Report

2012 Waikato River Bed Degradation Analysis

4 MARCH 2013

Prepared for

Mighty River Power

160 Peachgrove Rd
P O Box 445
Hamilton
3240

42189500

URS

Project Manager:

M. C. C. Mabin
……………………………
Dr Mark Mabin
Principal Environmental Scientist

Principal-In-Charge:

p.p. Mel
……………………………
Walter Lewthwaite
Principal Environmental Engineer

URS New Zealand Limited

273 Cashel Street
Christchurch 8011
PO Box 4479, Christchurch 8140New Zealand

T: 64 3 374 8500
F: 64 3 377 0655

Author:

M. C. C. Mabin
……………………………
Mark Mabin

Reviewer:

p.p. Mel
……………………………
Walter Lewthwaite

Date:	**4 March 2013**
Reference:	42189500/R001/E
Status:	Final

© Document copyright of URS New Zealand Limited.

No use of the contents, concepts, designs, drawings, specifications, plans etc. included in this report is permitted unless and until they are the subject of a written contract between URS New Zealand and the addressee of this report. URS New Zealand accepts no liability of any kind for any unauthorised use of the contents of this report and URS reserves the right to seek compensation for any such unauthorised use.

Document delivery

URS provides this document in either printed format, electronic format or both. URS considers the printed version to be binding. The electronic format is provided for the client's convenience and URS requests that the client ensures the integrity of this electronic information is maintained. Storage of this electronic information should at a minimum comply with the requirements of the Electronic Transactions Act 2002.

Where an electronic only version is provided to the client, a signed hard copy of this document is held on file by URS and a copy will be provided if requested.

Table of Contents

Table of Contents

Tables

Figures

Table of Contents

Appendices

Executive Summary

- URS New Zealand Ltd (URS) has analysed bed level data from cross sections of the Waikato River between Karapiro and Ngaruawahia.
- Bed level data were obtained by IX Survey using multibeam echosounding (MBES) and single beam echosounding (SBES) hydrographic survey of the bed of the Waikato River in February and March 2012, in order for Mighty River Power to be able to comply with the Primary Consents Conditions 6.9 and 6.11 vi and vii.
- A nearly complete hydrographic surface of the river bed was obtained, and cross sections were extracted from these data at 89 locations surveyed in previous bed degradation monitoring studies. River level was low during the hydrographic survey resulting in shortened cross sections that did not include information from the edges of the channel or lower river banks
- In order to allow comparison of the 2012 survey with previous data, the extracted cross sections were extended to the Nominal Water Level, being the water level at each cross section during a notional 420 m^3/s flood event. These extended cross sections were filled with data from the 2006 survey.
- Cross section parameters were calculated to show: mean bed level, cross section area, thalweg level, Thalweg Index, and section volume. In addition, rates of change for the period 1998 to 2012 were calculated using Mann-Kendall statistics appropriate for non-normally distributed data.
- Bed levels continued to decline between 2006 and 2012 at an overall mean rate of -13 mm/yr, which was faster than in the 2003 to 2006 period (-6 mm/yr), but still well within previously documented patterns.
- The pattern of bed level change is shown in Table ES-1. The rate is greatest in the short downstream sub-reach (#3). Across the three survey periods, 1998 – 2003 showed the greatest overall amount and rate of scour in all sub-reaches. The 2003 – 2006 period showed the least overall bed scour.

Table ES-1 Summary of bed level changes, Waikato River from Karapiro to Ngaruawahia, 1998 - 2012

Reach		1998 - 2003	2003 – 2006	2006 - 2012	1998 - 2012
Sub Reach 1	*Mean*	-0.12 m	-0.03 m	-0.13 m	-0.29 m
(Karapiro to just	*Max*	0.29 m	0.39 m	0.29 m	0.15 m
upstream of	*Min*	-0.54 m	-0.49 m	-0.91 m	-1.17 m
Narrows Bridge)	*Rate*[1]	-27 mm/yr	-9 mm/yr	-23 mm/yr	-18 mm/yr
Sub-Reach 2	*Mean*	-0.22 m	-0.02 m	-0.26 m	-0.22 m
(Narrows Bridge	*Max*	0.14 m	0.90 m	0.28 m	0.41 m
to upstream of	*Min*	-1.13 m	-0.32 m	-0.49 m	-1.01 m
Horotiu Bridge)	*Rate*[1]	-50 mm/yr	5 mm/yr	-2 mm/yr	-12 mm/yr
Sub-Reach 3	*Mean*	-0.16 m	-0.12 m	-0.12 m	-0.40 m
(Horotiu Bridge to	*Max*	0.14 m	0.16 m	0.55 m	-0.13 m
Ngaruawahia)	*Min*	-0.69 m	-0.44 m	-0.34 m	-0.76 m
	Rate	-35 mm/yr	-35 mm/yr	-31 mm/yr	-35 mm/yr
Karapiro to	*Mean*	-0.16 m	-0.02 m	-0.06 m	-0.27 m
Ngaruawahia	*Max*	0.14 m	0.90 m	0.55 m	0.4 m
	Min	-0.69 m	-0.49 m	-0.91 m	-1.17 m
	Rate[1]	-41 mm/yr	-6 mm/yr	-13 mm/yr	-19 mm/yr

[1] 1998 – 2012 rate (right-hand column) from Mann-Kendall test, all other rates in this column from linear regression.

Executive Summary

- There has been a small increase in the apparent rate of scour in the most recent survey period and this is likely to be due to the greater number of floods >500 m^3/s. However, bed degradation remains well within recent historical patterns.
- The thalweg line, or line of maximum depth along the river channel, averaged 7.34 m above mean sea level in 2012, which is 2.47 m below the average MBL. This is a drop of 0.06 m since 2006, and it returned the thalweg level to of 2003. It is considered the thalweg level is not showing any atypical pattern of change.
- The thalweg index (TI) is calculated to show the relative significance of the thalweg across the section line. The index usually ranges from 0 to 1.5, with values closer to zero showing the thalweg and mean bed level are very similar, while values greater than 1 indicate the thalweg is an isolated deep point in a generally shallower bed cross section. The overall mean TI value for the reach was 0.52 in 2012, and this has only varied between 0.50 and 0.52 in previous surveys.
- Scour is monitored at three infrastructure sites in Hamilton City. At the Hamilton Traffic Bridge only 0.05 m of scour occurred between 2006 and 2012 (9.5 mm/yr), and this was much less than between 1998 and 2003 (0.37 m). At Fairfield Bridge the bed level rose 0.26 m between 2006 and 2012 (46 mm/yr), but the overall trend here has been scour of -17 mm/yr since 1998. At the Hamilton Water Treatment Station the bed scoured 0.08 m (14 mm/yr) between 2006 and 2012. This represents a considerable slowing from the overall rate of -42 mm/yr since 1998.
- Data from the Hamilton Traffic Bridge flow gauging site can be used to derive a nearly 50-year detailed record of bed level change. This shows bed level can fluctuate rapidly up and down by 0.5 to 1.0m, presumably with the passage of sediment waves. While the overall rate of change has been -44 mm/yr, there have been periods of rapid degradation, interrupted by other periods of much slower change. At present the site has been in a +10 year period showing just 2 mm/yr of overall scour.
- Information presented to commissioners at the hearing for the Waikato Hydro System consents indicated the rate of bed degradation through Hamilton City was declining due to the cessation of sand mining activities, and that it would be expected to continue to decline into the future. This pattern has continued, with some variation due to increased or decreased flood activity. Thus between 2003 and 2006 scour rates declined, but between 2006 and 2012 there was a small increase in overall rate due to more floods of >500 m^3/s. This is considered consistent with the pattern expected when the consent was granted.
- Taking a long-term view, the bed degradation of the last fifty years appears to have been a reversal of 800 years of aggradation along the Waikato River that had raised the bed about 10 m. That period of aggradation had replaced a 1,000 years of relative bed stability that had ensued after a few decades of very rapid bed degradation as the Waikato River adjusted to the effects of the Taupo Pumice Eruption of 181 AD. Thus, the recent bed degradation probably has at least 5 m to go before it returns the bed level to these pre-historic levels.
- The multi-beam echosounding method shows considerable promise for the collection of very detailed bed degradation data.

Introduction

1.1 Purpose and scope

This report analyses and interprets bed level data along the 54 km reach of the Waikato River between Karapiro Dam and Ngaruawahia.

Resource consent numbers 105226, 105227 and 105228 (known as the Primary Consents) granted by the Waikato Regional Council authorise the operation of the Waikato Hydro System. Condition 6.9 of the Primary Consents requires Mighty River Power to "*design a monitoring programme for the purpose of assessing the effects of the on-going operation of the Waikato hydro system, and in particular to compare those effects with those anticipated and authorised by the grant of these consents with respect to the following matters: […] - River bed level changes below Karapiro, at least as far downstream as Ngaruawahia"*.

The monitoring programme is further specified in condition 6.11 vi to comprise a "*five-yearly survey of riverbed levels below Karapiro as far as Ngaruawahia",* and condition 6.11 vii requires '*river bed cross-sections in the vicinity of the Hamilton Traffic 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.*

The information in this report was drawn together so that Mighty River Power can comply with these resource consent requirements.

Numerous surveys of bed levels have been carried out in the past with the most systematic and complete coverage being in 1998, 2002/2003, 2006, and now in 2012. Only the last two surveys have been specifically designed to comply with these resource consent conditions. Discovery Marine Ltd (DML) undertook single beam echo sounding in 2002/2003, and 2006, and IX Survey undertook multi beam and single beam echo sounding in 2012. These captured data at 84, 87, 93, and 90 cross sections respectively, located along the 54 km of the river channel between Karapiro and Ngaruawahia. The mean spacing between the sections in 2012 was 0.6 km, ranging between 0.2 km and 1.8 km.

Less complete surveys had also been carried out in 1963 (13 cross sections), 1973 (40 cross sections), 1987/1988 (27 cross sections), and 1994 (25 cross sections). At the time the Waikato Hydro System resource consents were being decided, these data had shown a long history of bed degradation arising from a combination of factors including in-channel sediment mining. However, it was also apparent that the Karapiro Dam would have played a significant role in this pattern of bed scour as it has effectively shut off the supply of mobile bed sediment from upstream. While sediment mining along the river has now ceased, the dam of course remains, hence continued monitoring of bed levels downstream of Karapiro is required. In an alluvial system it would be expected that the bed degradation would be greatest upstream near the dam, and decline downstream towards Ngaruawahia. At this town the Waikato River is joined by a major tributary, the Waipa River, and this delivers a significant sediment load which is the first major tributary contribution of bed load below Karapiro and should partly ameliorate bed degradation further downstream of Ngaruawahia.

1.2 Data Sources

Key information for this report is the bed cross section level data obtained by IX Survey and described in their 2012 report. For the 2012 survey the data were obtained using multibeam echo sounding that is capable of capturing bathymetric data of the whole bed of the river from Karapiro to Ngaruawahia. Cross sections were cut from these data at the locations established in previous surveys.

Data collected in previous cross section surveys were obtained from the compilations provided with the previous bed degradation report of Smart (2006).

1.3 Waikato River flow regime 2006 – 2012

Bed degradation is a natural process driven by river flow eroding and transporting bed sediment downstream, particularly in flood conditions. Therefore it is likely that more bed degradation will occur in periods when the flow regime includes more floods.

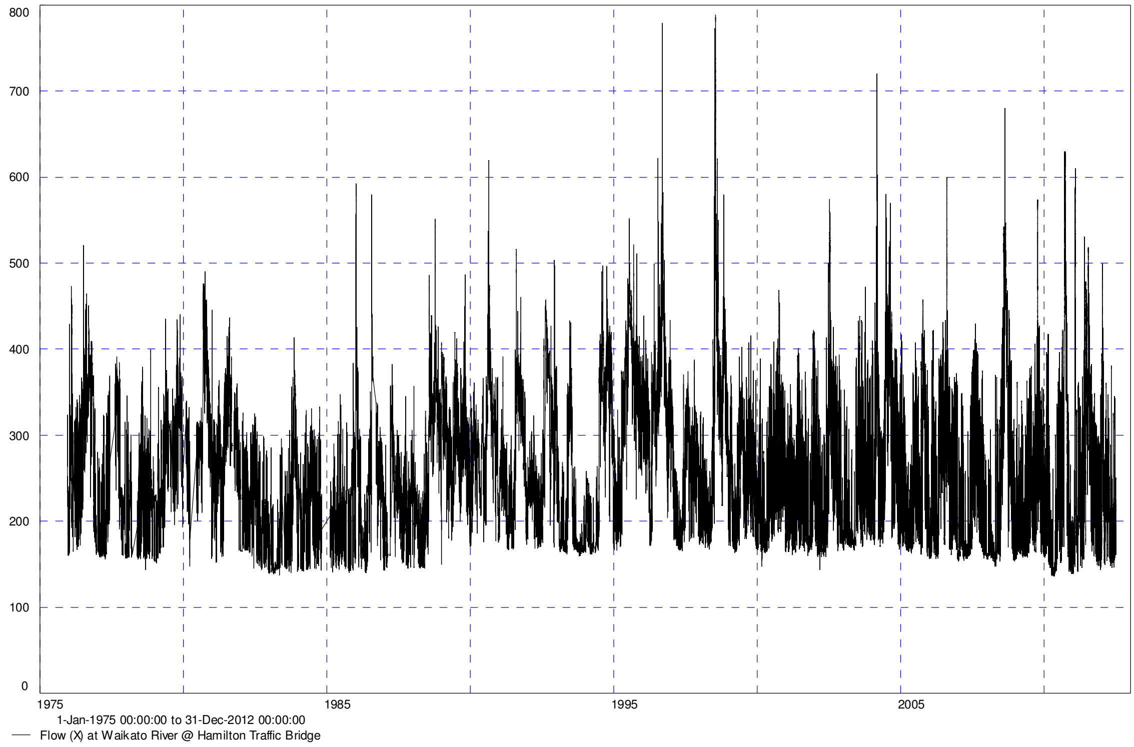


Figure 1-1 Waikato River flow (m^3/s) at Hamilton Traffic bridge, 1975 - 2012

Figure 1-1 shows the flow regime 1975 – 2012, and an increase in baseflow is evident from the late 1980s. At this scale there is no obvious difference in flow regime since the mid-late 1990s. However, there are some subtle changes as discussed below.

Mean flow for the period of record was 258 m^3/s, and during the period between the 2006 and 2012 surveys is was slightly less than this long term average at 248 m^3/s. From 2003 – 2006 the mean flow had been 266 m^3/s.

From 2006 to 2012 there were 18 events with peak flow greater than 400 m^3/s, and eight floods with flow greater than 500 m^3/s. The largest event was 680 m^3/s on 16th August 2008. This was generally similar to the shorter period between the previous two surveys from 2003 to 2006 that had 19 events peaking at greater than 400 m^3/s, five were greater than 500 m^3/s and the peak flood reached 720 m^3/s on 1st April 2004.

2

Methodology

2.1 Previous surveys

Previous surveys of bed levels had used a combination of terrestrial surveys of the banks above the water line, and various hydrographic survey techniques for the actual river bed below the water line. These surveys were conducted at a series of cross sections taken at semi regular intervals. Previous survey methodologies were described by Smart (2006) and DML (2006).

2.2 Multi-beam surveys

Multi-beam echosounding (MBES) is a method of hydrographic surveying that, as the name suggests uses multiple echo beams rather than a single beam (SEBS). It allows surveying of a wide path from a single vessel track. In recent years the technology has advanced so that it can be deployed from small launches, allowing it to be used for river hydrographic surveys and other shallow water applications.

2.2.1 2006 Survey

The first multi-beam survey of the Waikato River was undertaken as part of a master's thesis research project by Adam Wood, *Morphodynamic Channel and Stability of the Waikato River: Karapiro to Ngaruawahia Reach.* A nearly complete bathymetric surface was generated along this 54 km reach, but it was not supported by accurate GPS survey so is not suitable as a starting point for evaluation of subsequent bed level changes.

2.2.2 2012 Survey

The 2012 multi-beam survey was carried out by IX Survey as described in their report *Waikato River – 2012 Riverbed Survey* (29 March 2012). The whole length of the river was surveyed in two parts from 7 – 12 February, and 1 March 2012, apart from a short section upstream of Cambridge where it was too shallow to safely deploy the equipment. River flow was quite low (ranging between 150 m^3/s and 220 m^3/s) and so water levels were at least a metre lower than normal and this reduced the width of bed that was covered.

The survey methodology was supported by precision GPS surveying so that accurate x/y/z coordinates could be obtained for the millions of survey points.

IX Survey then cut 90 of the previous cross section survey lines from the bathymetric surface generated from the MBES data. As a comparison check, a Single Beam Echo Sounder (SBES) was used to test for the similarity between the MBES and SBES data at six representative cross sections.

2.3 Analytical methods

The 2012 MBES survey generated a continuous record of the morphology of the river bed, from Karapiro to Ngaruawahia. While in the future this will provide an excellent baseline record of the entire river bed, comparison with older survey data can only be performed by comparing cross sections in the same locations that were previously used.

2.3.1 Development of Adjusted 2012 Cross Sections

While the multi-beam survey methodology captures a very detailed record of the river bed, it is limited to the bed below the water surface at the time the survey was carried out. Low water levels experienced during the 2012 bathymetric survey meant that data obtained did not extend up to the nominal water level (NWL) used in earlier surveys. The NWL approximately represents a discharge of ~420 m^3/s, which is around the maximum flow through the Karapiro Power Station and would be a small flood in this reach of the Waikato River. The NWL would have been about 2 m above the water level at the time the hydrographic survey was carried out. Extensions to the 2012 cross sections were therefore needed to in-fill this missing lower bank data and allow comparison with previous surveys[2].

The in-fill data were sought from available topographic and hydrographic information. In a number of cases the 2007 LiDAR survey data were consulted, however the resolution of these was not sufficient to be of use. This left the 2006 SBES and terrestrial survey data as the most recent available information. Extensions to 2012 cross sections were thus created by inserting the relevant data at each cross section from the 2006 survey. Where anomalies were found to exist between the 2006 and 2012 extracted sections, a "best fit" approach was employed to produce a feasible result. The resulting adjusted 2012 cross sections are shown in Appendix B.

It is considered that bank changes between the survey water level and NWL are unlikely to reflect significant changes in river bed aggradation or degradation. Extrapolating data from 2006 and the highest measured levels in 2012 is therefore not expected to introduce significant errors into the analysis.

2.3.2 Calculation of parameters

To compare 2012 cross sectional data to previous years a number of different parameters have been calculated for each section. As with previous years these include the weighted mean bed level, thalweg level (the deepest point across the section line), cross sectional area, and thalweg index. For 2012 we have also included the width at the Nominal Water Level (NWL), generated from the 2006 data, along with river bed scour volume calculations for each section. The river has been split up into the three sub-reaches used by Smart (2006) and are shown in Table 2-1 below. These reaches are not the same as those used in the bank erosion monitoring reports.

Table 2-1 Waikato River sub-reaches, Karapiro to Ngaruawahia

Sub Reach	Chainage distance from mouth	Length	# cross sections	Notes
1. Karapiro to just upstream of the Narrows	126.36 – 148.25 km	21.9 km	25	Cambridge is between 141.2 and 143.75 km (xs 161A – 16)
2. Narrows to upstream of Horotiu Bridge	102.66 – 126.36 km	23.7 km	48	Hamilton is between 107.5 and 119.2 km (xs 138A – 160)
3. Horotiu Bridge to Ngaruawahia	95.88 – 104.03 km	8.15 km	14	Ngaruawahia is between 95.9 and 98.5 km (xs 133 – 138)
TOTALS	95.88 to 148.25 km	53.75 km	87	Data for 90 sections were supplied by IX Survey[3].

[2] Some of the cross sections had also needed to be extended in the 2006 survey.
[3] Ninety four cross sections had been surveyed in 2006, and IX Survey extracted 90 of these from the MBES data in 2012 (xs 142A, xs 145Z, xs 152Z, and xs 172 were not extracted). At xs 5, xs 158G, and xs 164 there were significant mismatches with the 2006 data and these sections have not been analysed in this report.

The calculation of these cross section parameters is described in Smart (2006). In most cases the calculation requires knowing the NWL, which was defined as the water level during a 420 m^3/s flood event. This varies at each cross section and was determined for the 2006 survey.

Cross section area is measured with respect to the NWL, and the mean bed level (MBL) is then that distance which when multiplied by the width at the NWL results in the measured cross section area. Thus MBL = section area ÷ width at NWL. Thalweg Level (TL) is the minimum bed depth along the section line, and the Thalweg Index (TI) is the ratio (MBL – TL)/(NWL – MBL). Section volume is defined as the cross section area times half the distance upstream and downstream to the adjacent cross sections.

All of these parameters have been calculated for each cross section and are listed in the data spreadsheets in Appendix E. Electronic EXCEL files of the spreadsheet data and calculations accompany this report.

2.3.3 Identification of changes

Cross sections of the river bed (see Appendix A) provide a graphical illustration of the shape of the river bed, allowing for visual identification of changes. These changes can be quantified by comparison with data from previous surveys to assess whether the section has experienced aggradation or degradation (scour).

2.4 Trend analysis

Collection of bed level change data over time invites statistical analysis to detect trends of change (erosion or deposition) over time, and indeed the purpose of this monitoring was to document scour at these cross sections. However, only a small number of surveys have been carried out (typically four surveys at each cross section, 1998, 2003, 2006, and 2012), and the data are not ‘normally’ distributed. Thus statistical trend analysis by standard linear regression techniques is not appropriate.

NIWA[4] have developed software to analyse for trends in non-normally distributed environmental data, and in this case the Mann-Kendall test is appropriate. The Mann-Kendall test computes a Kendall statistic (S) which assesses all pairwise steps that can be formed between each data point and the preceding points in the series, and returns the sum of all differences. If there is an underlying trend of erosion, the Kendall statistic will be negative. A large value of the test statistic suggests the presence of a trend. In this case with only four data points the maximum Kendall statistic will be +6 if all values are increasing or -6 if all values are decreasing. Kendall statistics of ±5 to 0 can result from one to three of the values increasing/decreasing depending on their order in the series. The software also calculates a ‘p’ value to test for the statistical significance of the trend. If $p<0.05$ the trend is considered significant at the 95% confidence level.

Where statistical trends are reported here, they are calculated using Mann-Kendall trend analysis, unless there are only two data points when a simple linear trend is reported. However, none of the trends are statistically significant as the data sets are currently too small. Calculations of trend significance using a synthetic data set with an erosion ‘trend’ of 45 mm/yr and five-yearly surveys, show that after 43 years the apparent trend would only be significant at $p = 0.5$ (ie 50% confidence level). It would take about 50 years (10 surveys) to detect a trend that was significant at the more

[4] NIWA (2009) *Time Trends- Trend Analysis and Equivalence Testing for Environmental Data v3.0.*

usual p = 0.05 (ie 95% confidence level). Thus the trends reported in this study should not be regarded as statistically significant (unless otherwise stated).

2.4.1 Assumed survey dates

Each five-yearly set of cross section surveys was carried out over several days, often months apart, and in the case of the previous but one survey in two different years (2002 and 2003). Although the dates of the 2006 and 2012 surveys are reasonably accurately recorded, the dates of the earlier surveys are only known approximately. To simplify calculation scour trends, it was assumed that the surveys were carried out on 1/3/2012, 1/7/2006, and 1/1/2003. These dates are approximately at the mid-point of the survey periods. No information was found for the 1998 and earlier surveys, thus a mid-year date is assumed in all those cases (i.e. 1/7/1998).

Given the inherent inaccuracy of these dates, the trend statistics should be treated as approximations only. However, it is considered unlikely that the true trends will be materially different from these approximations.

2.5 Template for future surveys

MBES surveys have several advantages over previous survey methodologies.

- They provide a continuous detailed record of riverbed morphology (where water depth allows) rather than isolated sections.
- They have the advantage over SBES of not requiring a riverbank benchmark network, which has become increasingly difficult to occupy due to access and sustainability issues (IX Survey 2012).
- During SBES data acquisition, errors can be introduced when the survey vessel drifts off the planned line, resulting in a cross section that may not be in exactly the same location as previous surveys.

As noted above, a comparison between SBES and MBES survey methods was conducted by IX survey at 6 different survey locations. They found there to be generally good agreement between the two methods, with any differences being reasonably explicable (IX Survey, 2012). Given the similarity between results it is considered that future MBES surveys would not need to be calibrated against SBES methods.

Although the MBES method offers considerable benefits for future monitoring, it should be noted there will be very large amounts of data generated, and this will likely require a higher level of IT support. Software to appropriately analyse the data may be costly, and require specialised expertise to run. It is possible the software and computers required to do this will be owned by the hydrographic survey companies themselves rather than by external consultants. In future this may require there to be a working relationship between surveyors and fluvial geomorphologists.

The MBES hydrographic survey method had not been contemplated at the time the original cross section surveys were established. In the light of the much more complete bed level information that can now be obtained, it would be appropriate to reconsider the details of this monitoring programme. It may well be that the monitoring purpose, frequency, and data coverage could be re-evaluated in order to maximise the potential benefits to Environment Waikato as the regulator and other stakeholders with relevant interests in the Waikato River, while minimising the cost burden on Mighty River Power.

Bed changes in the Karapiro to Ngaruawahia Reach

3.1 Bathymetric surface

The bathymetric surface of the Karapiro to Ngaruawahia Reach derived from the MBES survey data is shown in Figures A1 – A30 in Appendix A. It has been overlain on the 1:50,000 topographic map base where the grid lines are 1000 m apart. Sub-reach 1 is shown on Figures A1 to A12; sub-reach 2 is shown on Figures A12 to A26; and sub-reach 3 is shown on Figures A26 to A30. Colour shading on these figures is arranged in order from highest to lowest elevation above sea level as follows: crimson – red – orange – yellow – green – blue – purple, ranging from about 20 m (crimson) through 0 m (mid-blue) to -5 m (purple).

3.1.1 Sub-reach 1

Sub-reach 1 shows three types of bathymetry. The upstream ~11 km is very irregular with the narrow channel having many deep and shallow sections. There are some 16 holes or longer deep sections. The holes are typically closed and elongated depressions on the river bed, several tens of metres long and wide and often more than 5 m deep. Large holes can be several hundred metres long. Only three of the holes are associated with the outside of bends and all of these can be seen on Figure 4. The longer holes are associated with narrow sections of channel. One extends ~500 m downstream from a prominent sill (about 2 km upstream of the upper bridge at Cambridge, see Figures A2 and A3), and there is a 1.3 km long complex of holes and deeps near the Cambridge Oxidation Ponds (Figure A5, xs 171 – 172).

Downstream of here the bed widens and becomes somewhat more uniform for ~8 km (Figures A6 – A9). There are 7 holes all associated with the outsides of bends.

In the last ~3 km of sub-reach 1, the channel again narrows and the bed becomes more irregular, culminating in The Narrows. There are no well-defined holes, rather there are deeper sections running for several hundred meters in association with the narrower channel segments.

3.1.2 Sub-reach 2

Downstream of The Narrows the Waikato River widens and the bed becomes more regular, and two characteristic bed types can be identified. The upstream ~9 km to Graham Island downstream of the Cobham Bridge (xs 160 – 152B, see Figures A10 – A16) shows about nine broad low swells and depressions in the bed, with a wavelength of about 0.75km – 1 km. The deeper depressions are ~ 500 m long, and there are some holes on the outside of bends and where the channel narrows slightly.

From xs 152 downstream the bed becomes more uniform, with deeper sections occurring where the channel narrows, or on the outside of bends. This section is shown on Figures A16 – A24.

3.1.3 Sub-reach 3

At the scale of the figures, the bed of sub-reach 3 is the most uniform of the sub-reaches between Karapiro and Ngaruawahia, and shows a largely planar bed. There are five short deeper sections that are mostly associated with narrower parts of the river channel. Only one hole is on the outside of a bend.

The holes and deeper sections occur at and around XS 133 (at the road and rail bridges in Ngaruawahia, Figure A30); at ~200 m downstream of xs 134 (Figure A29); at xs 134A (Figure A28);

on the outside of a bend at about 500 m downstream of xs 135A (Figure A28), and most obviously at and upstream of the Horotiu Bridge (Figure A26). Here the river passes through a ~800 m straight narrow section and the river has formed a ~8 m deep elongated hole (see xs 137 and 137A).

3.2 Representative bed types

Five representative bed surface types have been identified from the above descriptions, and these are illustrated in 3-D views in Appendix D.

Figure D1 shows a deep hole near Cambridge. The upper two frames are plan views showing a 1.2 km strip, with the smooth and rough surface water patterns a clear response to the bed irregularities below. Flow is right to left across these images. The lower two frames show 3-D views of the main hole from different perspectives. The 2x vertical exaggeration brings out the probable presence of a sill controlling the upstream end of the hole.

Figure D2 shows a hole on the outside of a bend about 3.5 km downstream of D1. The upper frames show about 0.6 km of the river, and the flow is right to left. There is a constriction of the channel at the hole, and this has probably contributed to its formation.

Figure D3 shows an elongated hole on the northern outskirts of Hamilton. Some 0.75 km of river is shown, and flow is from right to left. The upstream part of the hole is in a channel constriction, and it extends ~300 m downstream to another slight narrowing of the channel.

Figure D4 shows a plane bed section just downstream of the Horotiu Bridge. About 900 m of channel is shown, and flow is from right to left.

Figure D5 shows a prominent sill near the Cambridge Golf Course. The upper panels show ~600 m of channel with flow right to left. The lower panels show 3-D perspective views that focus on the sill, which appears to be the up-thrown side of a fault. The river has exploited weakness along this fault to form a new narrow channel, and it has abandoned the much wider channel which formerly flowed to the north of the golf course. The 100 m long by 40 m wide embayment extending to the north is a remnant of this channel.

3.3 Bed levels

Bed levels along the Karapiro to Ngaruawahia reach are shown in Figure 3-1. This long section, while showing a typical general exponential decline in gradient, is irregular with numerous data points falling well below the general trend. From the bathymetric surface plots shown in Appendix B it can be seen that 14 of the cross sections have been located in holes, as listed in Table 3-1. Most of these holes were apparently scoured to deeper levels between 2006 and 2012.

3.4 Change in bed levels since 2006

The change in mean bed level for the Karapiro to Ngaruawahia reach is shown in Figure 3-1, and at this scale there has been little change in the pattern of bed degradation in the 5.5 years between the 2006 and 2012 surveys.

The overall mean bed level in 2012 was 9.82 m, a fall of 0.065 m since 2006. Thirty-three cross sections showed aggradation (maximum 0.55 m, mean 0.14 m), while 54 cross sections showed scour (maximum 0.91 m, mean -0.19 m).

3 Bed changes in the Karapiro to Ngaruawahia Reach

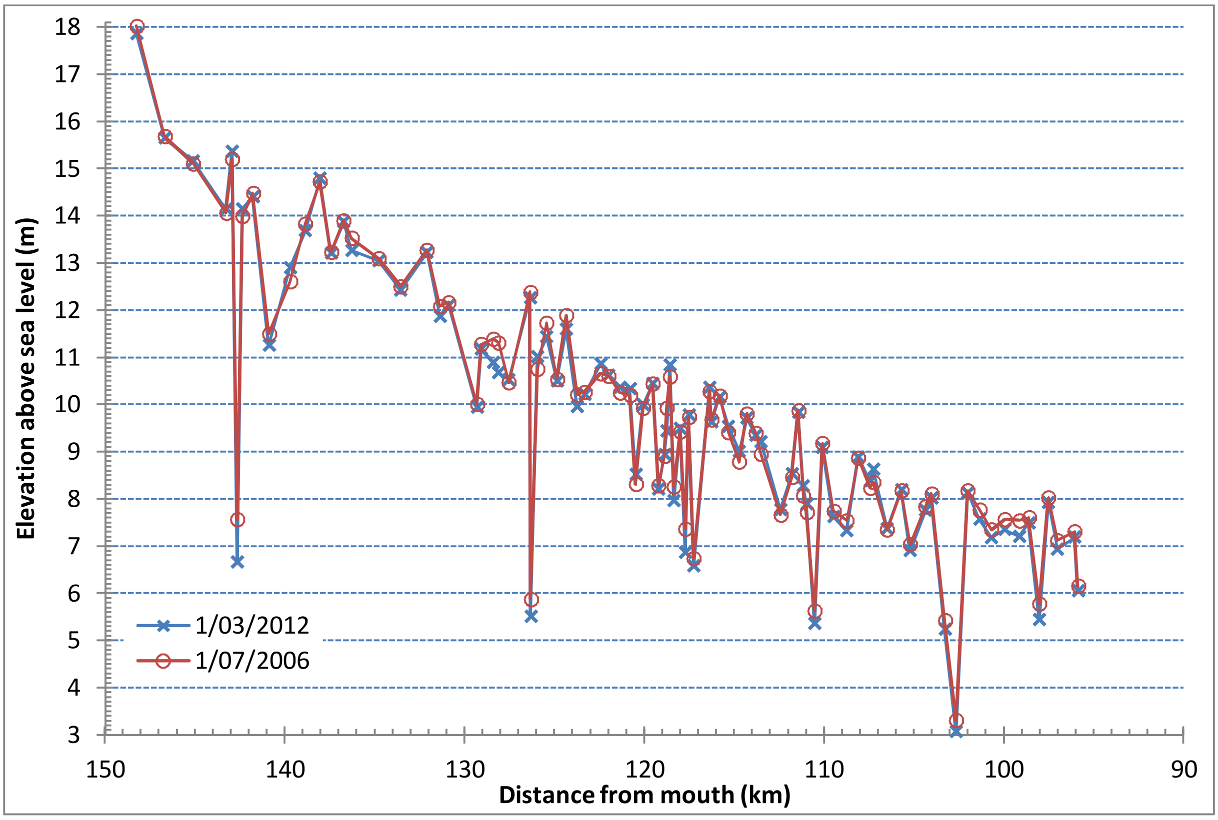


Figure 3-1 Waikato River bed mean levels Karapiro to Ngaruawahia, 2006 – 2012

The simple linear rate of cross section change from 2006 to 2012 was -12 mm/yr, compared to -5 mm/yr from 2003 to 2006, and -41 mm/yr from 1998 to 2003.

Table 3-1 Cross sections in holes along the bed of the Waikato River, Karapiro to Ngaruawahia Reach

Hole #	Chainage (km)	xs
1	142.7	17
2	140.9	173B
3	139.7	173
4	126.3	159
5	120.5	155
6	119.2	154
7	118.9	153B
8	118.4	153
9	117.7	152B
10	117.3	157
11	110.5	145
12	103.3	137A
13	102.7	137
14	98.0	134A

3 Bed changes in the Karapiro to Ngaruawahia Reach

Figure 3-2 shows the Mann-Kendall trends of bed level change 1998 – 2012 at each cross section along the Karapiro to Ngaruawahia reach. Most cross sections (80%) show erosion trends, but there are some cross sections throughout the reach that show apparent aggradation. There is no statistically significant trend in this scatter, although there is a very weak downstream increase in erosion rate.

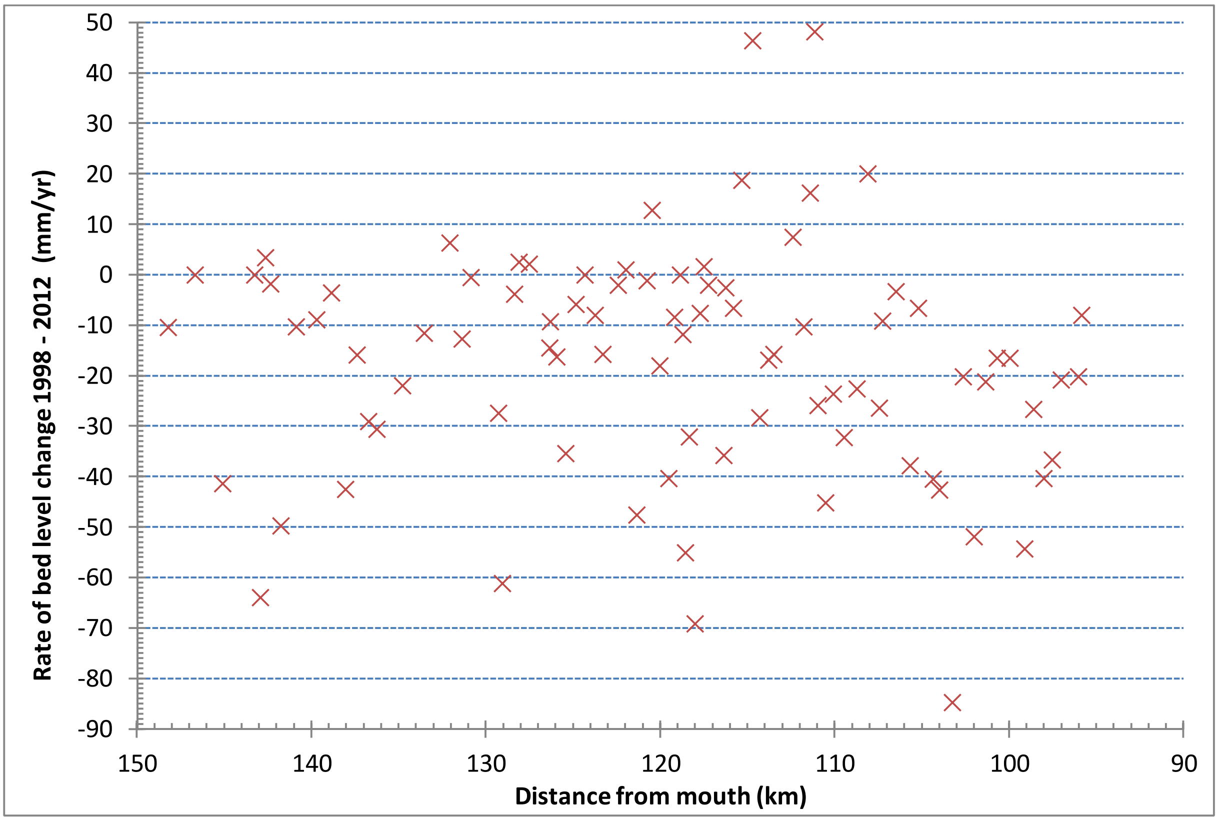


Figure 3-2 Rates of bed level change along the Karapiro - Ngaruawahia reach, 1998 - 2012

In an alluvial system, (a system wherein the river channel is formed in river-deposited alluvium that it is able to shape with each passing flood and along which bedload sediment is freely transported), with an upstream dam it would be expected that erosion rates would be greatest in the reaches closer to the dam, and the rate of erosion would decline downstream.

This pattern is not evident along the Waikato River, which suggests the river does not behave as a typical alluvial system. Rather the variability in scour rates suggests it is more akin to a bedrock channel where deep holes form in zones of weaker rock. While there is still bed load sediment moving through the system, the overall pattern of bed degradation is likely to be highly complex and responding to many local controls (identified as 'sills' in previous reports) as well as more system wide sediment transport processes. The move to MBES hydrographic monitoring will greatly assist in pin-pointing the locations and importance of these local controls.

3.5 Thalweg parameters

Previous analyses of bed level change have discussed cross section thalweg parameters. The thalweg is the line of maximum depth along a river channel, and this can be readily extracted from the cross section survey data. The average thalweg level in 2012 was 7.34 m above mean sea level (ie

2.47 m below the average MBL), and while this represents a drop of 0.06 m since 2006, it merely returned this level to that seen in 2003. At this stage, the overall thalweg level is not showing any atypical pattern of change.

Smart (2006) used a thalweg index (TI) calculation to show the relative significance of the thalweg across the section line. Was the thalweg significantly deeper than the rest of the bed, or not greatly different? The TI generally lies in the range of 0 to 1.5, with values closer to zero showing the thalweg is not greatly different to the mean bed level, while values greater than 1 indicate the thalweg is an isolated deep point along a generally shallower bed cross section. Smart (2006) further suggested that the TI was an indicator of cross section shape, varying between rectangular (TI ~0), and triangular (TI ~1). However, the inputs for the TI calculation are all one dimensional (vertical) measures of depth (NWL, MBL, TL) and it is unclear how a ratio of these could return a value that defines a 2-D shape.

In any event, the overall mean TI value for the reach was 0.52 in 2012, and this has only varied between 0.50 and 0.52 in previous surveys. While there are some cross sections that show modest changes in TI values, overall there appears to be no systematic change in this index occurring over time, and it will not be discussed further in detail.

3.6 Long term context of bed degradation

The bed degradation experienced over the past few decades is part of a history of Waikato River bed level change through the Hamilton Basin. URS (2007, Section 5) reviewed this history, documenting an extensive literature on the longer-term history of the Waikato River valley. The present river corridor was first formed between about 17,600 and 14,000 years[5] before present (BP) during a period of landscape adjustment after the massive Oruanui Eruption from Lake Taupo around 26,000 years BP. The Waikato River bed was probably 20 m deeper than at present, in a valley only a little wider than at present.

The next phase of valley development occurred after the Taupo Pumice Eruption of 181 AD. In a complex series of events lasting several decades, the Waikato River valley through the Hamilton Basin was first partly filled with pumice sediments, then re-excavated during massive floods derived from Lake Taupo, This reformed Waikato River valley was scoured out to a depth of 6 – 9 m below the present bed level, and it remained in that form until about 1200 AD when humans first began to have an effect on the landscape. Catchment-wide erosion began to occur, and although this erosion was probably at a modest level, sediments entered the Waikato River and the bed began to aggrade. About 150 years ago Europeans arrived, land clearing gathered pace, and the rate of river bed aggradation increased greatly. Other processes also contributed, for example in 1928 the construction of the Arapuni spillway released over five million cubic metres of sediment that made its way down river over the next ten years. It is believed that the Waikato River bed may have aggraded up to 10 m as a result of these processes over the last 800 years.

In 1947 the Karapiro Dam was completed and the 800 year history of bed aggradation came to an end, to be replaced by bed degradation as the Waikato River has become a ‘hungry river’ without a supply of bed load sediment from upstream. However, the post-1947 bed scour was for many years exacerbated by sand mining from the bed, so it is only recently that the pattern of bed degradation has started to predominantly reflect the effects of the dam.

[5] Years determined by the radiocarbon dating method. These are not the same as calendar years.

3 Bed changes in the Karapiro to Ngaruawahia Reach

This longer term history of the Waikato River has important ramifications for understanding the present bed degradation issues. Firstly, there have been two previous Waikato River valleys in the same location as at present, and with almost the same width and valley side slopes. However, these valleys have been 10 – 20 m deeper than the present valley. The present bed degradation that has been occurring since 1947 has reversed an 800 year history of aggradation along the valley, and although the cause of the degradation is not natural, the valley has previously experienced much greater rates and amounts of natural scour. Since 1947 the bed has probably been scoured by 2 – 3 m, but the rate has slowed since sand mining has ceased. Given the amount of aggradation that had occurred in the last 800 years, there is probably more than 5 m of scour that could occur before the bed returned to its pre-800 years before present level.

Sub-reach bed level change

The broad reach-wide changes in bed levels were discussed above in Section 3. The present section will address in more detail the changes in bed levels within the three sub-reaches identified above in Table 2-1. Most attention will be given to mean bed levels as these are the focus of Mighty River Power's compliance requirements.

4.1 Sub-reach 1: Karapiro to upstream of The Narrows

Reach 1 is very irregular, and contains numerous holes, although the cross section lines only pick up four of these. Figure 4-1 shows the variations in mean bed levels over the four survey dates from 1998 to 2012.

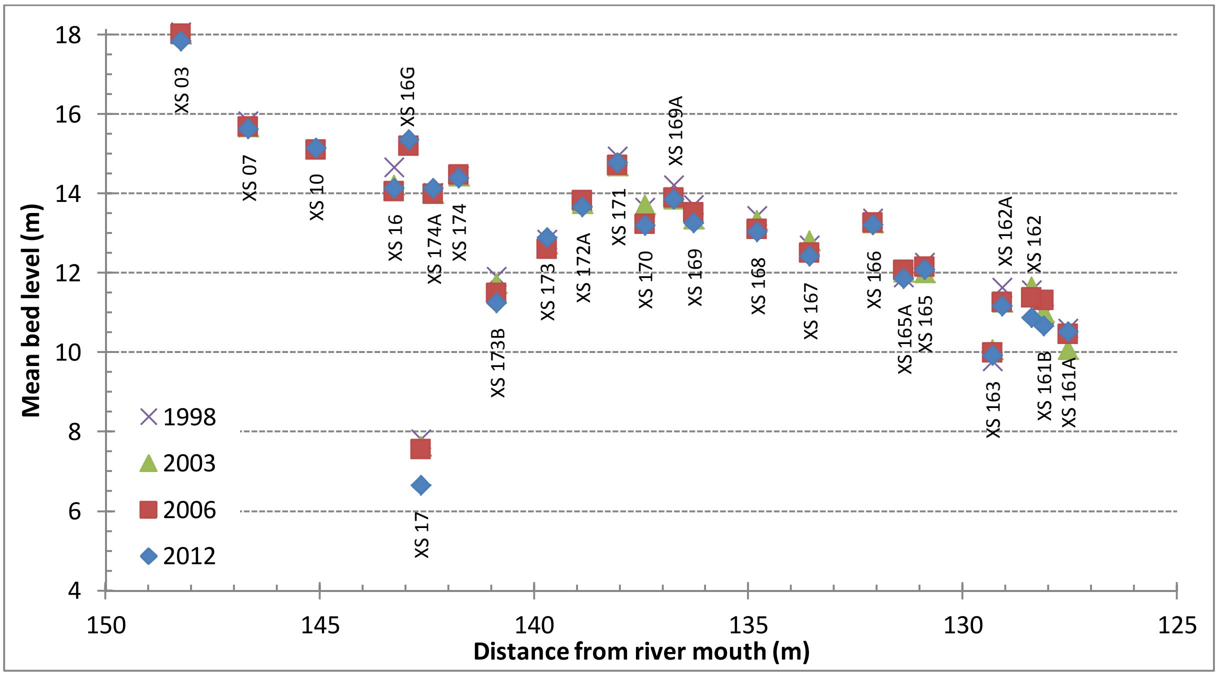


Figure 4-1 Sub-reach 1 mean bed levels 1998 - 2012

There were only small changes in mean bed level at most cross sections (2006 – 2012), apart from xs 17 and xs 173B, xs 162, and xs 161B. At xs 17, 0.91 m of scour occurred from, and the overall rate of change in this deep hole since 1998 has been -64 mm/yr (Mann-Kendall trend). The mean rate of change in bed level along the whole sub-reach has been -19 mm/yr from 1998 to 2012 (Mann-Kendall trend), although this has varied considerably from linear rates of -27 mm/yr between 1998 and 2003, to -9 mm/yr from 2003 to 2006, and -23 mm/yr from 2006 to 2012.

