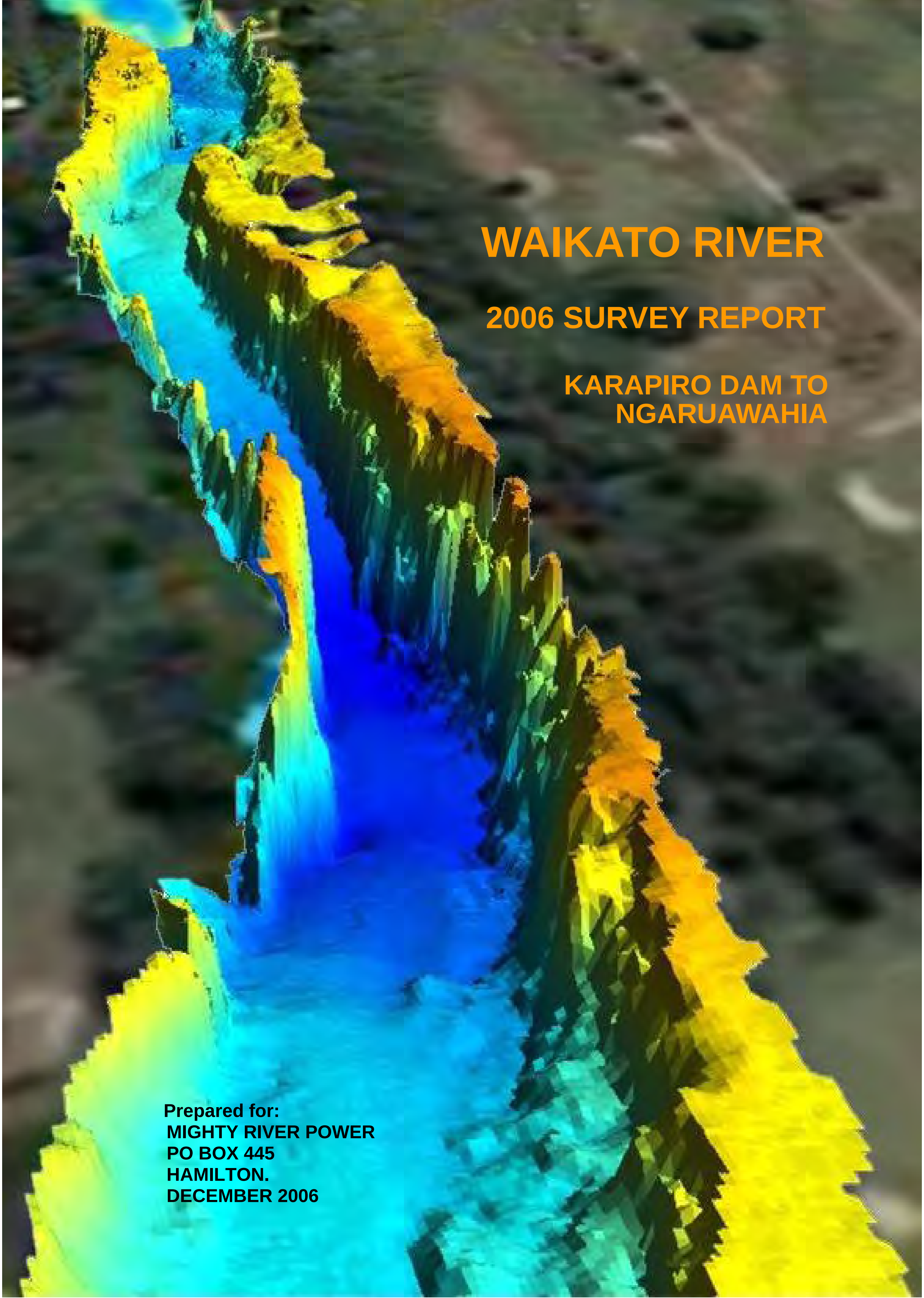

WAIKATO RIVER

2006 SURVEY REPORT

KARAPIRO DAM TO NGARUAWAHIA

Prepared for:
MIGHTY RIVER POWER
PO BOX 445
HAMILTON.
DECEMBER 2006

WAIKATO RIVER 2006 SURVEY REPORT

Karapiro Dam to Ngaruawahia

Prepared for: Mighty River Power

By: Dr Graeme Smart. MIPENZ

December 2006

Reviewed by: Prof M. J. Crozier,

Victoria University of Wellington.

Cover Picture: An underwater, multi-beam sonar scan of the Waikato River bed undertaken by Adam Wood as part of his Masters Degree studies. The view shown is looking north along 250m of the riverbed near the golf course, between cross-sections 161 and 161A, 1.25 km upstream of the Narrows Bridge. The bottom of the deep hole (navy blue) is at -2 m (i.e. below m.s.l. datum).

Table of Contents

List of Figures

List of Tables

1 EXECUTIVE SUMMARY

In June and August 2006, as part of the 2006 Waikato Hydro System Consents, the Waikato river-bed level was surveyed from Ngaruawahia to Karapiro Dam at 93 cross-sections. These included new sections at locations where previously undetected river bed sills existed and where there was a high slope stability hazard.

Between the last survey in 2002/03 and the 2006 survey there was a net loss of 60,000 cubic metres of bed material from Karapiro Dam to the Narrows, a net loss of 114,000 cubic metres from the Narrows through Hamilton to Section 138 (upstream of Horotiu) and a net loss of 118,000 cubic metres between Section 138 and Ngaruawahia Bridge. The section with the greatest increase in cross-sectional area was at Horotiu Landfill (section 136).

In the Karapiro to Narrows reaches there was a markedly lower degradation rate from 2003 to 2006 than occurred from 1998 to 2003. Several cross-sections which scoured in the 1998 to 2003 period re-filled from 2003 to 2006. In the reaches through Hamilton the average degradation from 2002 to 2006 also reduced substantially compared to the 1998 to 2002 years, mainly due to infilling at the deepest sections and at section 149 in the middle of the city. In the lower reaches from upstream of Horotiu to Ngaruawahia Bridge the degradation rate was higher between 2003 and 2006 than occurred between 1998 and 2003, especially in the vicinity of Horotiu.

Annual degradation rates depend on many factors including flood peaks, flow duration curves and hydrograph rates of rise, as well as bank erosion rates and local bed material. Eventually bed degradation will reduce as the river slope becomes flatter due to down-cutting of the bed. The rate of bed degradation has fluctuated between past surveys and although the recent decrease in degradation rate in middle and upper reaches could be seen as a positive sign, the 2006 data do not point to a statistically significant change in the long-term trend. Consequently, it is premature to interpret the degradation rate variations evident in the latest survey as an emerging long-term tendency. The next survey (in 5 years) will augment the information and enable a reassessment of long term trends.

At index cross-sections, the long-term trends show the mean bed levels are dropping at a fairly constant rate of 15 mm/yr upstream of Hamilton near the Narrows, at a rate of 29 mm/yr at Victoria Bridge within Hamilton, and at 32 mm/yr in the vicinity of cross-section 140 (just downstream of Hamilton).

The latest survey data does not change the mean bed level predictions for 2050 made on the basis of earlier survey data by Smart (2003). If present river conditions continue, this represents future degradation of 0.76 metres (± 0.49 metre at 95% confidence interval) for average bed levels just downstream of the Narrows, degradation of 1.25 metres (± 0.37 m) by 2050 at Hamilton's Victoria Bridge and degradation of 1.4 metres (± 0.62 m) by 2050 in the vicinity of cross-section 140, downstream of Hamilton City.

2 BACKGROUND

The measurement of riverbed levels below Karapiro Dam has been undertaken regularly since the 1960's, and early soundings go back as far as 1913. The purpose of the regular surveys has been to monitor the riverbed to identify any changes as a result of natural processes and human interventions (such as sand mining and the Waikato Hydro dams).

During the recent application for the renewal of the Waikato Hydro System Consents it was determined that the rate of riverbed level change requires continued monitoring.

Given this, as part of the 2006 Waikato Hydro System Consents, Mighty River Power are required to undertake surveys of the riverbed levels below Karapiro as far downstream as Ngaruawahia.

Condition 6.11 of the Hydro System Consents has the following requirements:

vi. A five-yearly survey of riverbed levels below Karapiro as far as Ngaruawahia,

vii. River bed cross-sections in the vicinity of the Hamilton Traffic Bridge (also called the "Bridge St Bridge" and "Victoria Bridge"), of the Fairfield Bridge, and of the subfluvial water supply main to Hamilton East from the Hamilton Water Treatment Station. These are to be located and measured in a manner sufficient to demonstrate any changes in bed level which may threaten the structural integrity of these facilities.

To achieve this, Discovery Marine Ltd (DML) was commissioned to undertake a 2006 survey of the Waikato River between Karapiro Dam and Ngaruawahia. DML is a company experienced with this type of hydrographic survey and surveyed the same Waikato River reaches during 2002 and 2003.

For the present investigation, 40 sections within the Hamilton Reach were surveyed from 20 June to 29 June 2006. Surveys of the remaining sections were undertaken between 10 July and 18 August 2006.

Condition 6.12 of the Waikato Hydro System Consents requires the following to be undertaken once the survey data is collected:

> The results of the monitoring programme shall be forwarded to the Waikato Regional Council at agreed times, but at least annually, and shall include:
>
> - A review of all data collected under the monitoring programme.
> - A summary of the monitoring results and a critical analysis of that information.
> - A comparison of the data with previously collected data identifying any emerging trends.
> - Recommendations on alterations to the monitoring programme.
> - Any other issue considered important by the consent holder.

2.1 Cross Sections Surveyed

Approximately 114 cross-sections, established in earlier surveys, can still be found in the Karapiro to Ngaruawahia reaches of the Waikato. These cross-sections originally had a benchmark located on each side of the river. However, human disturbance, riverbank slips and riparian land conversion and development has meant many of the earlier benchmarks have been lost.

On this basis, and given that some of the cross-sections have shown little morphological change over the previous surveys, a selection panel was established to determine which cross-sections should be resurveyed in the 2006 survey. The selection process involved Environment Waikato, Hamilton City Council, DML, Mighty River Power and Graeme Smart. Cross-section locations were chosen based on historical value, morphologic and hydraulic significance and proximity to city structures, roads and buildings.

As a result, 93 cross-sections were chosen to be re-surveyed and four new cross-section sites were established. The new cross-sections were established in areas where previously undetected high river bed sills existed, where there was a high slope stability hazard and near Nukuhau Pa. A map of cross-section locations is contained in Appendix A and a list of dates on which sections were previously surveyed is contained in Appendix C.

2.2 Data Accuracy

The accuracy of depth data, obtained in the 2006 survey, was checked by overlapping the data with land and hydro soundings. Hydrographic and topographic data were also overlapped whenever possible to provide a further check on data accuracy and consistency. Table 1 summarises the data point accuracy relative to benchmarks. Further detail can again be found in DML (2006).

Table 1. Summary of cross-section data point accuracy relative to bench marks (From DML, 2006)

Topographic Survey	**Horizontal Accuracy**	**Vertical Accuracy**
Total Station & Leveling	Shots within +/- 0.5 m of line	+/- 0.02 m
RTK Positioning	+/- 0.02m	+/- 0.03 m

Hydrographic Survey	**Horizontal Accuracy**	**Vertical Accuracy**
DGPS Positioning	Better than +/- 0.60 m	+/- 0.01 m + 0.5% of water depth
Manual Positioning (Total Station, tape measure etc)	Boat maintained within 1m of cross-section alignment	+/- 0.01 m + 0.5% of water depth
RTK Positioning	Better than +/- 0.10 m	+/- 0.03 m + 0.5% of water depth

2.3 Survey Methodology

DML used the same methodology as was used in the 2002 - 2003 survey. This involved a combination of manual and automated positioning techniques. Where good satellite coverage could be obtained, an onboard DGPS positioning system or RTK unit was used to provide continuous data acquisition across the river sections. If no satellite coverage was available, spot heights across the river were obtained using a Total Station and Prism method. Full details of the survey methodology can be obtained in the “Waikato River Riverbed Resurvey – Report of Survey” (DML, 2006).

2.4 Survey Results

Cross-section location maps are contained in Appendix A.

The 2006 data have been over-plotted on previous survey information in Appendix B.

Appendix C contains detailed summary tables.

3 DATA ANALYSIS

As major morphologic changes are often associated with floods, any analysis of cross-section changes over time should also consider flood history. A hydrograph of monthly maximum daily mean flows at Hamilton’s Victoria Bridge is shown for the last 30 years in Fig. 1. During the last decade, three major floods occurred (1996, 1998 and 2004). The 2004 flood occurred after the previous cross-section survey was carried out in 2002 and 2003.

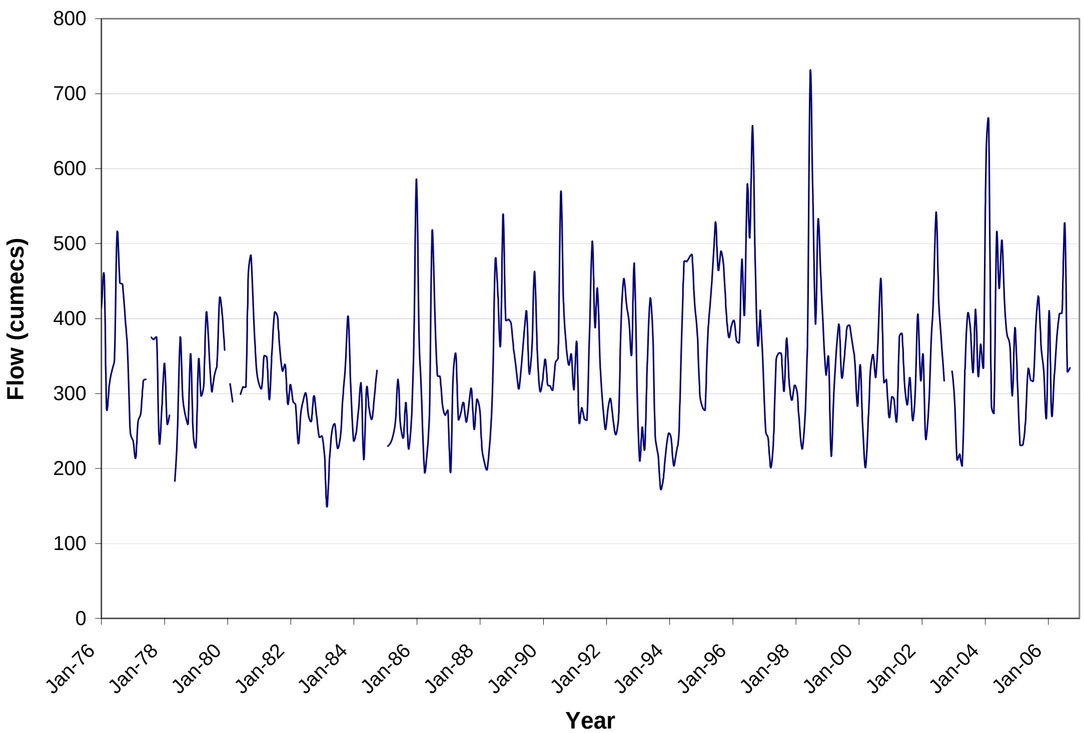

Figure 1 Flow hydrograph for the Waikato River at Hamilton’s Victoria Bridge, showing monthly maxima of daily mean flows.

3.1 Cross section parameters

In order to monitor river morphology and quantify any changes in cross-section shape that may occur over the years, it is necessary to measure parameters that portray the river cross-sections in a way that is meaningful, measurable and unambiguous. The parameters used in this report are presented in Fig. 2.

A schematic river cross-section is shown at the top of Fig. 2. The Nominal Water Level (NWL) is a fixed reference datum that has been assigned to each cross-section at a level above which no morphological change is expected. Cross–section area is calculated by summing the elemental areas $(x_{i+1}- x_i)*(NWL-0.5(y_{i+1}+ y_i))$ that lie between the survey points (that define the cross-section shape) and the NWL. Section volume is calculated by assuming that a cross-section's area extends half the distance to the next upstream cross-section and half the distance to the next downstream cross-section. The Mean Bed Level (MBL) is the level of the base of a rectangle having the same NWL and the same cross-sectional area (below the NWL) as the surveyed cross-section. The Thalweg Level (TL) is the minimum level on a surveyed cross-section. These parameters were calculated in a similar manner in earlier Waikato River surveys.

The ratio (MBL-TL)/(NWL-MBL) is an index of the thalweg significance at a section. The bottom of Fig. 2 shows examples of the Thalweg Index (TI). This index is zero for a rectangular section and 1.0 for a triangular cross-section.

Volume, MBL and TI all depend on where the NWL datum is placed, however, provided NWL is allocated in a logical manner (and not varied over the years) these parameters will provide valuable information on changes over time and changes between sections.

The volume parameter depends on inter cross-section spacing and care must be taken that comparisons of reach volume changes over time are based on the same set of reach cross-sections.

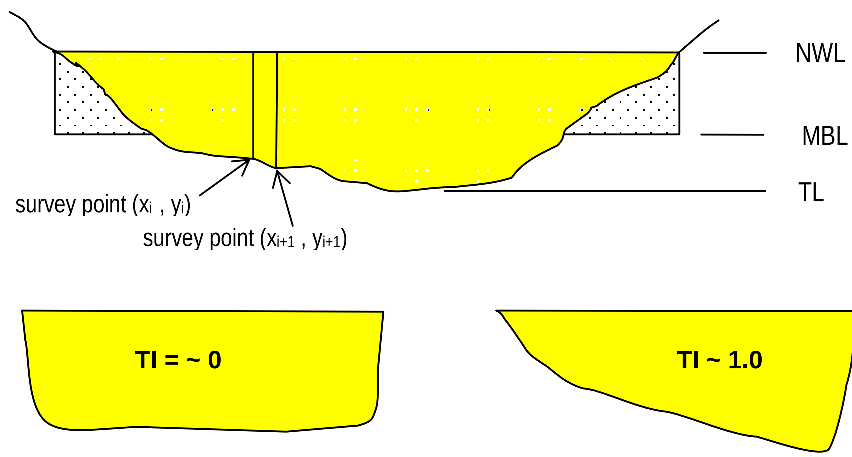

Figure 2 Schematic cross-sections showing Nominal Water Level, Mean Bed Level, Thalweg Level and Thalweg Index.

3.2 2006 results.

Mean bed levels, thalweg levels & channel shape.

The 2006 cross-section mean bed levels and thalweg levels are shown by longitudinal profiles in Fig. 3.

Typically an exponential relation will describe such longitudinal bed profiles, however, particularly from Horotiu Bridge to Cambridge, these reaches are better fitted by a linear bed plane than by an exponential profile (a comparison of linear and exponential bed profiles is shown in Fig. 4). The fitted mean bed plane and thalweg plane (minimum bed level plane) are essentially parallel. The thalweg plane lies about 3 metres below the mean bed plane.

The Thalweg Index (TI), indicating the significance of the thalweg at cross-sections surveyed in 2006, is shown in Fig. 5. Overall there is a tendency for the channel to be more rectangular (low TI value) from section TB16, downstream of Karapiro, to section 165 upstream of the Fieldays site. From the Fieldays site down through Hamilton to section 139 the thalweg effect is more pronounced at every second or third section, indicating alternate outer bank scour. There is a more rectangular series of cross-sections through Horotiu and the thalweg then becomes significant again above Ngaruawahia.

Where cross-sections are located close together the thalweg index can be used to identify the meander wavelength of a river. There is no dominant meander wavelength evident from the sections surveyed in 2006.