The volume of sediment lost from this sub-reach has been calculated following the methodology of Smart (2006). This assumed that the cross section area of each section extended half the channel distance upstream to the next cross section, and half the distance to the downstream cross section. Cross section area times this distance gives the sub-reach volume (of water) below the NWL, and the bed volume change between surveys is the difference between these two volumes giving either scour (an increase in sub-reach volume), or deposition (a decrease in sub-reach volume).

Table 4-1 shows scour volumes in sub-reach 1 between the 1998 – 2003, 2003 – 2006, and 2006 – 2012 surveys. The volume of apparent scour fluctuates widely, but has declined in the most recent survey period. However, given the irregularity of the bed between the cross section lines, this estimate of scour is likely to be approximate only. The ability to determine the total change in the bed surface between further MBES surveys will resolve this issue.

Table 4-1 Sub-reach 1 volume change 1998 - 2012

	1998 - 2003	2003 - 2006	2006 - 2012
Total volume change[6]	-62,760 m^3	-179,733 m^3	-215,969 m^3
Scour rate	-13,935 m^3/yr	-51,408 m^3/yr	-38,108 m^3/yr

4.2 Sub-reach 2: Narrows to upstream of Horotiu Bridge

The bed of sub-reach 2 is somewhat more regular than upstream, but there still are numerous deep holes many of which are picked up by the cross sections. Figure 4-2 shows the variations in mean bed levels over the four survey dates from 1998 to 2012.

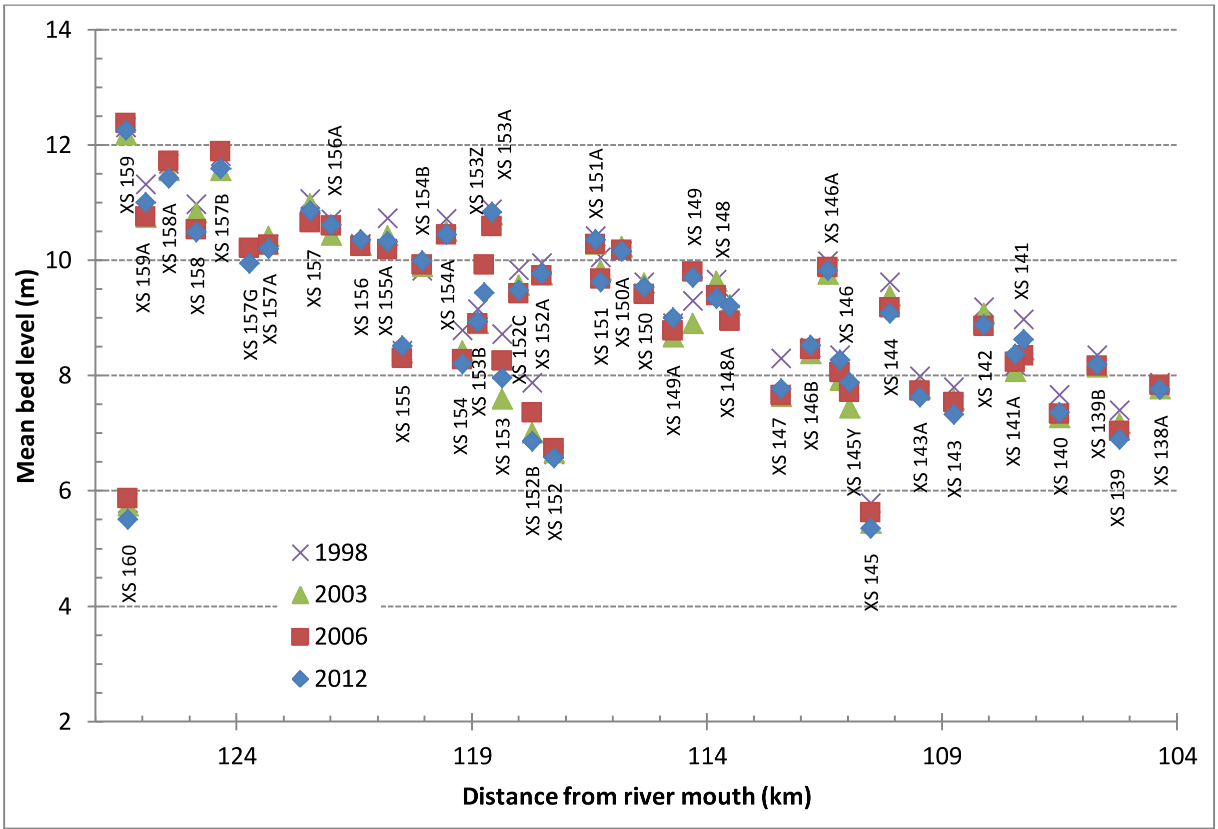


Figure 4-2 Sub-reach 2 mean bed levels 1998 - 2012

Bed level changes through this sub-reach have been noticeable since 1998. However, in detail it can be seen that most of the change occurred between 1998 and 2003. The sub-reach average bed level in 1998 was 9.31 m, and this dropped to 9.06 m in 2003 (-0.25 m), but it has stayed at around this level since then (9.12 m in 2006, and 9.09 m in 2012).

[6] These volumes have been calculated for this report following the methodology of Smart (2006). However, Smart's reported volumes (p 20 of his report) could not be replicated using his method.

4 Sub-reach bed level change

The overall mean rate of change in this sub-reach has been -12 mm/yr since 1998, which is the slowest rate of change of the three sub-reaches between Karapiro and Ngaruawahia. However, the rate has varied widely: from 1998 to 2003 the linear rate of change was a rapid -50 mm/yr, but this trend reversed to +5 mm/yr between 2003 and 2006, with a modest erosion trend of -2 mm/yr resuming between 2006 and 2012.

Table 4-2 Sub-reach 2 volume change 1998 - 2012

	1998 - 2003	2003 - 2006	2006 - 2012
Total volume change[7]	-382,535 m^3	33,679 m^3	-141,947 m^3
Scour rate	-84,937 m^3/yr	9,633 m^3/yr	-25,046 m^3/yr

The volume of sediment lost from this sub-reach has been calculated following Smart (2006), and is shown in Table 4-2. Scour volume fluctuates widely, with 2003 – 2006 showing an apparent increase in bed material volume. In common with the rapid bed lowering between 1998 and 2003, bed scour was also rapid in this period. Again however, given the irregularity of the bed between the cross section lines, this estimate of scour is likely to be approximate only. Future MBES surveys have the potential to provide much more realistic estimates of volume change.

4.3 Sub-reach 3: Horotiu Bridge to Ngaruawahia

The downstream-most sub-reach 3 has the most uniform bed along the Karapiro to Ngaruawahia reach. There are only five major holes, and the cross section lines appear to have picked up three or four of these. Figure 4-2 shows the variations in mean bed levels over the four survey dates from 1998 to 2012.

Bed level changes have been at a constant and relatively high rate in the sub-reach. The overall trend has been scour of 35 mm/yr (Mann-Kendall trend). The linear rate was -35 mm/yr for both the 1998 to 2003 and the 2003 to 2006 survey periods, falling slightly to -31 mm/yr from 2006 to 2012.

The volume of sediment lost from this sub-reach has been calculated following Smart (2006), and is shown in Table 4-3. There has been a steady increase in the volume of scour from 1998 to 2012. This is counter-intuitive given the small variation in overall bed level change during this period. However, in 2003 there were four cross sections that had increased in bed level, and three in 2006. These would have acted to reduce the apparent volume of scour in those years, with a larger reduction in 2003. In 2012, only one cross section showed an increase in bed level thus contributing to the recent survey period showing a higher total volume of scour.

Table 4-3 Sub-reach 3 volume change 1998 - 2012

	1998 - 2003	2003 - 2006	2006 - 2012
Total volume change[8]	-110,379 m^3	-112,324 m^3	-207,327 m^3
Scour rate	-24,508 m^3/yr	-32,127 m^3/yr	-36,583 m^3/yr

[7] Volumes calculated for this report following the methodology of Smart (2006). However, Smart's reported volumes (p 19 of his report) could only be approximately replicated for the '98-'06 survey period.
[8] Volumes calculated for this report following the methodology of Smart (2006) closely approximated those listed by Smart (p 14 of his report).

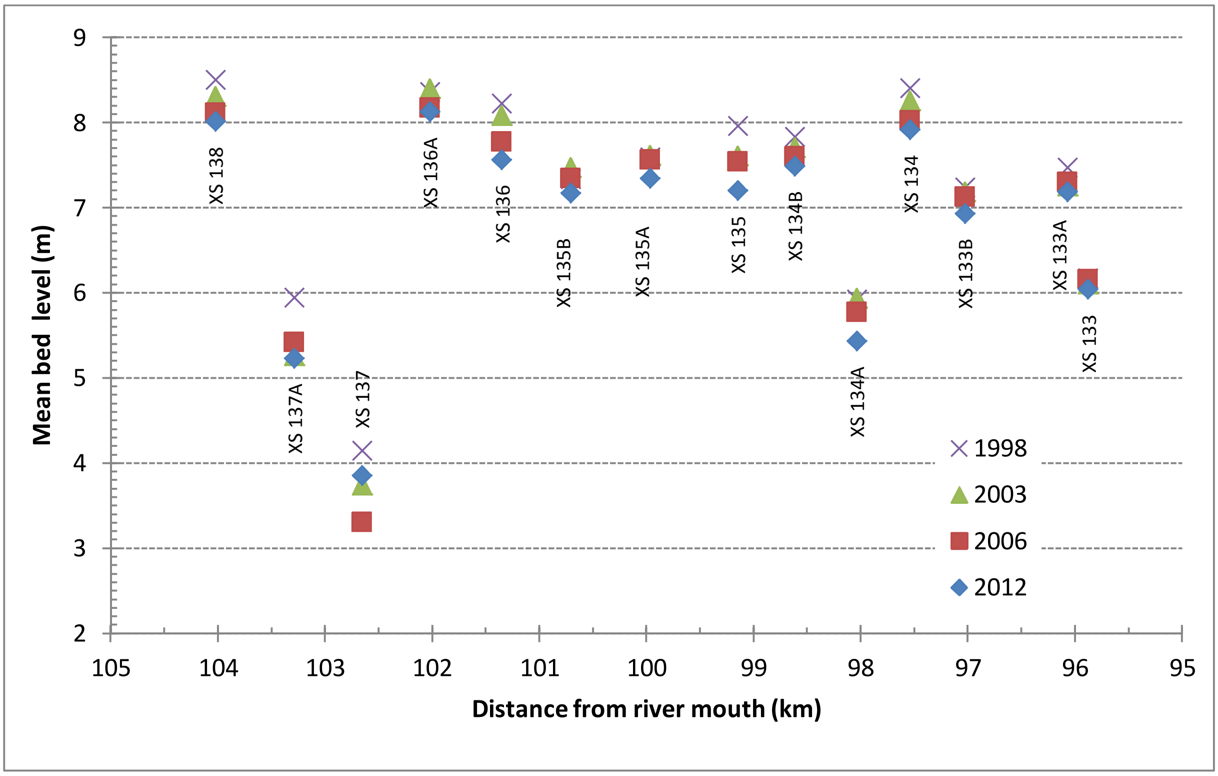


Figure 4-3 Sub-reach 3 mean bed levels 1998 – 2012

4.4 Changes at key infrastructure locations

The Primary Consents Condition 6.11 vii requires river bed cross sections to be surveyed in the vicinity of three key infrastructure sites through Hamilton City, in order to demonstrate any changes that may threaten their structural integrity. Images of these sites have been extracted from the MBES data as shown in Appendix D.

4.4.1 Hamilton Traffic Bridge

4.4.1.1 Bed level change from cross section surveys

Cross section 151 is located at the Hamilton Traffic Bridge. The bridge is ~110 m long, 87 m of which crosses the channel (as defined by nominal water level). The bridge has no piers, and appears to not have abutments that significantly constrict the channel.

The cross section shown in Appendix B shows a deeper central portion of 45 m length that is ~8 m deep below the NWL. This constricts the channel and the river has formed a ~175 m long deep section through here.

From 1998 to 2012 the bed was scoured some 0.42 m, but half of this occurred between 1998 and 2003, and only 0.05 m of scour occurred between 2006 and 2012, so the apparent rate has slowed in recent years. The calculated rate of change for the period 1998 – 2012 is -35.8 mm/yr, but with p =

4 Sub-reach bed level change

0.63 the trend is not significant. At this stage bed degradation here does not appear to be a cause for concern.

4.4.1.2 Bed level change from gauging data

There has been a long term water level site at the Hamilton Traffic Bridge, maintained by Waikato Regional Council. Regular river gaugings are undertaken here to ensure long-term stability of the stage/discharge relationship. Over 300 gaugings have been carried out since 1960, and where these have included water level, flow area and wetted perimeter, it is possible to determine hydraulic radius which is a close approximation of mean depth. From this the mean bed level can be calculated by subtracting mean depth from water level.

Figure 4-1 shows this much longer and more complete record of bed level changes at the Hamilton Traffic Bridge up to late 2010[9]. This shows a long-term decline of bed level at the bridge, with a fall of ~2 m since 1960. The long-term trend[10] was 44 mm/yr. However, it also shows there can be large short-term changes in bed elevation of up to one metre, presumably as mobile sediment bed forms pass the bridge. The short-term variability (about ±500 mm) is more than ten times greater than the calculated trend.

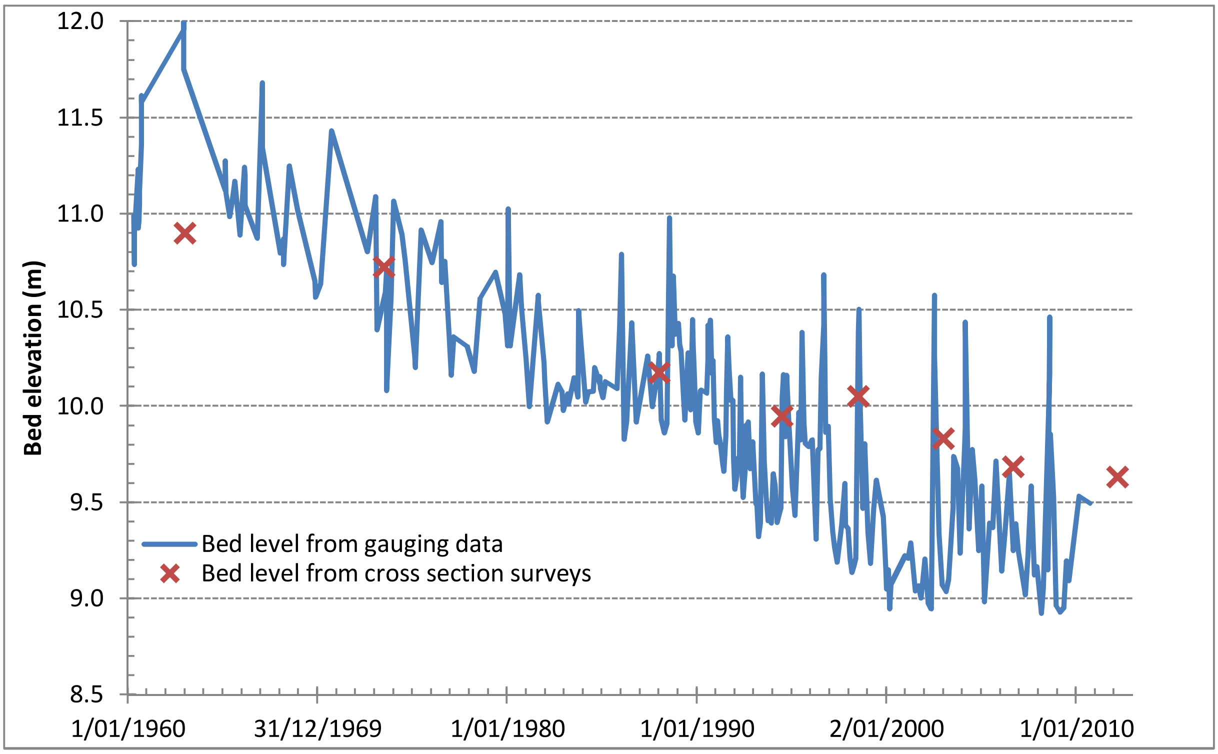


Figure 4-4 Waikato River mean bed levels at Hamilton Traffic bridge (xs 151), 1960 - 2012

Several periods are evident in the long term decline. From 1960 to 1981 the bed declined at ~42 mm/yr, while between 1982 and 1990 the degradation trend reversed, and the bed rose at 14 mm/yr.

[9] Since 2010 the gauging data does not include hydraulic radius, so mean bed level cannot be calculated. It is recommended that Environment Waikato resume reporting this in the gauging data.
[10] All trends quoted here calculated using the Mann-Kendall test.

Degradation resumed from 1991 until 2000 when the bed lowered at 56 mm/yr, the fastest rate over the period of record. From 2001 until 2010 bed degradation slowed to ~2 mm/yr. This reduced rate of bed lowering adds further weight to the above interpretation that degradation here is not currently threatening the stability of this bridge.

Figure 4-4 also shows the bed levels measured in the eight bed level surveys carried out at the bridge. It can be seen that these points form a different trend to the more frequently surveyed gauging data. For these the overall rate of degradation is 27 mm/yr.

These observations have potentially important ramifications for interpretation of the five-yearly bed degradation data. If the bed is generally as mobile as these data suggest, changes determined from the infrequent 5-yearly surveys could be giving an incorrect impression of the overall pattern of bed degradation.

This detailed record of bed level change for this site should be maintained, and bed levels analysed as part of this monitoring programme. It is important that the reporting of hydraulic radius data be resumed. There is also a river gauging station at the Cambridge Golf Course, operated by Mighty River Power, and if hydraulic radius data were reported from that site as well, there would be two such records of detailed bed level change for the river.

4.4.2 Fairfield Bridge

Cross section 148 is located at Fairfield Bridge. The bridge is ~130 m long, of which 110 m spans the river. The cross section shown in Appendix B has a fairly simple parabola shape and there is no apparent constriction of the channel and no obvious depression in the bed as the river passes the bridge.

From 1998 to 2012 the bed apparently scoured 0.13 m, but it has both scoured and aggraded at different times, dropping 0.1 m between 1998 and 2003, and rising 0.26 m from 2006 to 2012. The overall rate has been scour at -17 mm/yr, but the trend is not statistically significant ($p = 0.63$).

4.4.3 Water Treatment Station

Cross section 154 is located at the water treatment station. The water intake is located on the true left bank near the downstream end of a long hole in the river bed, where the bed is climbing out of the hole. Since 1998 the bed has been scoured -0.58 m at an overall rate of -40 mm/yr. The bulk (-0.36 m) of this scour occurred between 1998 and 2003, and since 2006 the rate has been only -14 mm/yr

At this stage the structural integrity of the sub-fluvial water intake does not appear to be under threat from river bed degradation.

4.5 Expected bed level changes

Dr McConchie of the Victoria University of Wellington presented evidence at the hearing for the Primary Consents (McConchie, 2003). This covered many aspects of river geomorphology, including his Section 10 that addressed bed degradation through the Hamilton City reach of the Waikato River. He noted that bed degradation was a natural process that would be occurring with or without the Waikato Hydro Scheme. While this is in detail somewhat at odds with the river history outlined above (Section 3.6), the fundamental point is considered correct – in the absence of human intervention in this landscape, the bed would likely be experiencing long-term degradation.

4 Sub-reach bed level change

The pattern of bed degradation was described at several cross sections (xs 148, 151, 152, 155, and 157) up to the 2003 bed survey period. Dr McConchie noted a general slowing in rate from earlier decades when the effects of sand mining were still being felt. It was his view that in the future the rate of bed degradation would continue to decline, and eventually effectively cease, although he did not offer a time frame for this reduction to occur.

Bearing in mind that Dr McConchie's interpretations were based on the Hamilton reach of the Waikato River, the data collected in the 2006 bed degradation survey for the whole Karapiro to Ngaruawahia reach showed a decline in amount and rate, consistent with Dr McConchie's expectations. The 2012 survey has shown an increase in bed degradation since 2006. The increase is small and consistent with a slightly higher energy flood regime between 2006 and 2012. The 2012 data do not suggest there has been any significant change in the bed degradation regime.

The detailed record at Hamilton Traffic Bridge shows the rate of bed degradation there continues at a very slow rate, and this is entirely consistent with Dr McConchie's expectations that were specifically related to this part of the river.

4.6 Effects of floods on bed degradation

The rates of bed level change have been documented for the three survey periods, 1998 to 2003, 2003 to 2006, and 2006 to 2012. Of these periods, the 2003 – 2006 period was the quietest with a slowing in the rate of bed degradation, and in some instances aggradation occurring over this survey period. The 2006 – 2012 period has reversed this, showing a small increase in bed degradation, which in part will be due to the longer period between surveys (2.5 years from 2003 to 2006, and 5.5 years from 2006 to 2012).

As noted above in Section 1.3, the flow regimes of 2003 to 2006 and 2006 to 2012 were generally similar, although the earlier period experienced a slightly higher mean flow. However, the 2006 to 2012 period did experience more flood events that peaked above 500 ^{3}/s (5 events 2003 – 2006, vs 8 events 2006 – 2012). Furthermore, the flow duration curves indicate that while the 2006 – 2012 flow regime curve mostly lies below those of the other survey periods, in the 420 – 520 m^3/s flow band the 2006 – 2012 period had a higher proportion of flows. Thus, it appears that the 2006 to 2012 period did experience a slightly more active flood regime, and this will have contributed to the observed increase in bed degradation.

4.7 Evaluation of survey methods

The Karapiro to Ngaruawahia reach of the Waikato River is very well served with an impressive network of channel survey lines, making it one of the best monitored sections of river in New Zealand using these traditional cross section survey techniques. However, the introduction of the MBES hydrographic survey method has demonstrated the deficiencies of the traditional method. The ~90 cross sections represent a sampling rate of just one section every 0.6 km. Assuming each section line covers a 0.5 m swath, only 0.08% of the 54,000 m length of Waikato River bed here has been sampled. In this regard, there is simply no comparison to the potential for 100% coverage (i.e. sampling) of the bed using the MBES hydrographic survey equipment.

This is not to say that the cross section survey methodology delivers no useful information. Far from it, but with the ability to observe the variability of the bed surface away from each cross section line, it is clear that these lines are not always representative of the surrounding bed morphologies. Improved interpretation of the cross section survey data would be possible by correlating these data with the MBES-derived bed surface.

The SBES and MBES methods are of course closely related, and as IX Survey (2012) has demonstrated, the results from each method at the same locations are very close, bearing in mind the difficulty a vessel undertaking an SBES survey has when trying stay on line while tracking across the river flow direction.

4.8 Recommendations for future surveys

Experience with the MBES and SBES hydrographic survey methodologies shows that MBES offers an excellent way forward for future surveys. The method allows for the continuation of the repeated cross section surveys into the future at modest expense, but the information that will become available through comparison of full bed surveys will provide much more detailed monitoring information.

Therefore, it is recommended that:

- Future bed degradation monitoring employs the MBES methodology;
- Prior to the next survey the existing cross sections should be reviewed to determine those sites that will provide the most relevant data for ongoing understanding of bed level changes in the lower Waikato River;
- Analysis of bed surface change should fully utilise the MBES surfaces from successive surveys;
- Cross sections should be extracted from the MBES data at the current locations (as reviewed above) and these analysed as before for the next five-year survey to ensure good continuity and overlap of the monitoring methods.

In order to simplify the analysis of the cross section survey data it is recommended that the use of the NWL as a reference level point be discontinued. Mean bed level can be very simply determined using the standard end area method employed in civil construction work, and widely used for river cross section analysis. The calculation is very similar to that used by Smart (2006) but it does not rely on the NWL. Rather, river bed edge markers are defined for each cross section and the weighted mean bed level determined between these for each survey period. The edge of bed markers would be placed at the inflection point where the river bed turns upwards into the river bank.

The advantages of this approach are that it removes the necessity to extend the section lines using old data; it removes reliance on the NWL; it concentrates the analysis on the river bed, rather than including parts of the river bank where other processes occur; and it removes from the analysis the often suspect data where data from the terrestrial and hydrographic survey techniques had been joined together. A disadvantage is that it would not be possible to derive the Thalweg Index in the same way that it has been calculated to date. However, this index is of limited use, and a similar ratio could easily be developed that showed how deep the thalweg was in relation to the mean bed level.

Summary

IX Survey carried out a combined MBES and SBES bed survey programme in February and March 2012, in order for Mighty River Power to be able to comply with the Primary Consents, Conditions 6.9 and 6.11 vi and vii. They obtained a nearly complete hydrographic surface of the bed of the Waikato River between Karapiro and Ngaruawahia, and cross sections were extracted from these data at 88 locations surveyed in previous bed degradation monitoring studies. Although the MBES technique delivered an impressive data set, river level was low during the hydrographic survey resulting in shortened cross sections, although this has not significantly impacted on the results.

In order to allow direct comparison of the 2012 cross sections with previous data, the extracted sections were extended to the Nominal Water Level, being the water level at each cross section during a notional 420 m^3/s flood event. These extended cross sections were filled with data from the 2006 survey. Cross section parameters were calculated to show: mean bed level, cross section area, thalweg level, Thalweg Index, and section volume. In addition, rates of change for the period 1998 to 2012 were calculated using Mann-Kendall statistics appropriate for non-normally distributed data.

Bed levels have continued to decline between 2006 and 2012 as shown in Table 5-1, at an overall mean rate of -13 mm/yr, which was faster than in the 2003 to 2006 period (-6 mm/yr), but still well within previously documented patterns. The rate is greatest in the short downstream sub-reach (#3), and across the three survey periods, 1998 – 2003 showed the greatest overall amount and rate of scour in all sub-reaches. The 2003 – 2006 period showed the least overall bed scour. There has been a small increase in the apparent rate of scour in the most recent survey period and this is likely to be due to the greater number of floods >500 m^3/s. However, bed degradation remains well within recent historical patterns.

Table 5-1 Summary of bed level changes, Waikato River from Karapiro to Ngaruawahia, 1998 - 2012

Reach		1998 - 2003	2003 – 2006	2006 - 2012	1998 - 2012
Sub Reach 1	*Mean*	-0.12 m	-0.03 m	-0.13 m	-0.29 m
(Karapiro to just	*Max*	0.29 m	0.39 m	0.29 m	0.15 m
upstream of	*Min*	-0.54 m	-0.49 m	-0.91 m	-1.17 m
Narrows Bridge)	*Rate*[11]	-27 mm/yr	-9 mm/yr	-23 mm/yr	-19 mm/yr
Sub-Reach 2	*Mean*	-0.22 m	-0.02 m	-0.01 m	-0.22 m
(Narrows Bridge	*Max*	0.14 m	0.90 m	0.28 m	0.41 m
to upstream of	*Min*	-1.13 m	-0.32 m	-0.49 m	-1.01 m
Horotiu Bridge)	*Rate*[11]	-50 mm/yr	5 mm/yr	-2 mm/yr	-12 mm/yr
Sub-Reach 3	*Mean*	-0.16 m	-0.12 m	-0.12 m	-0.40 m
(Horotiu Bridge to	*Max*	0.14 m	0.16 m	0.55 m	-0.13 m
Ngaruawahia)	*Min*	-0.69 m	-0.44 m	-0.34 m	-0.76 m
	Rate[11]	-35 mm/yr	-35 mm/yr	-31 mm/yr	-35 mm/yr
Karapiro to	*Mean*	-0.16 m	-0.02 m	-0.06 m	-0.27 m
Ngaruawahia	*Max*	0.14 m	0.90 m	0.55 m	0.4 m
	Min	-0.69 m	-0.49 m	-0.91 m	-1.17 m
	Rate[11]	-41 mm/yr	-6 mm/yr	-13 mm/yr	-19 mm/yr

[11] 1998 – 2012 rate (right-hand column) from Mann-Kendall test. All other rates in this table are from linear regression.

5 Summary

The thalweg follows the line of maximum depth along a river channel, and the average thalweg level in 2012 was 7.34 m above mean sea level, which is 2.47 m below the average MBL. This represents a drop of 0.06 m since 2006, but it has returned the thalweg level to that seen in 2003, and it is considered the overall thalweg level is not showing any atypical pattern of change.

The thalweg index (TI) calculation shows the relative significance of the thalweg across the section line. The TI generally lies in the range of 0 to 1.5, with values closer to zero showing the thalweg and mean bed level are very similar, while values greater than 1 indicate the thalweg is an isolated deep point in a generally shallower bed cross section. The overall mean TI value for the reach was 0.52 in 2012, and this has only varied between 0.50 and 0.52 in previous surveys. While there are some cross sections that show modest changes in TI values, overall there appears to be no systematic change in this index occurring over time.

Scour is monitored at three infrastructure sites in Hamilton City. At the Hamilton Traffic Bridge only 0.05 m of scour occurred between 2006 and 2012 (9.5 mm/yr), and this was much less than between 1998 and 2003 (0.37 m). At Fairfield Bridge the bed level rose 0.26 between 2006 and 2012 (46 mm/yr), but the overall trend here has been scour of -17 mm/yr since 1998. At the Hamilton Water Treatment Station the bed scoured 0.08 m (14 mm/yr) between 2006 and 2012. This is a considerable slowing from the overall rate of -42 mm/yr since 1998.

Data from the Hamilton Traffic Bridge flow gauging site can be used to derive a nearly 50-year detailed record of bed level change. This shows bed level can fluctuate rapidly ± 0.5 to 1.0 m, presumably with the passage of sediment waves. While the overall rate of change has been -44 mm/yr, there have been periods of rapid degradation, interrupted by other periods of much slower change. At present the site has been in a +10 year period (since 2001) showing just 2 mm/yr of overall scour.

Information presented to commissioners at the hearing for the Primary Consents indicated the rate of bed degradation through Hamilton City was declining due to the cessation of sand mining activities, and that it would be expected to continue to decline into the future. This pattern has continued, with some variation due to increased or decreased flood activity. Thus between 2003 and 2006 scour rates declined, but between 2006 and 2012 there was a small increase in overall rate due to more floods of >500 m3/s. This is considered consistent with the pattern expected when the consent was granted.

Taking a long-term view, the bed degradation of the last fifty years appears to have been a reversal of 800 years of aggradation along the Waikato River that had raised the bed about 10 m. That period of aggradation had replaced 1,000 years of relative bed stability that had ensued from after a few decades of very rapid bed degradation as the Waikato River adjusted to the effects of the Taupo Pumice Eruption of 181 AD. Thus, the recent bed degradation probably has at least 5 m to go before it returns the valley to these pre-historic levels.

References

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

IX Survey, 2012: Waikato River – 2012 Riverbed Survey - Report of Survey. Surveyed for Mighty River Power

McConchie, J. A., 2003: Statement of Evidence to the Mighty River Power Waikato Hydro System Consents Hearing

Smart, G., 2006: Waikato River 2006 Survey Report, Karapiro Dam to Ngaruawahia, Report Prepared for Mighty River Power

7 Limitations

URS New Zealand Limited (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Mighty River Power and only those third parties who have been authorised in writing by URS to rely on this Report.

It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this Report.

It is prepared in accordance with the scope of work and for the purpose outlined in the contract dated 24 October 2012.

Where this Report indicates that information has been provided to URS by third parties, URS has made no independent verification of this information except as expressly stated in the Report. URS assumes no liability for any inaccuracies in or omissions to that information.

This Report was prepared between 1 and 30 November 2012, and is based on the information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This Report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This Report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Except as required by law, no third party may use or rely on this Report unless otherwise agreed by URS in writing. Where such agreement is provided, URS will provide a letter of reliance to the agreed third party in the form required by URS.

To the extent permitted by law, URS expressly disclaims and excludes liability for any loss, damage, cost or expenses suffered by any third party relating to or resulting from the use of, or reliance on, any information contained in this Report. URS does not admit that any action, liability or claim may exist or be available to any third party.

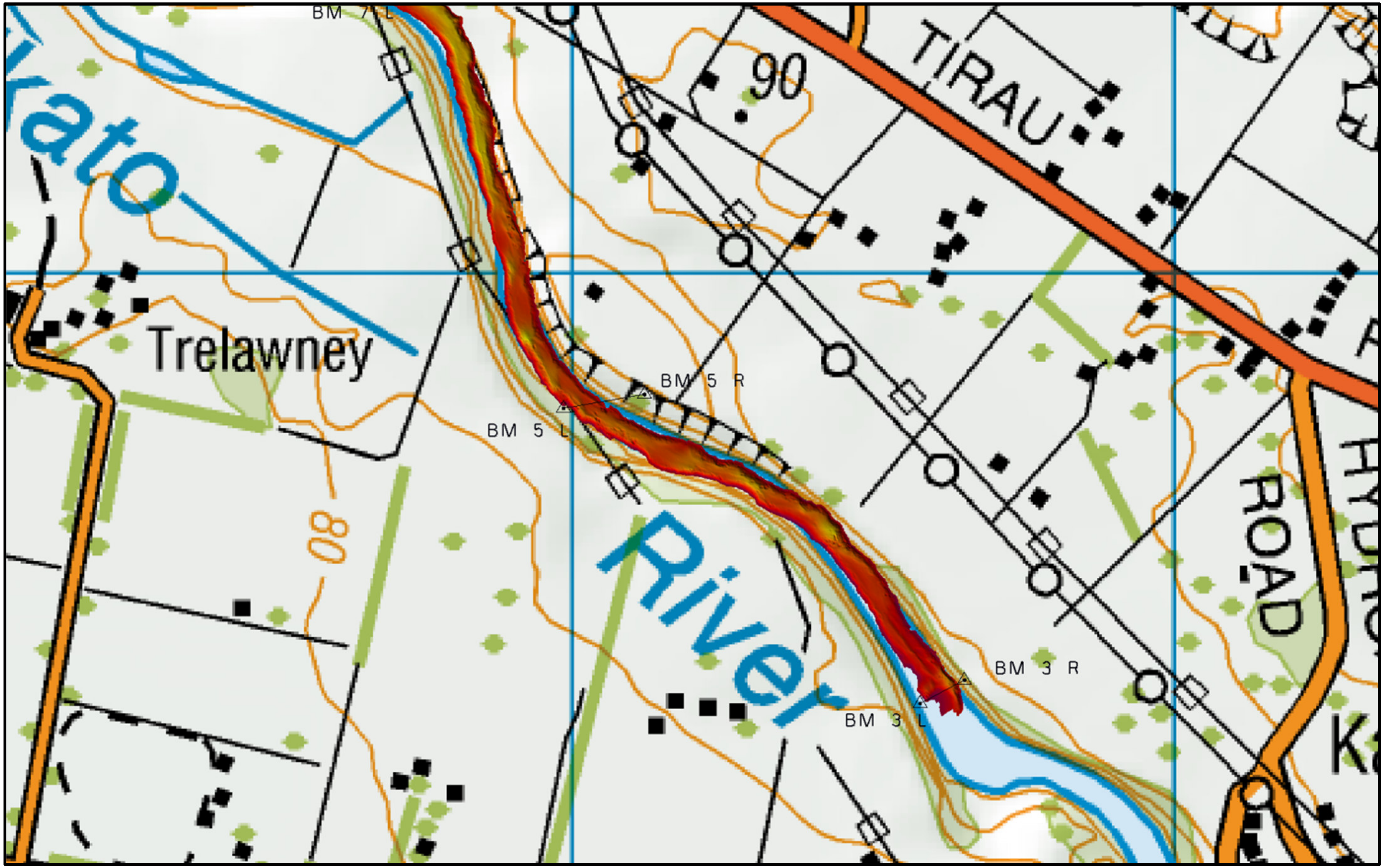
Except as specifically stated in this section, URS does not authorise the use of this Report by any third party.

It is the responsibility of third parties to independently make inquiries or seek advice in relation to their particular requirements and proposed use of the site.

Any estimates of potential costs which have been provided are presented as estimates only as at the date of the Report. Any cost estimates that have been provided may therefore vary from actual costs at the time of expenditure.

Appendix A Karapiro to Ngaruawahia bathymetric surface

See separate volume.



BM 7 L
kato
Trelawney
90
TIRAU
BM 5 R
BM 5 L
80
River
BM 3 R
BM 3 L
ROAD
HYDRO

Figure A1

Figure A2

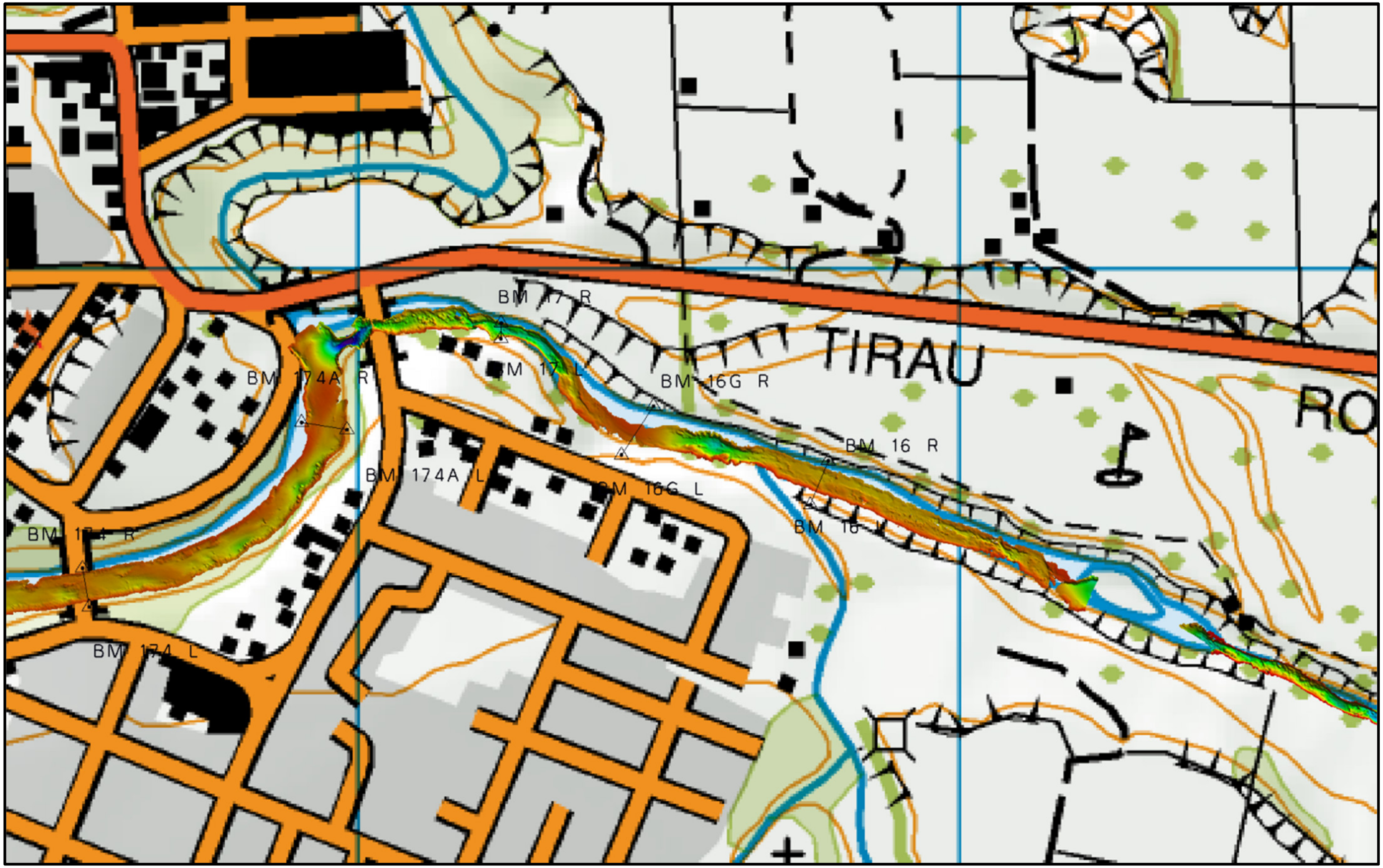

BM 17 R
BM 17 L
BM 174A R
BM 174A L
BM 16G R
BM 16G L
BM 16 R
BM 16
BM 174 R
BM 174 L
TIRAU
RO

Figure A3

Figure A4

Waikato
River
RD
LN
PUKERIMU LN
Oxidation ponds
BM 171 R
BM 171 L
BM 172 R
BM 172 L
BM 172A R
BM 172A L
BM 173 R
BM 173 L

Figure A5


BM 169 R
BM 169 L
BM 169A R
BM 169A L
BM 170 R
BM 170 L
BM 171 R
BM
Sch
HANLIN
RD
Waikat
ROAD

Figure A6

Figure A7

B14L
94m
BM 166 R
BM 166 L
165A R
BM 165A L
BM 167 R
BM 167 L
ROAD
ROAD

Figure A8

MARKEVIN LN.
PENCA
94m
BM 162A R
BM 163 R
BM 164 R
BM 164 L
BM 165 R
BM 165 L
BM 165A R
BM 165A L

Figure A9


LOCHIEL
RD
BM 161B L
BM 162 R
BM 162 L
TE AWA
BM 162A R
BM 162A
BM 163 R
BM 163 L

Figure A10

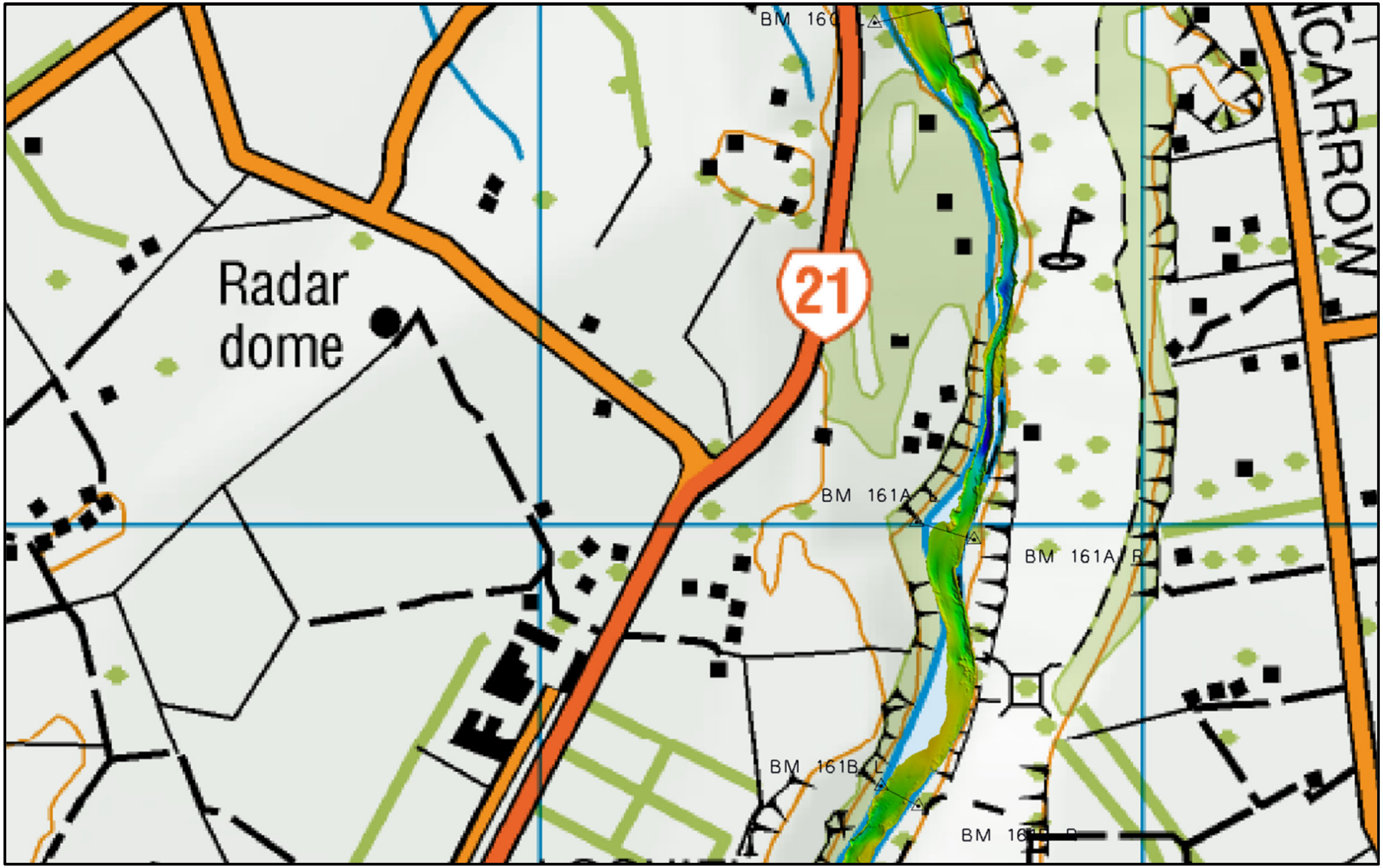
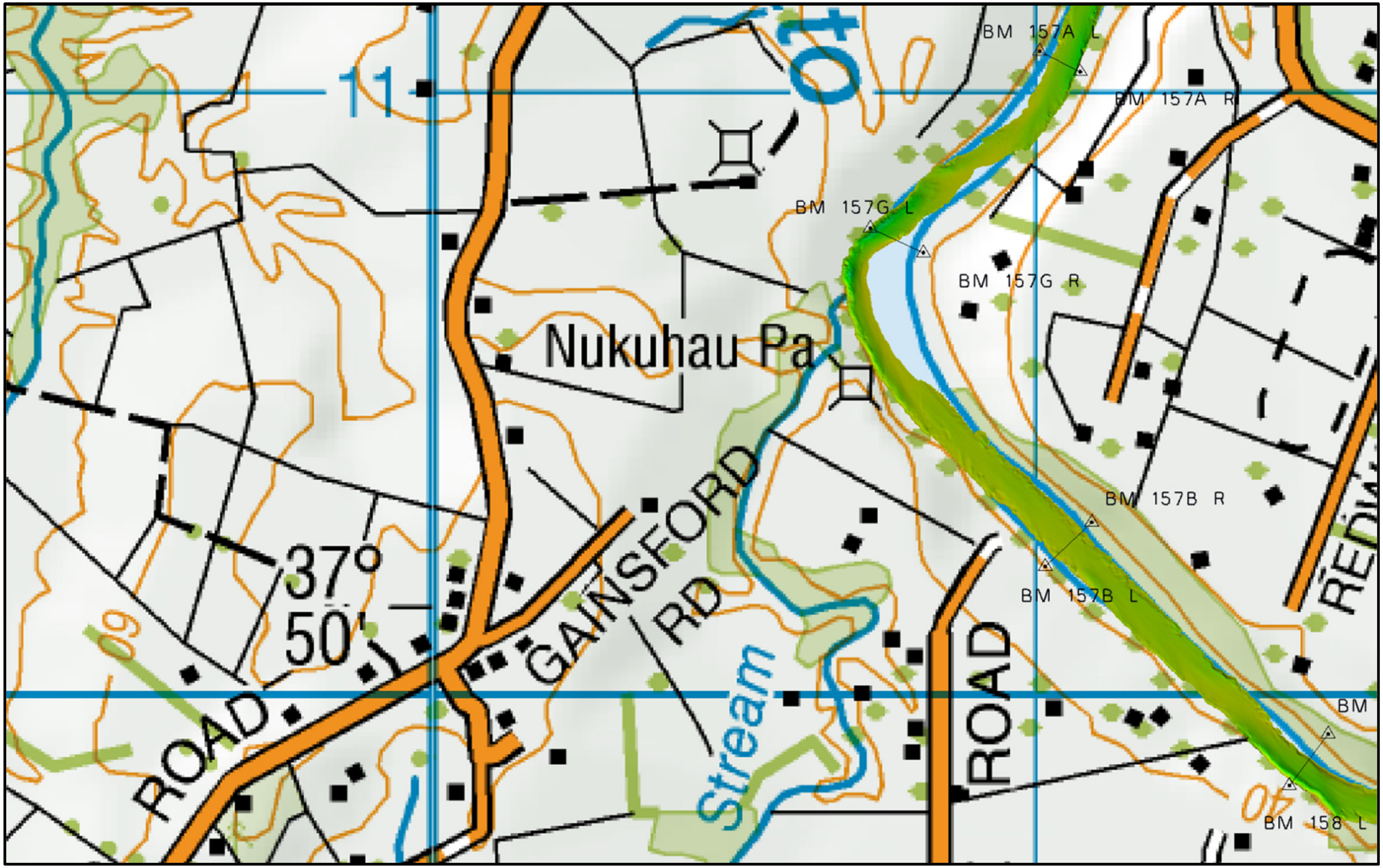