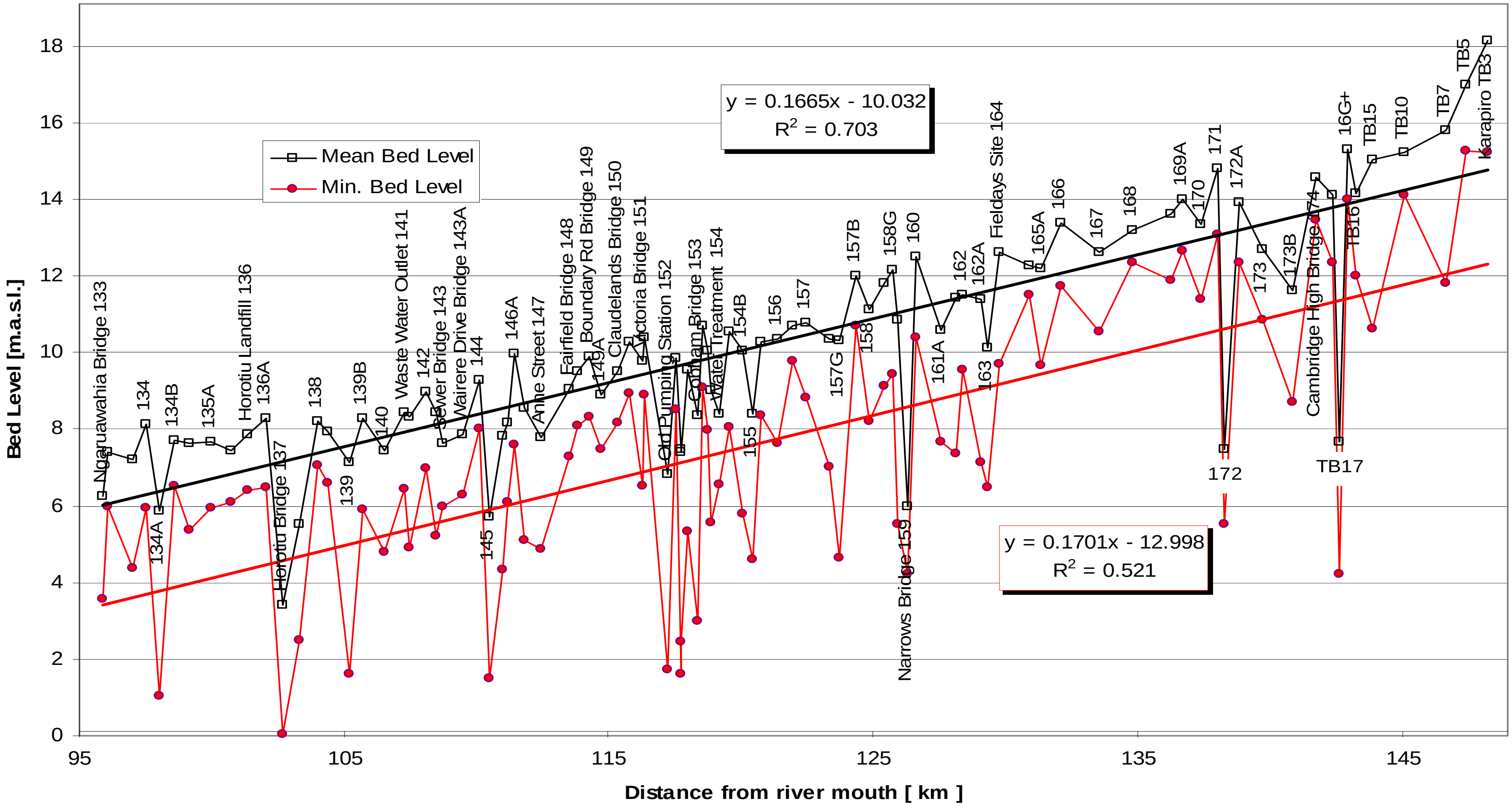

Figure 3 Mean bed levels & thalweg levels from 2006 survey data showing linear trendlines

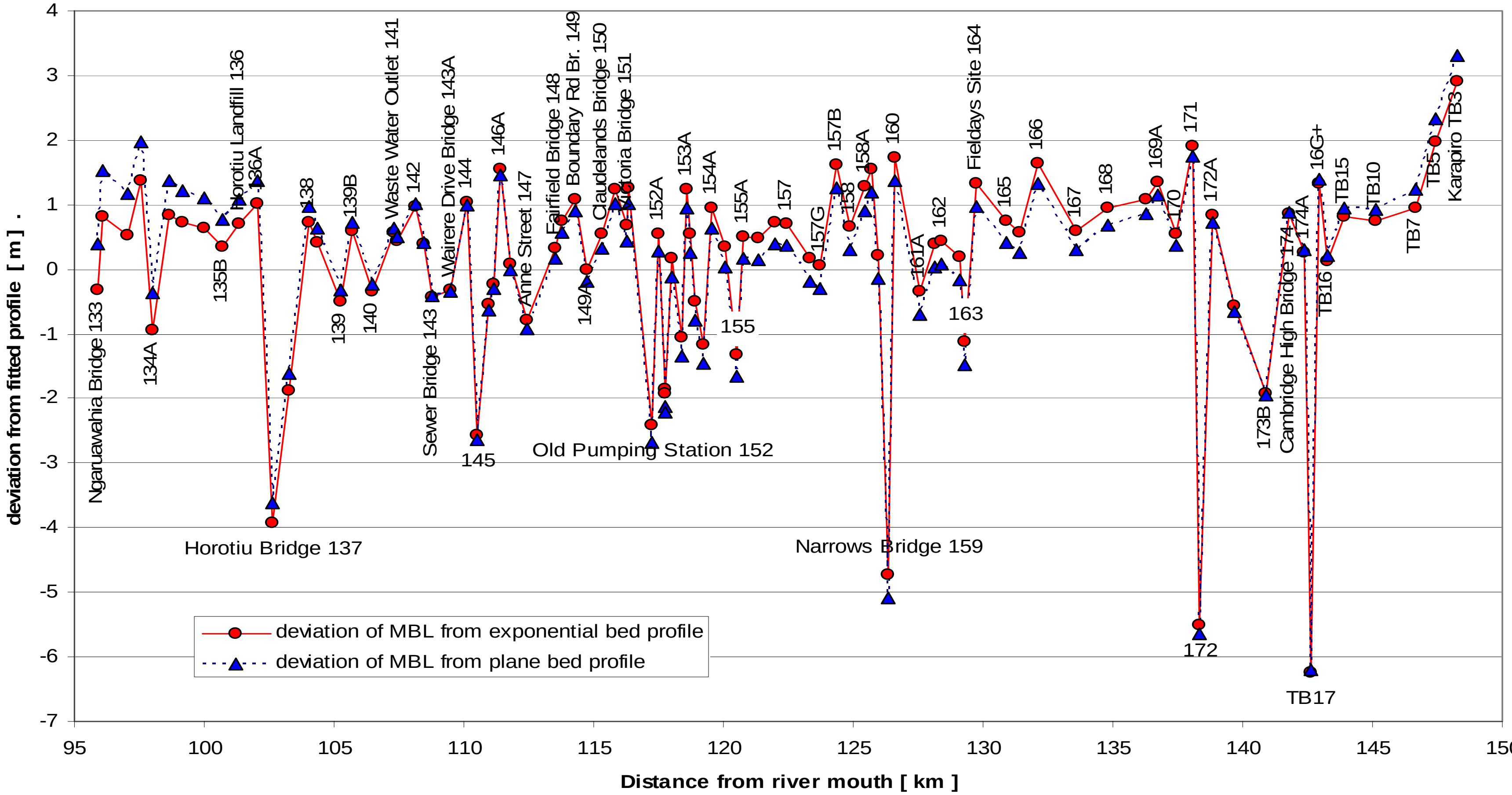

Figure 4 Deviations of mean bed level from fitted profiles using 2006 data.

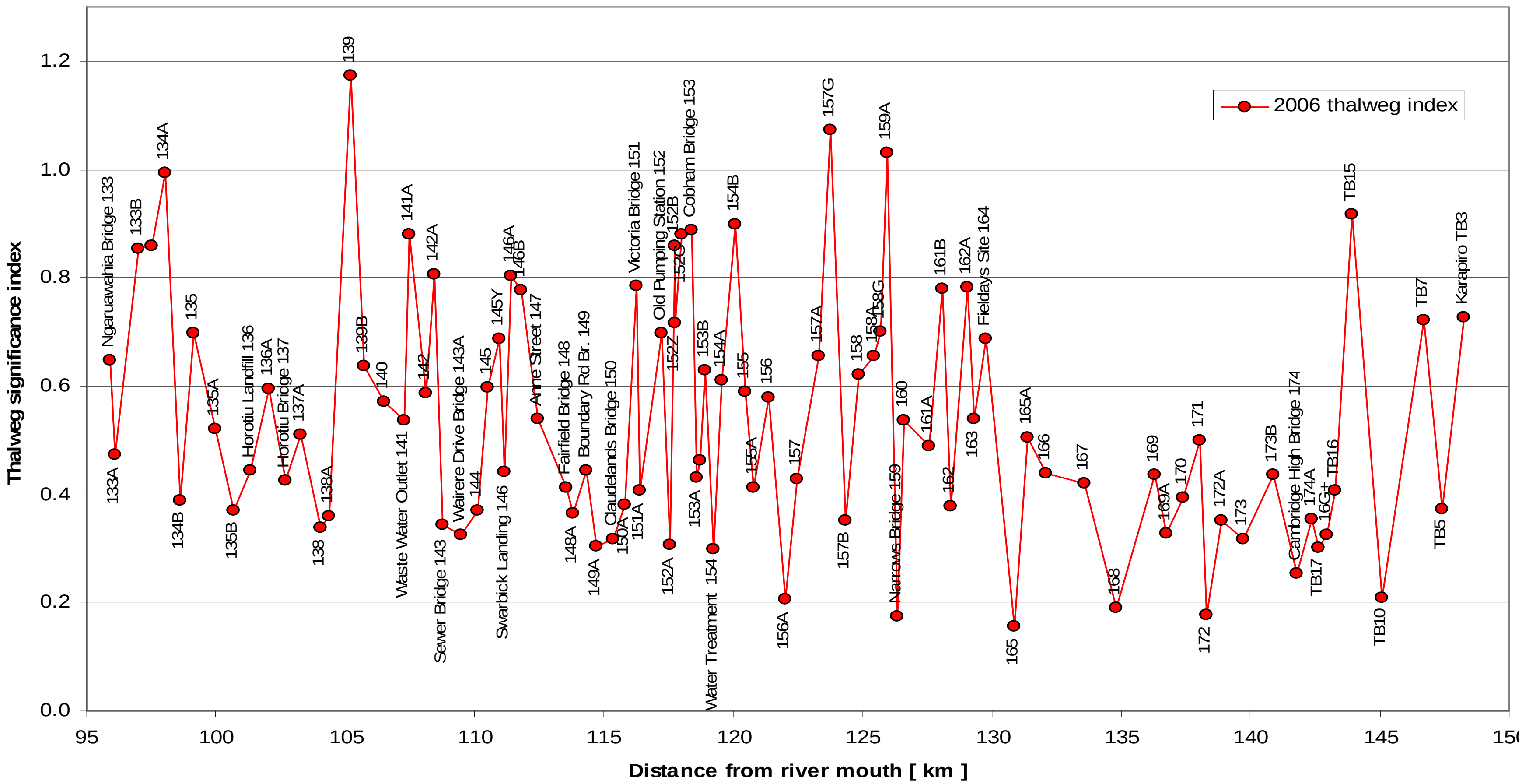

Figure 5 Thalweg significance indicated by 2006 survey

3.3 Changes from earlier surveys.

The parameters calculated from the 2006 survey are now compared with survey data from earlier years. Note that some earlier surveys that took more than a year to complete are named depending on context, e.g. the 2002 to 2003 survey may be labelled as 2002/03, 2002, or 2003 depending on which cross-sections are referenced.

Changes in thalweg significance.

Changes in the thalweg index since 1998 are shown in Fig. 6.

From 1998 to 2002 there was little change in the thalweg character except at Cobham Bridge (cross-section 153) where the deepest part of the cross-section was in-filled.

From 2002 to 2006 the thalweg became noticeably more pronounced at sections 141A, Cobham Bridge (cross-section 153) and 161B. The thalweg appears to have been in-filled at Boundary Rd bridge (cross-section 149) before the 2006 survey.

Changes in volume.

A comparison of the volume change from the 1998 survey to the 2002 survey with the volume change from the 2002 survey to the 2006 survey is given in Fig. 7. Several sections which were degrading from 1998 to 2002 then aggraded from 2002 to 2006. Examples are found at cross-sections 133A, 140, 147, 153, 158, 169A and 174A. Conversely, cross-sections which were aggrading from 1998 to 2002 then degraded from 2002 to 2006. Examples are at cross-sections: 135B, 136A, 154B, 157A, 161B and 170.

Comparison of volumes between cross-sections at different locations can give a misleading picture as volumes depend on the cross-section spacing. A better comparison of local changes is indicated by the cross-section areas up to the NWL.

3.4 Changes in sub-sections of the river.

To allow comparisons with previous analyses of cross-sections, the surveyed river is now divided into three sub-sections. The river sub-sections are: Karapiro to the Narrows, the Hamilton Reaches and reaches from upstream of Horotiu to Ngaruawahia Bridge. These are discussed in order from downstream to upstream.

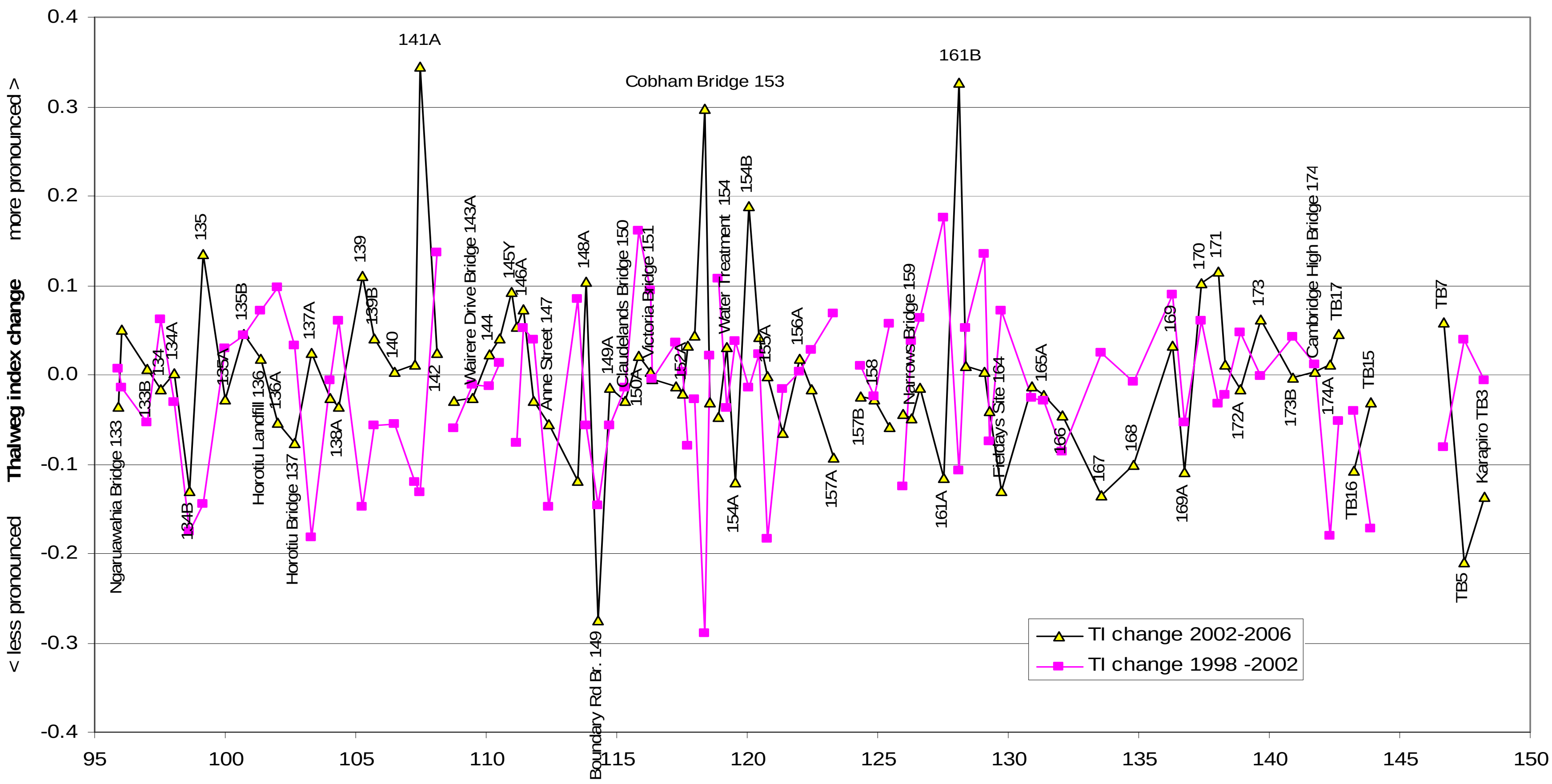

Figure 6 Changes in thalweg significance since 1998

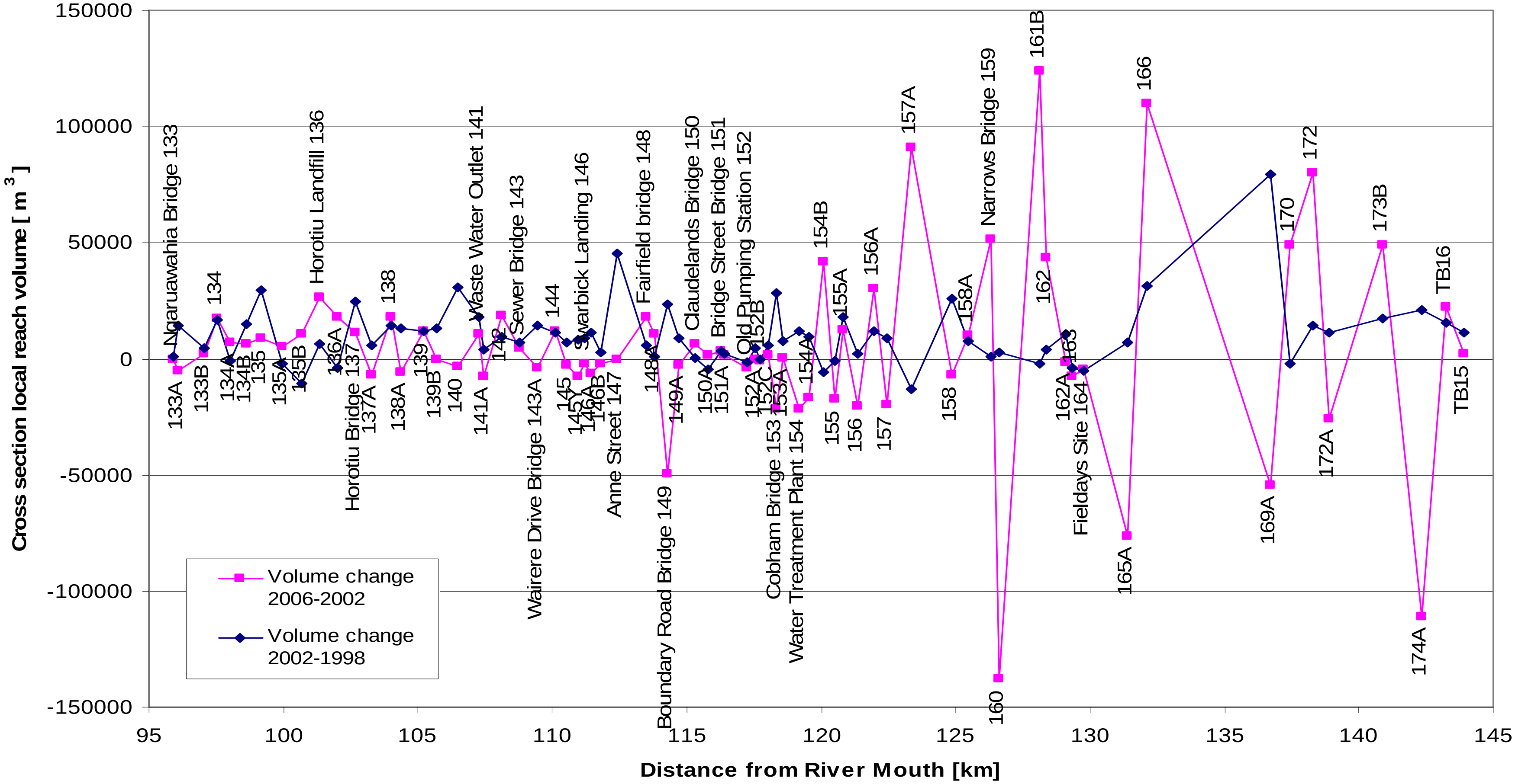

Figure 7 Change in sectional volumes between Karapiro and Ngaruawahia (a positive change indicates scour, a negative change indicates deposition).

3.4.1 Upstream of Horotiu to Ngaruawahia Bridge

Changes in mean bed level.

The 2006 survey results for mean bed levels in this reach are compared with earlier data in Fig. 8. Except for an episode of deposition prior to the 1987/88 survey, mean bed levels have continued to fall over time in this reach, especially in the vicinity of Horotiu (sections 136, 136A, 137 and 138).