Figure A11


BM 158 R
BM 158 L
40
River
BM 158A R
BM 158A L
BM 158G R
BM 158G L
BM 159A R
BM 159A L
The Narrows
BM 159 R
BM 159 L
BM 160 R
BM 160 L
AIRPORT
48
OAD
PENCARR

Figure A12



11
Nukuhau Pa
BM 157A L
BM 157A R
BM 157G L
BM 157G R
BM 157B R
BM 157B L
BM
BM 158 L
37°
50'
GAINSFORD
RD
ROAD
ROAD
Stream
60
40

Figure A13


PEACOCKES LN
PEACOCKES ROAD
RIVERGLADE DR
NEWELL
BIR
Waikato
12
11
BM 156A R
BM 156A L
BM 157 R
BM 157 L
BM 157A L
BM 157A R

Figure A14

153A R
BM 153Z R
BM 153B R
BM 153B L
BM 154 R
BM 154
BM 154A R
BM 154A
BM 154B L
BM 155 R
BM 155 L
BM 155A R
BM 155A L
BM 156 L
BM 156A L
WESTON LEA DR
PEACOCKES RD
PEACOCKE
Substation
20

Figure A15

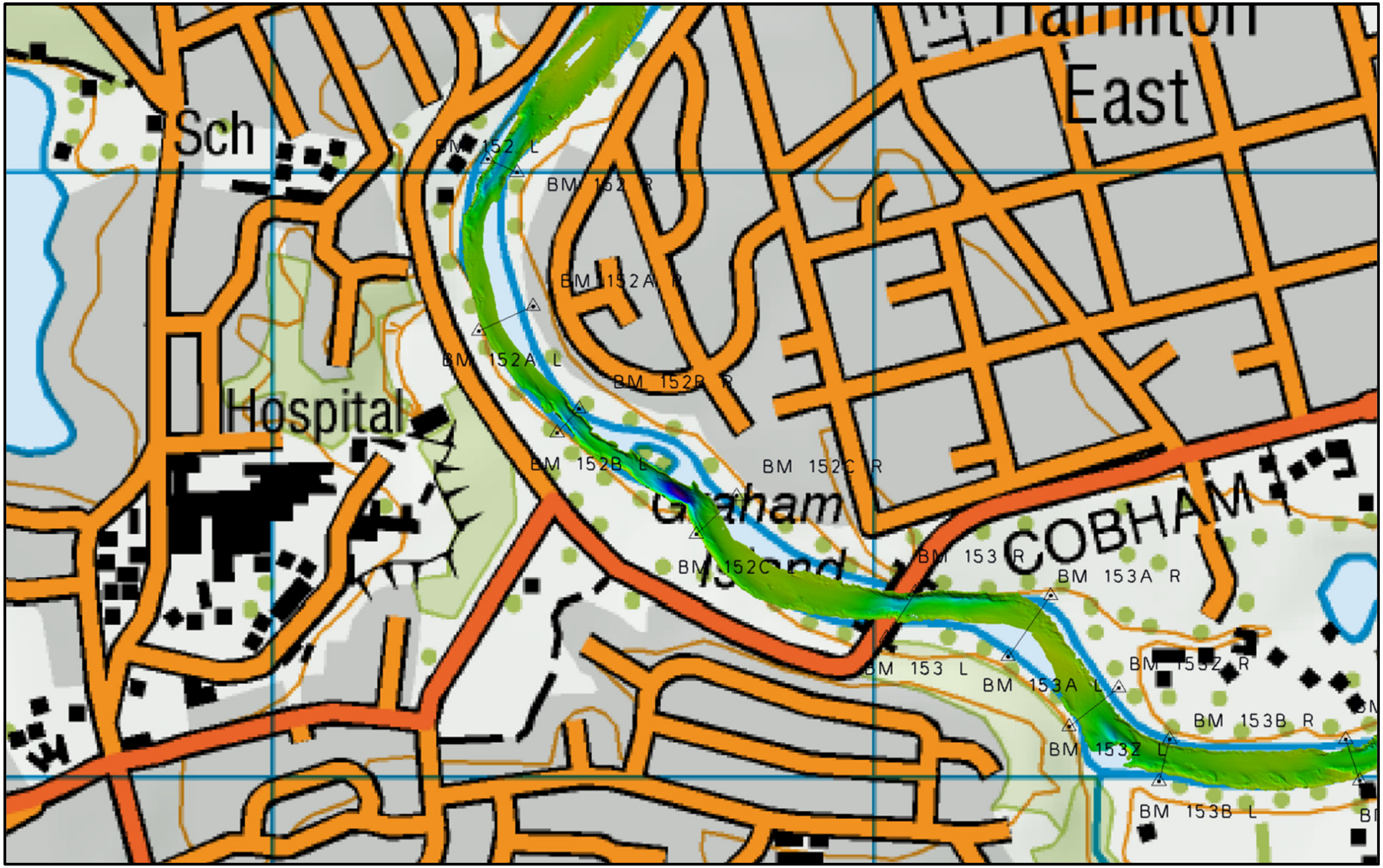

Hamilton
East
Sch
Hospital
Graham
Island
COBHAM
BM 152 L
BM 152 R
BM 152A R
BM 152A L
BM 152B R
BM 152B L
BM 152C R
BM 152C L
BM 153 R
BM 153A R
BM 153 L
BM 153A L
BM 153Z R
BM 153Z L
BM 153B R
BM 153B L

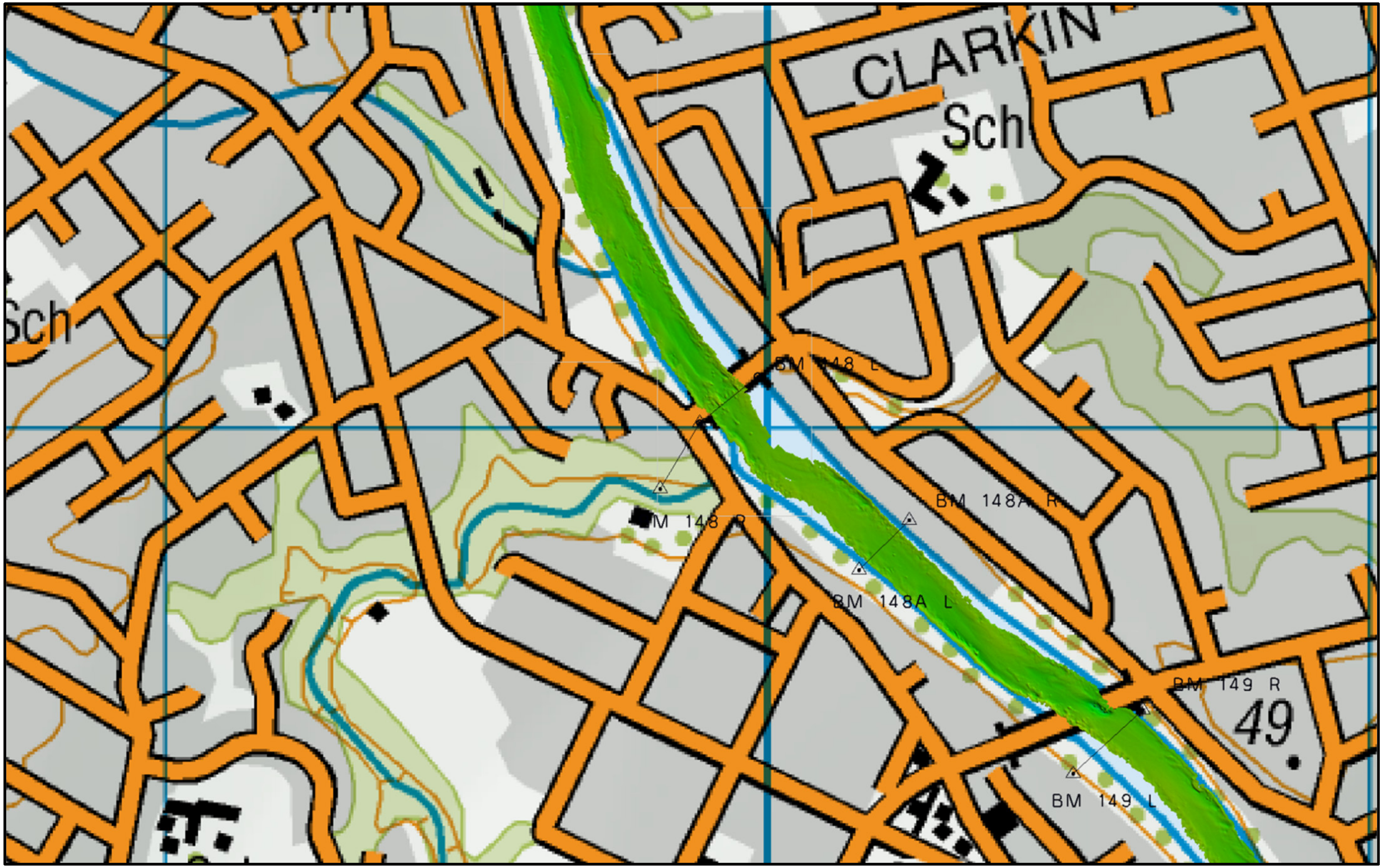
Figure A16


BM 150A R
150A L
GREY
BM 151 R
BM 151 L
Sch
milton
West
BM 151A L
Sch
BM 151A R
STREET
Hamilton
East
Sch
BM 152 L

Figure A17


49
BM 149 L
Sch
BM 149A R
BM 149A L
Claudelands
HA
BM 150 R
BM 150 L
BM 150A R

Figure A18



CLARKIN
Sch
Sch
BM 148 L
BM 148 R
BM 148A R
BM 148A L
BM 149 R
BM 149 L
49

Figure A19

BM 146A R
BM 146B L
BM 146B R
RIVER
ROAD
Sch
Sch
Sch
B140
BM 147
BM 147 L
50m
urse

Figure A20

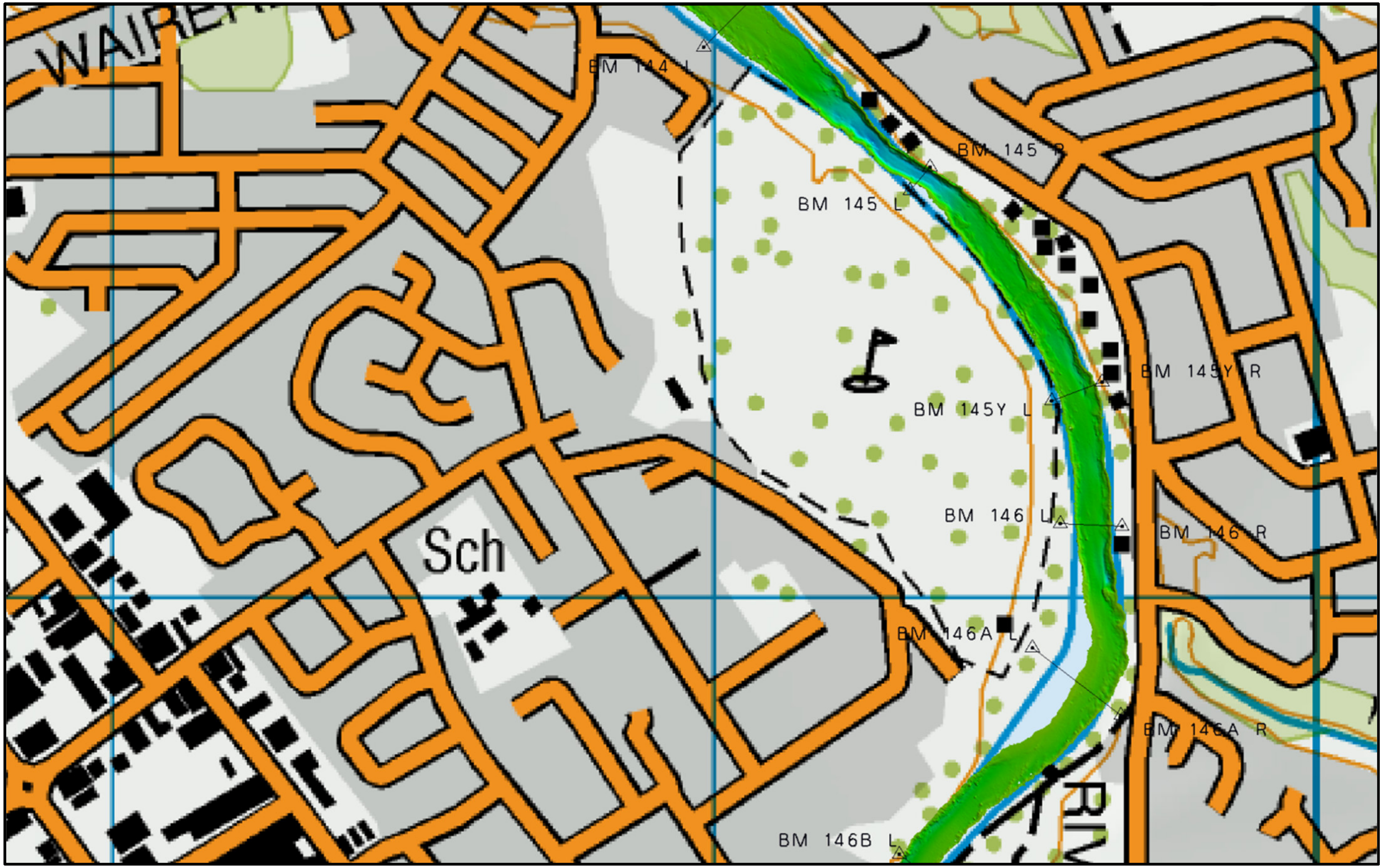

WAIRE
BM 144 L
BM 145 R
BM 145 L
BM 145Y R
BM 145Y L
BM 146 L
BM 146 R
Sch
BM 146A L
BM 146A R
BM 146B L
RIV

Figure A21

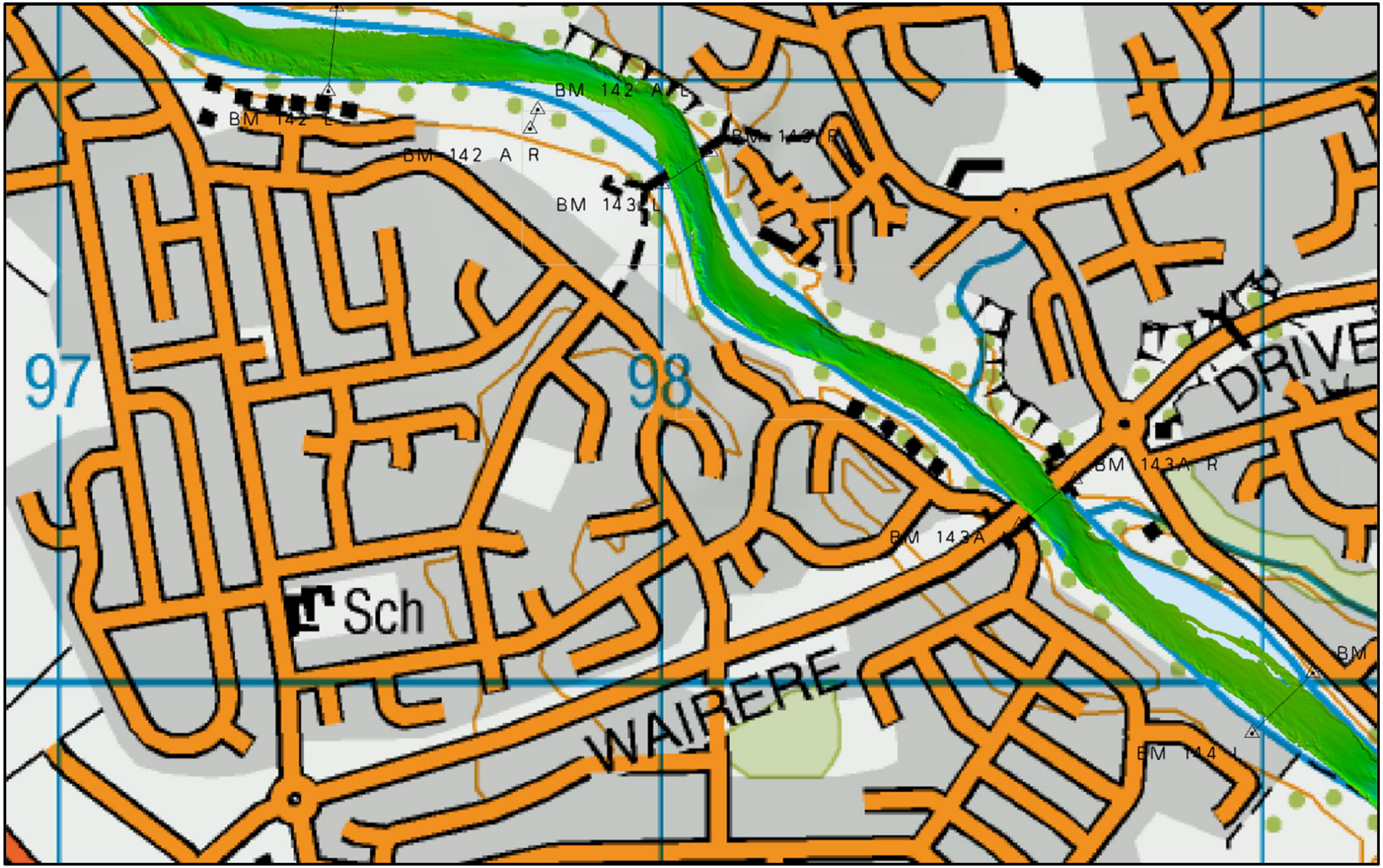

BM 142 L
BM 142 A R
BM 143 L
BM 143A R
BM 143A
BM 144 L
BM
97
98
Sch
WAIRERE
DRIVE

Figure A22


Water treatment plant
ROAD
ROAD
BM 141A R
BM 141A
BM 142 R
BM 142 A R
RAPA

Figure A23

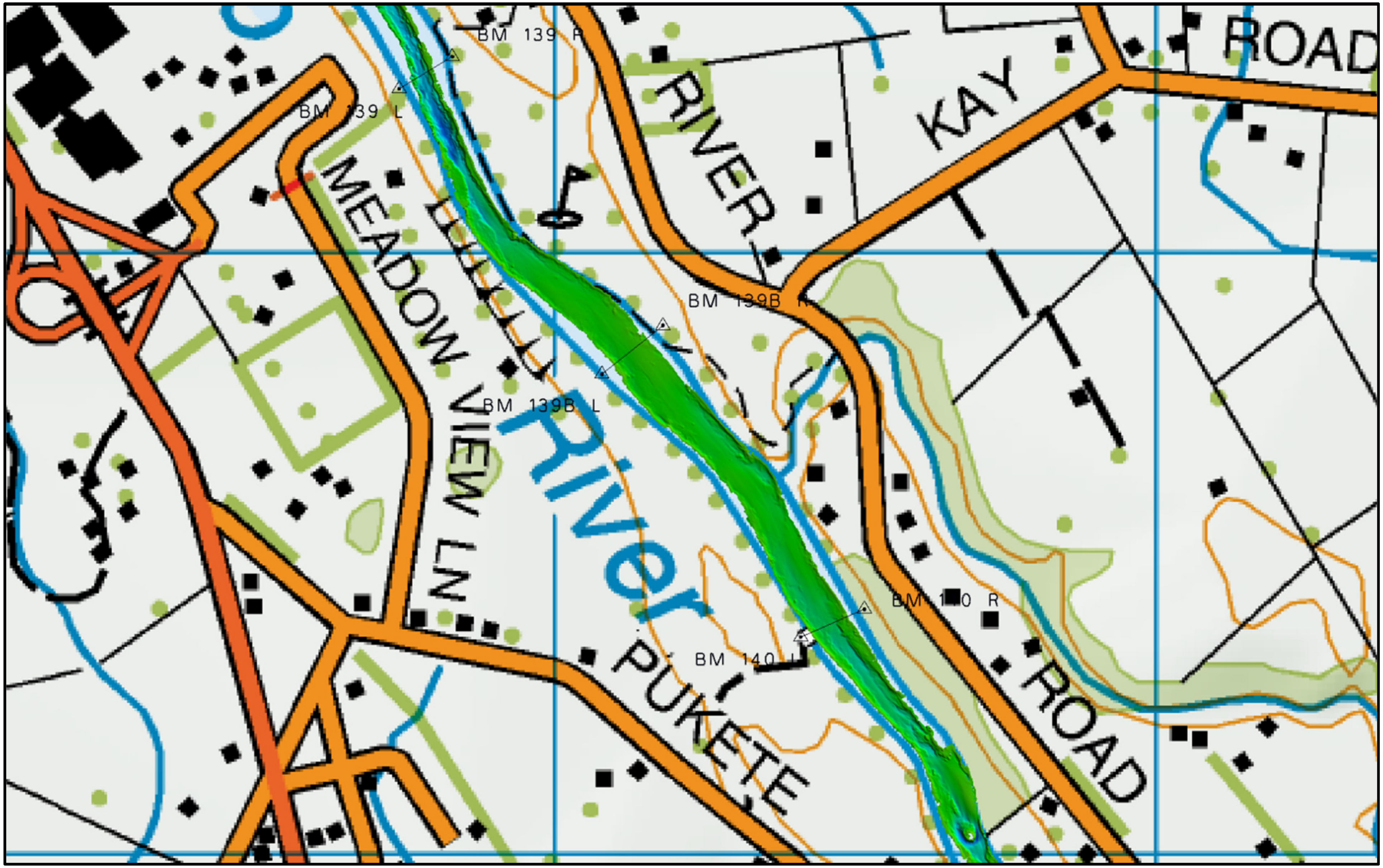

BM 139 R
BM 139 L
ROAD
KAY
RIVER
MEADOW VIEW LN
BM 139B R
BM 139B L
River
BM 140 L
PUKETE
ROAD

Figure A24

Figure A25

BM 136A L
BM 137 R
BM 137 L
BRIDGE
HOROTIU
26
Substn
TRUNK
Sch
BM 137A R
BM 137A L
Quarry
BM 138 L

Figure A26


25
SLAND
Landfill
Quarry
BM 135B R
BM 135B L
BM 136 R
BM 136 L
BM 136A R
BM 136A L
PARK
MAIN
ROAD

Figure A27

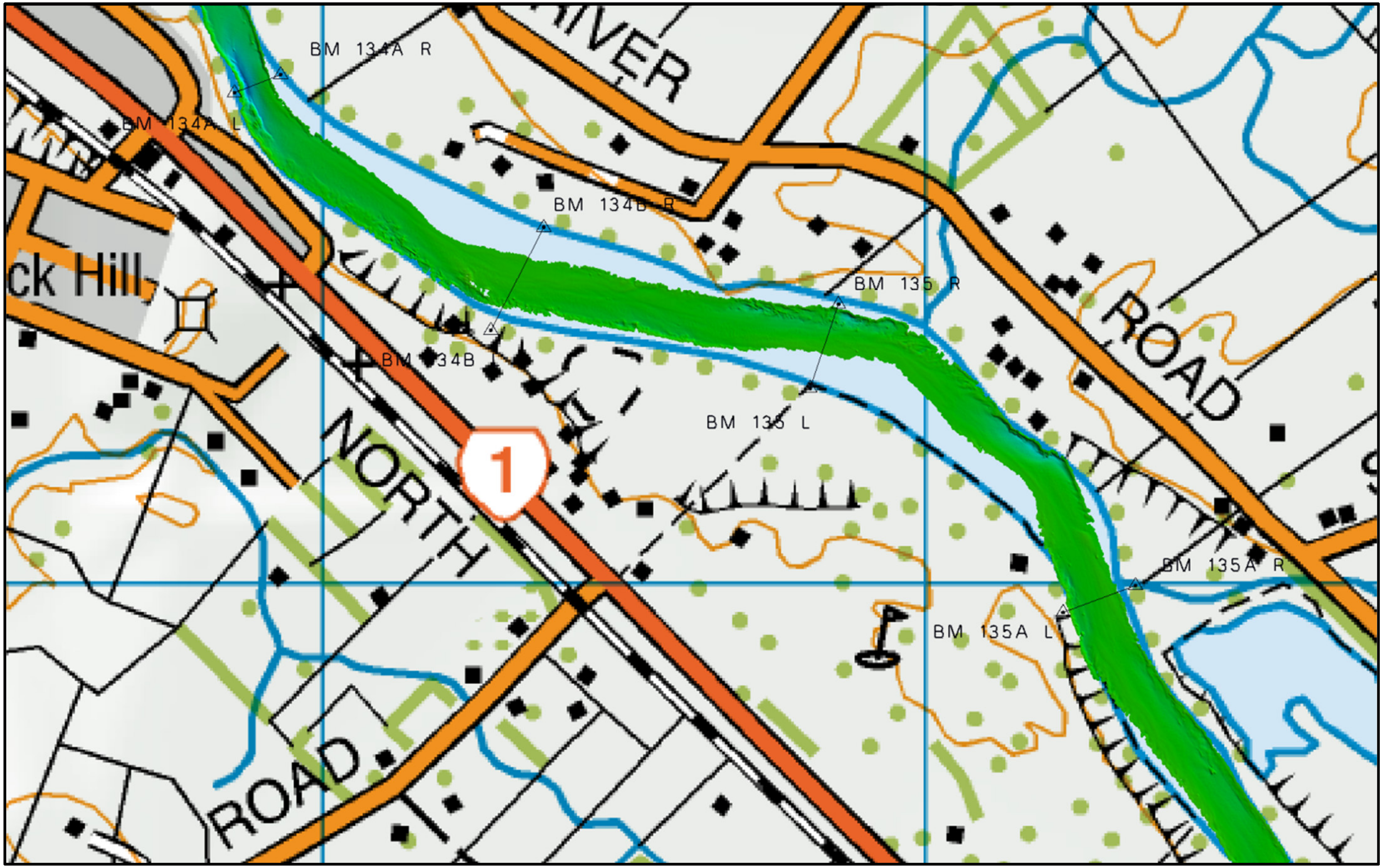

RIVER
BM 134A R
BM 134A L
BM 134B R
BM 134B
ck Hill
BM 135 R
BM 135 L
ROAD
NORTH
1
BM 135A R
BM 135A L
ROAD

Figure A28

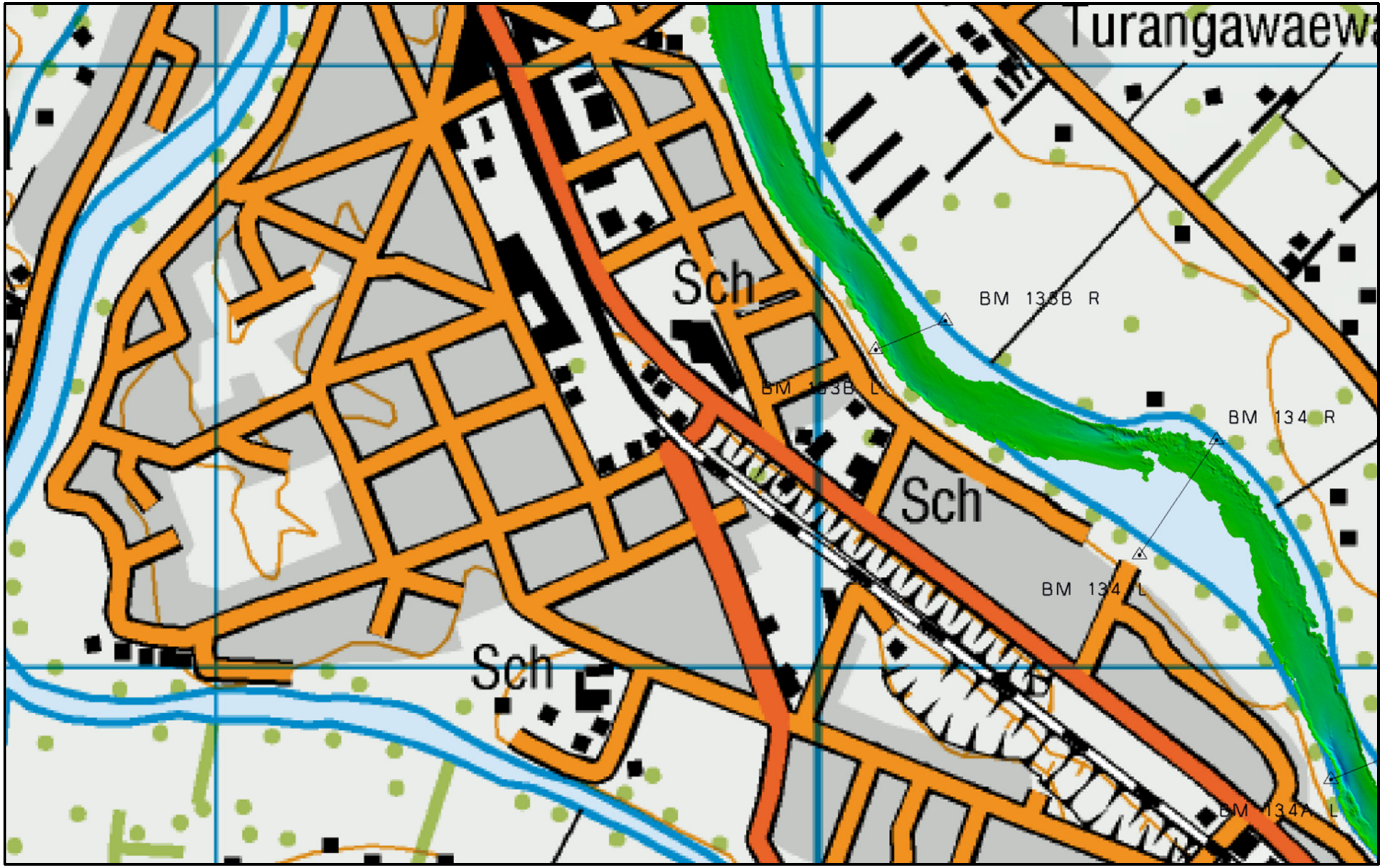


Figure A29

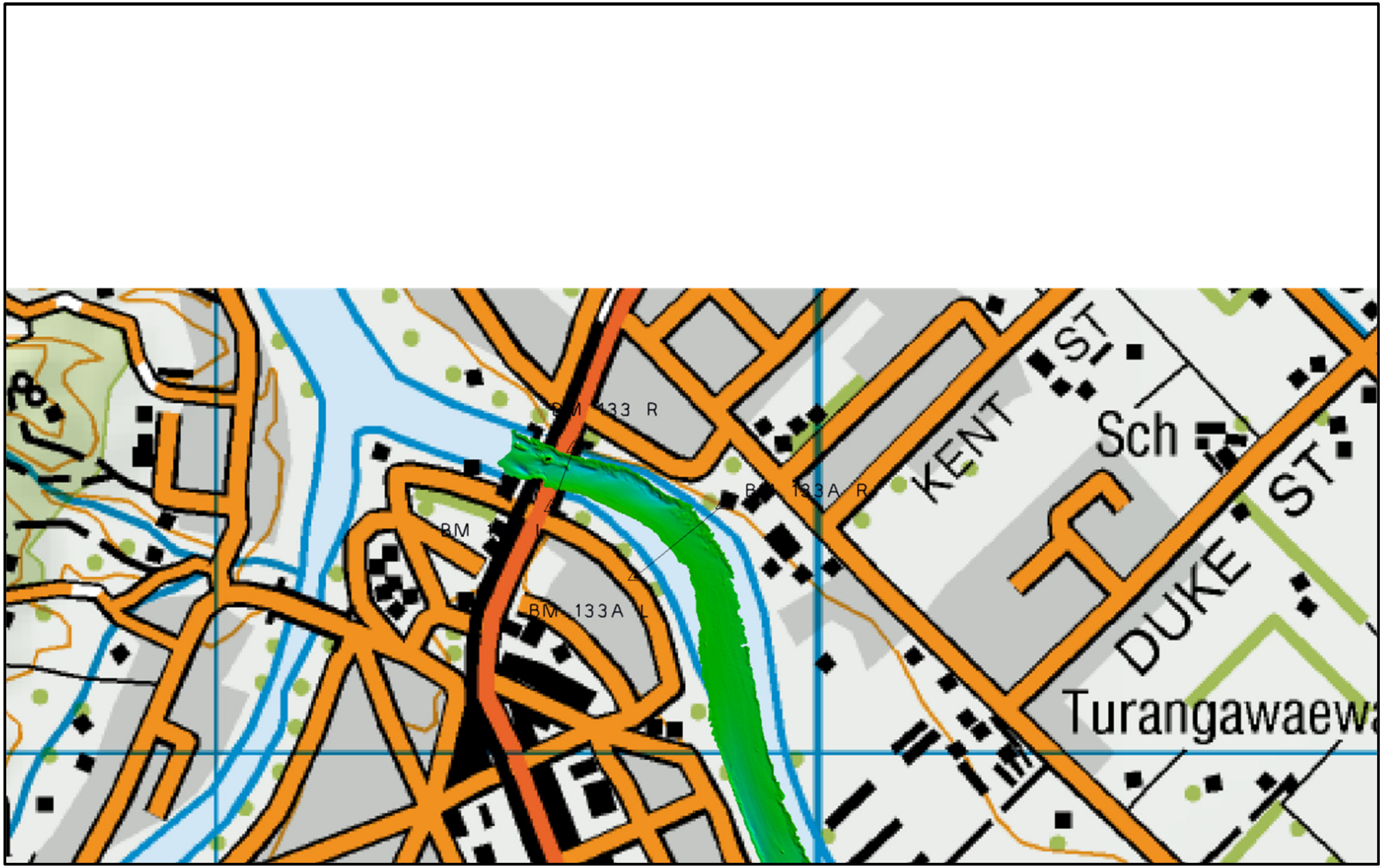
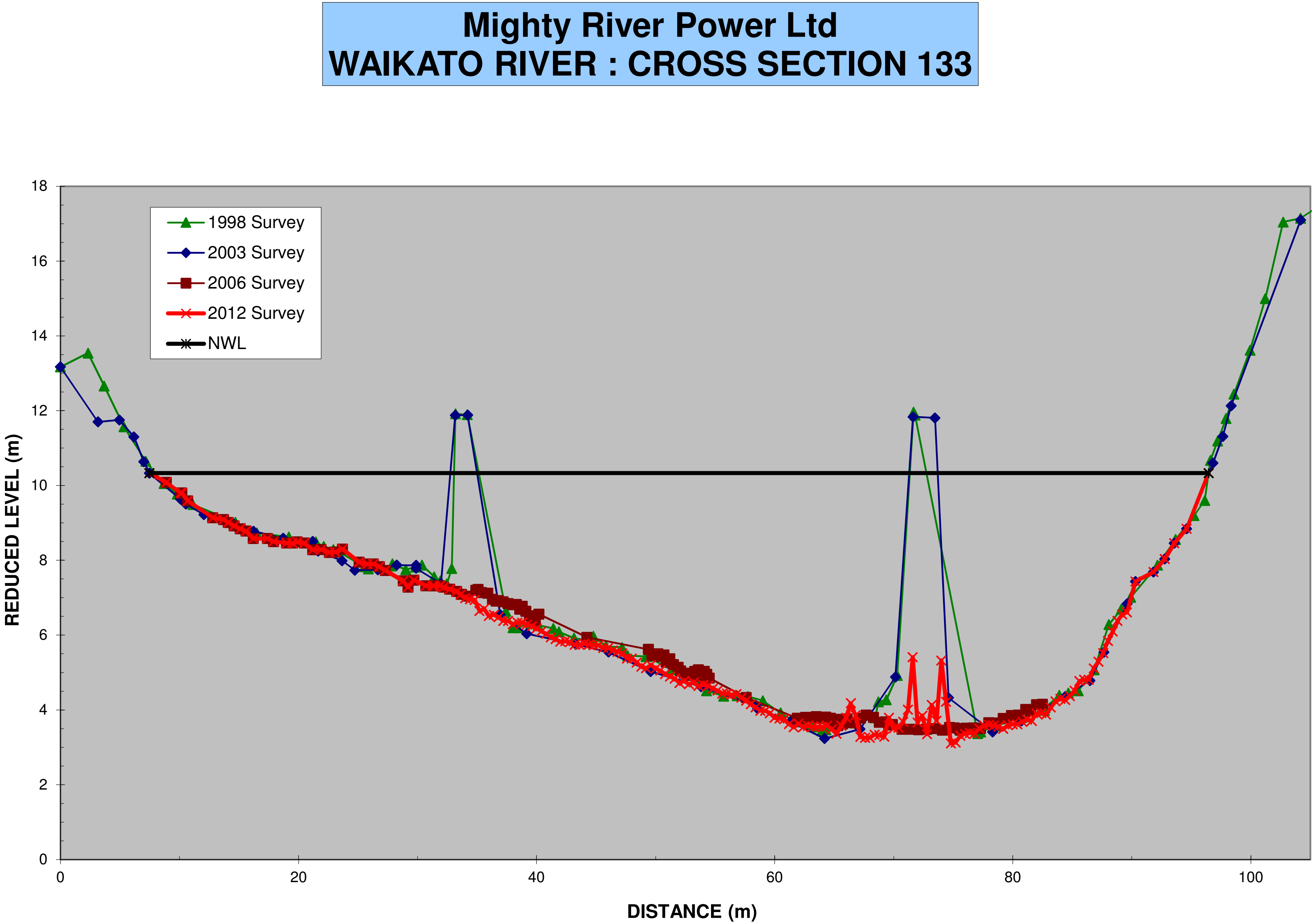


Figure A30

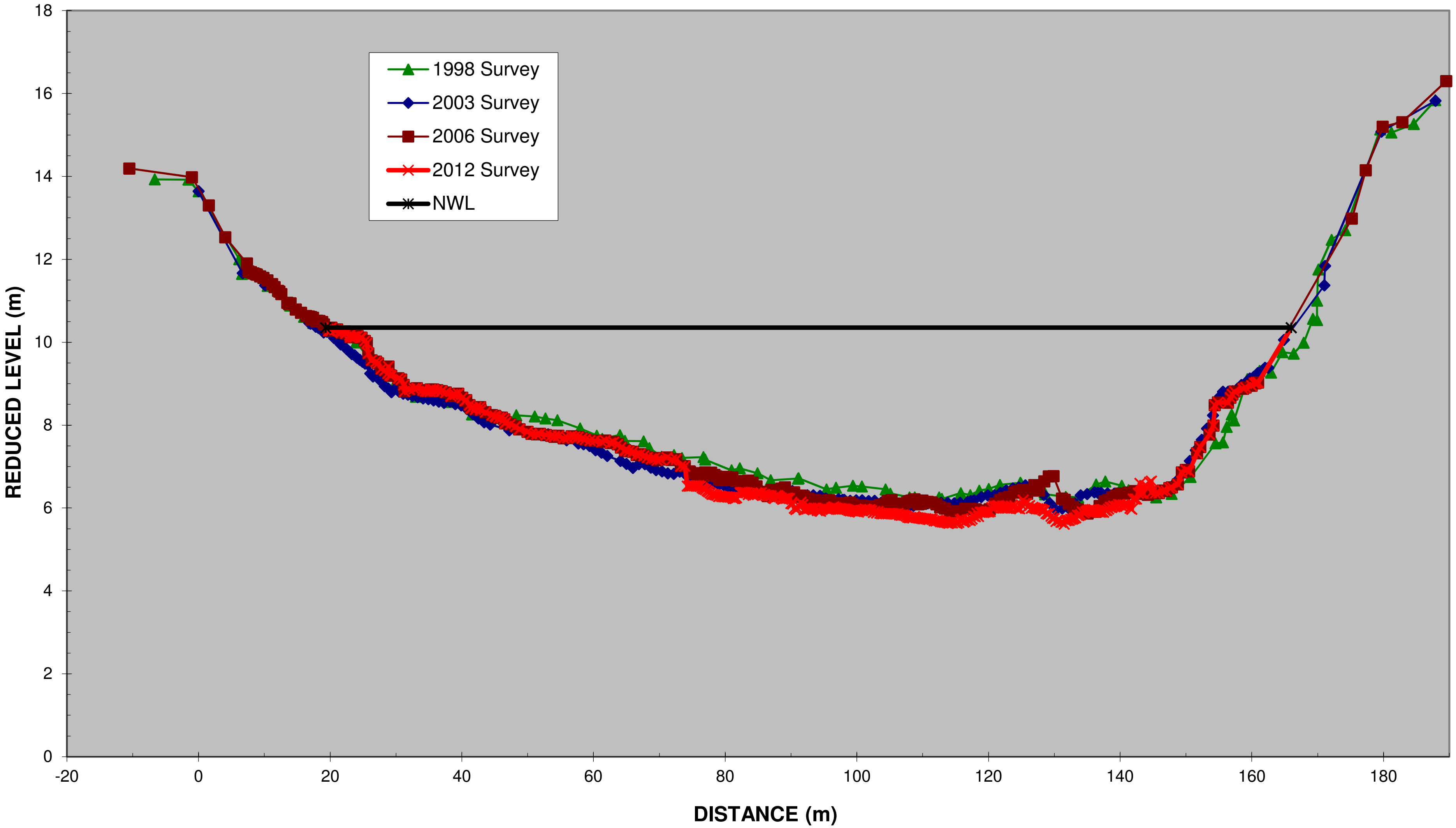
B

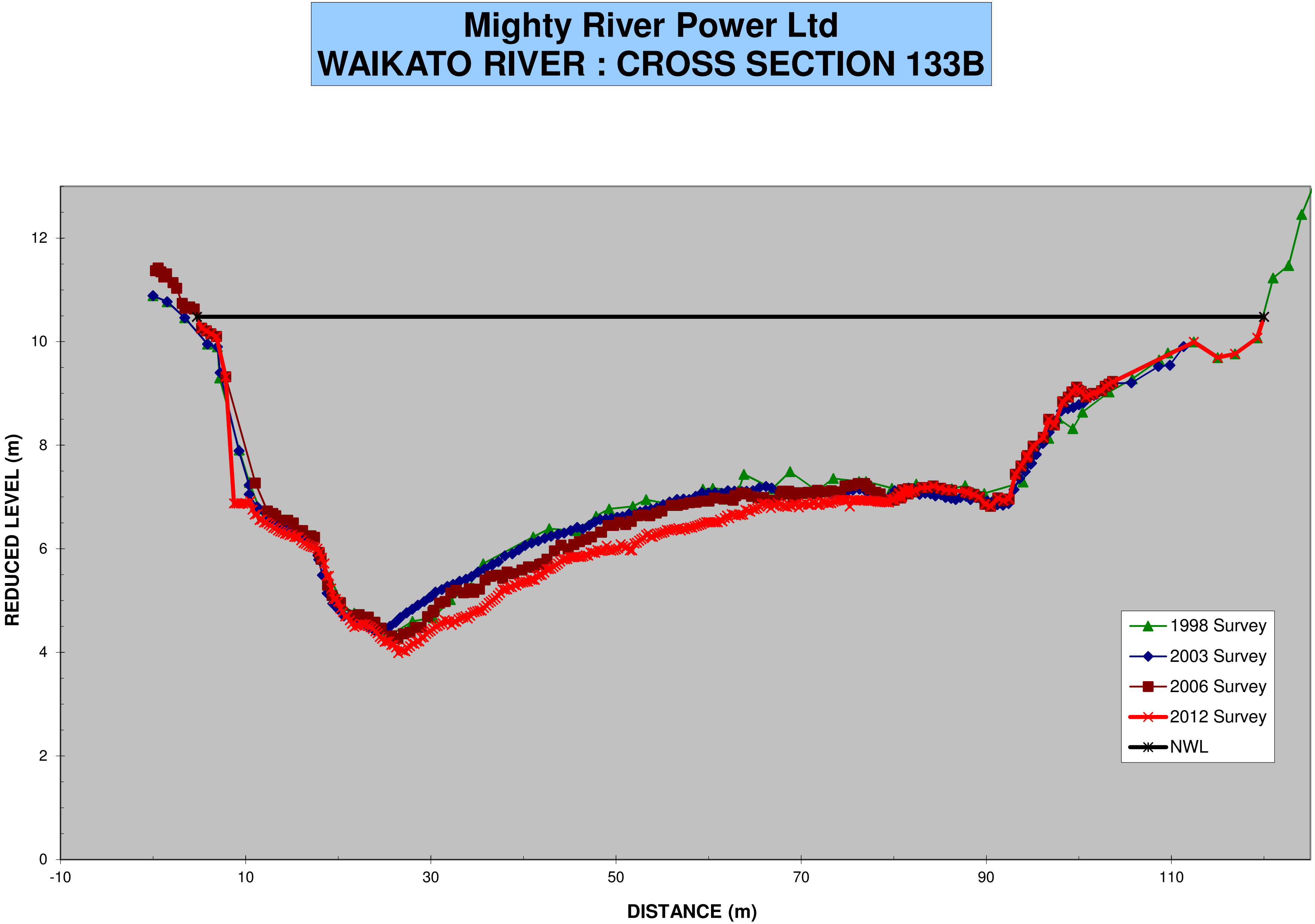
Appendix B Cross sections

See separate volume.

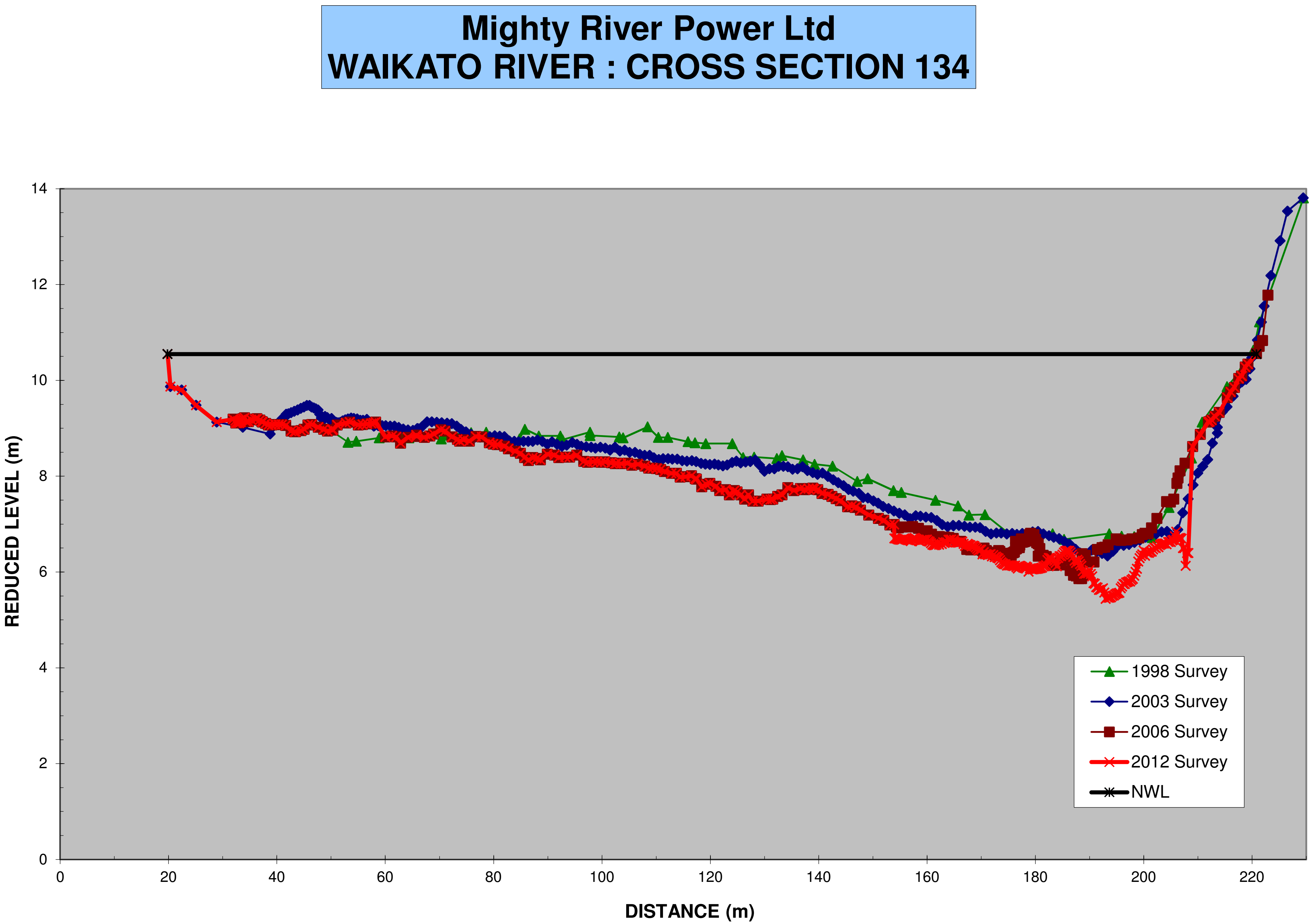

Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 133
1998 Survey
2003 Survey
2006 Survey
2012 Survey
NWL
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
14
16
18
0
20
40
60
80
100

Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 133A

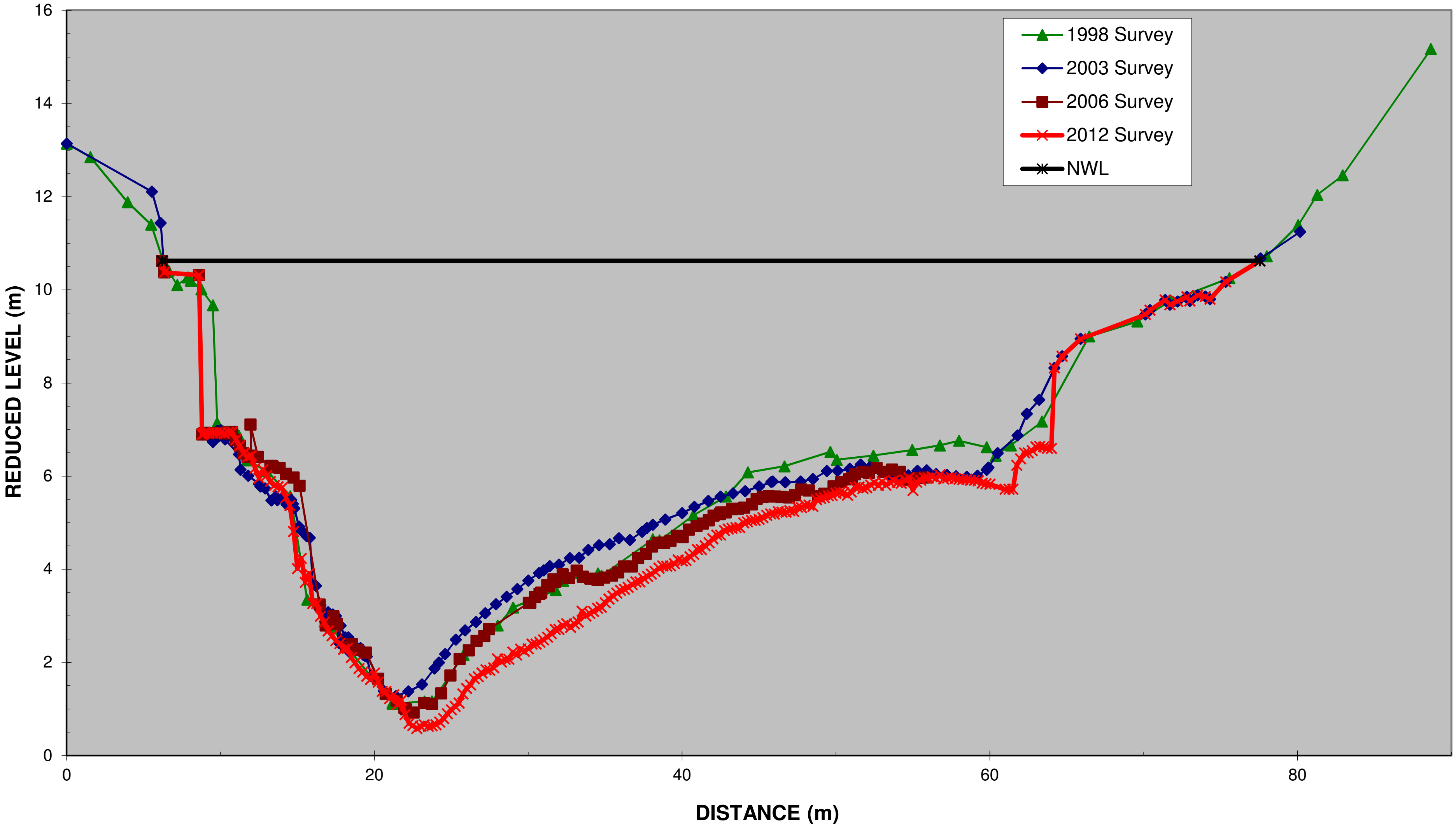




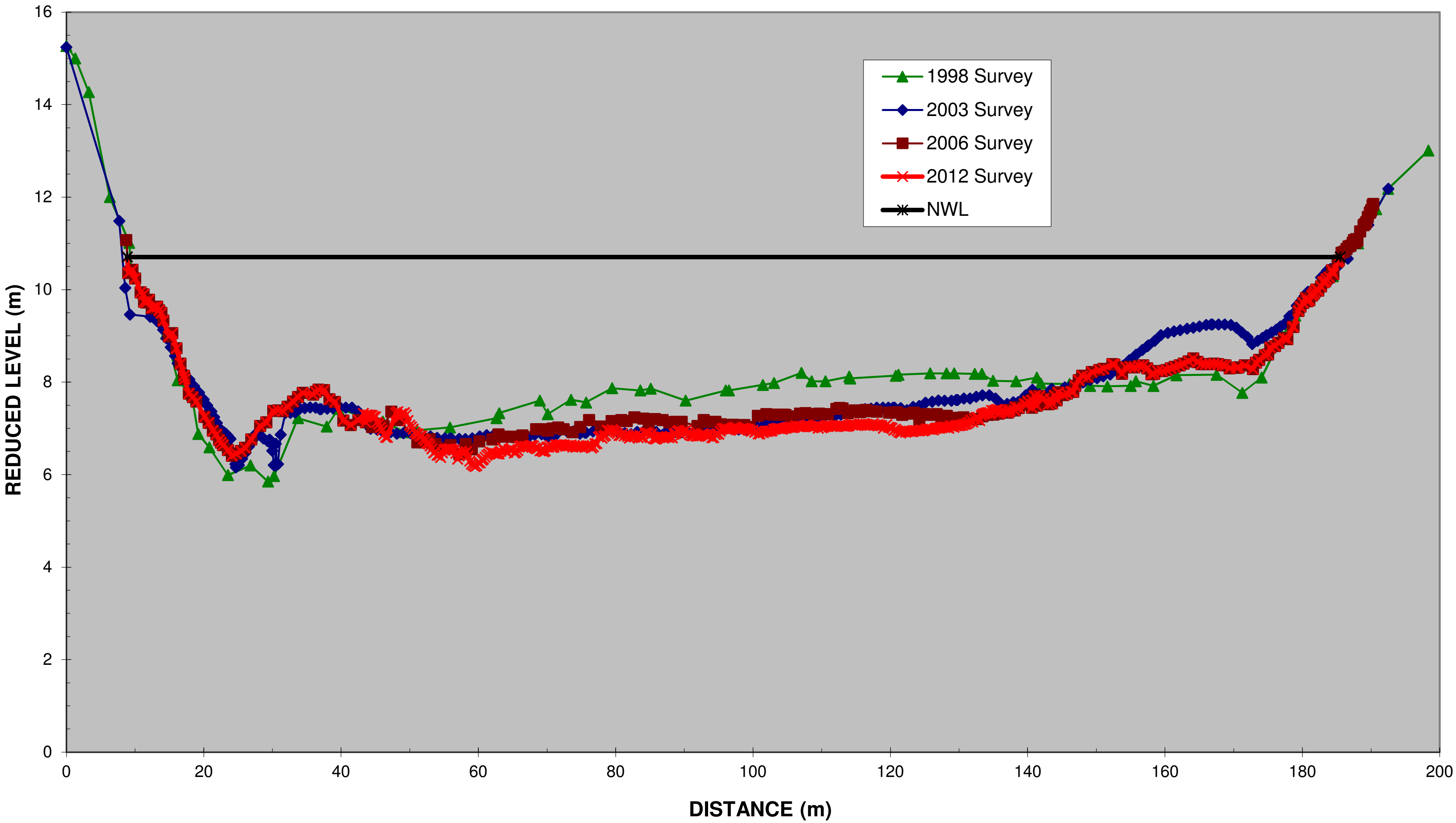
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 133B
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
-10
10
30
50
70
90
110
1998 Survey
2003 Survey
2006 Survey
2012 Survey
NWL


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 134
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120
140
160
180
200
220
1998 Survey
2003 Survey
2006 Survey
2012 Survey
NWL

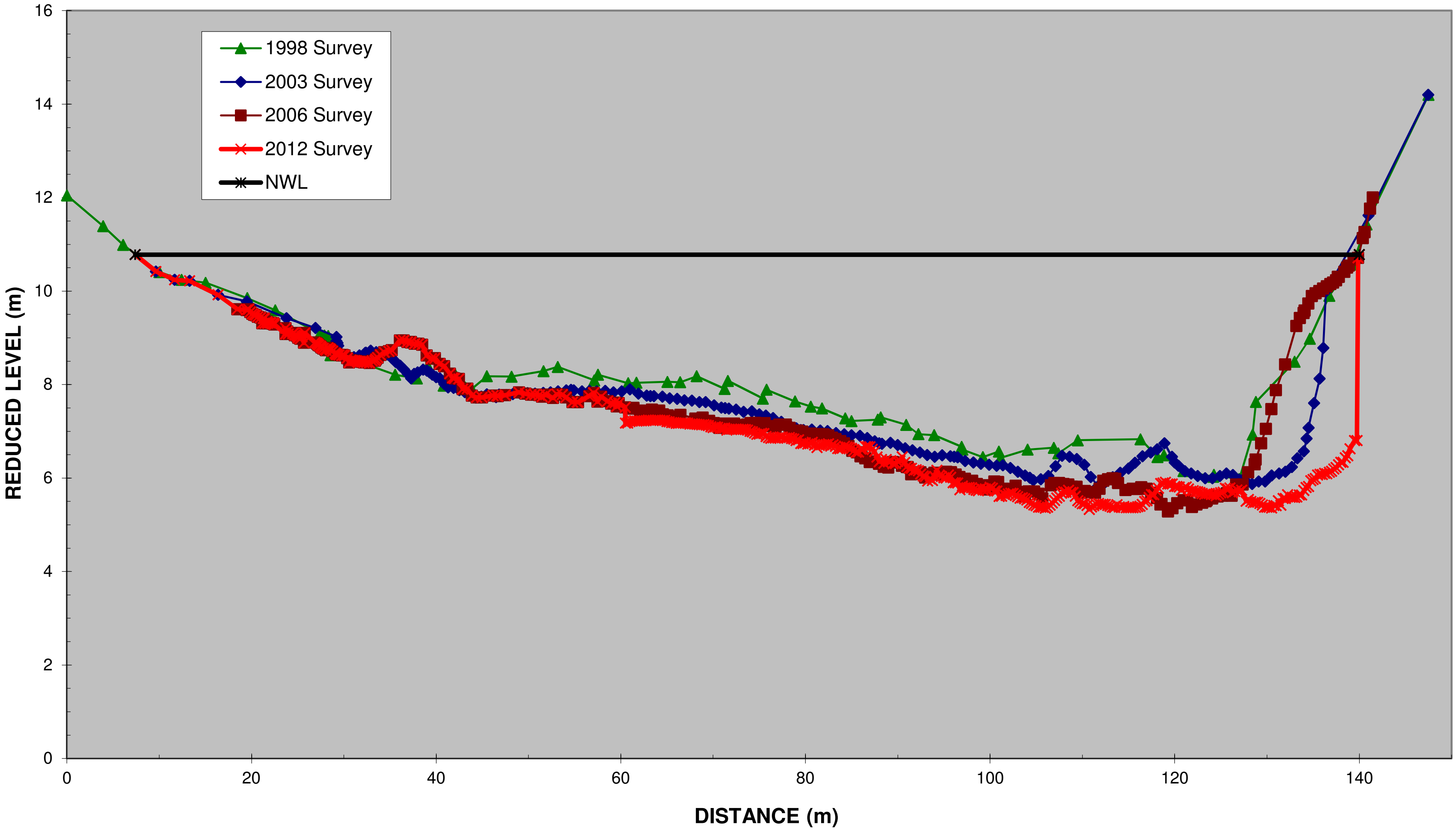
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 134A



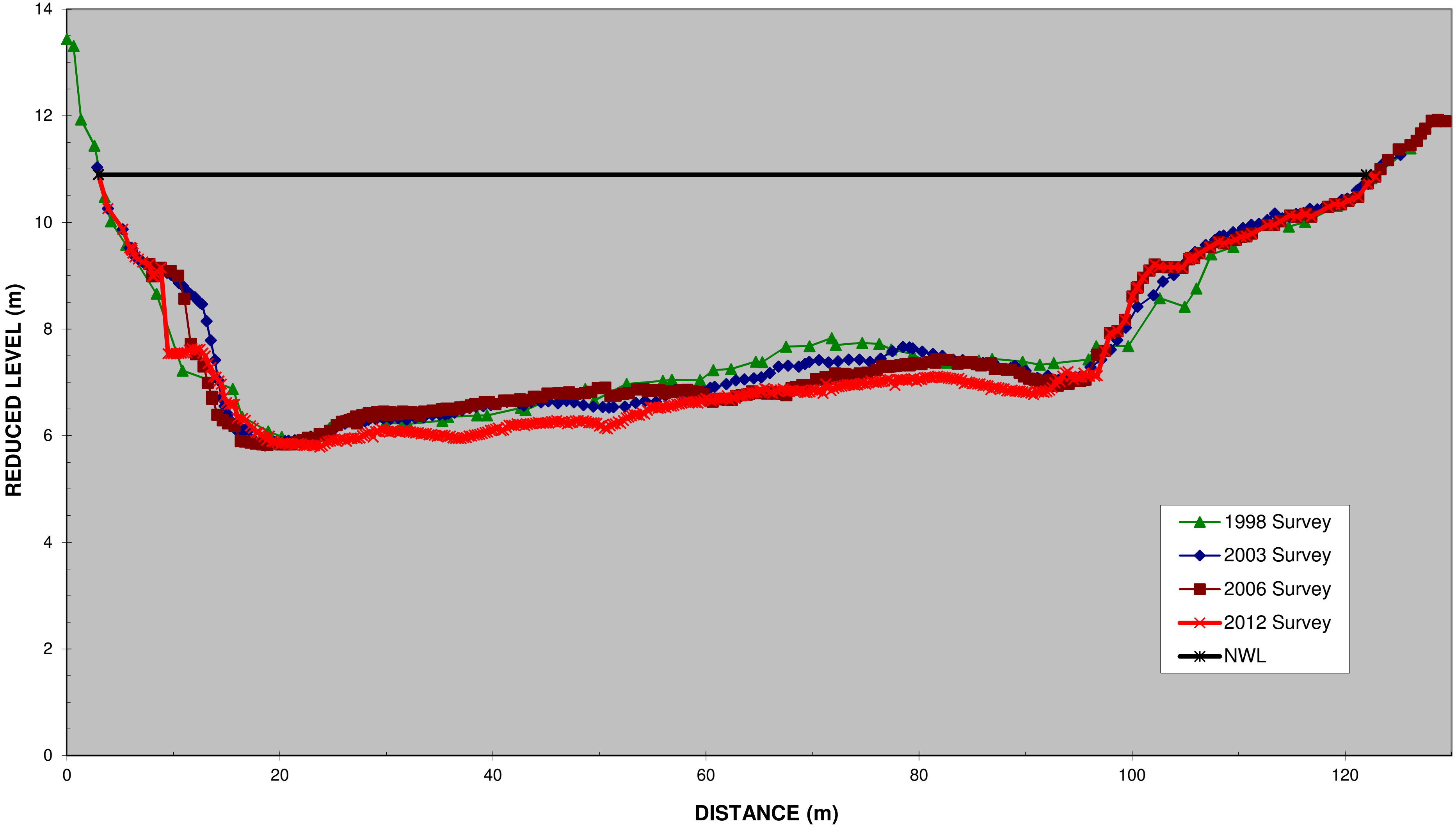
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 134B

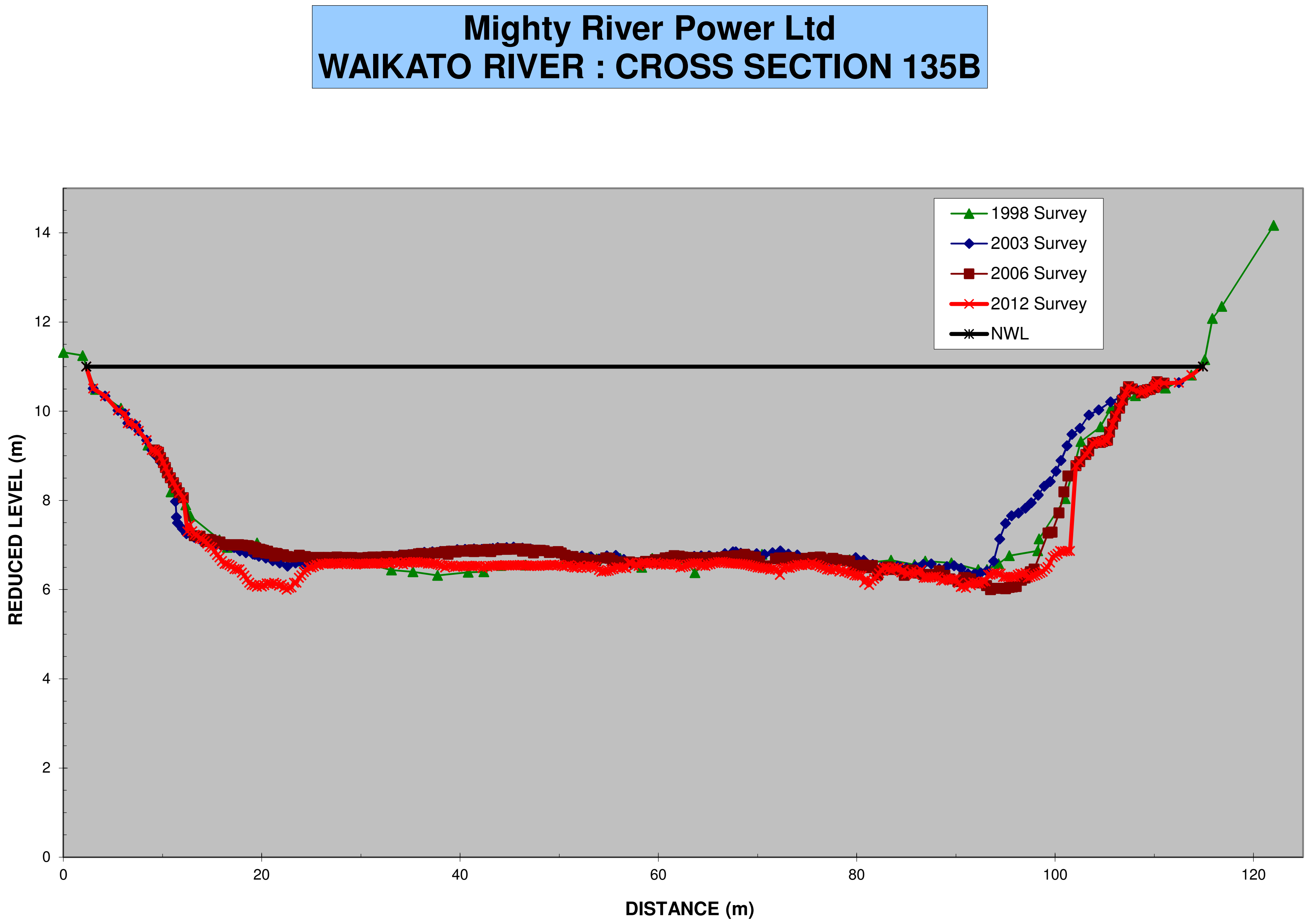


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 135

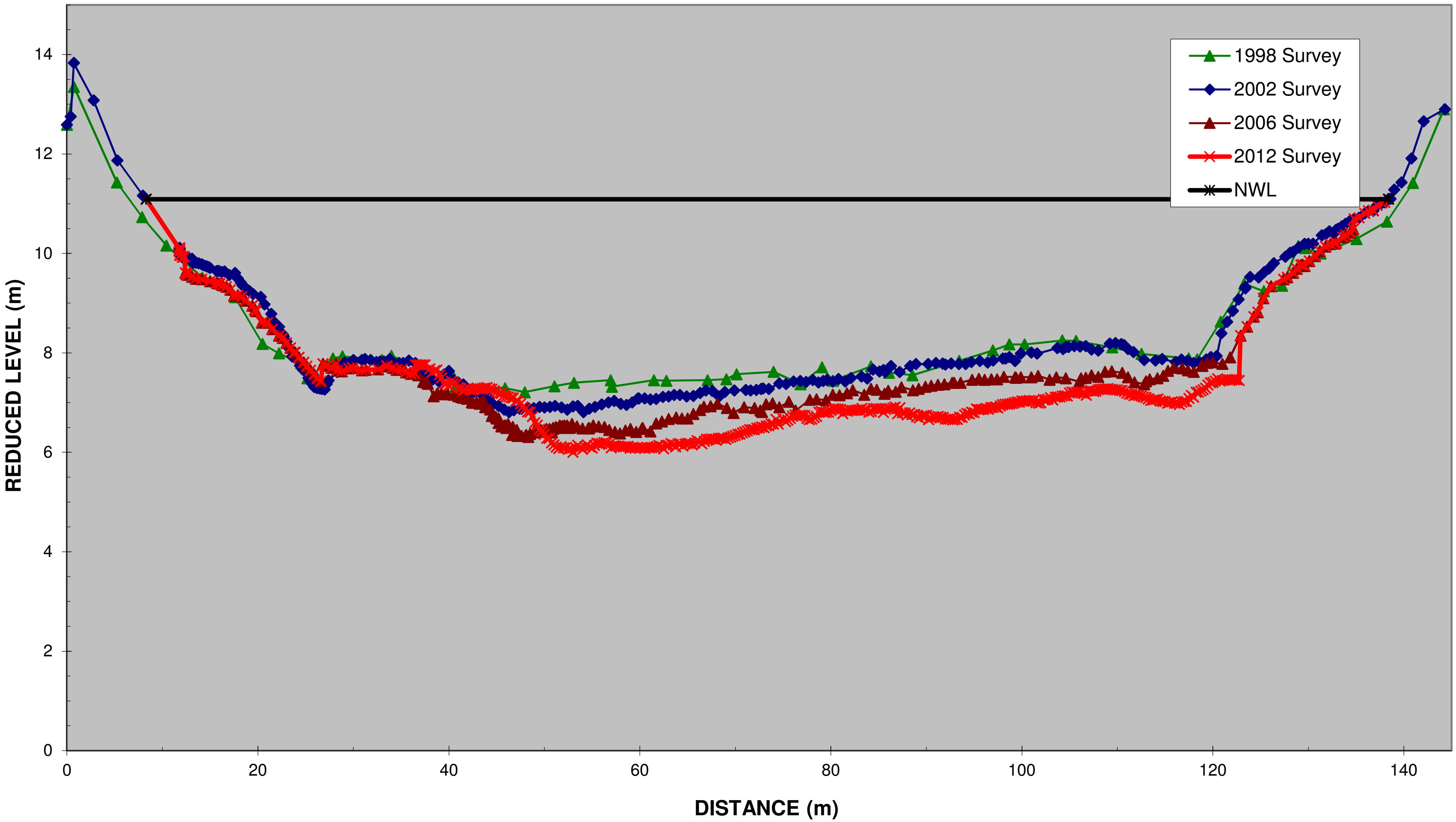


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 135A

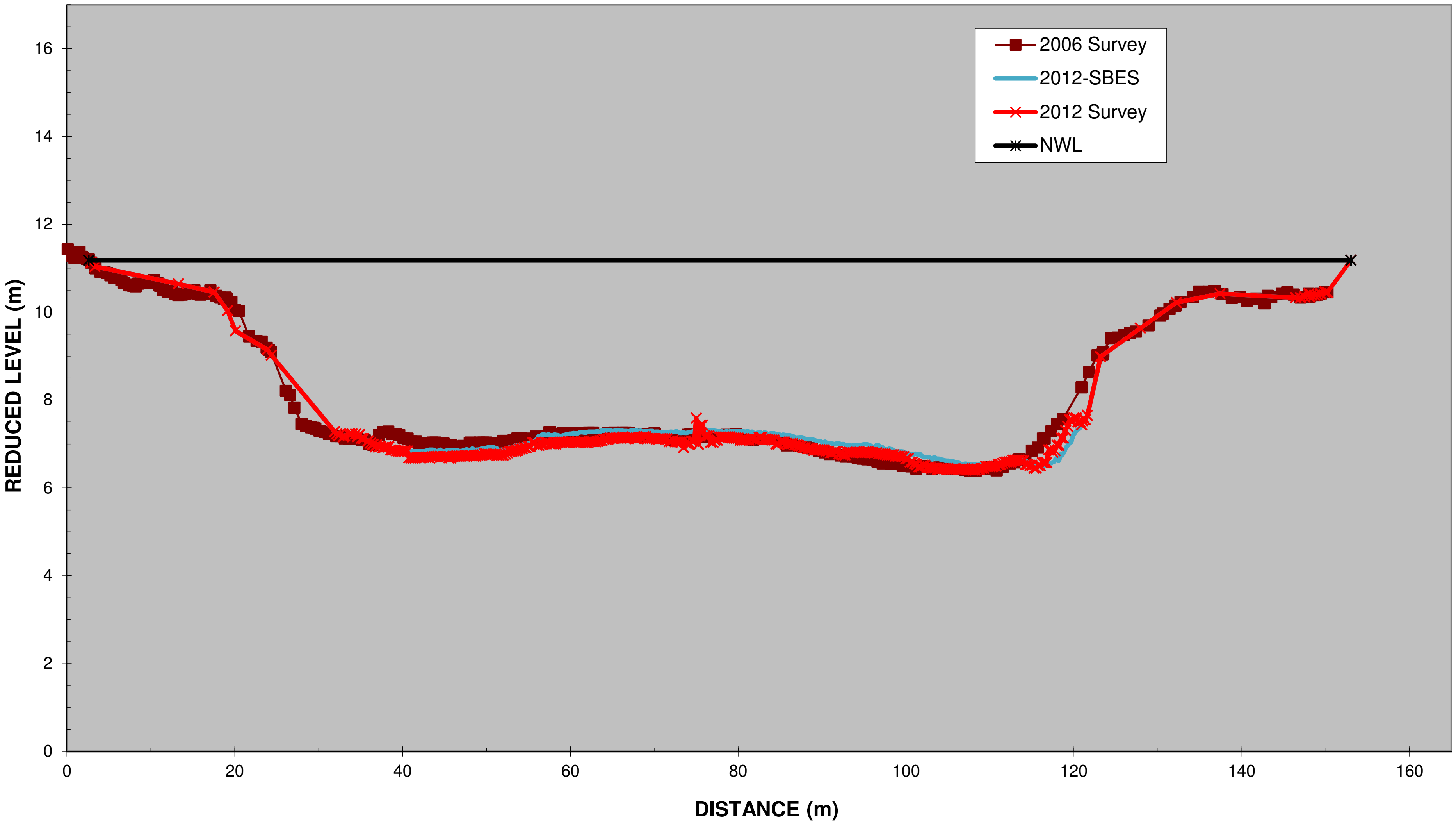



Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 135B
1998 Survey
2003 Survey
2006 Survey
2012 Survey
NWL
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
14
0
20
40
60
80
100
120

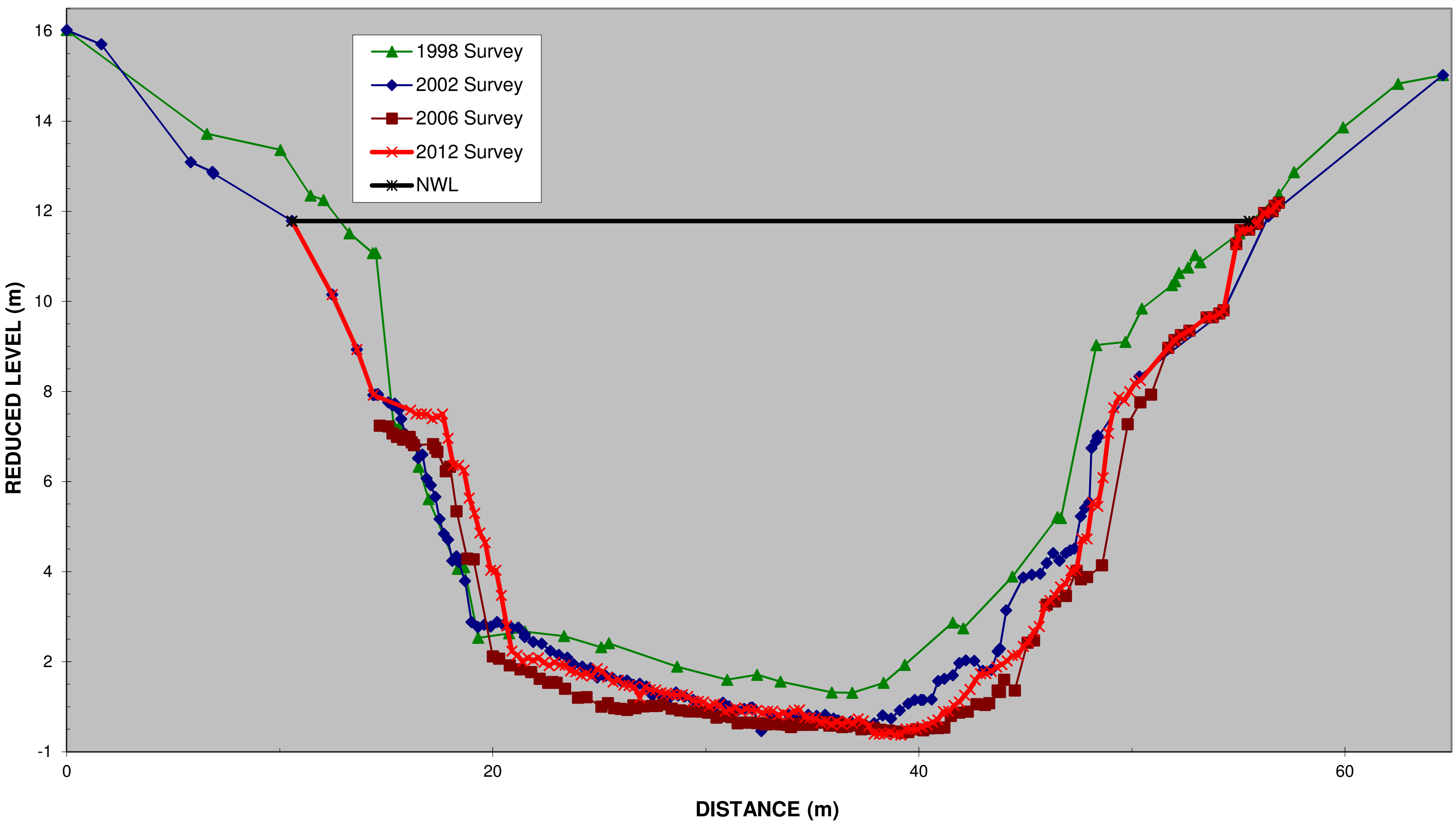
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 136



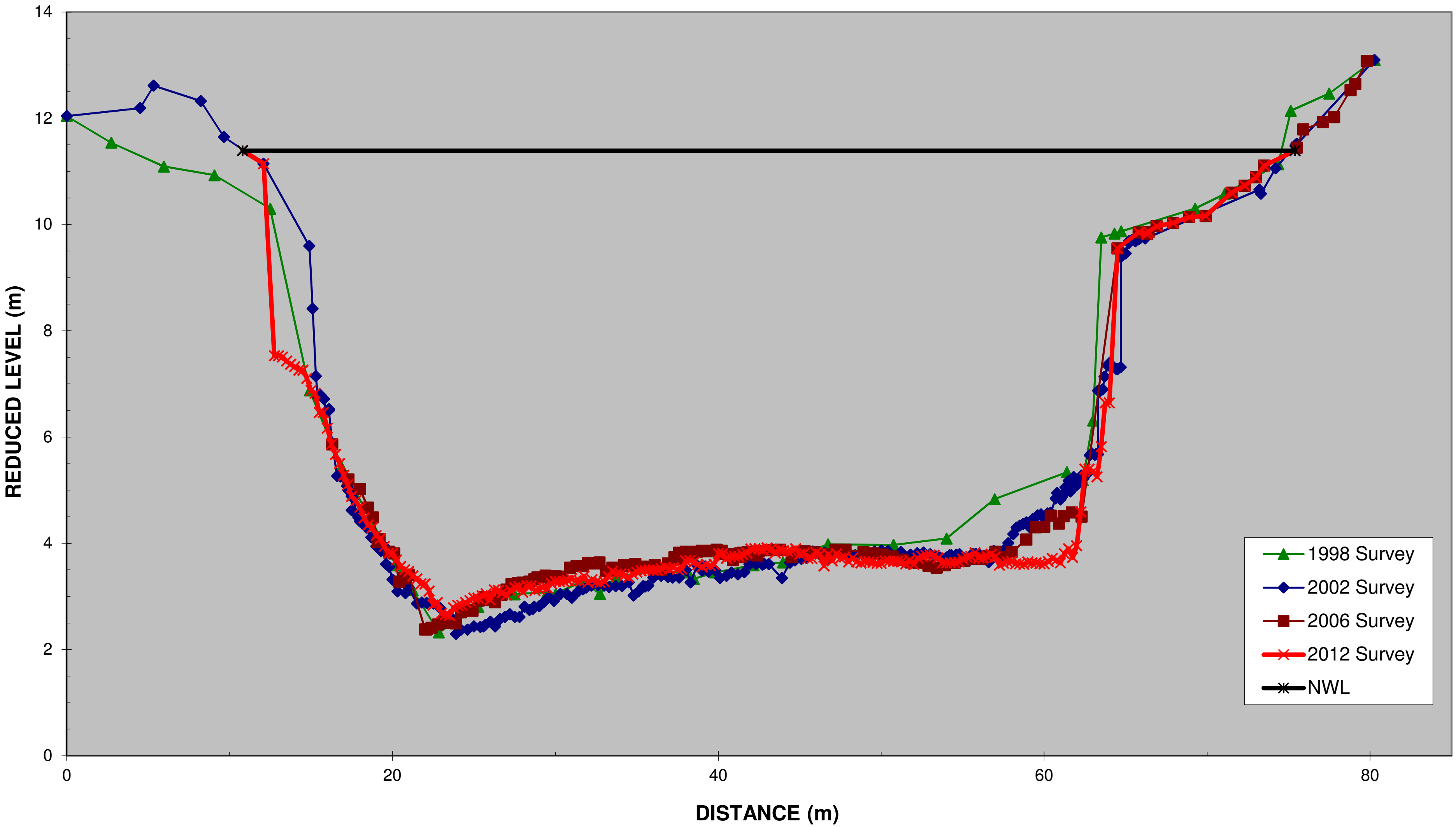
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 136A

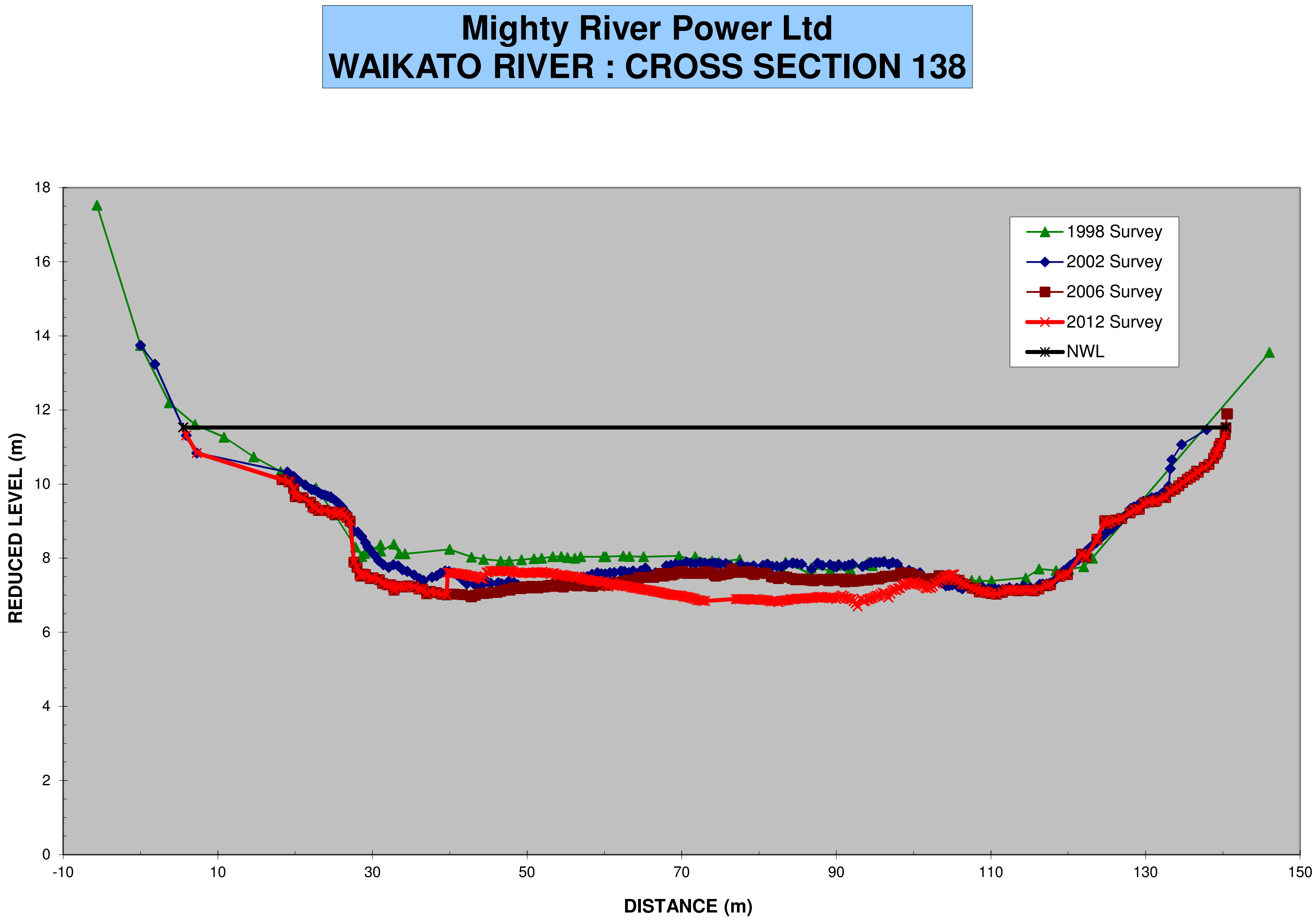


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 137



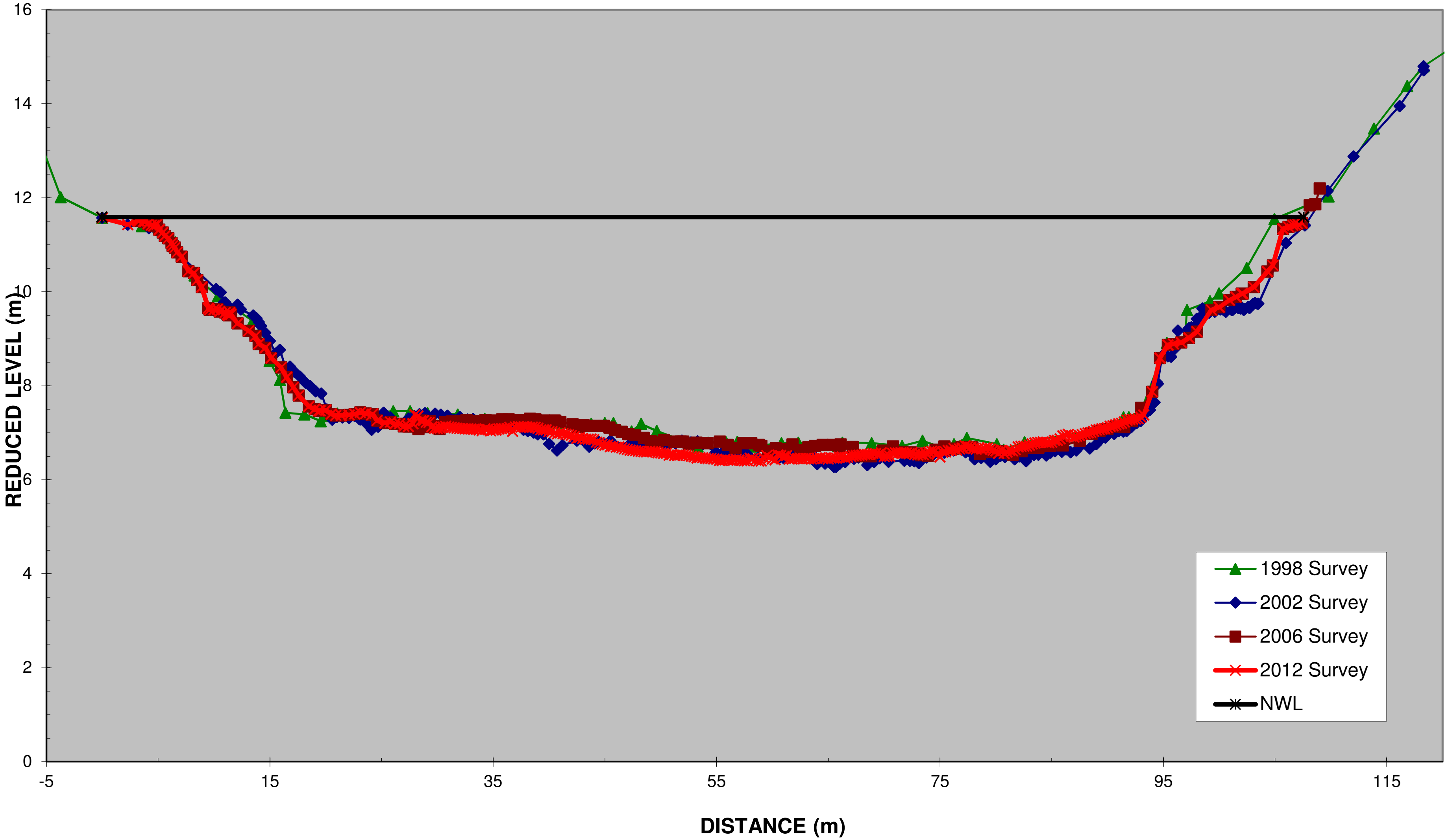
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 137A