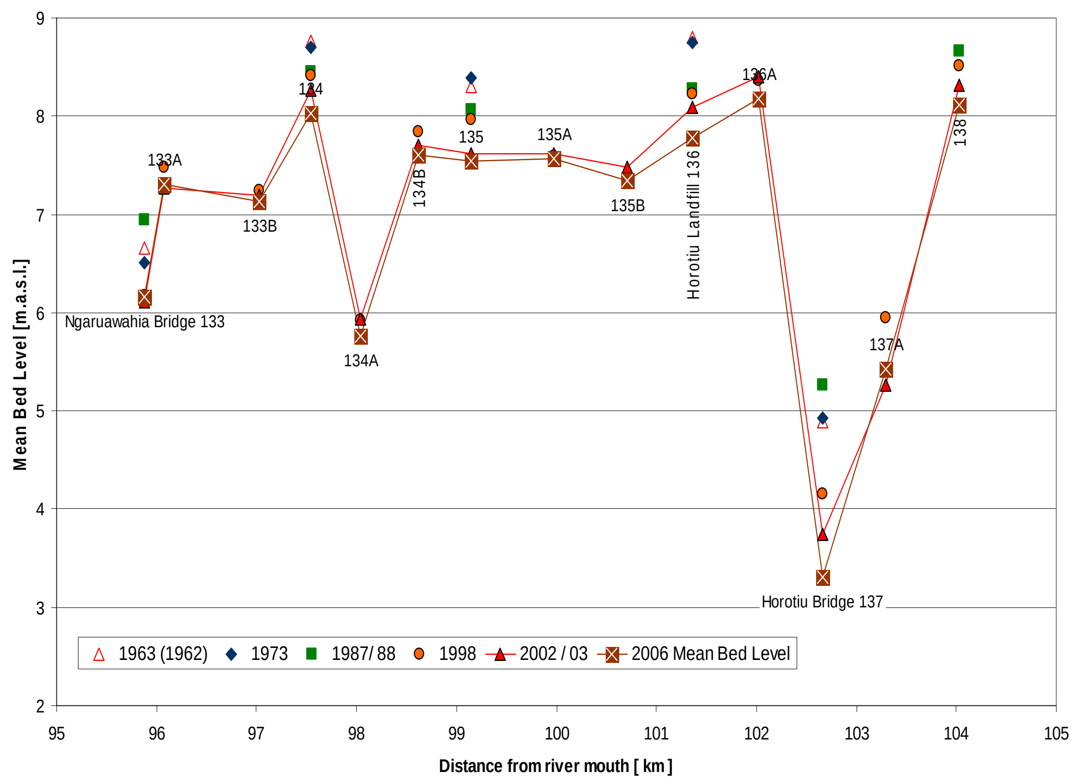

Figure 8 Time evolution of mean bed levels from upstream of Horotiu to Ngaruawahia Bridge

Changes in thalweg level.

The recent survey results for thalweg levels from upstream of Horotiu to Ngaruawahia Bridge are compared with earlier thalweg levels in Fig. 9. The thalweg level appears to be stable at sections 133B, 135A and 137A. The thalweg has fallen significantly in the vicinity of Horotiu (sections 135, 135B, 136, 137) and risen slightly at section 134B.

Changes in volume.

At a given location, the change in volume per unit length of river is given by the change in cross-sectional area. This is shown in Fig. 10 from upstream of Horotiu to Ngaruawahia Bridge.

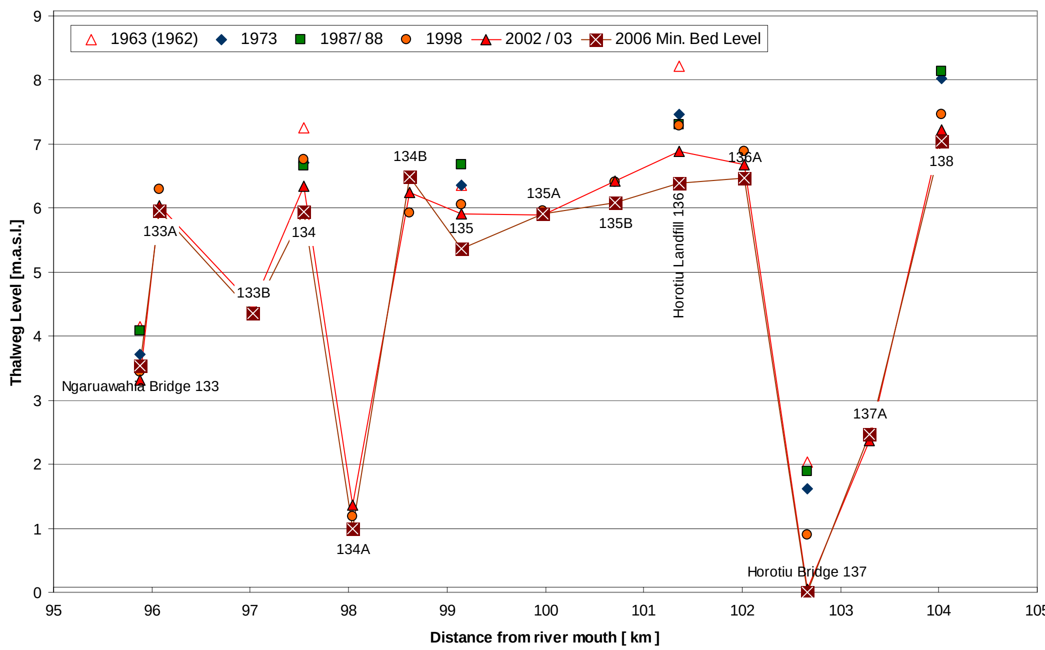

Figure 9 Time evolution of thalweg levels from upstream of Horotiu to Ngaruawahia Bridge

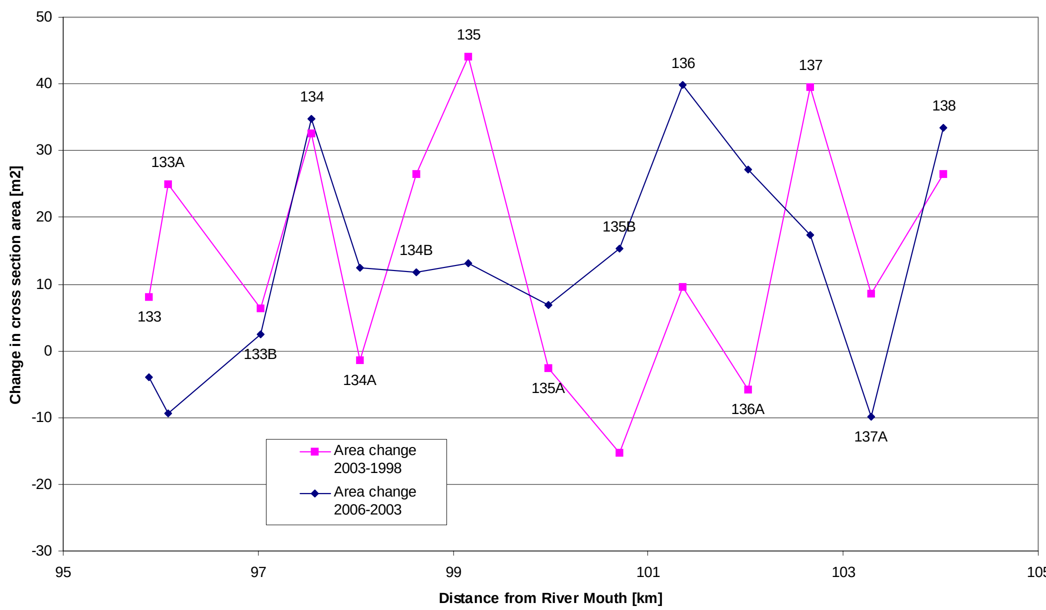

Figure 10 Change in sectional areas from upstream of Horotiu to Ngaruawahia Bridge (a positive change indicates scour, a negative change indicates deposition).

The largest rate of degradation was at section 135 in the 1998 to 2003 period. This section was more stable from 2003 to 2006. The largest rate of degradation in the most recent period was at section 136.

The largest degree of degradation was at sections 134 and 138 which are scouring steadily.

For the reaches from just upstream of Horotiu to Ngaruawahia (defined by the cross-sections shown in Fig. 10), overall changes in volume are: 1998 to 2003 115,000 m^3 of scour, 2003 to 2006 118,000 m^3 of scour.

3.4.2 Hamilton Reaches

Changes in mean bed level.

In the river from upstream of Horotiu Bridge, through Hamilton to upstream of the Narrows Bridge there are 22 reference cross-sections that have been measured five times over the last 33 years. The mean bed level of each cross-section is plotted in Fig. 11. For each of the five survey dates a linear trend line has been fitted to the mean bed levels from these reaches. The slope and intercept level of the trend lines are given in Table 2.

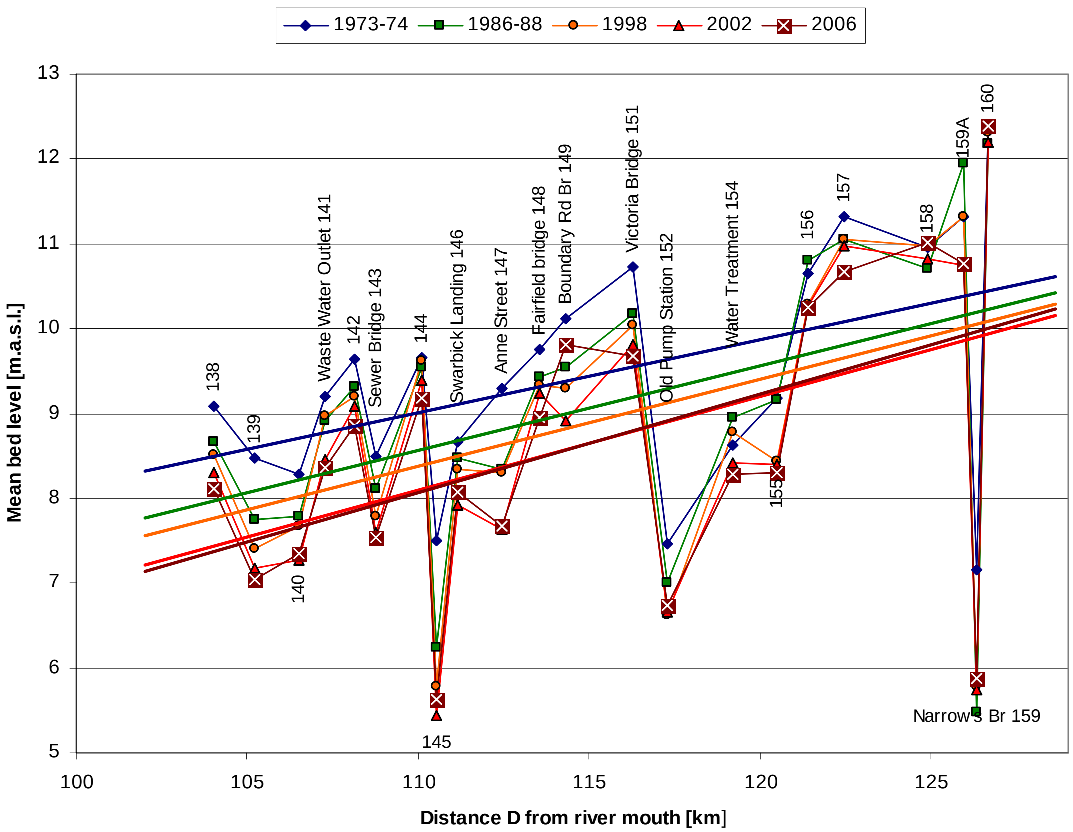

Figure 11 Time evolution of mean bed levels at 22 Hamilton cross-sections. Trendlines show a fitted bed plane.