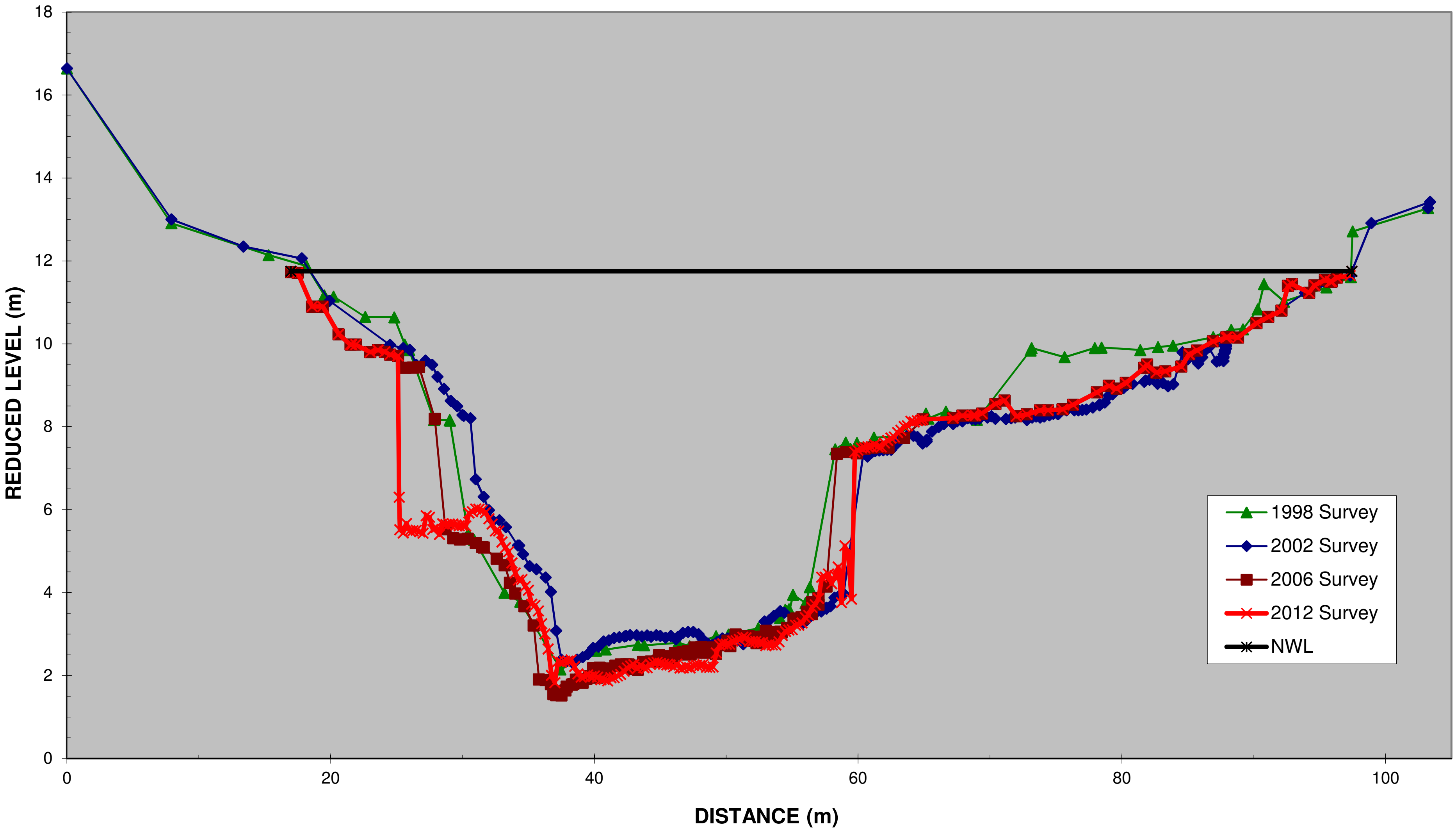


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 138
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
14
16
18
-10
10
30
50
70
90
110
130
150

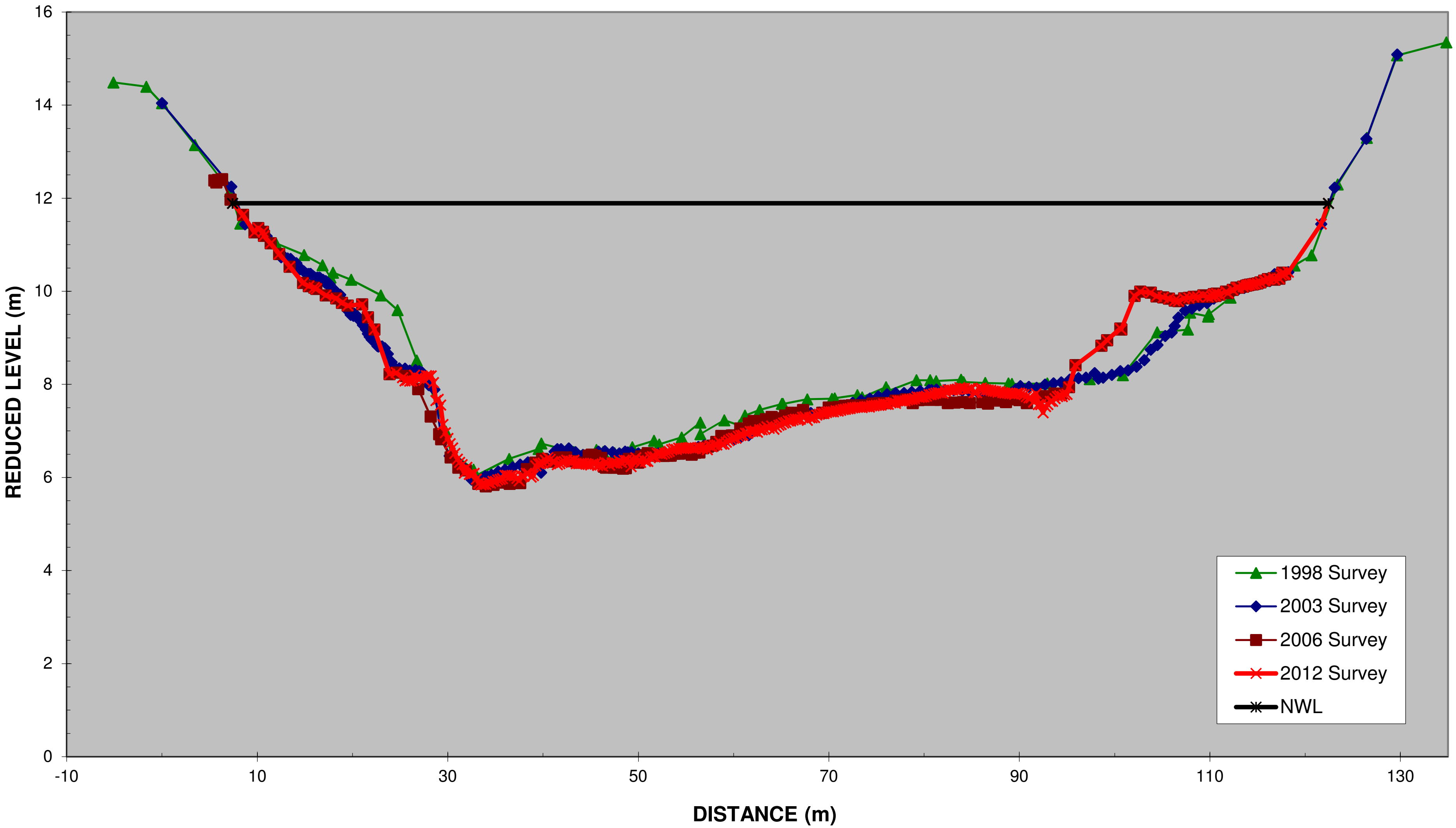
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 138A



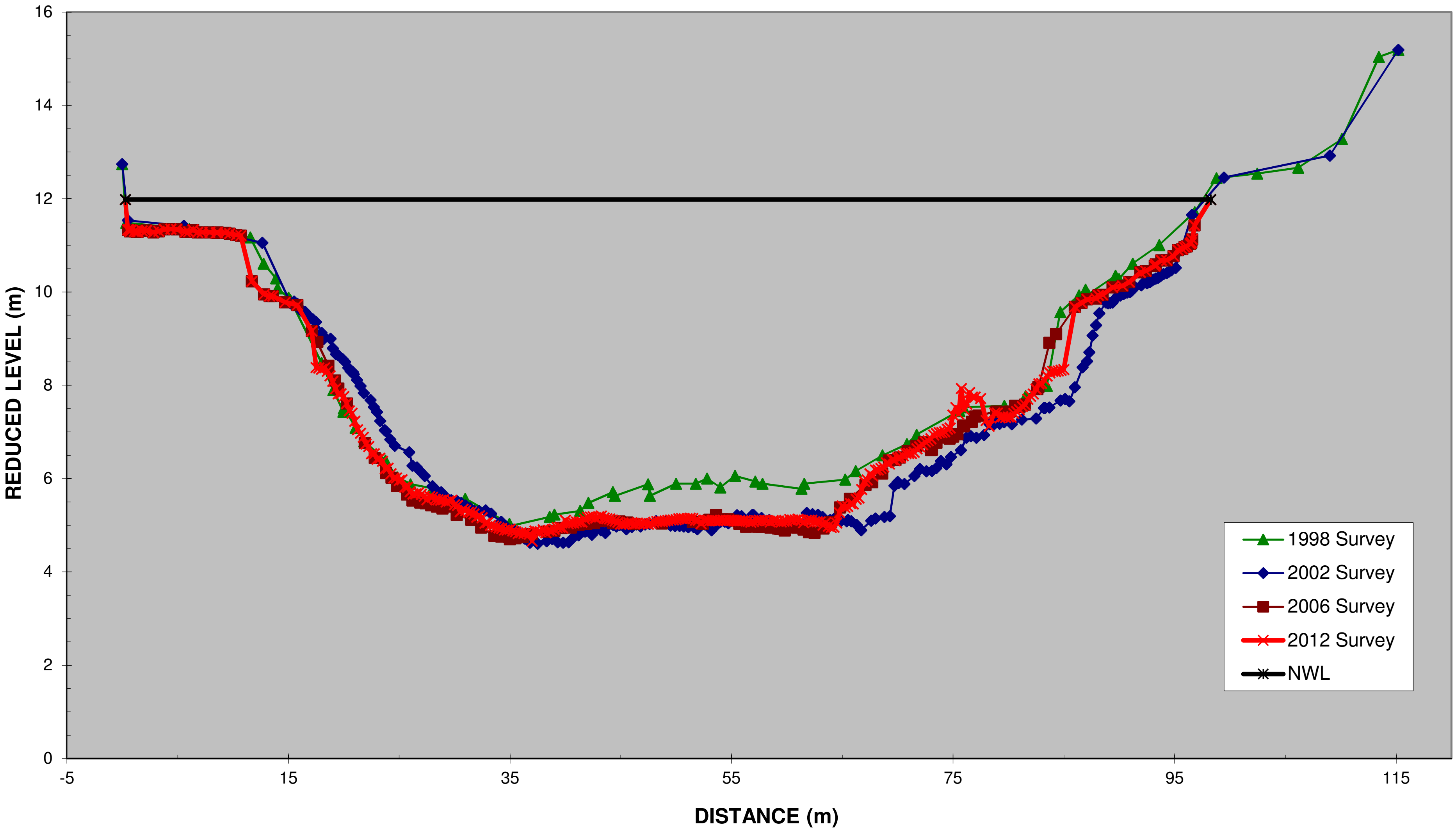
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 139



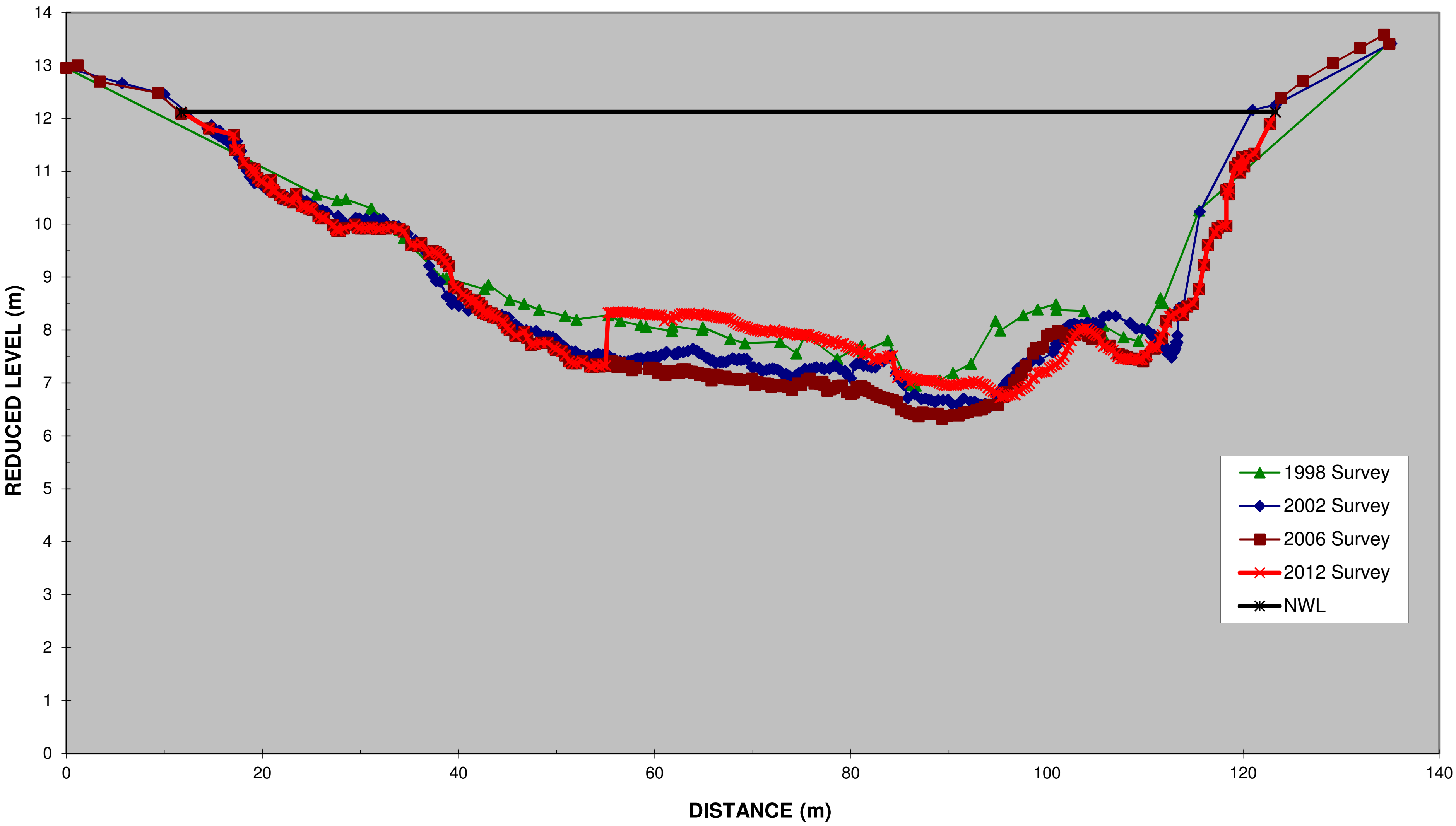
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 139B



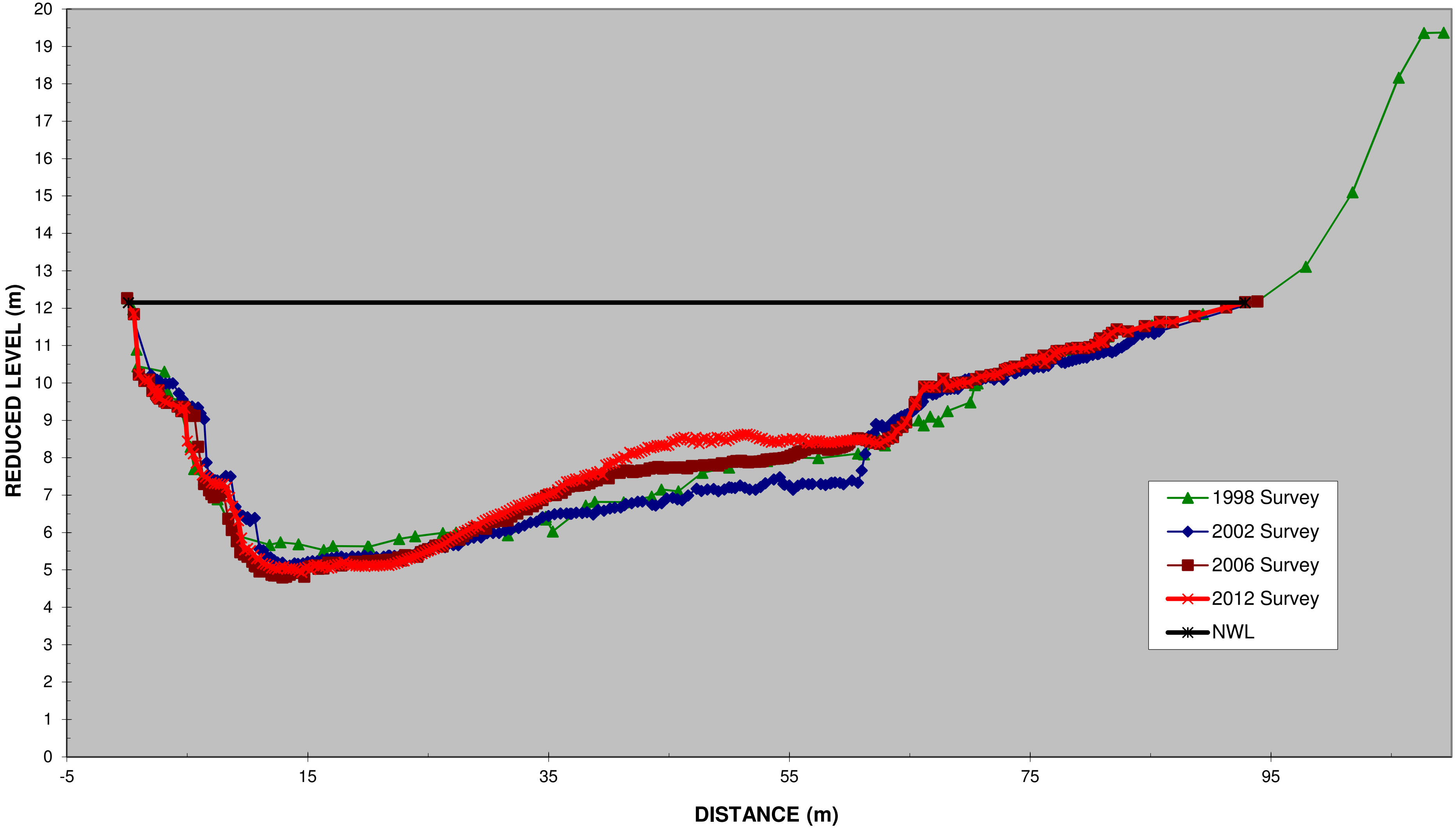
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 140



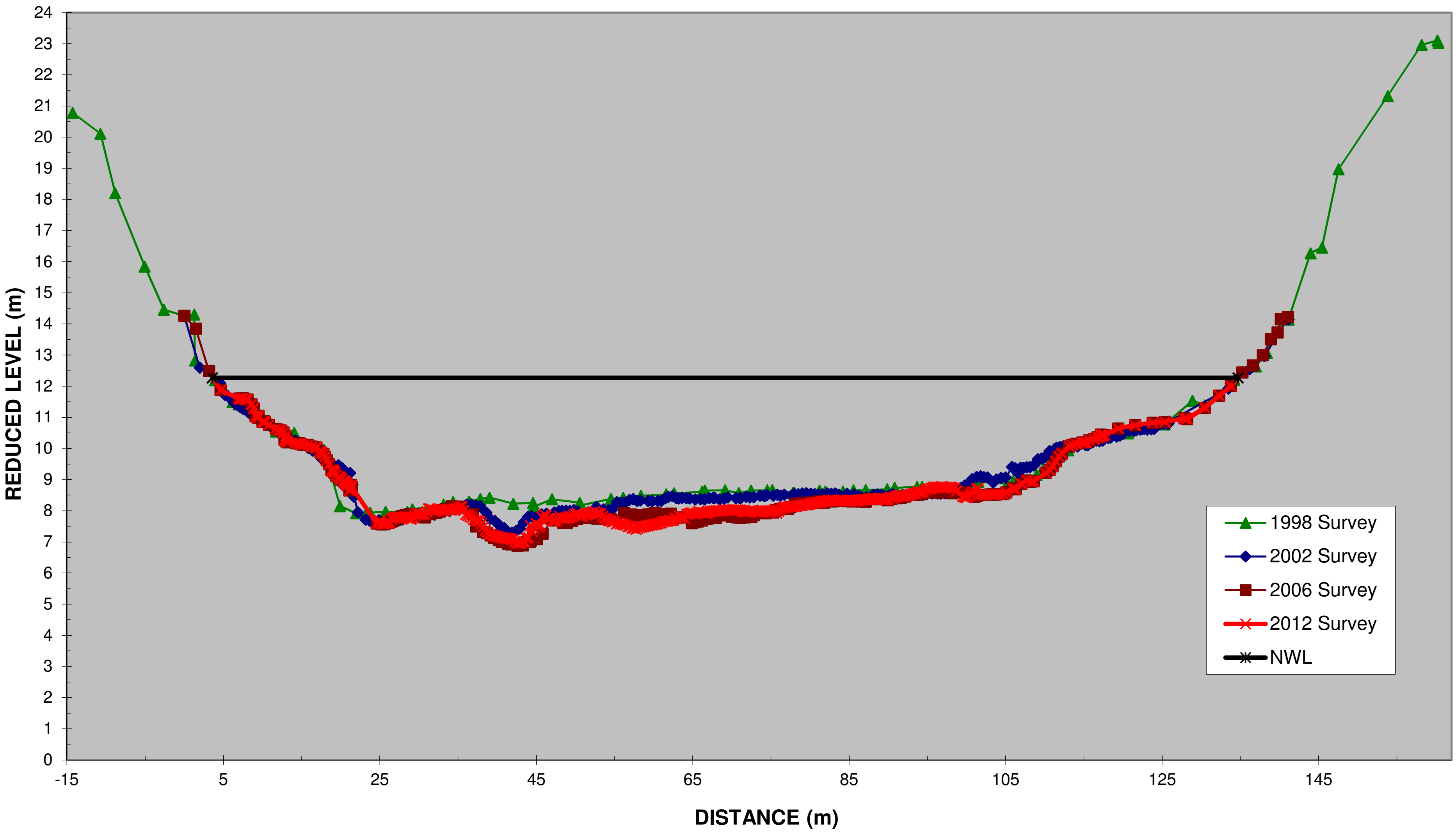
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 141



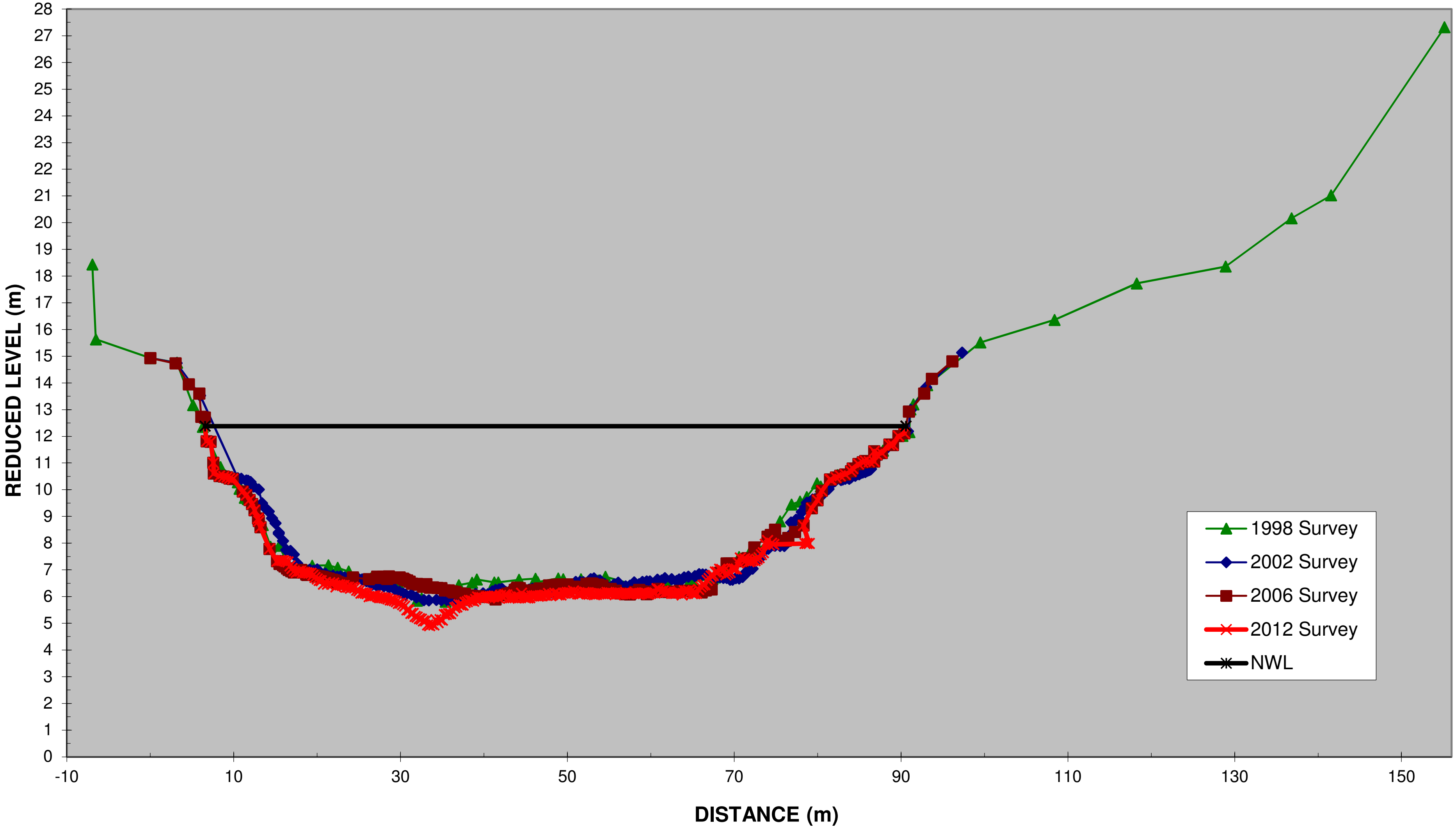
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 141A



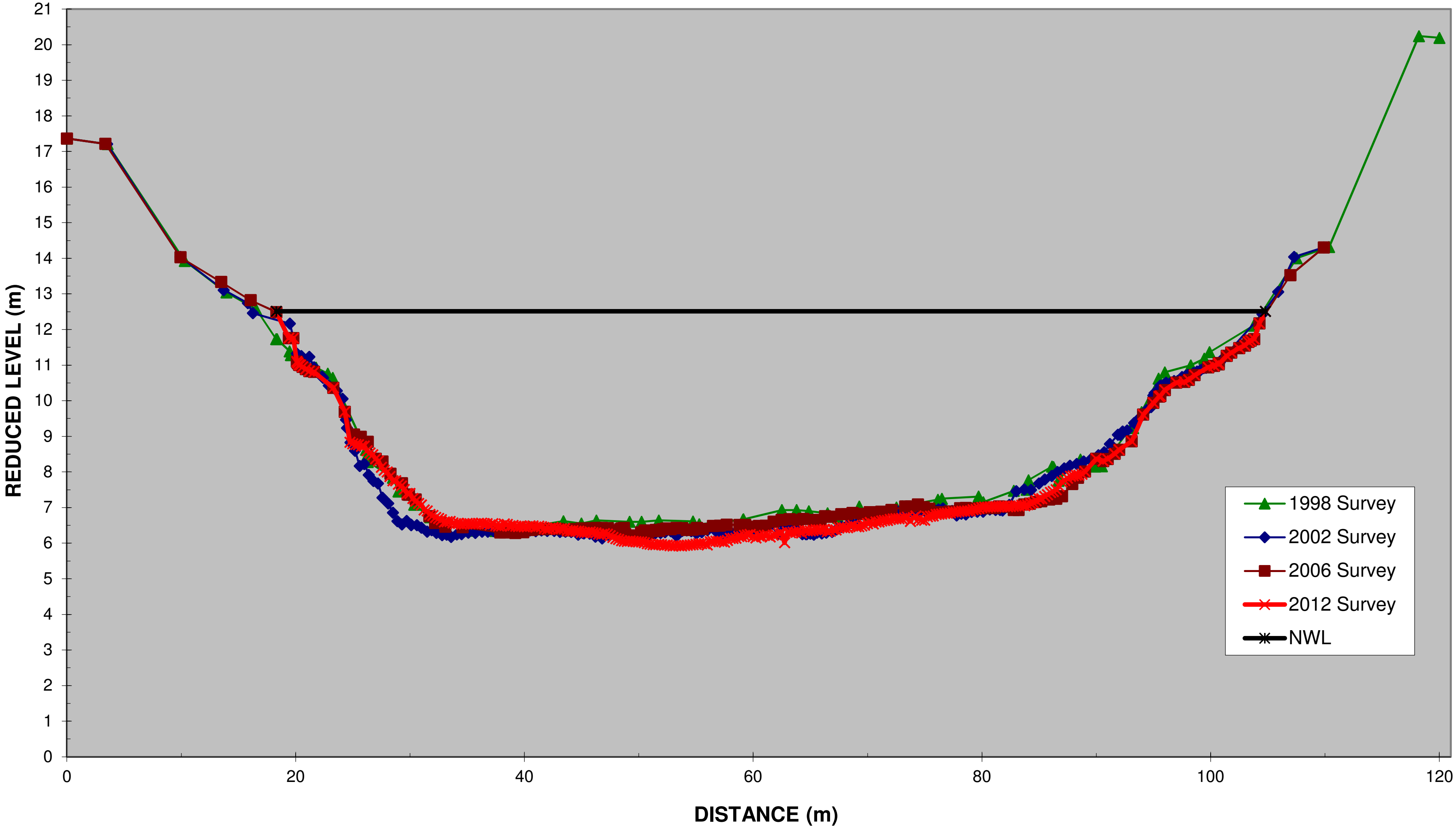
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 142



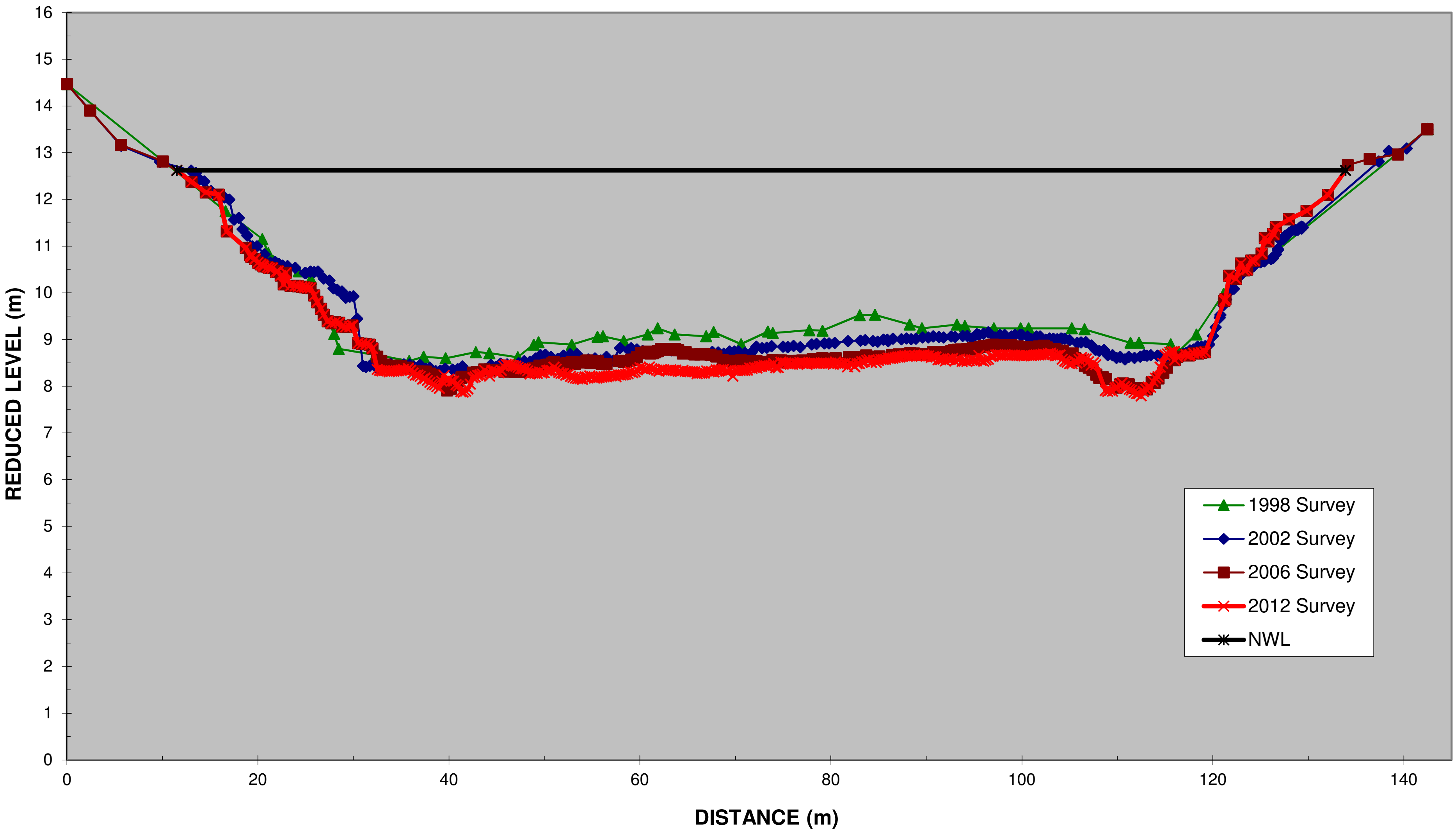
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 143

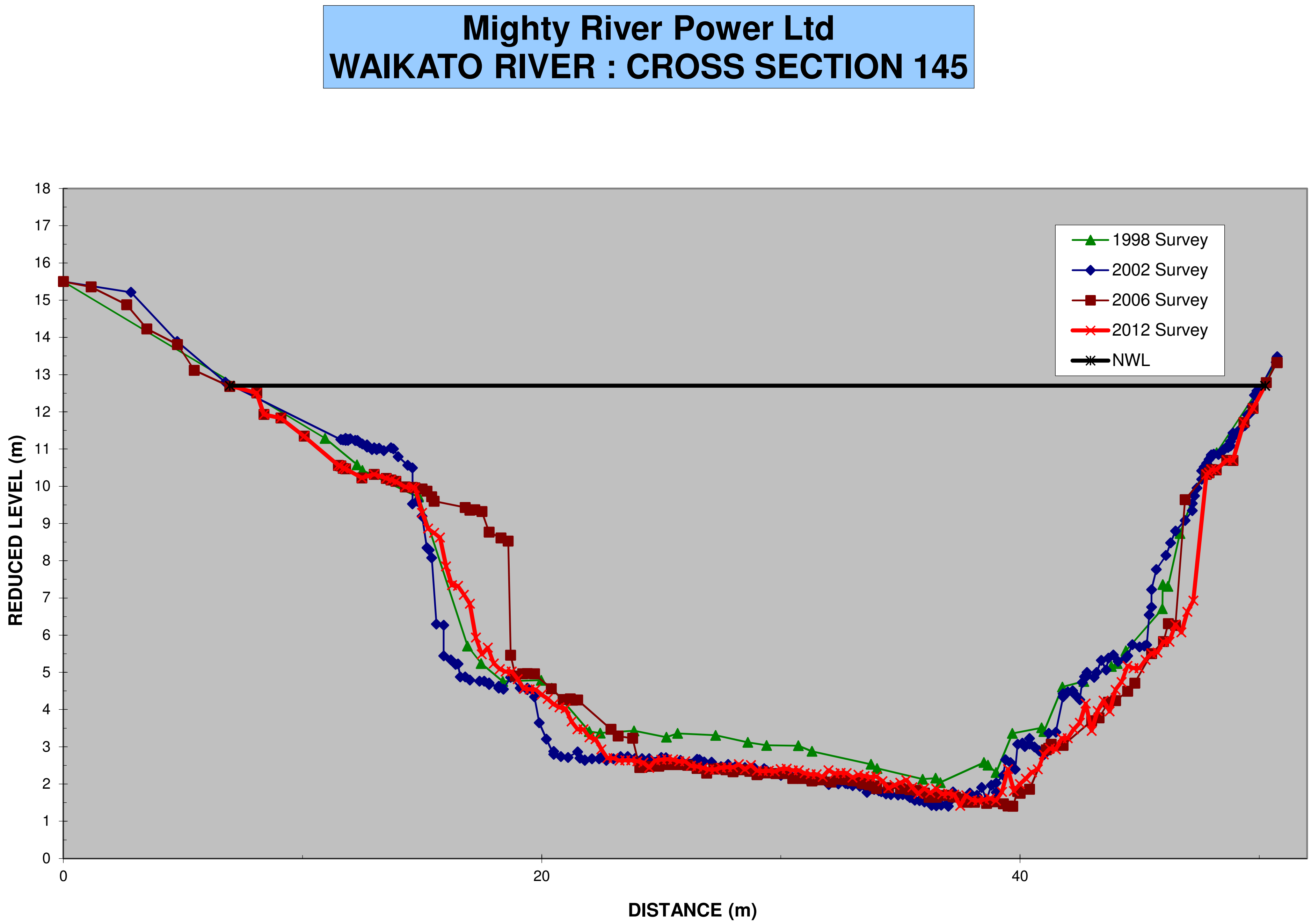


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 143A



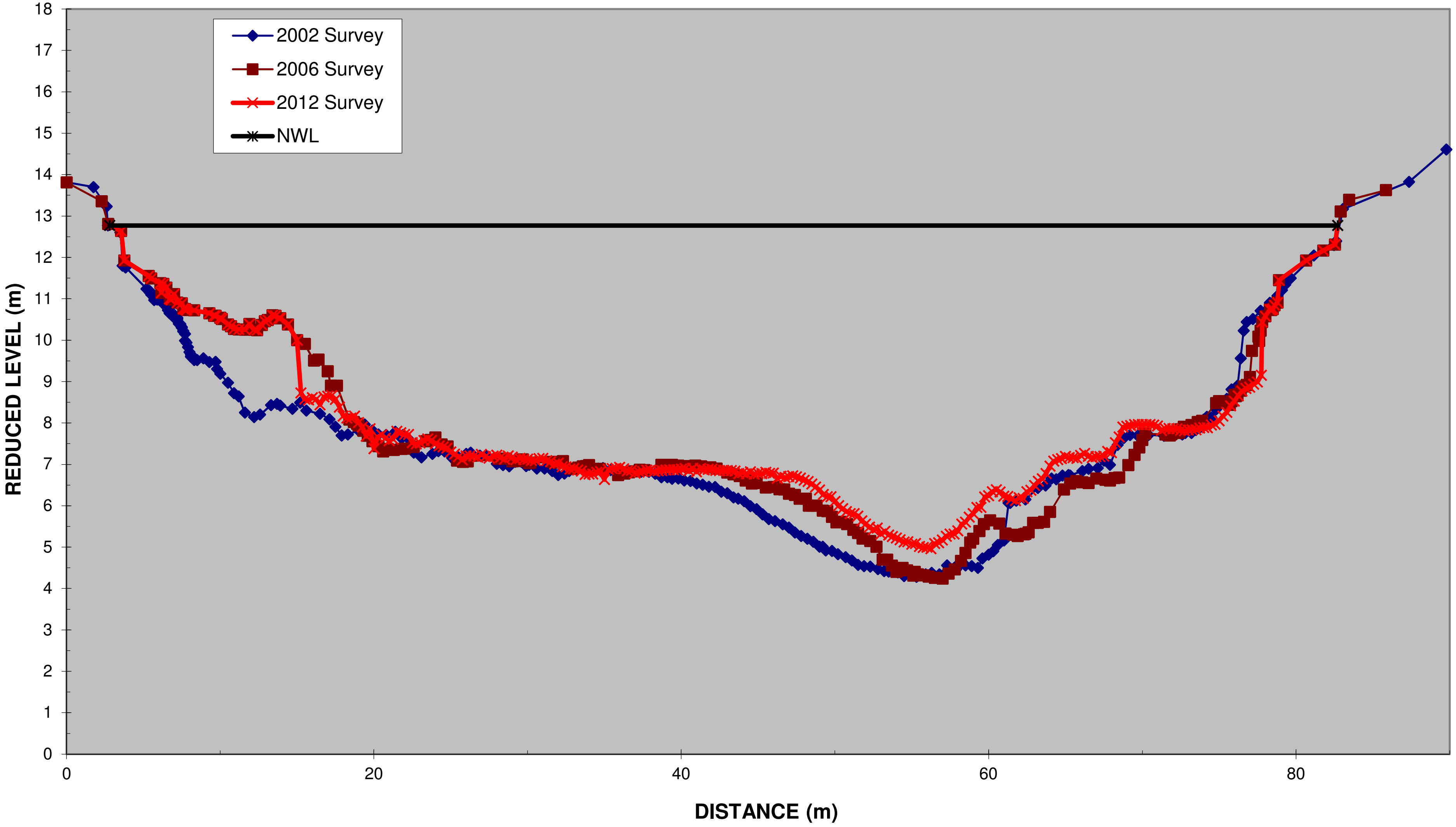
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 144



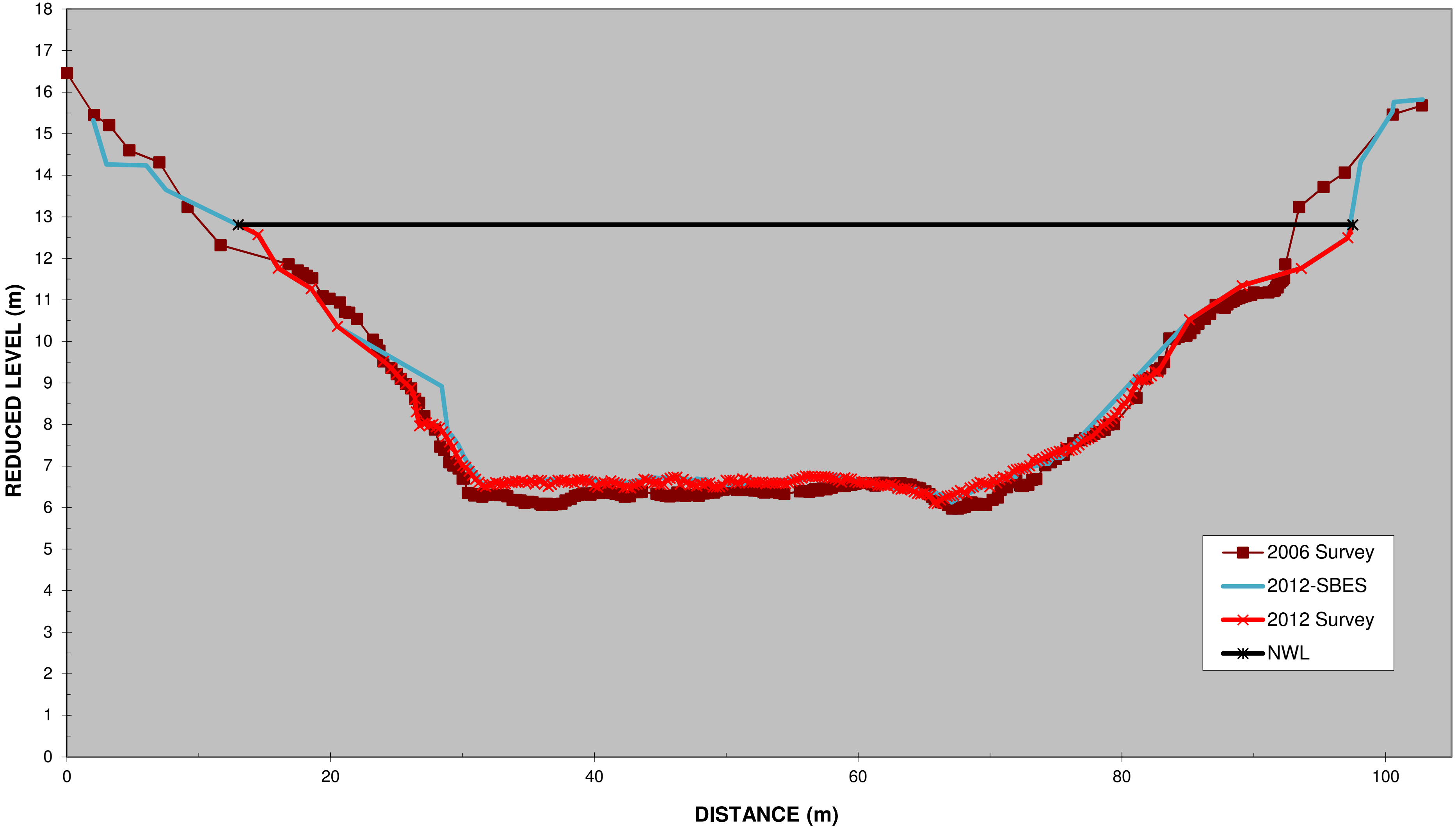


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 145
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
REDUCED LEVEL (m)
DISTANCE (m)
0
20
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

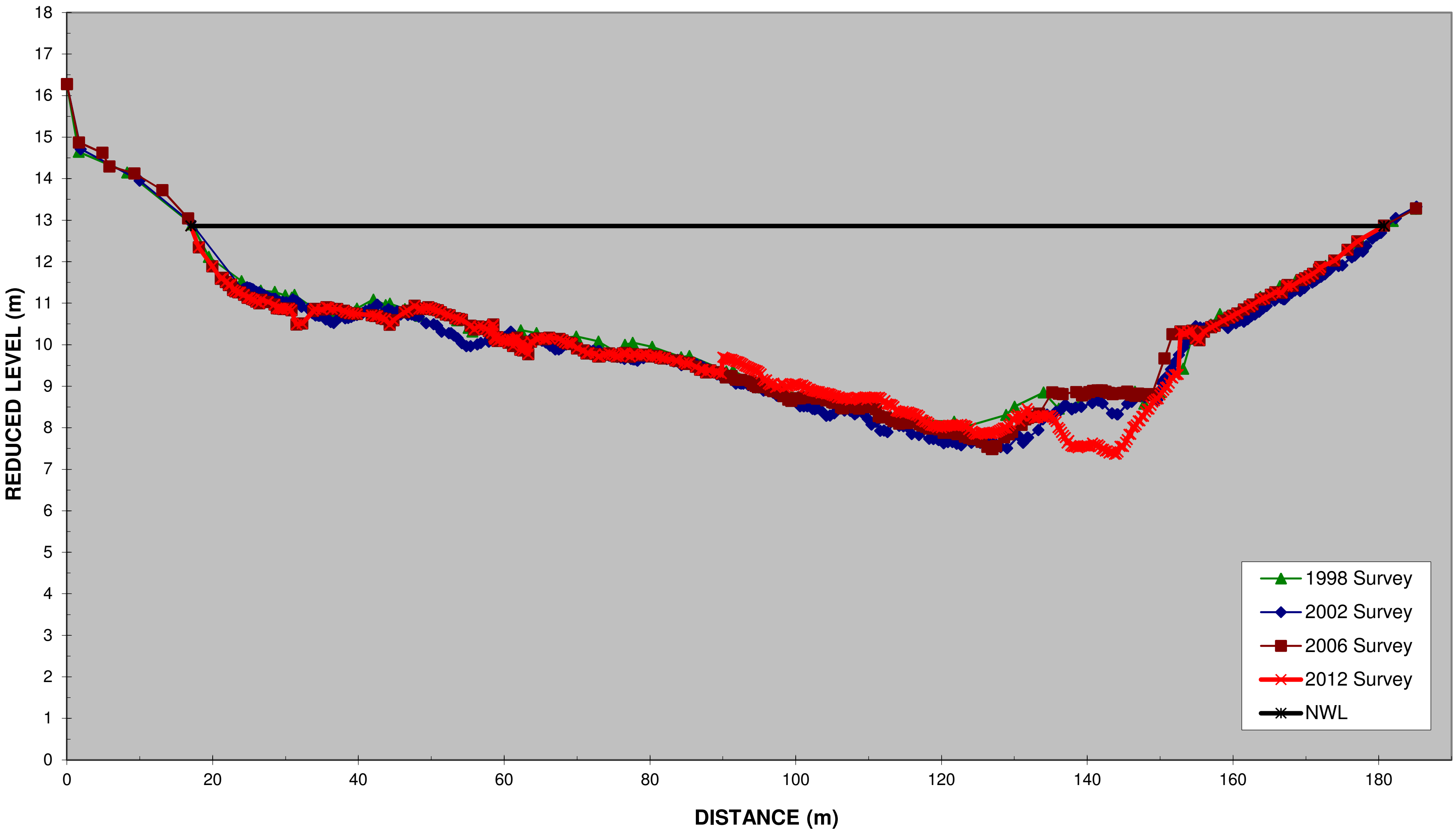
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 145Y



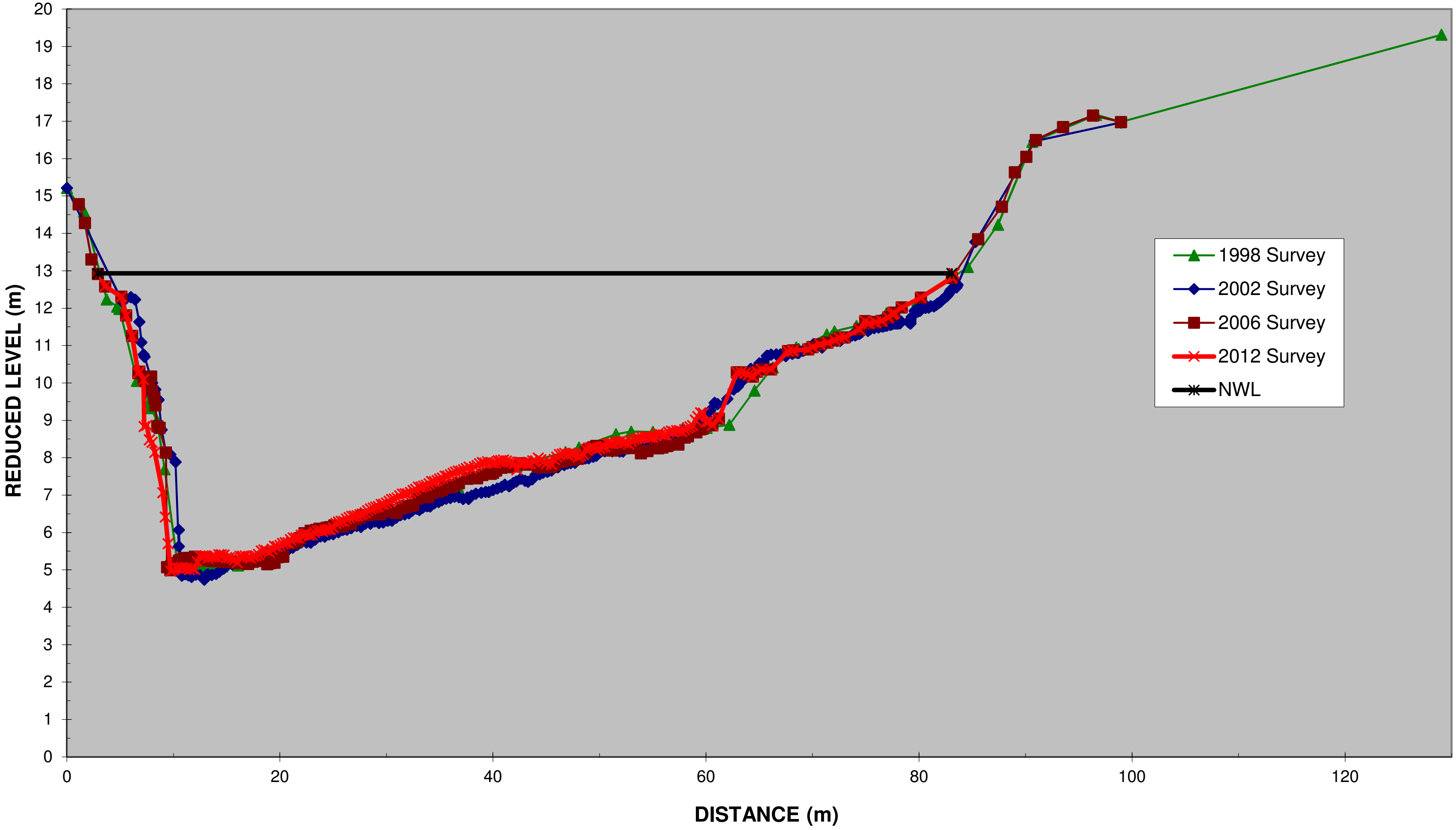
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 146



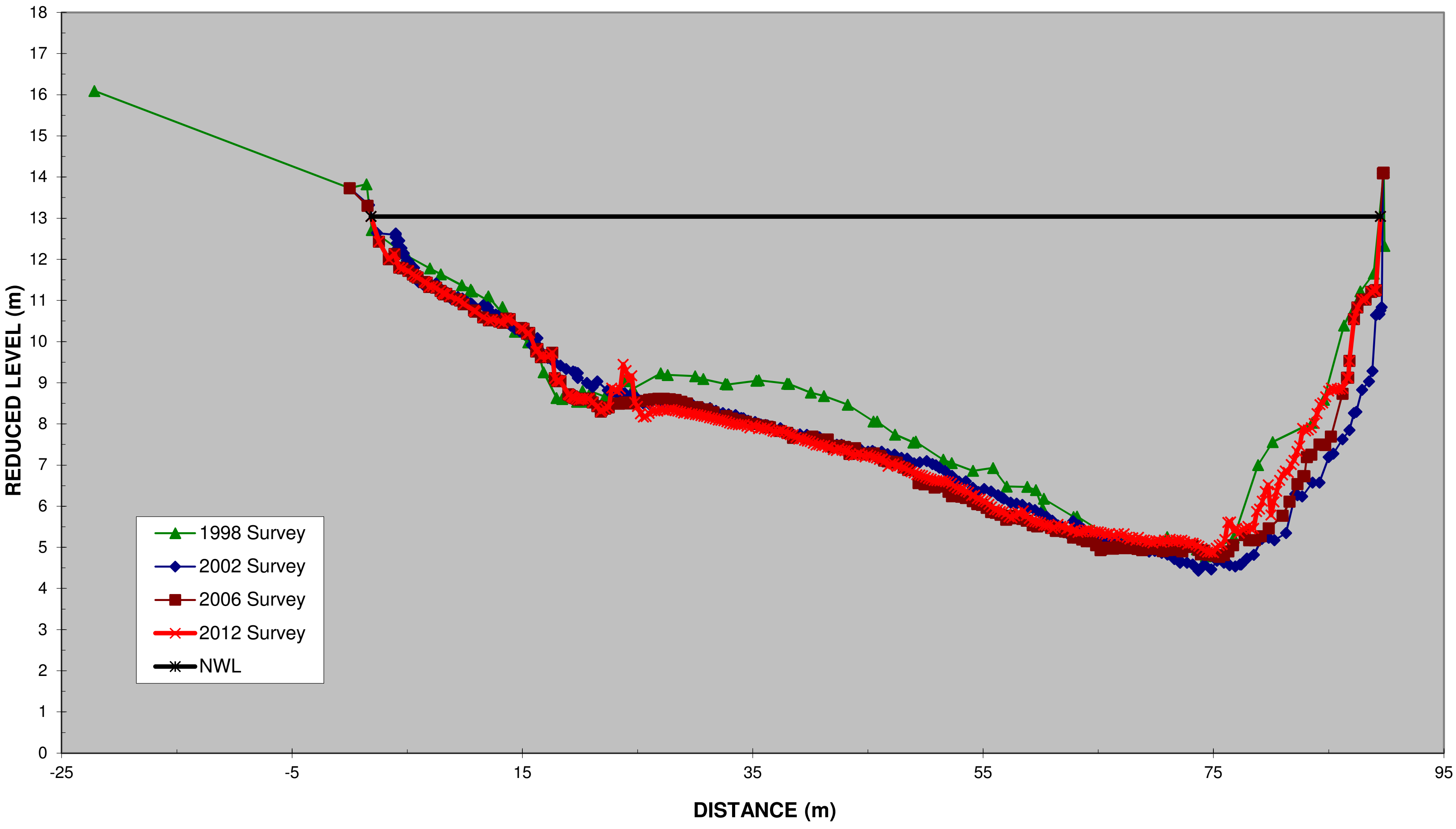
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 146A



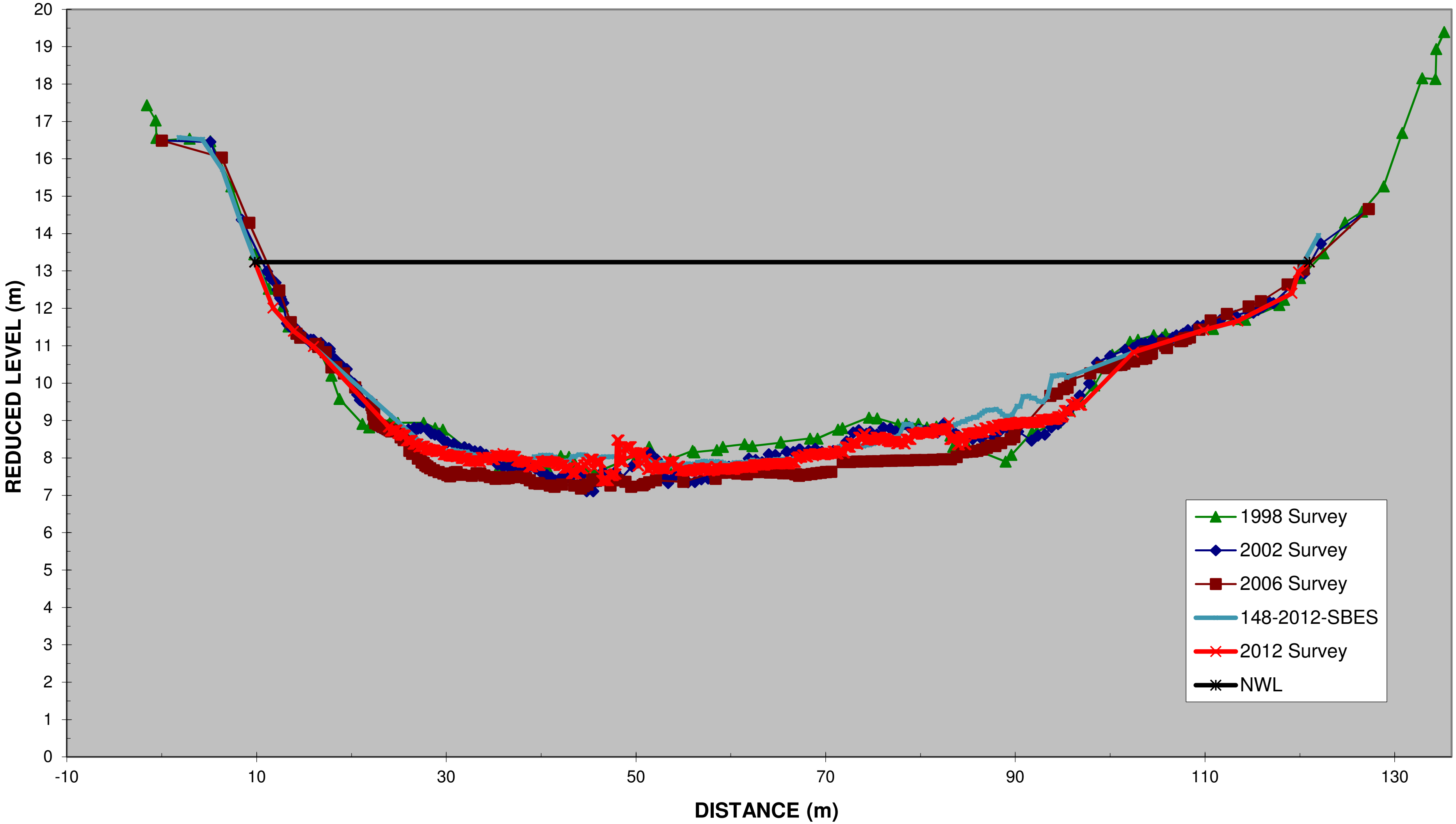
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 146B



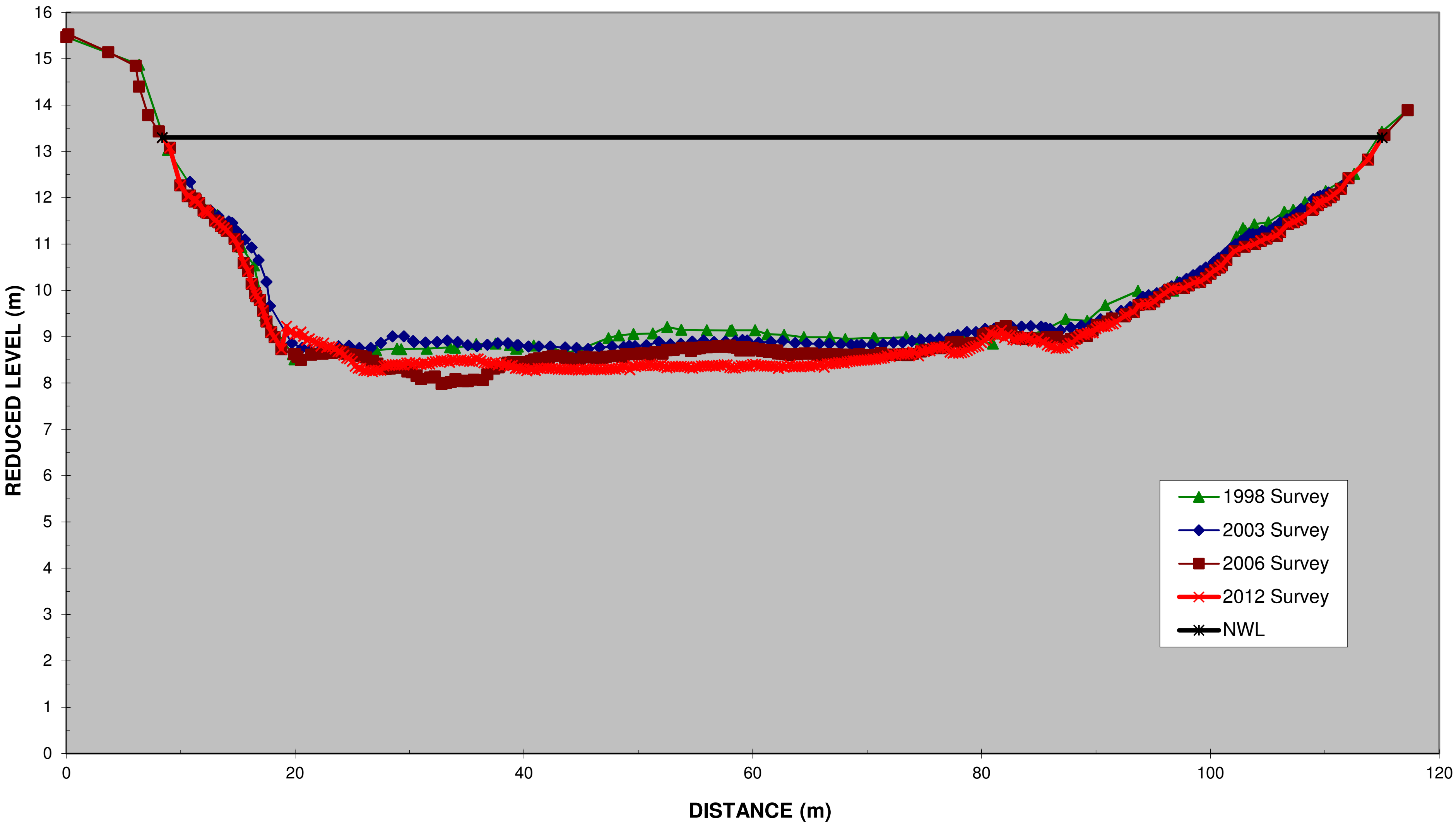
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 147



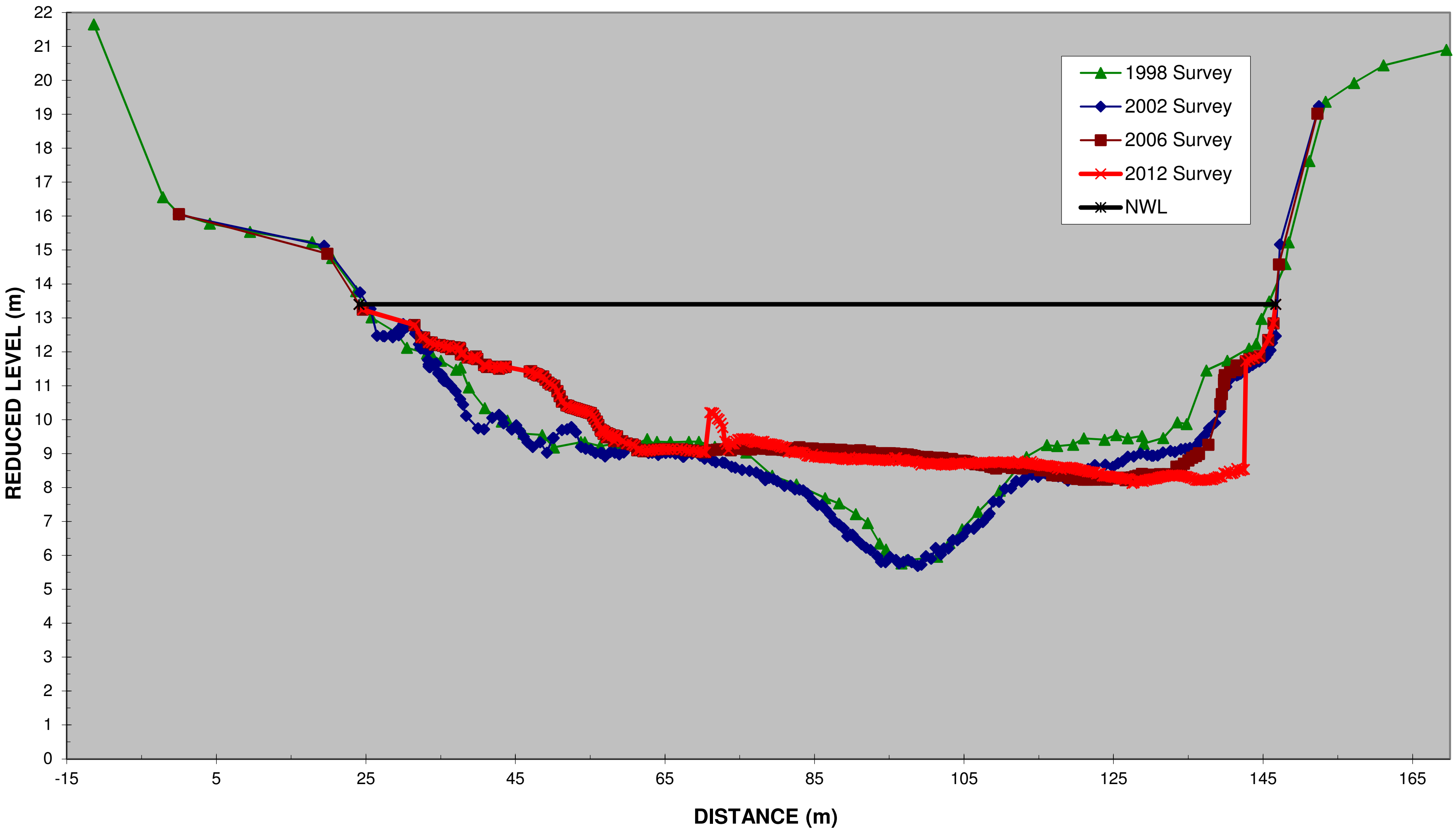
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 148

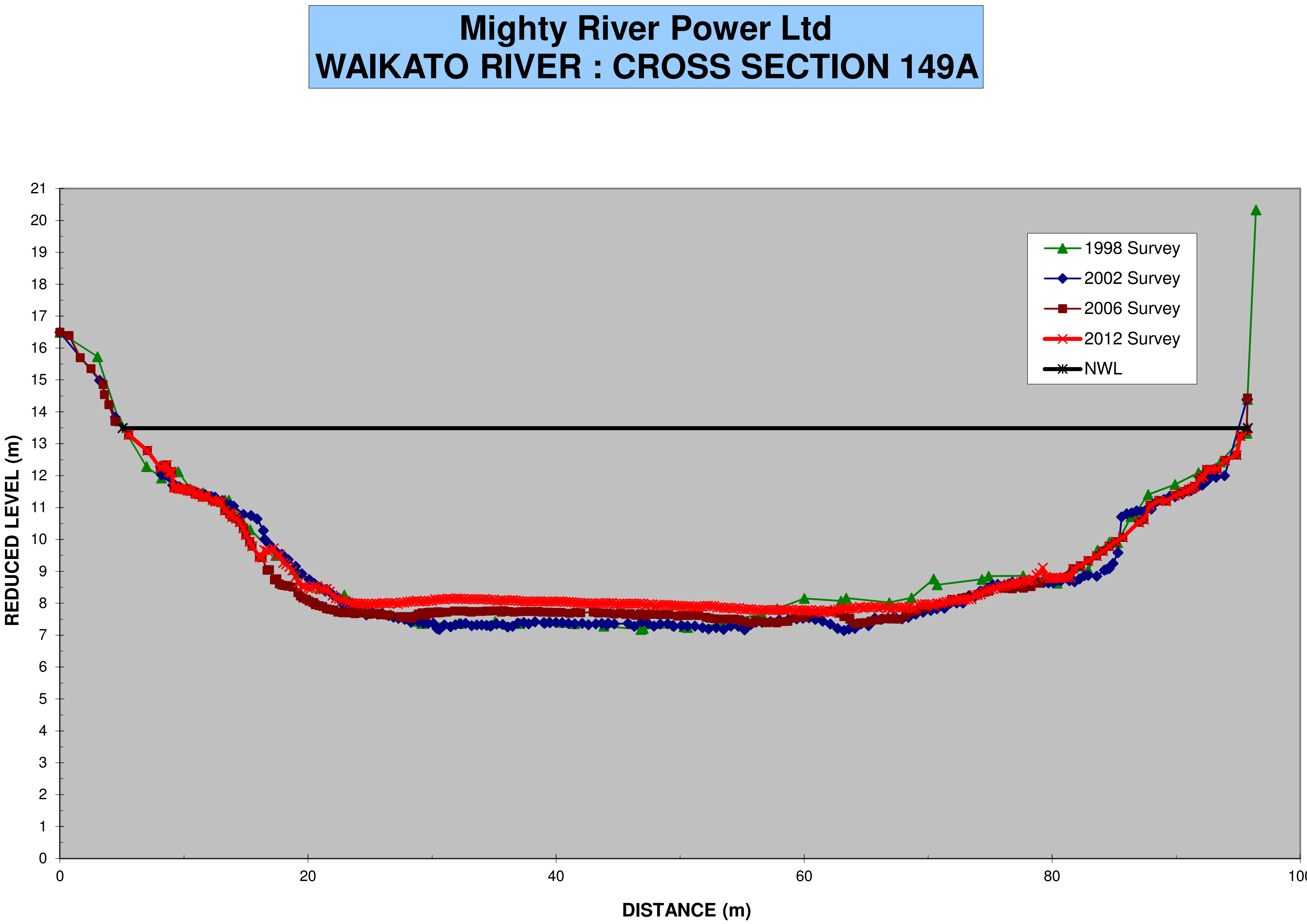


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 148A



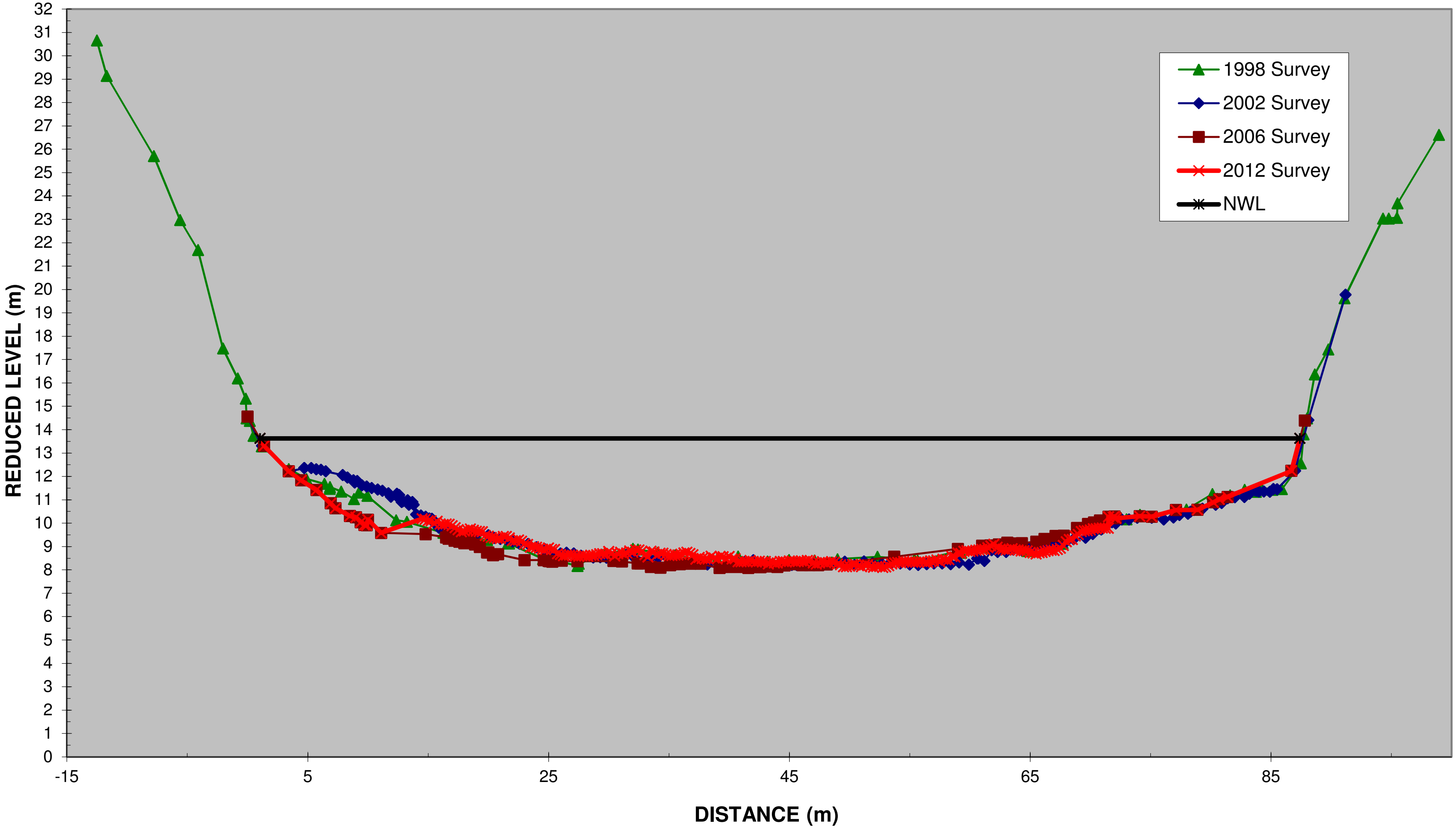
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 149



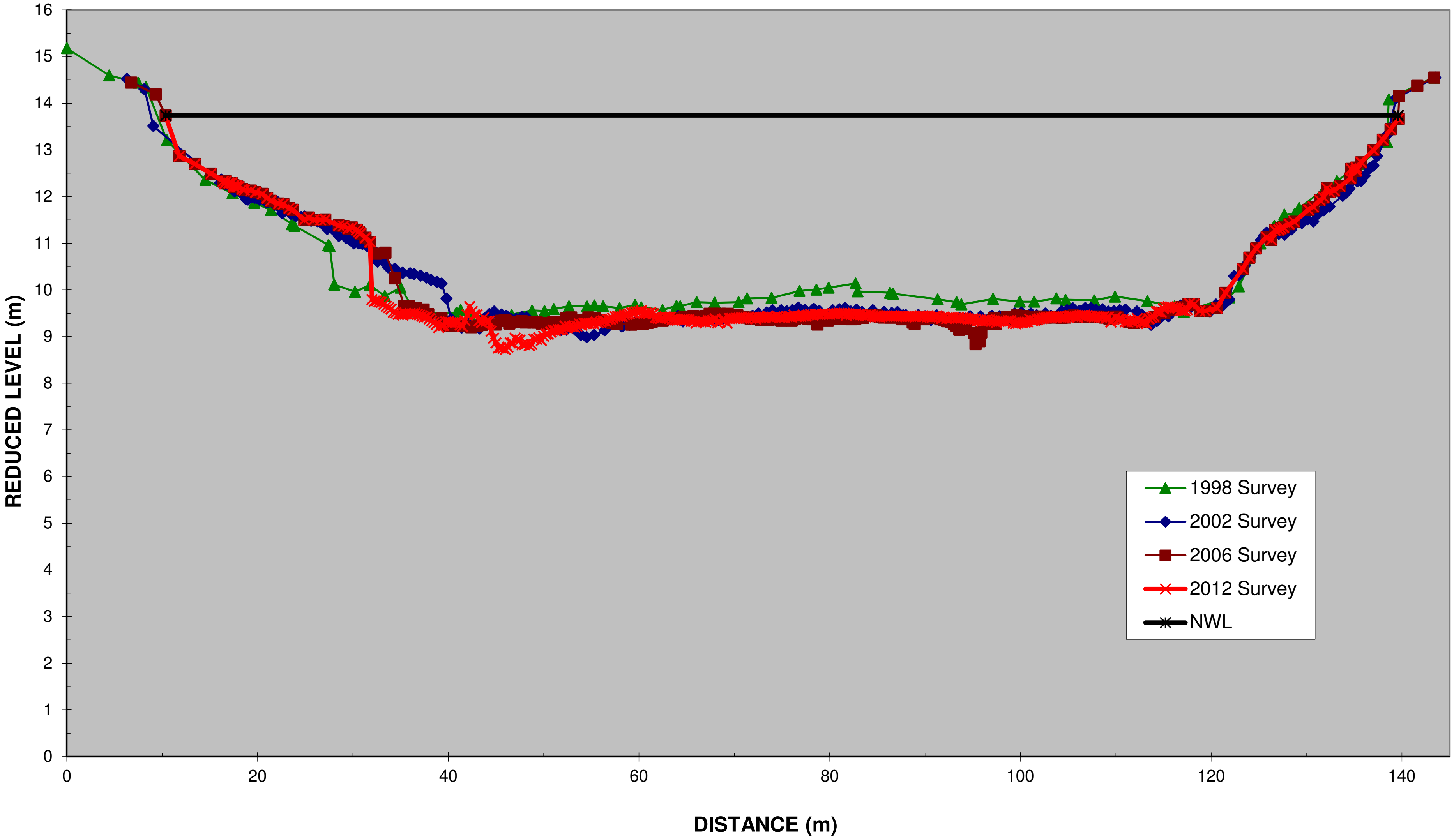


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 149A
REDUCED LEVEL (m)
DISTANCE (m)
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
0
20
40
60
80
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

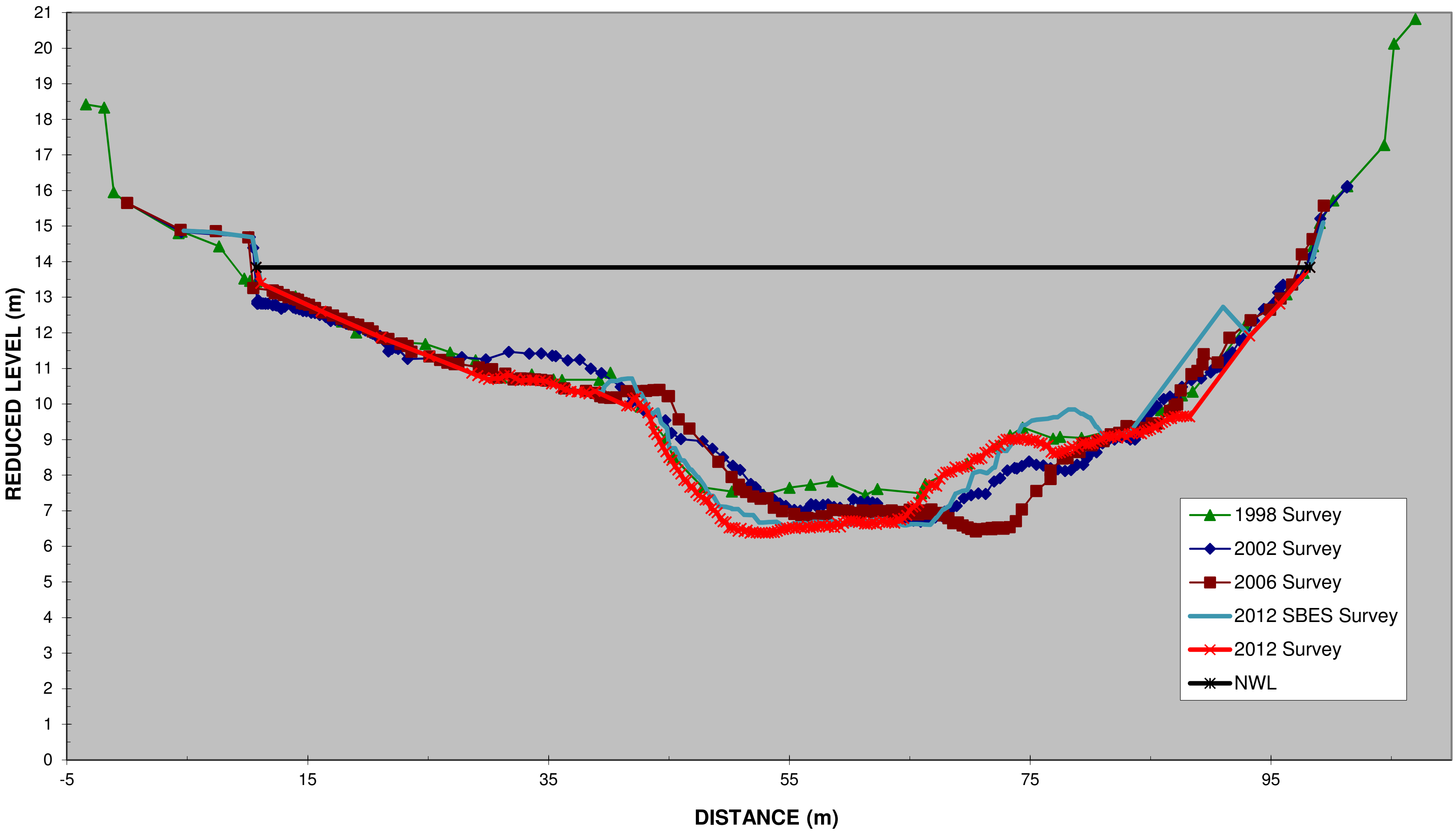
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 150



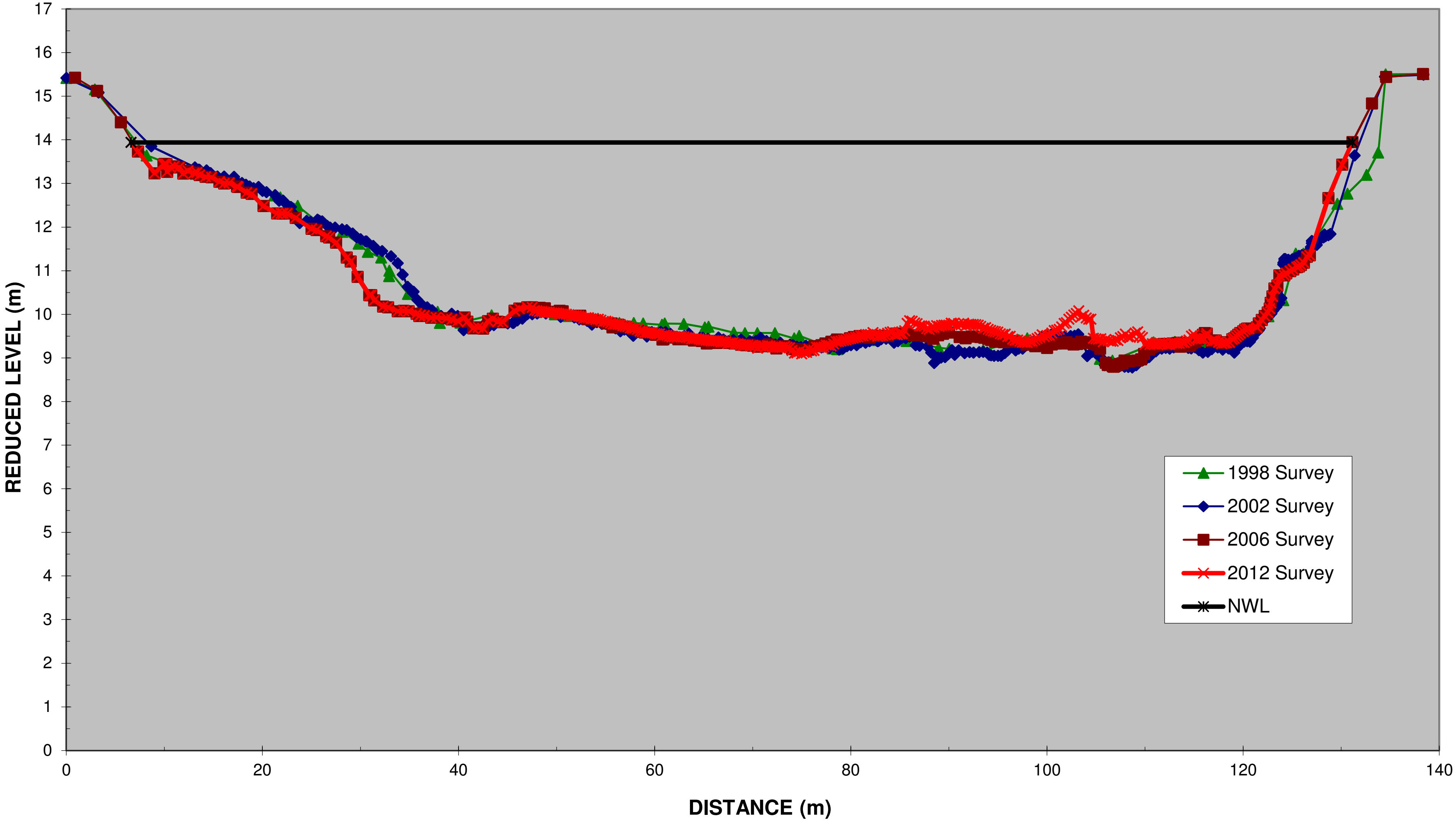
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 150A