Representing the bed in this way reveals basic trends that are obscured by local variations in the bed level. Smart (2003) noted that the mean bed level of the Hamilton reach is not only falling but its gradient has been getting steeper with time.

What is evident in the 2006 survey is that there has been less overall degradation from 2002 to 2006 than occurred from 1998 to 2002, mainly due to infilling at the deepest sections and at section 149 near the middle of the reach.

The slope of the Hamilton bed plane has increased from about 86 mm/km in 1973-74 to about 117 mm/km in 2006. Eventually the increase in slope of the bed must cease but the 2006 survey shows no sign of a reduction in the steepening of the bed plane.

Table 2 Trends in mean bed level (MBL) through the Hamilton Reach.

Year of Survey	Trend line equation: MBL = **D*****S**/1000+**C** Slope **S** [mm per km]	Level **C** at mouth [m.a.s.l]	Variance explained
1973-74	85.8	- 0.421	$R^2 = 0.21$
1986-88	99.8	- 2.422	$R^2 = 0.19$
1998	102.6	- 2.905	$R^2 = 0.20$
2002	110.4	- 4.054	$R^2 = 0.22$
2006	116.7	- 4.778	$R^2 = 0.25$

* **D** is the distance from the river mouth in km, **S** is the MBL gradient in mm/km, **C** is the level of the MBL when extrapolated to the coast.

It is not straightforward to establish the significance of the temporal change in Hamilton bed plane slope. To investigate statistical measures, the 22 cross sections are split into two groups of 11 cross sections representing “lower” Hamilton (from upstream of Horotiu Bridge to Fairfield Bridge) and “upper” Hamilton (from Boundary Road Bridge to upstream of the Narrows Bridge). Basic statistics on cross section MBLs of “lower” and “upper” Hamilton are compared in Fig. 12. For lower Hamilton, the graph shows that there was only a small decrease in the average of the section MBLs in 2006, compared to earlier surveys. This could be interpreted as an encouraging sign, however, for upper Hamilton, the MBL rose in the latest survey. This is not an indication of a stabilising bed but demonstrates that there is an active river bed (the deposited material has eroded from somewhere else).

The standard errors and standard deviations on Fig. 12 should be interpreted with caution as some of the variation in cross section mean bed levels is caused by the channel gradient. Upstream cross sections will tend to deviate from the average because they are naturally higher and downstream ones may deviate because they are naturally lower than the average level. Because the upper Hamilton cross sections are spread over a greater length of river than the lower Hamilton sections, if the overall river gradient does not change, there will be greater natural fall through upper Hamilton and a wider variation in bed levels could be expected. Notwithstanding this effect, from Fig. 11 it is clear that there are actually wider fluctuations in the upper Hamilton cross section bed levels compared to those of lower Hamilton.

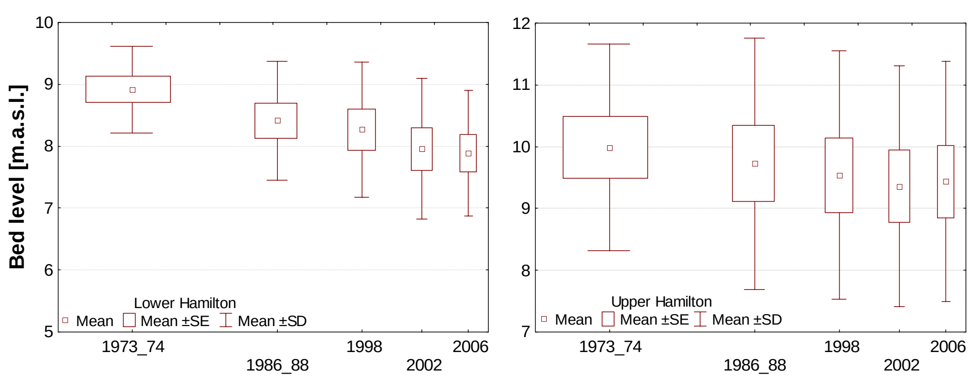

Figure 12 Hamilton City cross section mean bed level statistics from Fairfield Bridge downstream (left) and from Boundary Rd Bridge upstream (right) showing changes with time. SE = standard error, SD = standard deviation of the cross section mean bed level.

In addition to the 22 reference sections discussed above, there are three index sections within the Hamilton reaches that have been analysed for trend in earlier studies. To update future mean bed level predictions for these sections, the time evolution of MBL and bed plane level is shown in Fig. 13 for Pukete Boat ramp (Section 140, downstream of Hamilton), Hamilton Victoria Bridge (Section 151) and downstream of the Narrows Bridge (upstream of Hamilton). The temporal trend at these locations is extrapolated to year 2050 on Fig. 13.

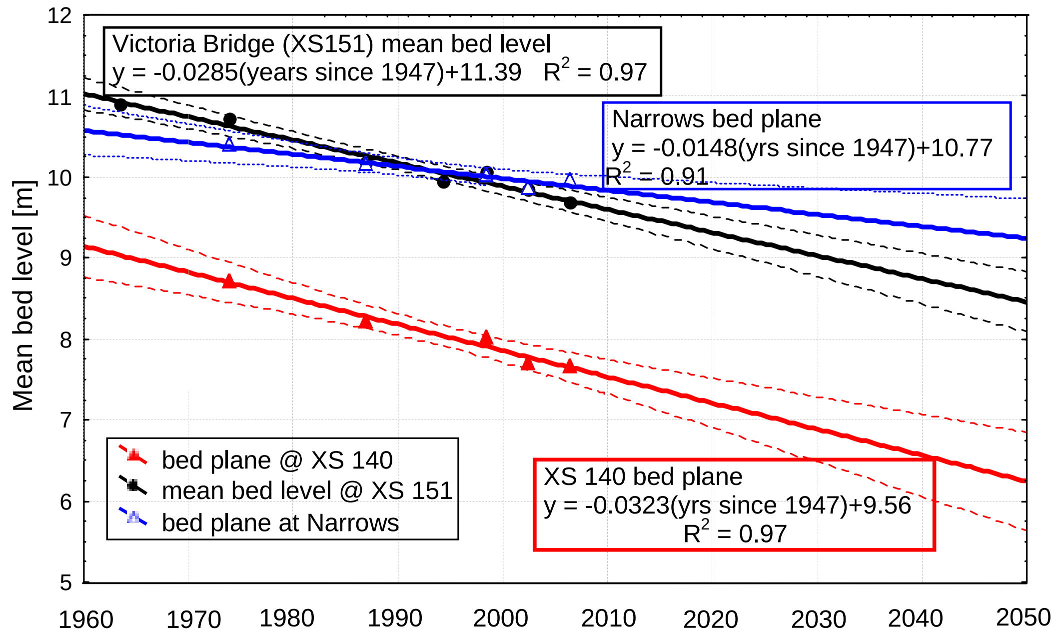

Figure 13 Trends in mean bed level at Victoria St Bridge (Section 151, black line) and trends in level of the bed plane at Pukete Boat Ramp (Section 140, red line) and downstream of Narrows Bridge (km 126, blue line), extrapolated to 2050, showing 95% confidence intervals.

From the trend equations on Fig. 13 it can be seen that the mean bed levels are dropping at a fairly constant rate of 32 mm/yr in the vicinity of cross-section 140 (just downstream of Hamilton) at 29 mm/yr at Hamilton's Victoria Bridge and at 15 mm/yr upstream, near the Narrows. These rates and the 2050 bed levels that will result if these rates continue, are shown in Table 3. The 95% confidence limits are shown by dashed lines on Fig. 13 and in the final column of Table 3.

Table 3 Future mean bed levels predicted by extrapolating present trends.

Location	Rate of fall in mean bed level [mm/yr]	Predicted fall over 44 years [m]	2050 bed level [m.a.s.l.]
Bed plane below Narrows	14.8	0.76	9.25 ± 0.49
Victoria Br. mean bed level	28.5	1.25	8.45 ± 0.37
Bed plane below Hamilton (Section 140)	32.3	1.42	6.23 ± 0.62

Although the most recent survey indicates a reduction in the rate of degradation, the 2006 survey points plot very close to the regression lines in Fig. 13. As these points do not lie outside of the confidence limits it cannot be concluded that the 2006 survey shows any statistically significant change in the degradation trend for these sections. The predicted 2050 bed levels are estimated mean values based on the continuation of present trends. It should be noted that the thalweg can lie several metres below the section mean bed level and, for the bed planes, there is variation in local mean bed level of up to 5 m about the trend lines. Including the 2006 survey data does not change the mean bed level predictions for 2050 (made on the basis of earlier survey data by Smart, 2003).

New Cross Sections.

A factor to consider is that recent investigations of river bathymetry have revealed that there are high sills not captured by the 22 reference sections. All cross-sections measured in the 2006 survey and their MBL's are shown in Fig. 14 in relation to the 22 standard reference sections. The inclusion of additional, higher sections changes the position of the average bed trend line and steepens it. As these sills play an important role in controlling water levels and scour depths, future surveys should compare trends which include these sections.