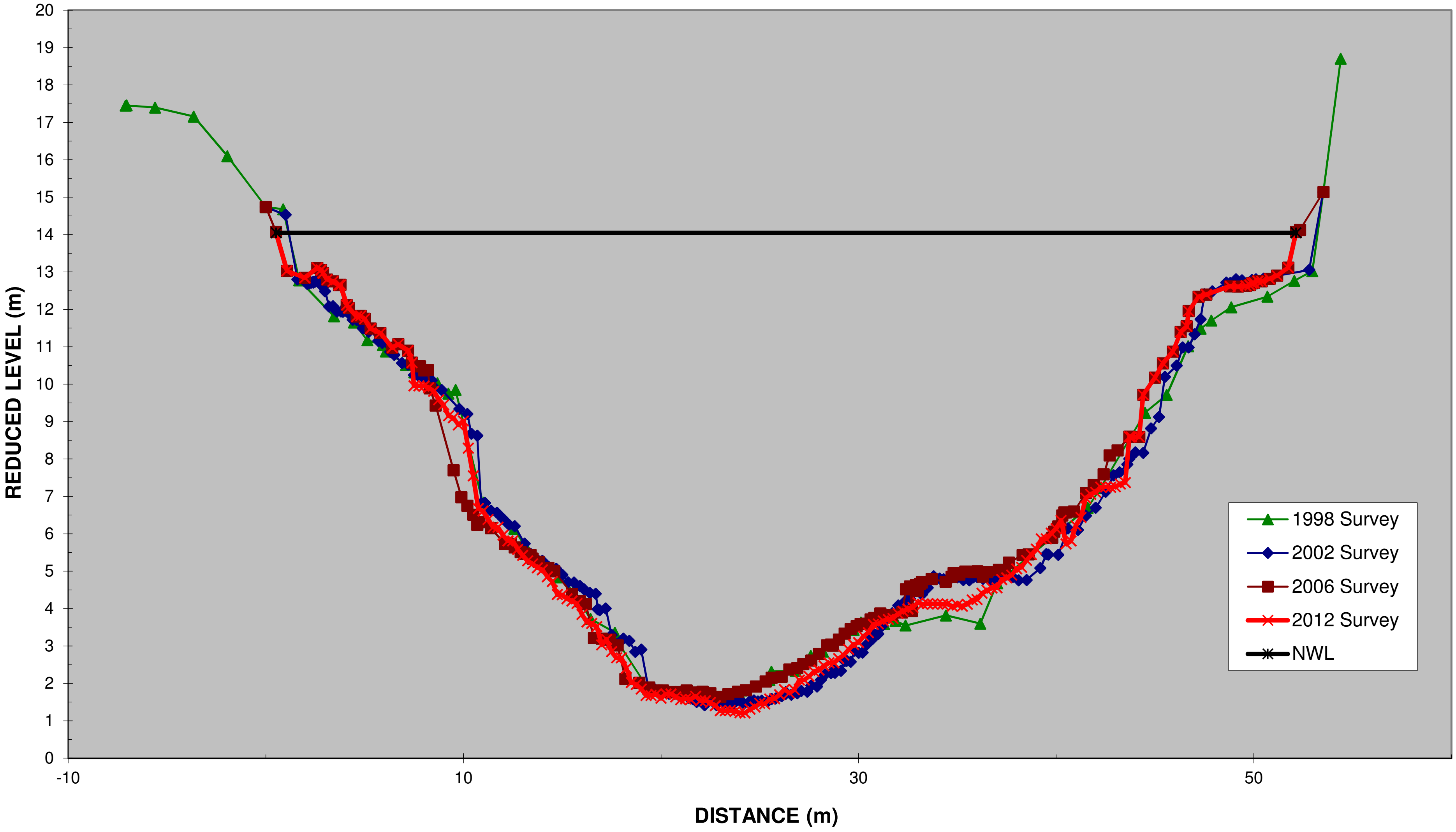
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 151



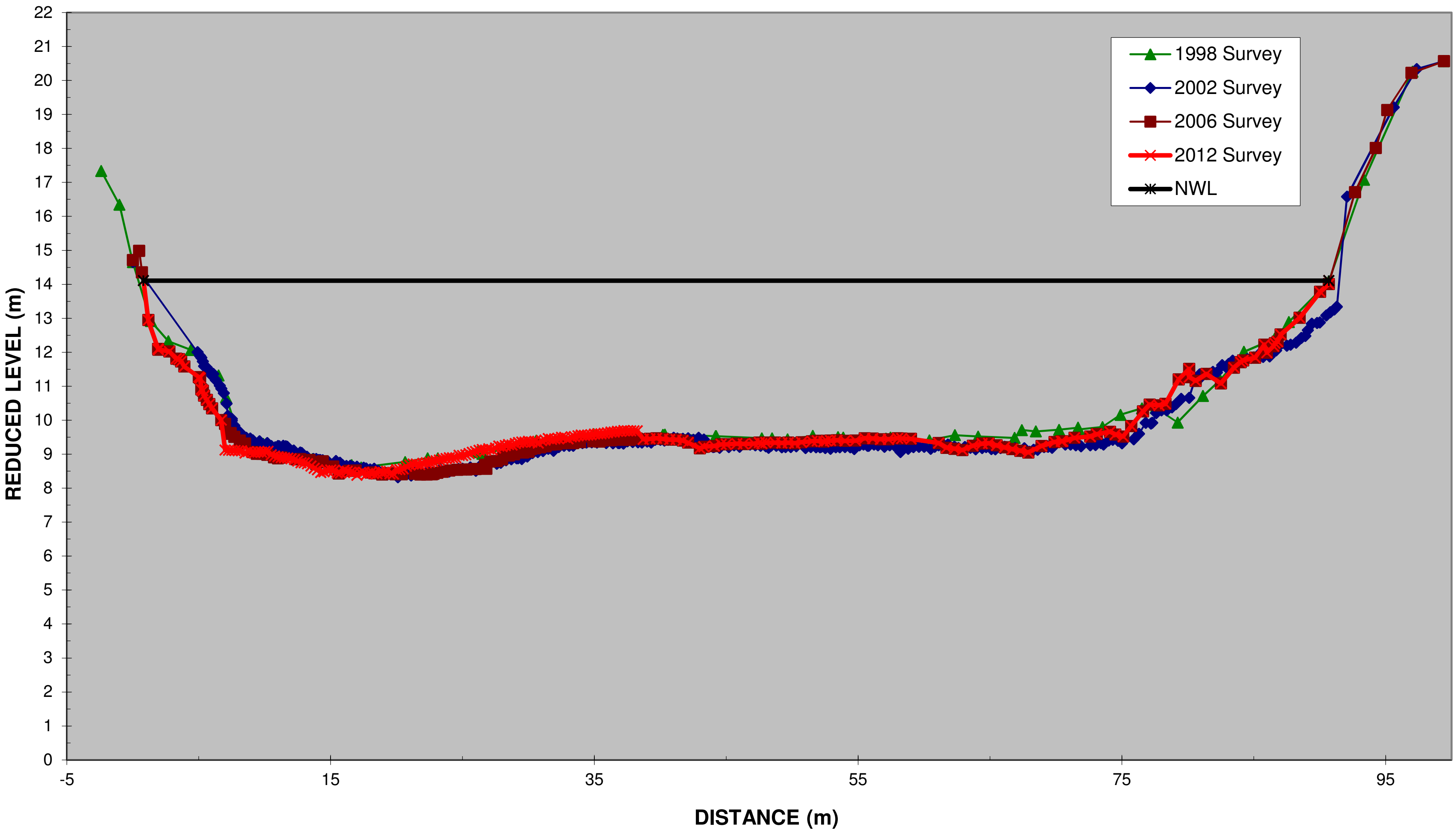
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 151A

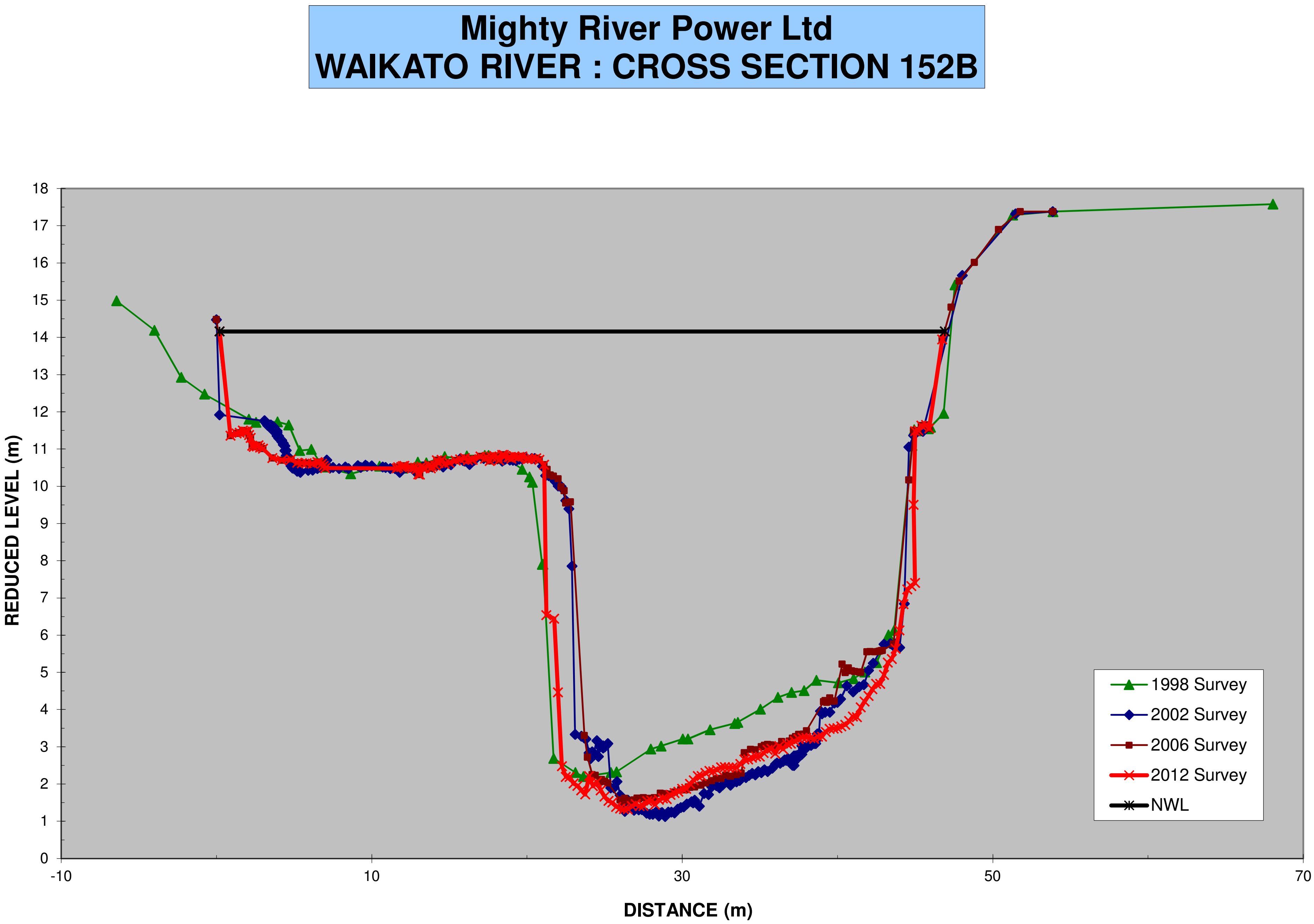


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 152

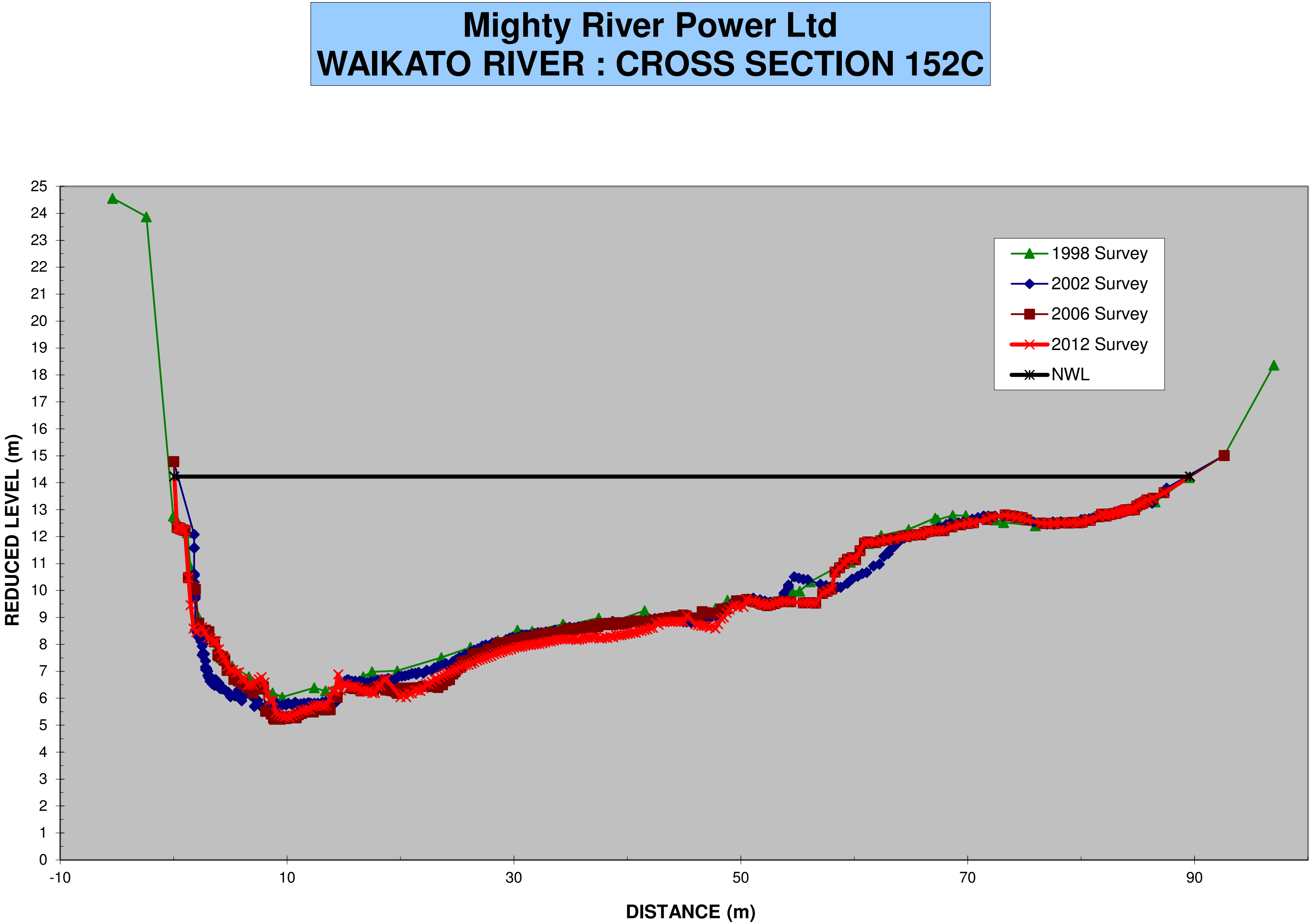


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 152A

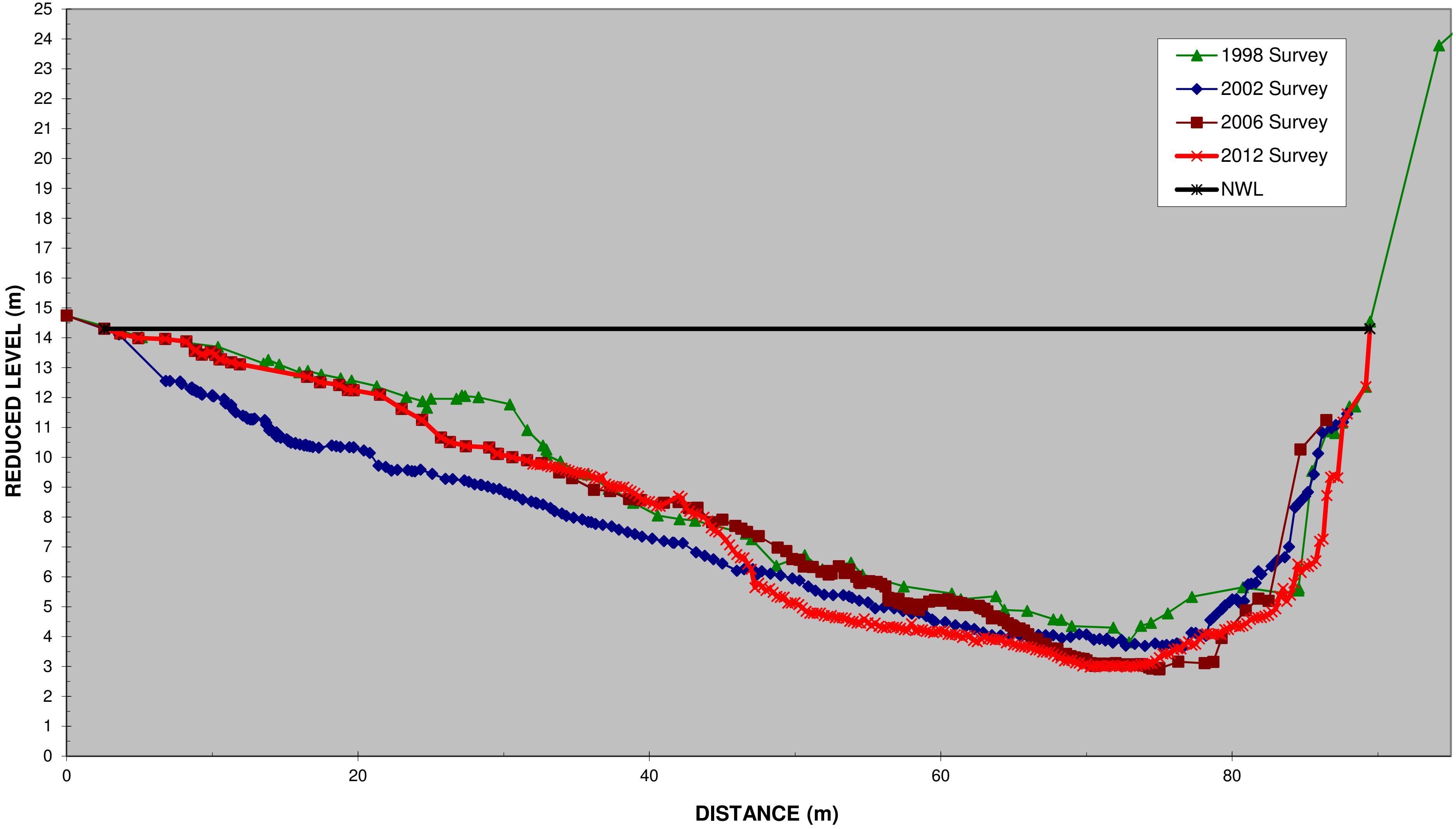




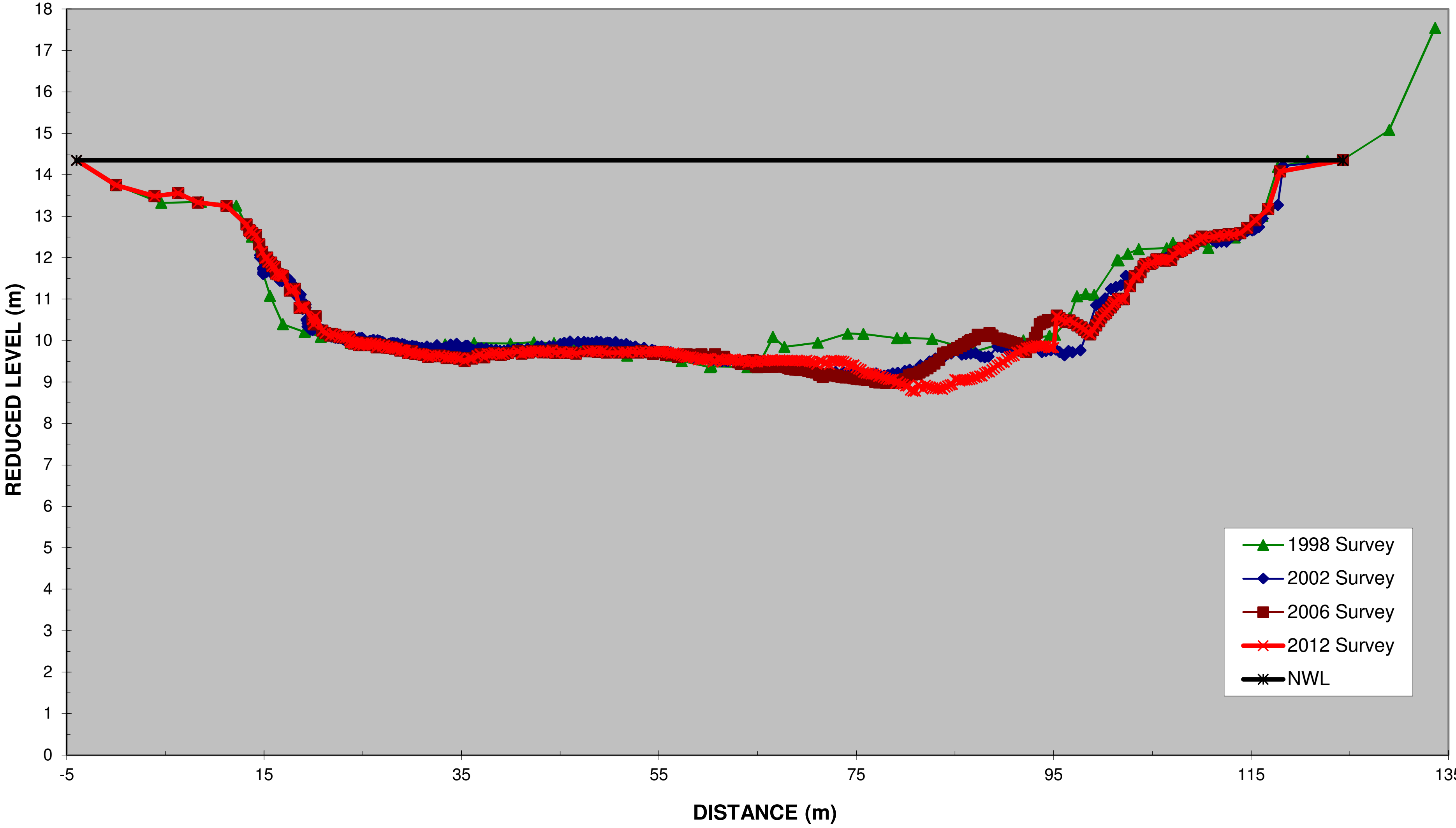
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 152B
REDUCED LEVEL (m)
DISTANCE (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
-10
10
30
50
70
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 152C
REDUCED LEVEL (m)
DISTANCE (m)
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-10
10
30
50
70
90

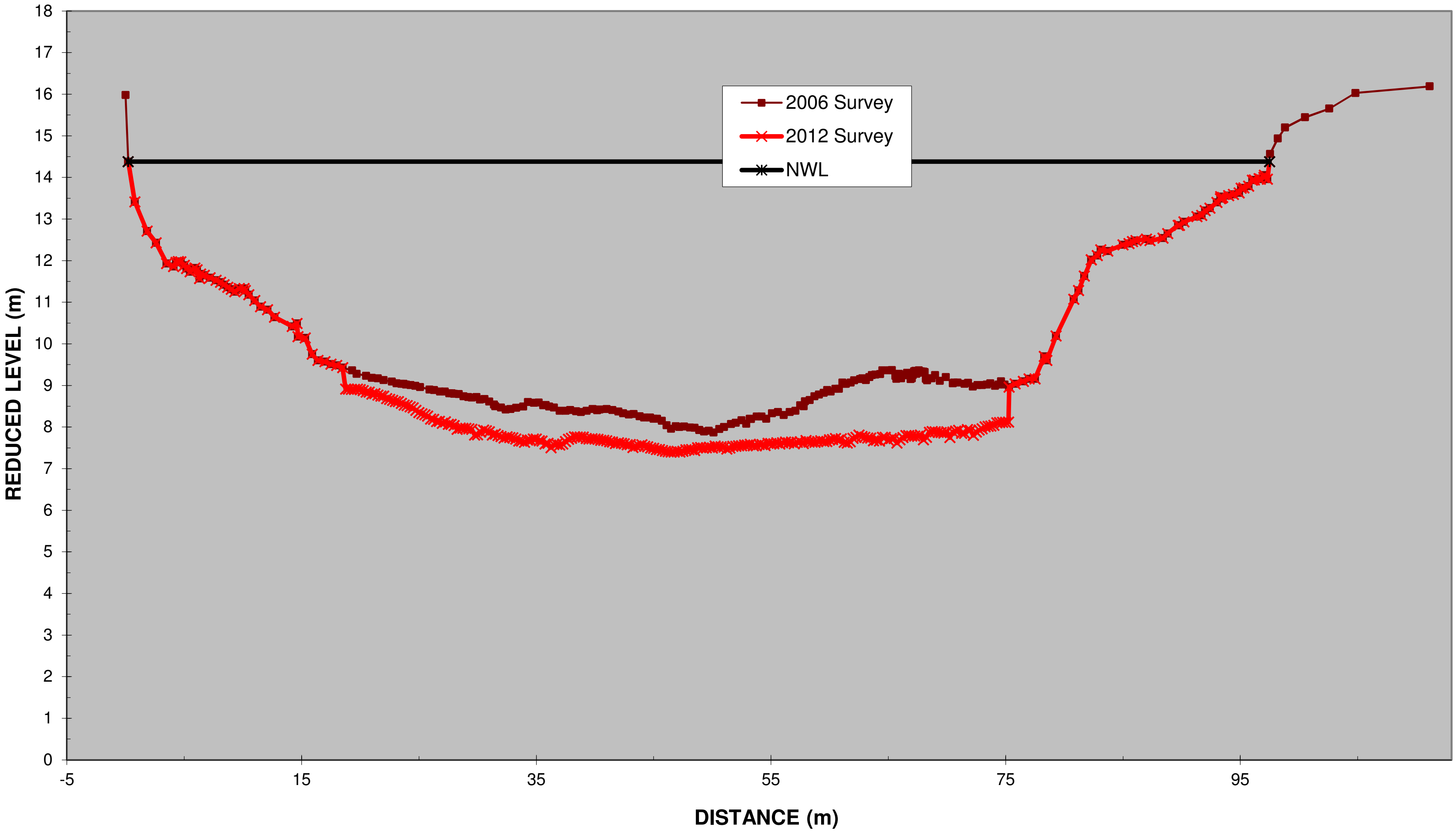
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 153



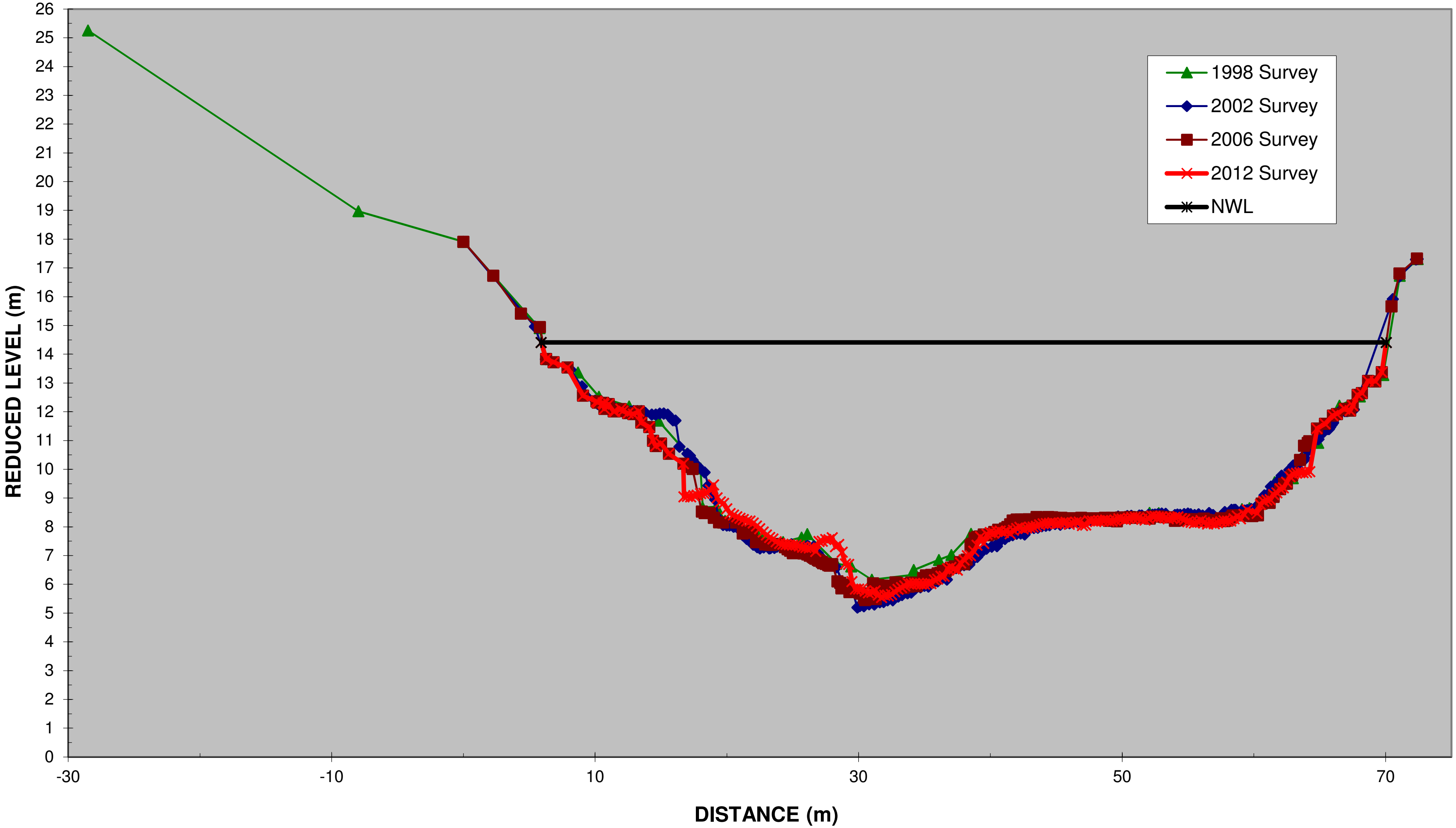
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 153A



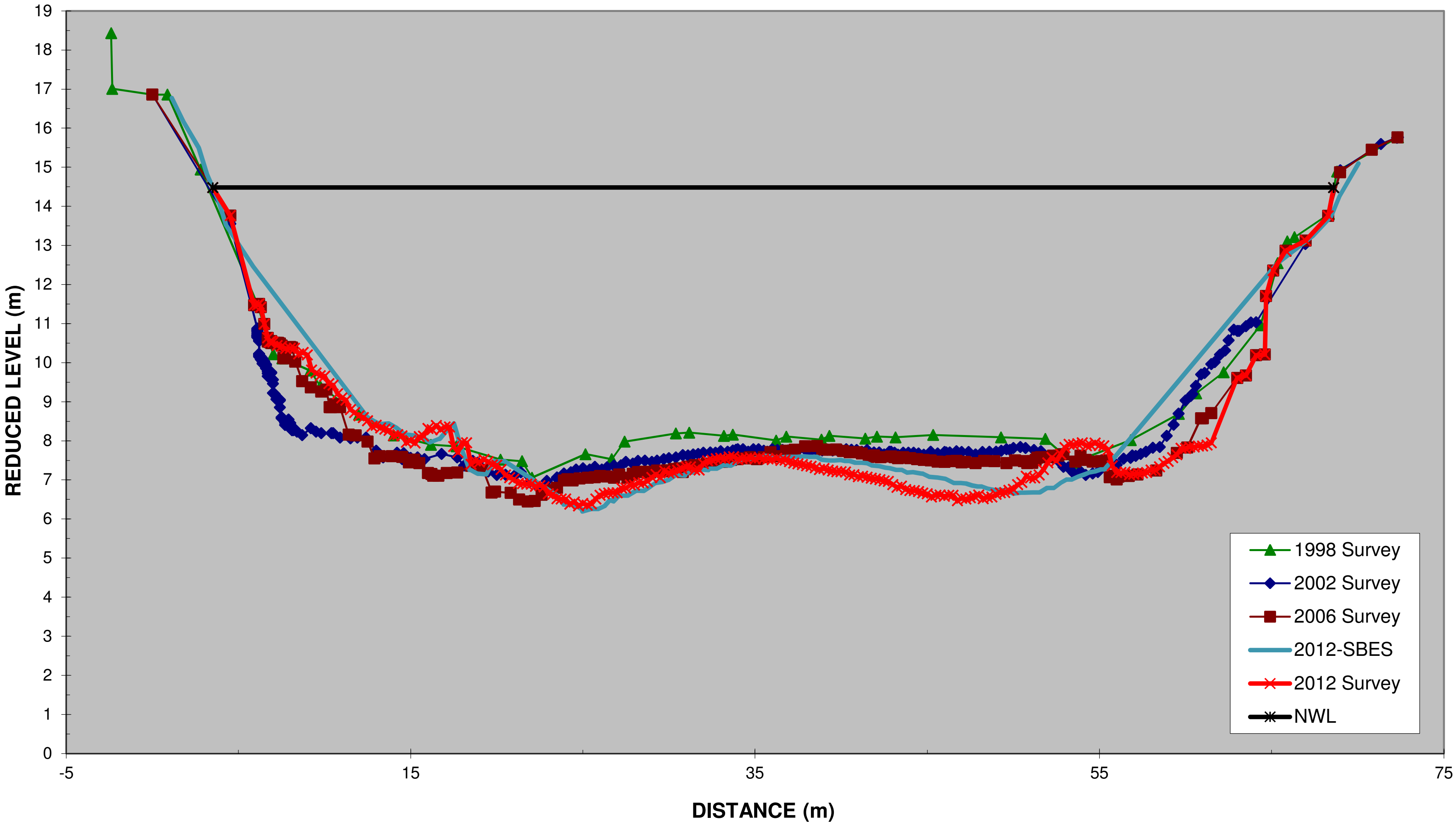
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 153Z

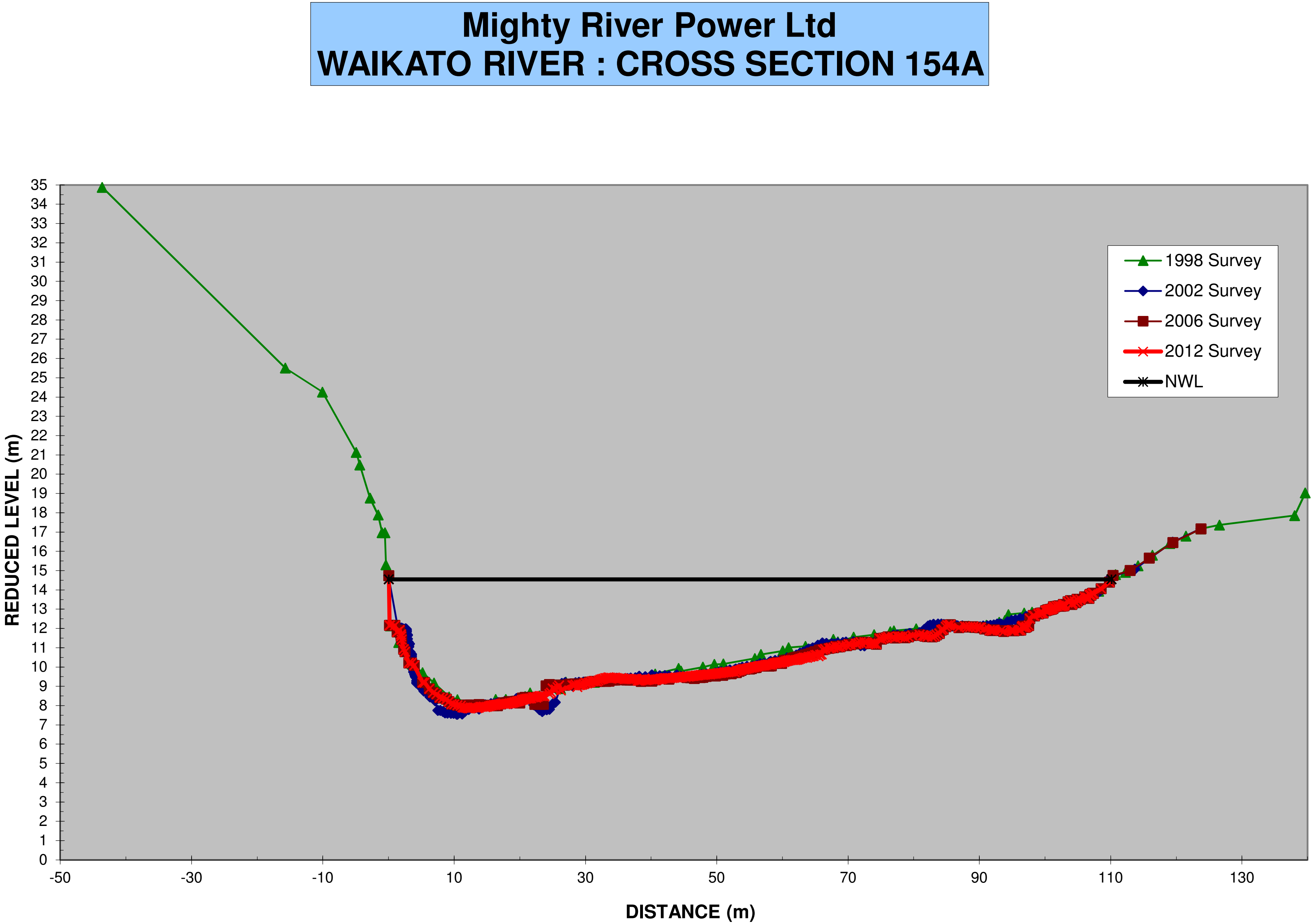


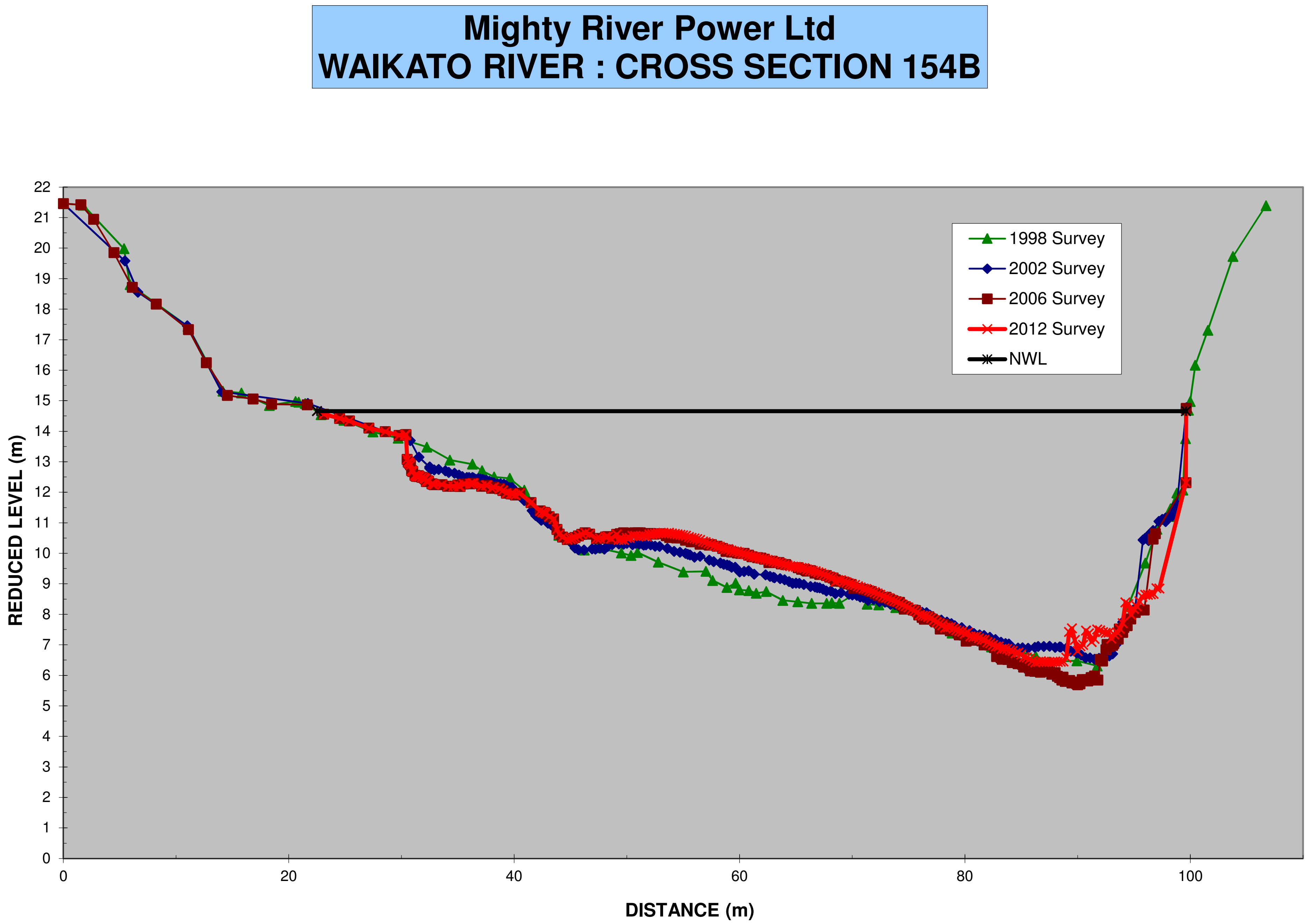
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 153B

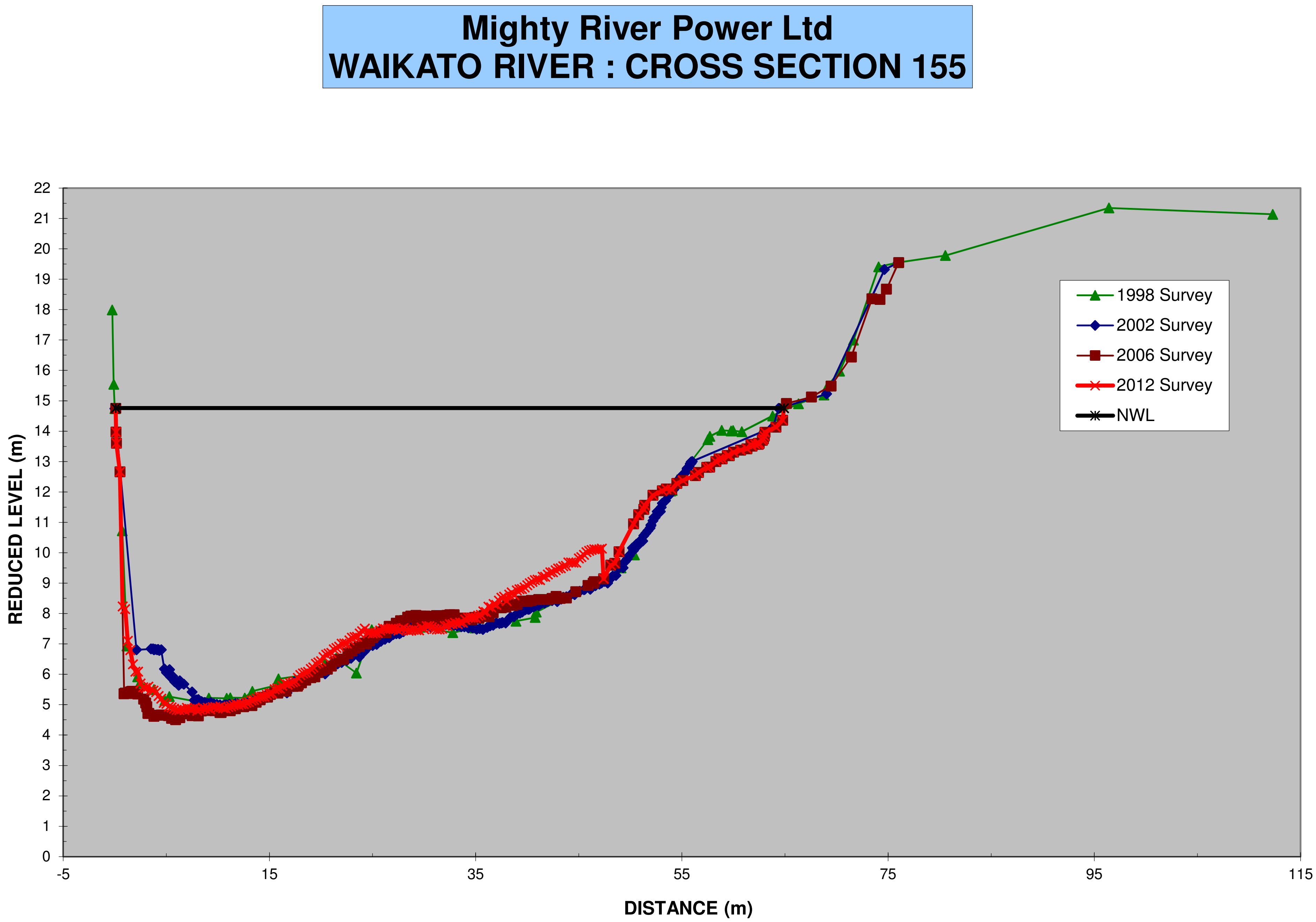


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 154

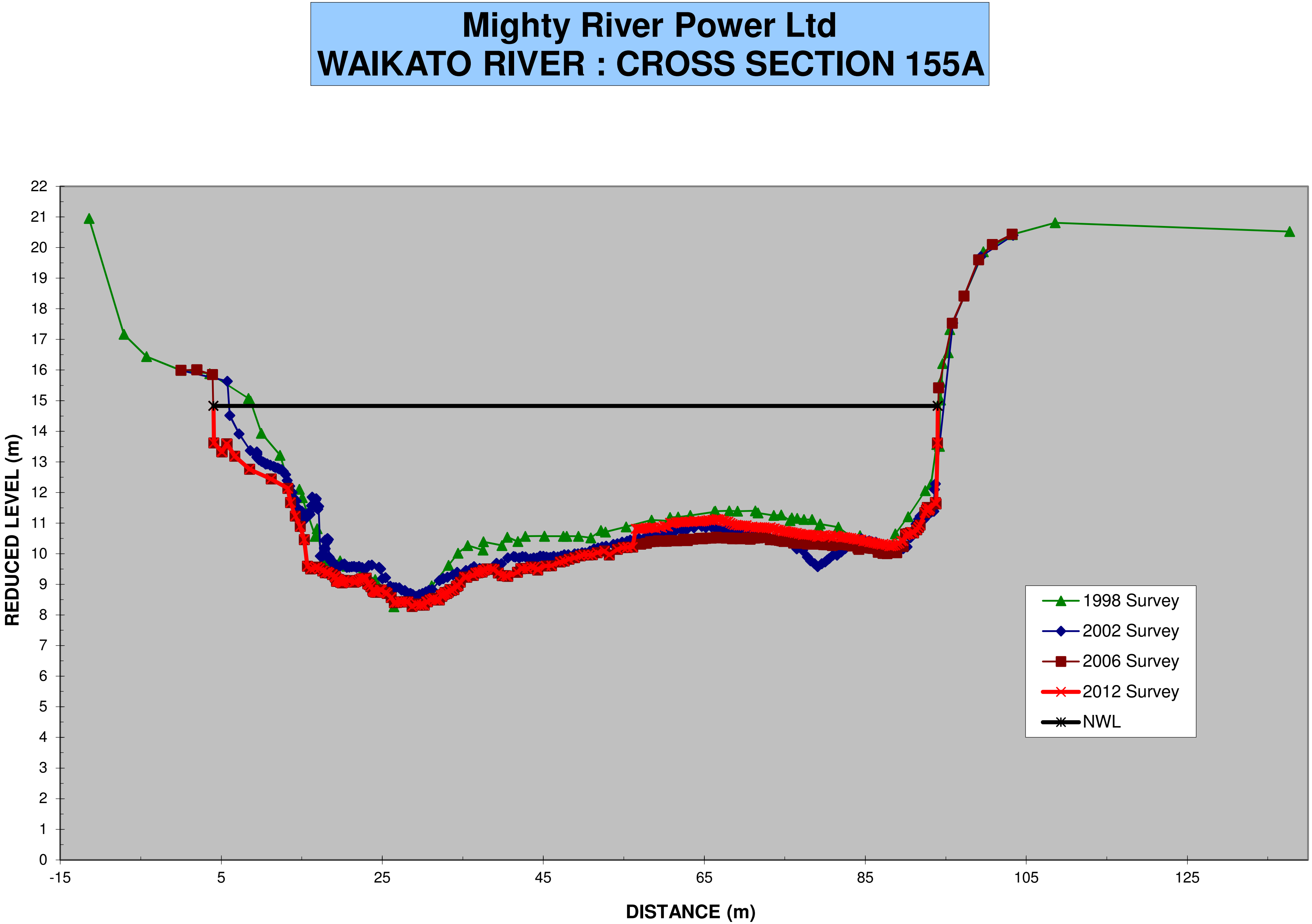



Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 154A
REDUCED LEVEL (m)
DISTANCE (m)
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-50
-30
-10
10
30
50
70
90
110
130