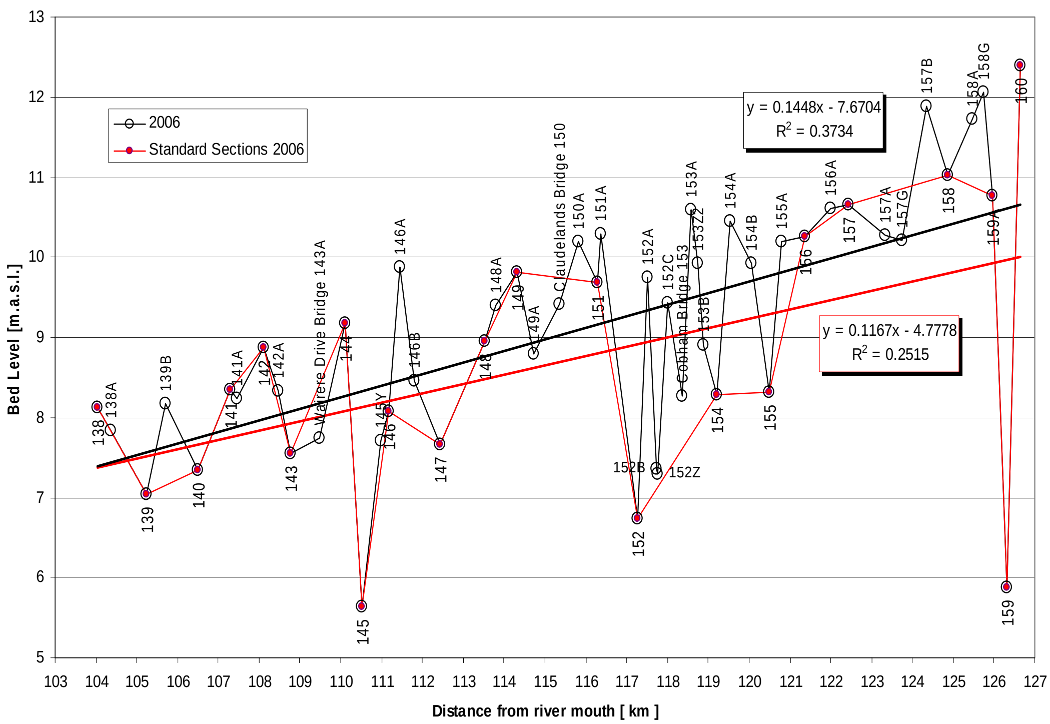

Figure 14 Location of the 22 standard sections (red) and newer sections (black) showing high sills captured in the 2006 survey.

Changes in thalweg level.

Changes in thalweg levels of the 22 reference sections over the years are shown in Fig. 15.

Slight infilling of the thalweg has occurred since 2002 at the top end of this reach and significant infill has occurred at Boundary Rd Bridge. Degradation has continued further downstream.

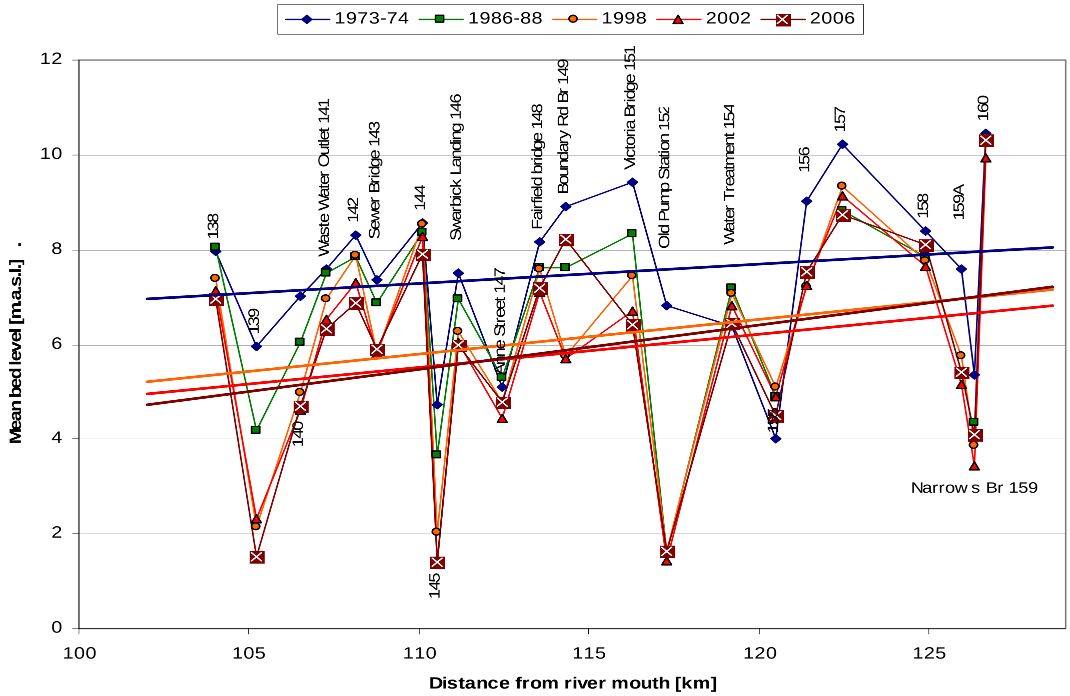

Figure 15 Time evolution of thalweg levels at 22 Hamilton cross-sections. Trendlines show fitted minimum bed level planes.

Changes in volume.

The volume changes per unit length for the Hamilton reaches are shown in Fig. 16. In the 2002 to 2006 period significant depositional changes occurred at cross-sections 149 (Boundary Rd Bridge) and 153 (Cobham Bridge). The cross-section 153 deposition follows significant scour at this site in the 1998 to 2002 period. For Hamilton reaches from cross-sections 138A to 159, according to the cross-sections shown in Fig. 16, the overall changes in volume are: 1998 to 2002 377,000 m^3 of scour, 2002 to 2006 114,000 m^3 of scour.

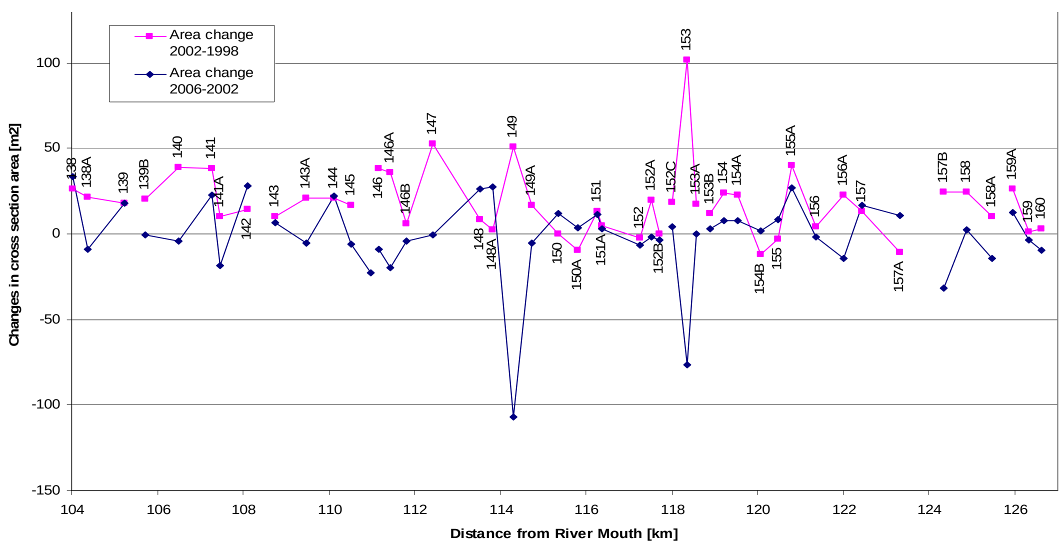

Figure 16 Change in sectional areas for Hamilton reaches (positive change indicates scour, negative change indicates deposition).

3.4.3 Karapiro to Narrows Reaches

Changes in mean bed level.

The 2006 survey results for mean bed levels in this reach are compared with earlier data as shown in Fig. 17.

There have been no recent major changes in mean bed level at sections between Karapiro and the Narrows. Between the 2003 survey and the 2006 survey mean bed level degraded at cross-sections 170 (0.5 m) and 164 (0.4 m). Cross-section 161A aggraded by 0.4 m.

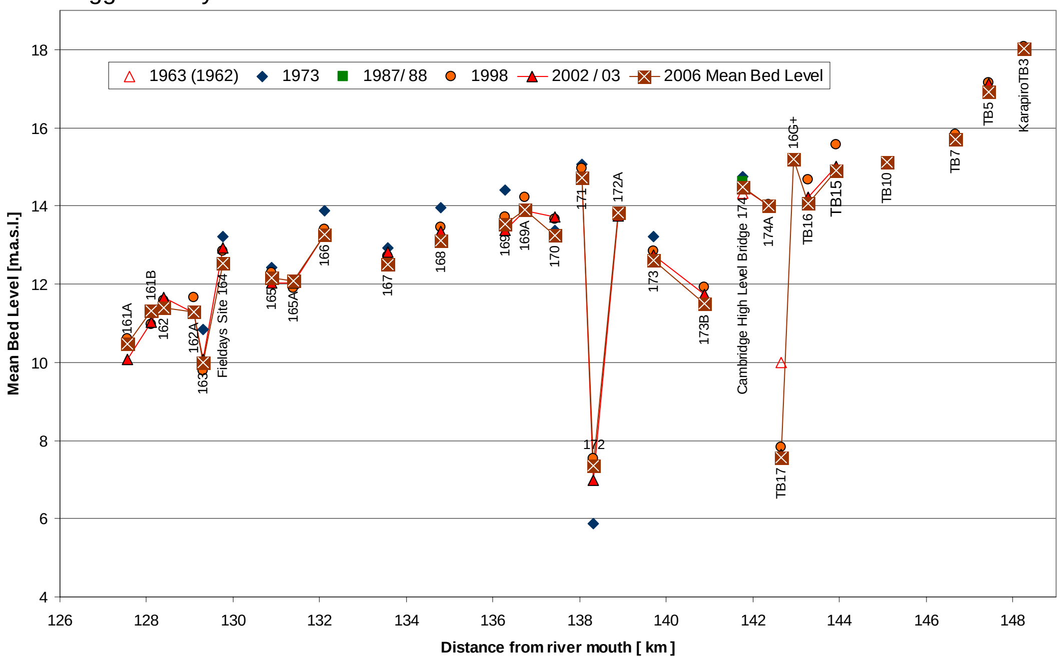

Figure 17 Time evolution of mean bed levels from the tailwater of Karapiro Dam to upstream of The Narrows

Changes in thalweg level.

The 2006 survey results for thalweg levels in the Karapiro to Narrows reaches are compared with earlier minimum bed levels in Fig. 18. There have been no recent unexpected changes in thalweg level between Karapiro and the Narrows. Between the 2003 survey and the 2006 survey thalweg scour of 1.1 m occurred at cross-section 170 and in-filling of 1.3 m occurred at cross-section 161A.

Changes in volume.

The changes in volume per unit length for the Karapiro to Narrows reaches are shown in Fig. 19. Section 161A is the most volatile in this part of the river having scoured in the 1998 to 2003 period and re-filled in 2003 to 2006. Other sections show similar behaviour but to a lesser extent and at times in the reverse order.

For the Karapiro to Narrows reaches defined by the cross-sections shown in Fig. 19, the overall changes in volume are: 1998 to 2003 213,000 m^3 of scour, 2003 to 2006 60,000 m^3 of scour.

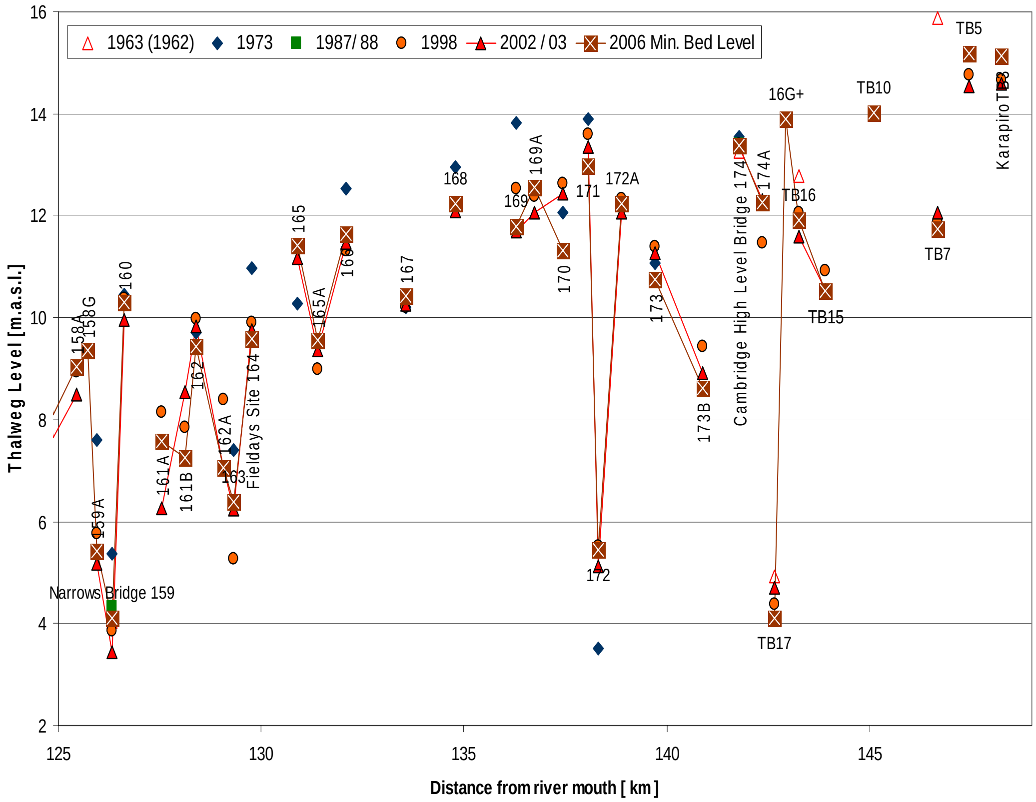

Figure 18 Time evolution of minimum bed levels from the tailwater of Karapiro Dam to upstream of The Narrows.

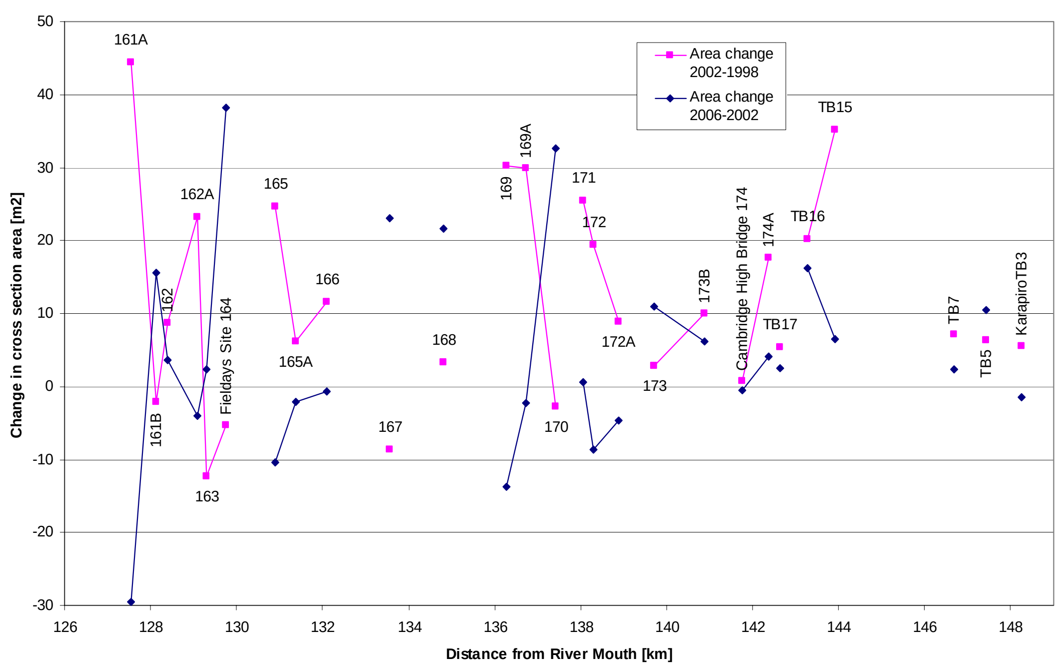

Figure 19 Change in sectional areas between the Narrows and Karapiro (a positive change indicates scour, a negative change indicates deposition).

4 SUMMARY & CONCLUSIONS

There was a significant flood following the 2002/03 survey which could be expected to affect the present (2006) survey results. Floods can cause both degradation and deposition.

In the Karapiro to Narrows reaches there was a markedly lower degradation rate between 2003 and 2006 than occurred between 1998 and 2003. Cross-section 161A was the most volatile having scoured in the 1998 to 2003 period and re-filled from 2003 to 2006. Several other cross-sections in this part of the river show similar behaviour but to a lesser extent.

In the Hamilton reaches the average degradation from 2002 to 2006 also reduced substantially compared to the 1998 to 2002 years, mainly due to infilling at the deepest sections and at section 149 in the middle of the city.

In the lower reaches from upstream of Horotiu to Ngaruawahia Bridge there was a higher average degradation rate between 2003 and 2006 than occurred between 1998 and 2003, especially in the vicinity of Horotiu.

A comparison of changes at individual cross-sections from the 1998 survey to the 2002/03 survey with the changes from the 2002/03 survey to the 2006 survey shows that several cross-sections which were degrading from 1998 to 2002 then aggraded from 2002 to 2006. Conversely, some cross-sections which were aggrading from 1998 to 2002 then degraded from 2002 to 2006.

Locations showing the greatest increase in cross-sectional area from the 2002/03 survey to the 2006 survey are at sections :136, 163, 134, 138, 134 and 170 (in order of decreasing area scoured).

A Thalweg Index was introduced in order to quantify any changes in cross-section shape. Overall there is a tendency for the channel to be more rectangular from downstream of Karapiro to upstream of the Fieldays' site. From the Fieldays' site through Hamilton to upstream of Horotiu the thalweg effect is more pronounced at every second or third section, indicating alternate outer bank scour. There is a more rectangular series of cross-sections through Horotiu and the thalweg then becomes significant again above Ngaruawahia. There is no dominant meander wavelength evident from the sections surveyed in 2006.

From 1998 to 2002/03 there was little change in the thalweg character. From 2002/03 to 2006 the thalweg became noticeably more pronounced at cross-sections 141A (just upstream of the Hamilton wastewater outlet), 153 (Cobham Bridge) and 161B (upstream of the Narrows). As found for mean bed level, the thalweg level has continued to fall significantly in the vicinity of Horotiu (cross-sections 136 and 137).

Considering long-term trends at index cross-sections in Hamilton, the mean bed levels are dropping at a fairly constant rate of 32 mm/yr in the vicinity of cross-section 140 (just downstream of Hamilton) at 29 mm/yr at Victoria Bridge and at 15 mm/yr upstream, near the Narrows. The inclusion of additional higher cross-sections, that are not part of the set of 22 historical reference cross-sections, changes the position of the mean bed plane and steepens it. As high sills play an important role in controlling water levels and scour depths, future surveys should compare trends which include these higher cross-sections.

The volume of material eroded in the most recent inter-survey period is compared with that of the previous period in Table 4. The data indicate that bed degradation rate has decreased notably between Karapiro and Hamilton and increased between upstream of Horotiu and Ngaruawahia.

Table 4 Volumes of erosion in cubic metres showing approx annual rate (corrected for survey date) in brackets

River reaches	1998-2002/03	2002/03-2006
Karapiro to Narrows	213 000 (42 600)	60 000 (12 000)
Hamilton reaches	377 000 (94 300)	114 000 (28 500)
Upstream of Horotiu to Ngaruawahia	115 000 (23 000)	118 000 (39 300)

Annual degradation rates depend on many factors including flood peaks, flow duration curves and hydrograph rates of rise, as well as bank erosion rates and local bed material. Eventually bed degradation will reduce as the river slope becomes flatter due to down-cutting of the bed. The rate of bed degradation has fluctuated between past surveys and although the substantial recent degradation rate decrease in upper and middle reaches could be seen as a positive sign, the 2006 data do not point to a statistically significant change in the long-term trend. Consequently, it would be premature to interpret the degradation rate variations evident in the latest survey as an emerging change in long-term trend.

5 REFERENCES

Asset Management Group, 1999: Lower Waikato River Survey 1998. Report prepared for Environment Waikato. Hamilton East, Hamilton.

Basheer, G. Podrumac, B. Lamb, R., 2002: Waikato River Survey Report: Horotiu Bridge to Narrows Bridge. Report by Environment Waikato and Asset Management Group. Hamilton East, Hamilton.

DML (Discovery Marine Limited), 2006: Waikato River Riverbed Resurvey – Report of Survey. Report Prepared for Mighty River Power. Mount Maunganui, Bay of Plenty.

Smart, G., 2003: Degradation of the Waikato River: Karapiro to Ngaruawahia, A Review of Existing Knowledge and Recommendations for Future Work. Report Prepared for Environment Waikato. Hamilton East, Hamilton.

Smart, G., 2005: Analysis of Degradation - Waikato River. Karapiro to Ngaruawahia. Report Prepared for Environment Waikato. Hamilton East, Hamilton.