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 154B
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
REDUCED LEVEL (m)
DISTANCE (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
20
40
60
80
100

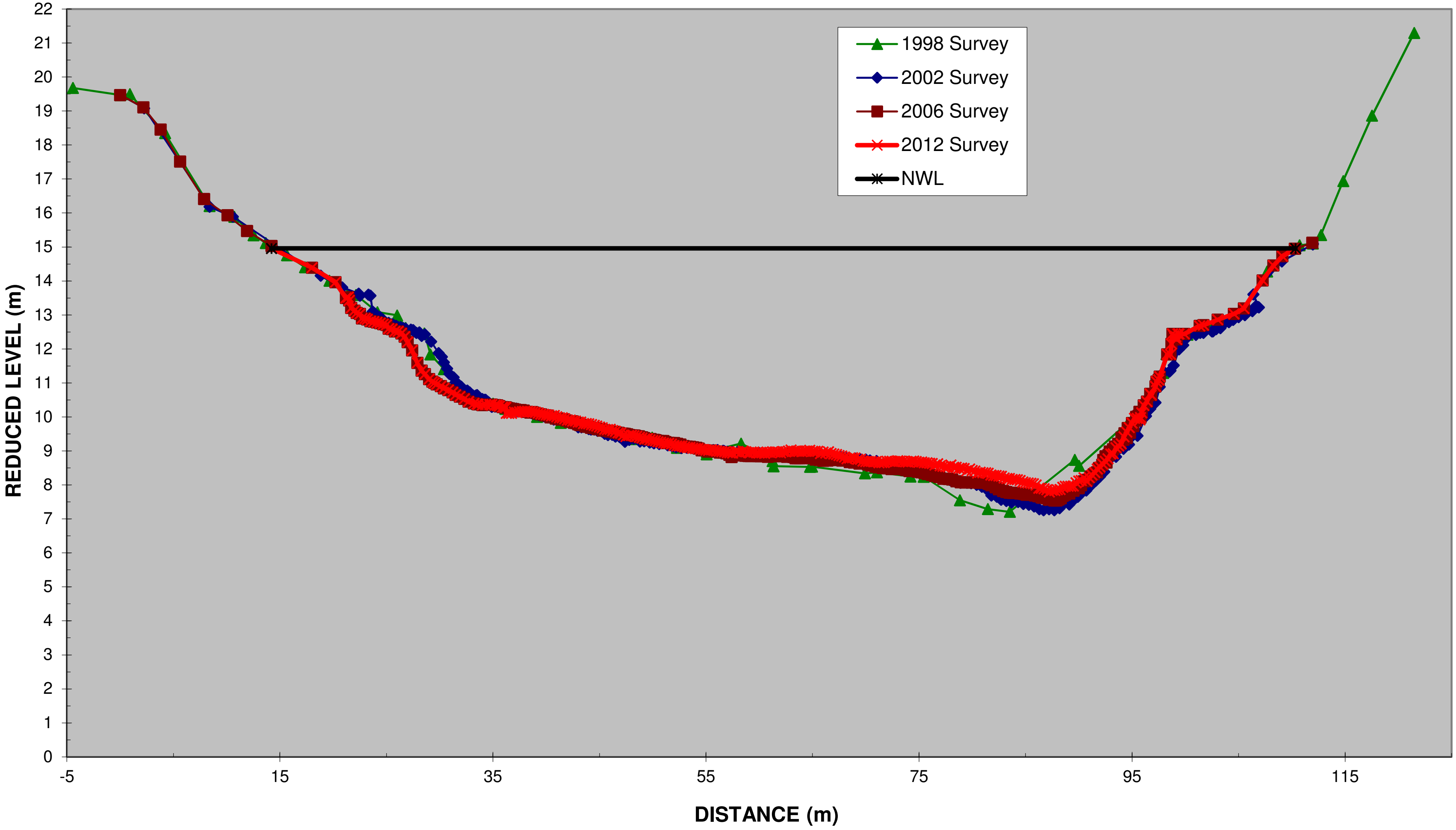


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 155
REDUCED LEVEL (m)
DISTANCE (m)
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-5
15
35
55
75
95
115

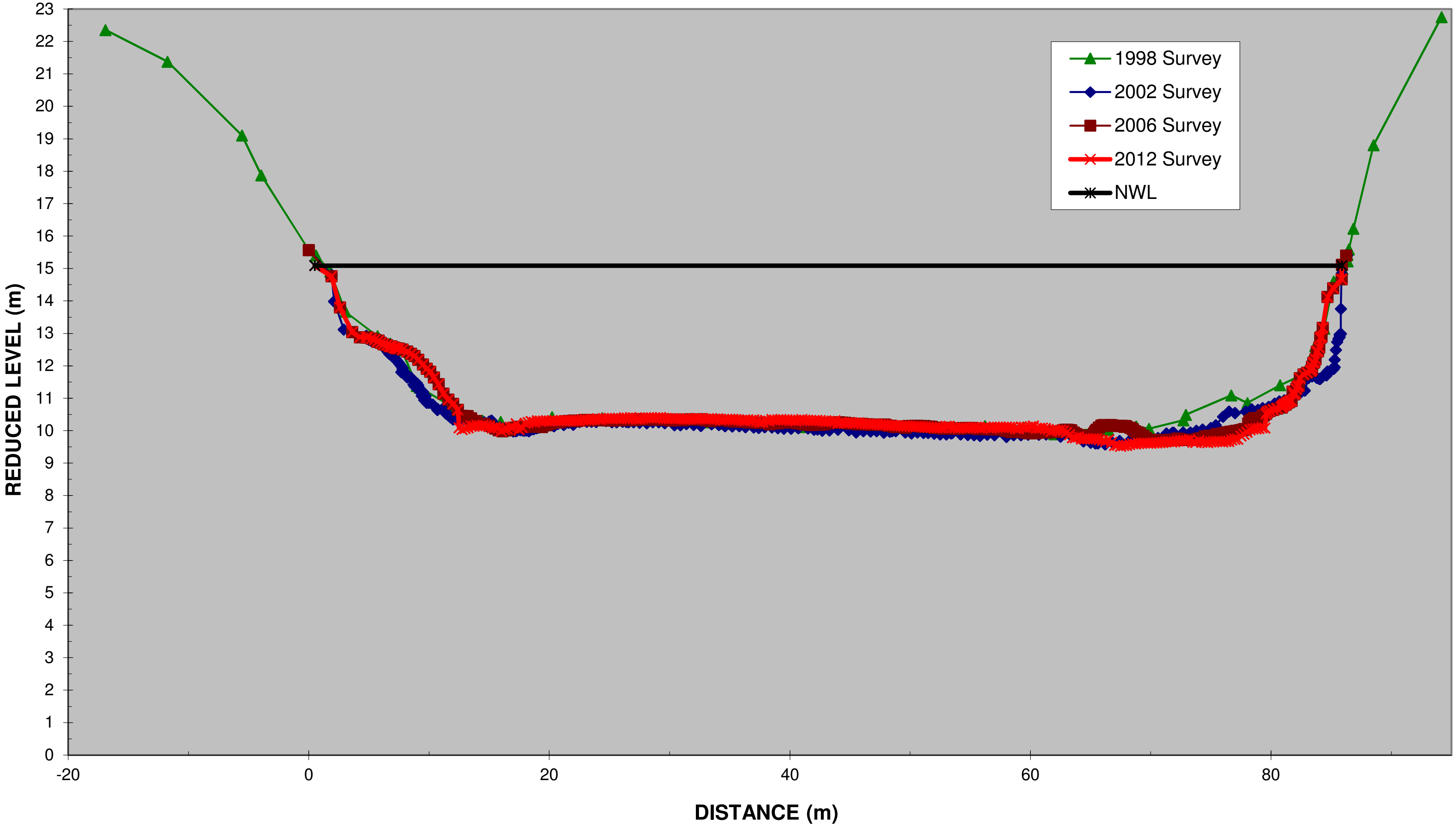


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 155A
REDUCED LEVEL (m)
DISTANCE (m)
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-15
5
25
45
65
85
105
125

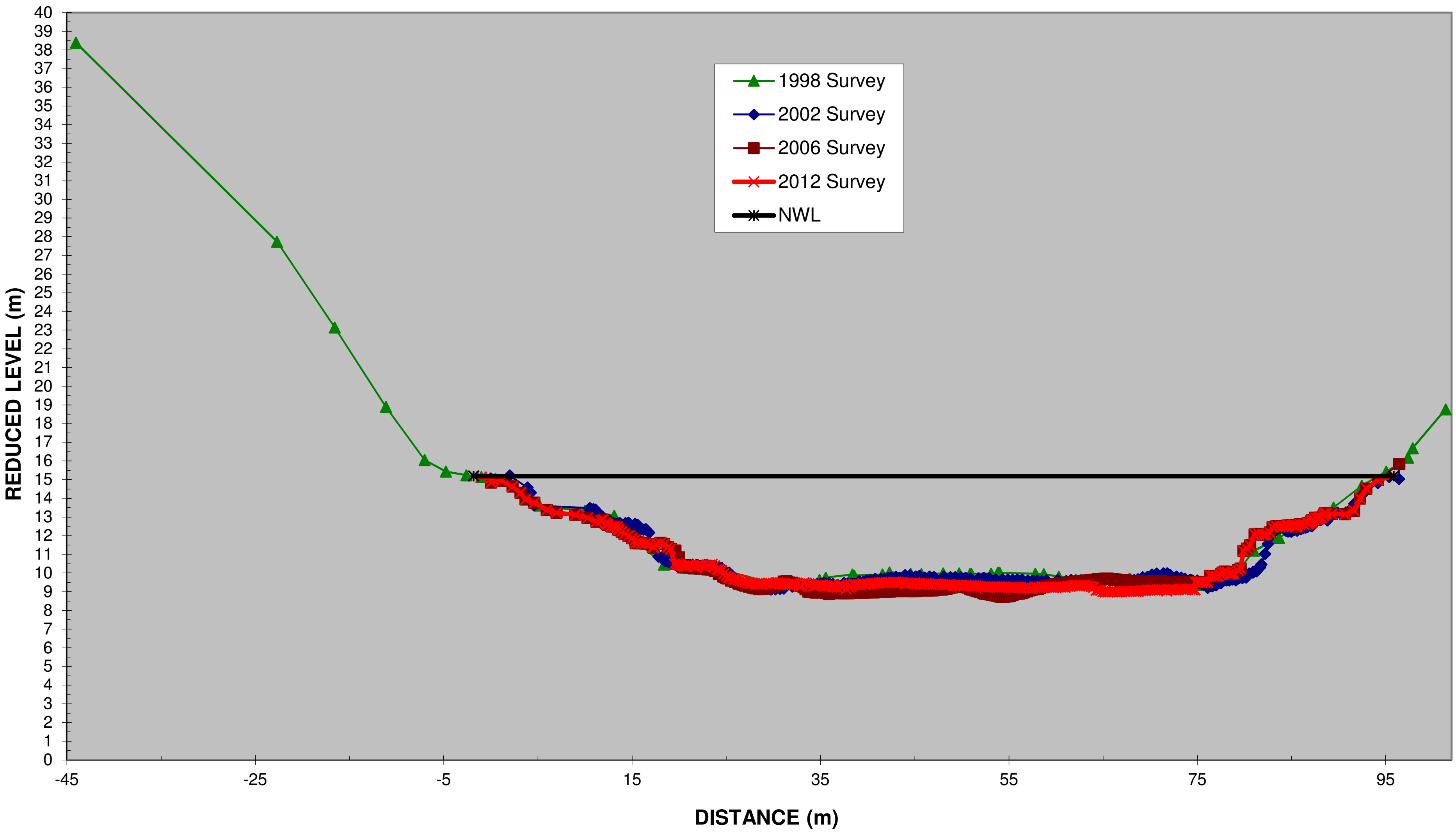
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 156



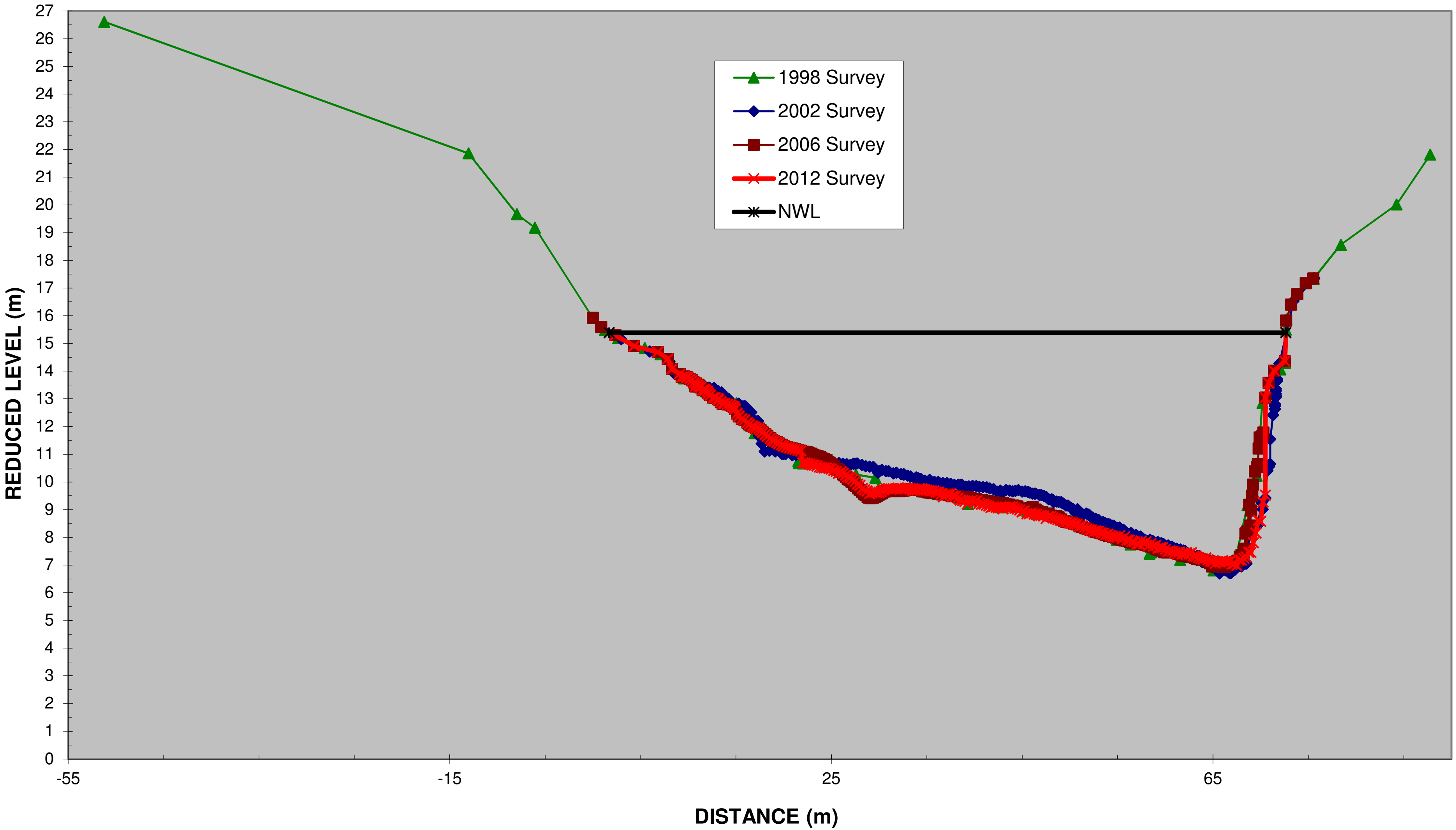
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 156A



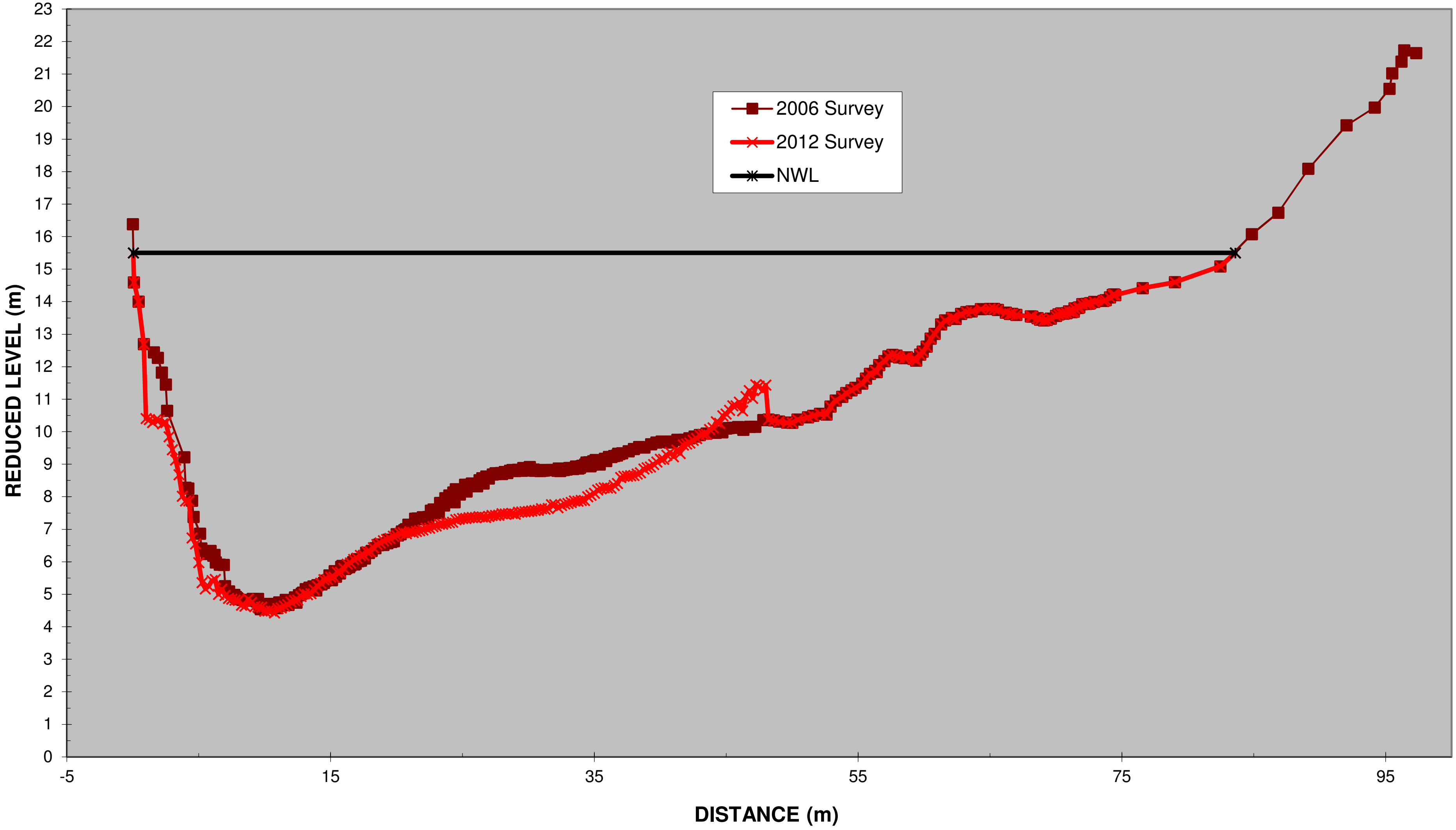
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 157



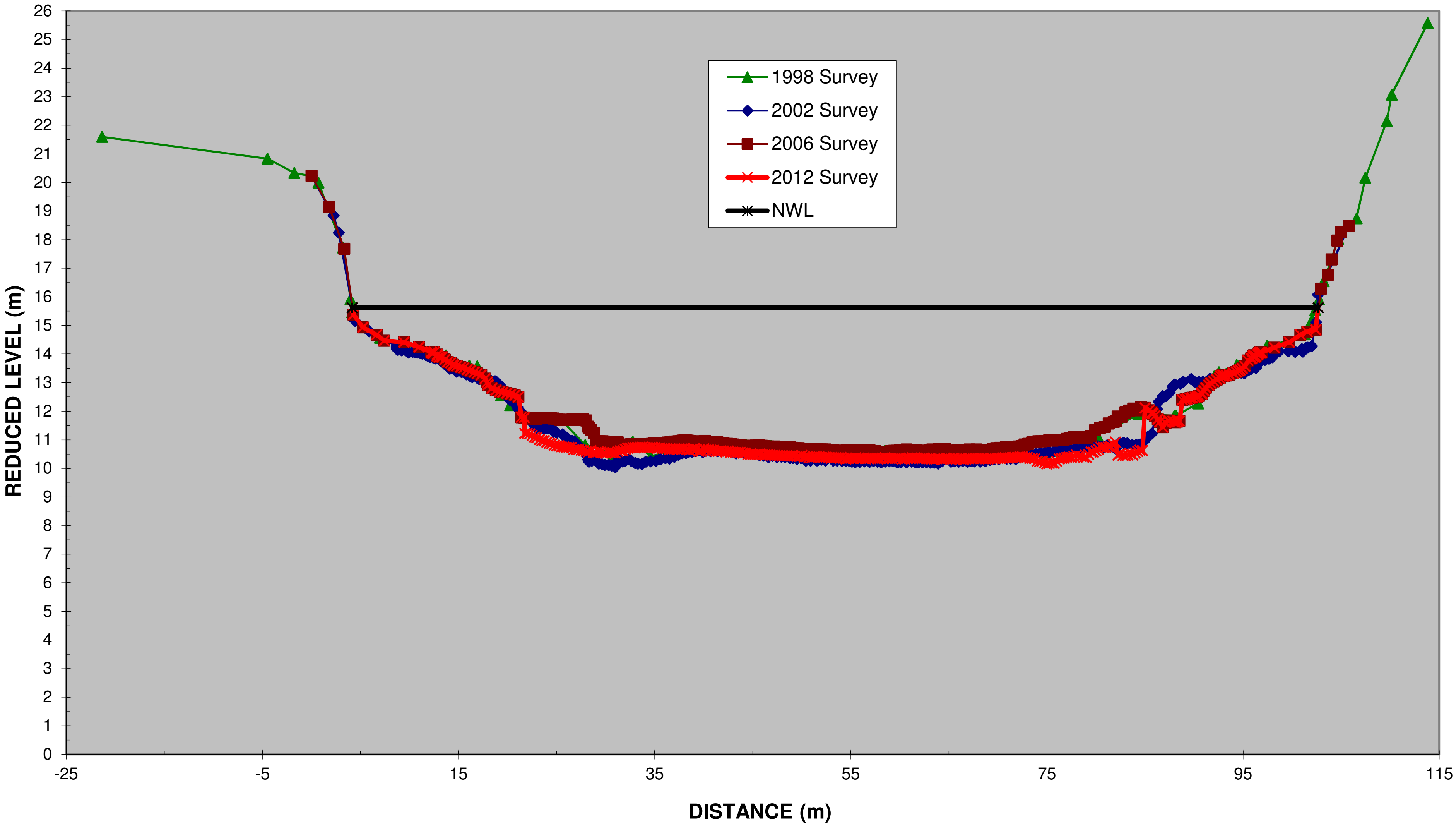
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 157A



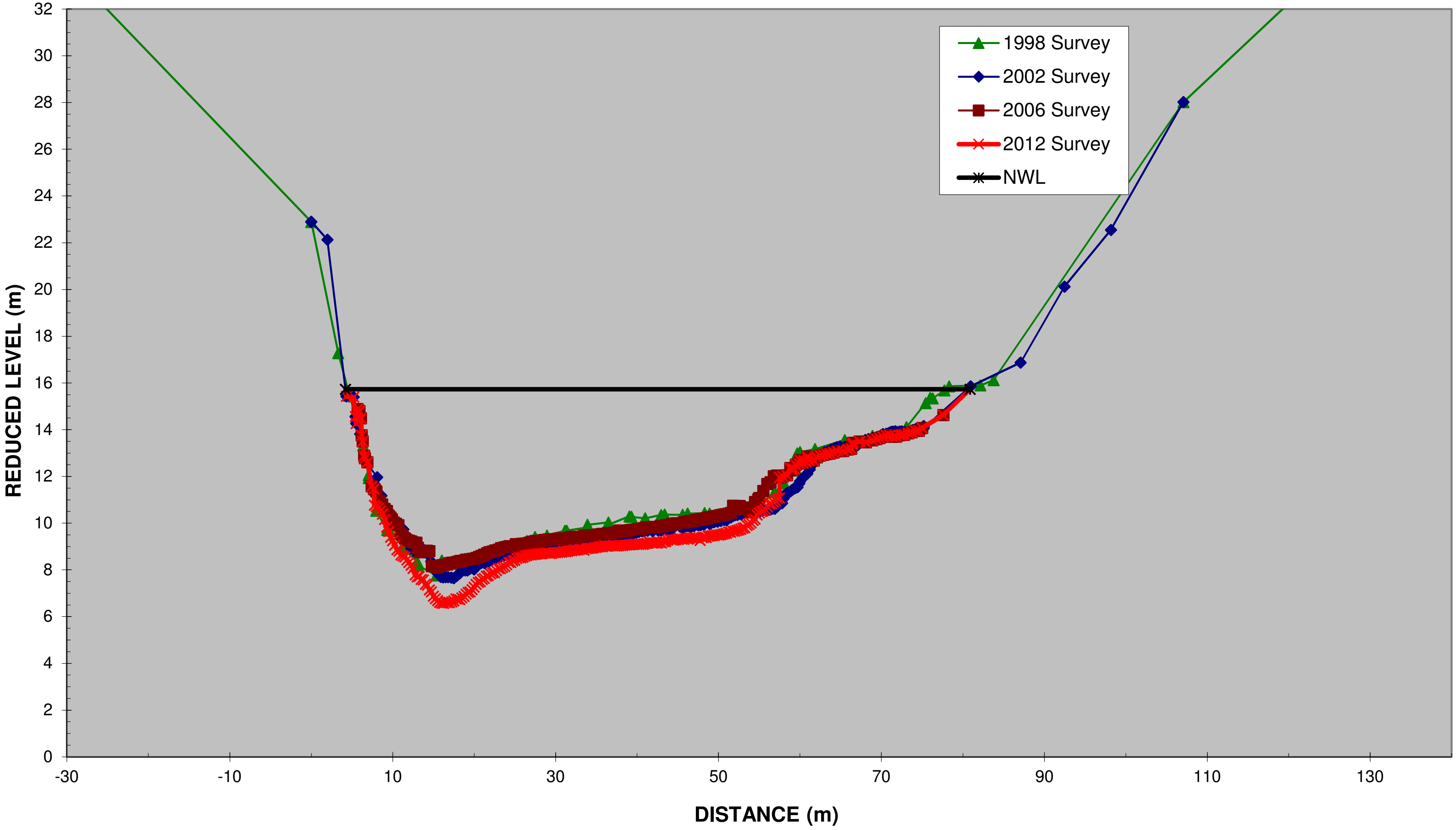
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 157G



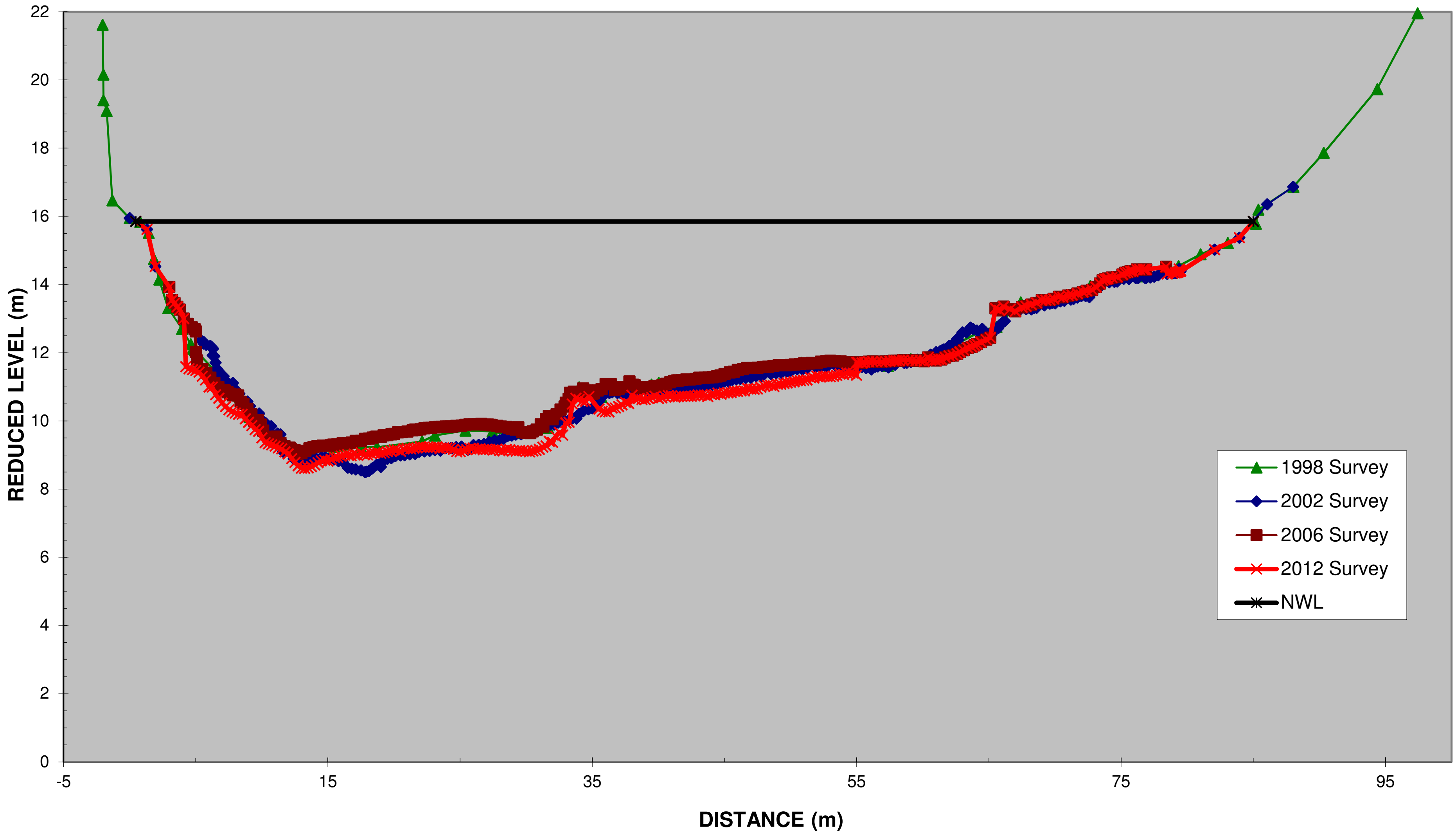
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 157B

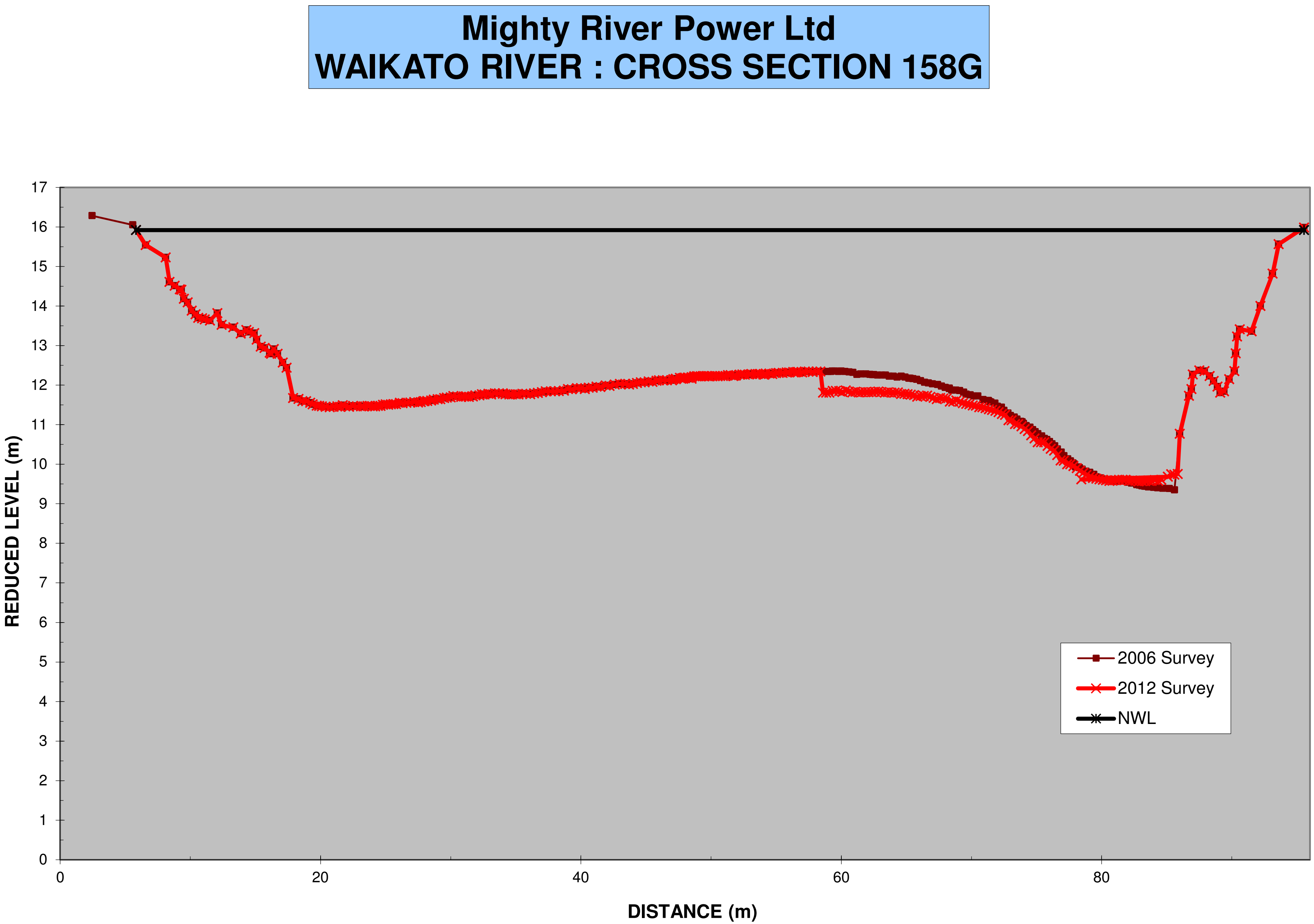


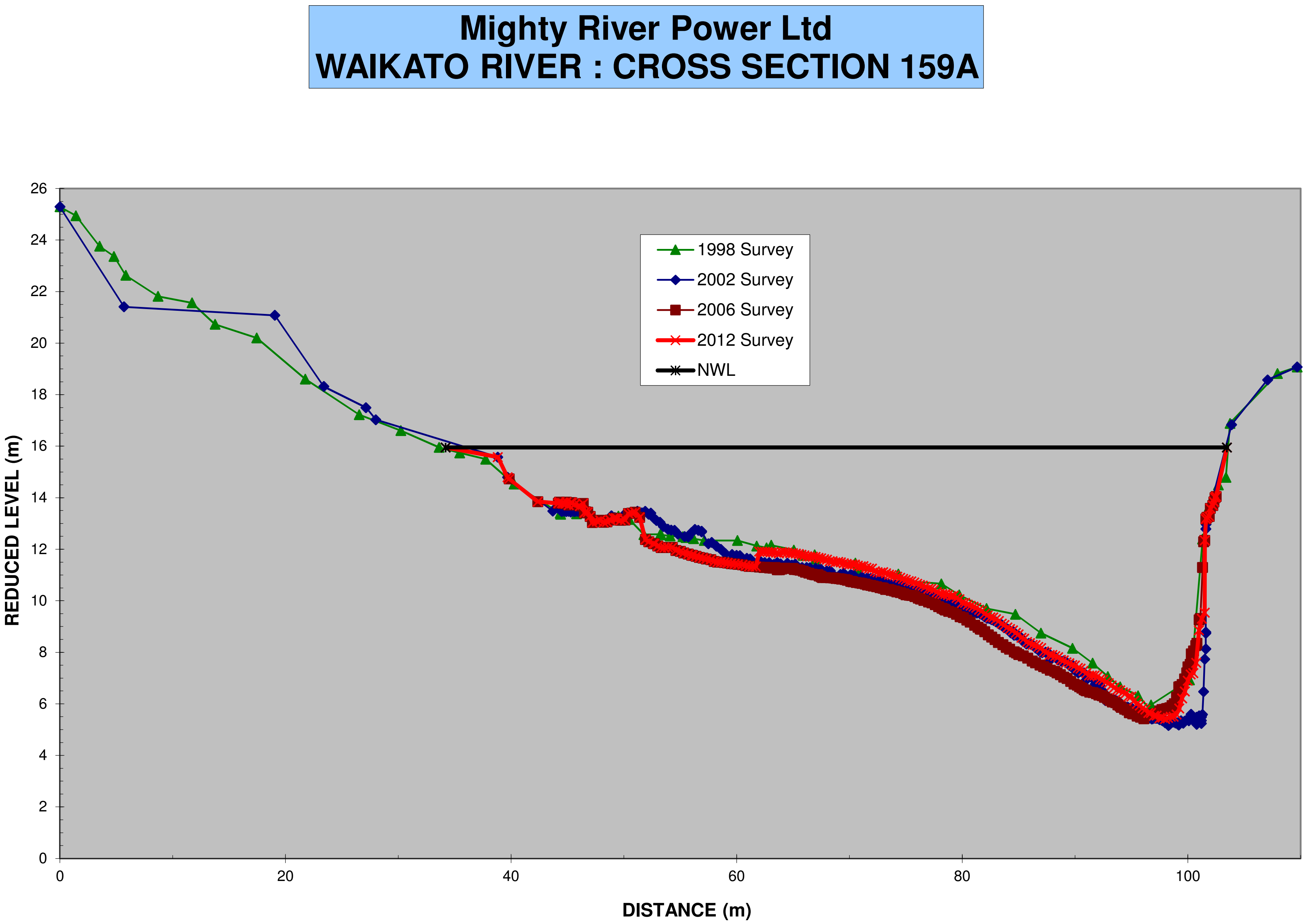
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 158



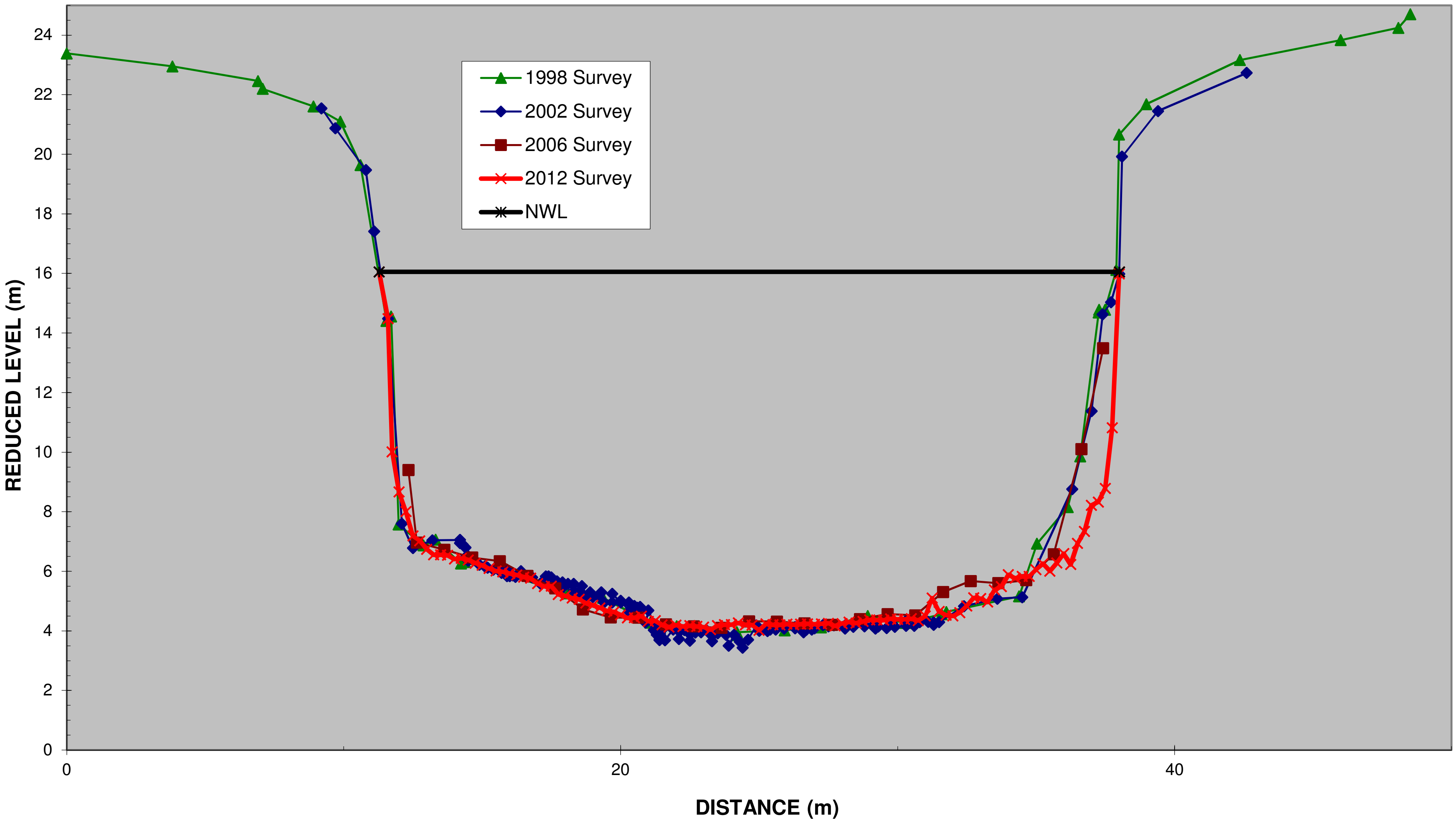
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 158A



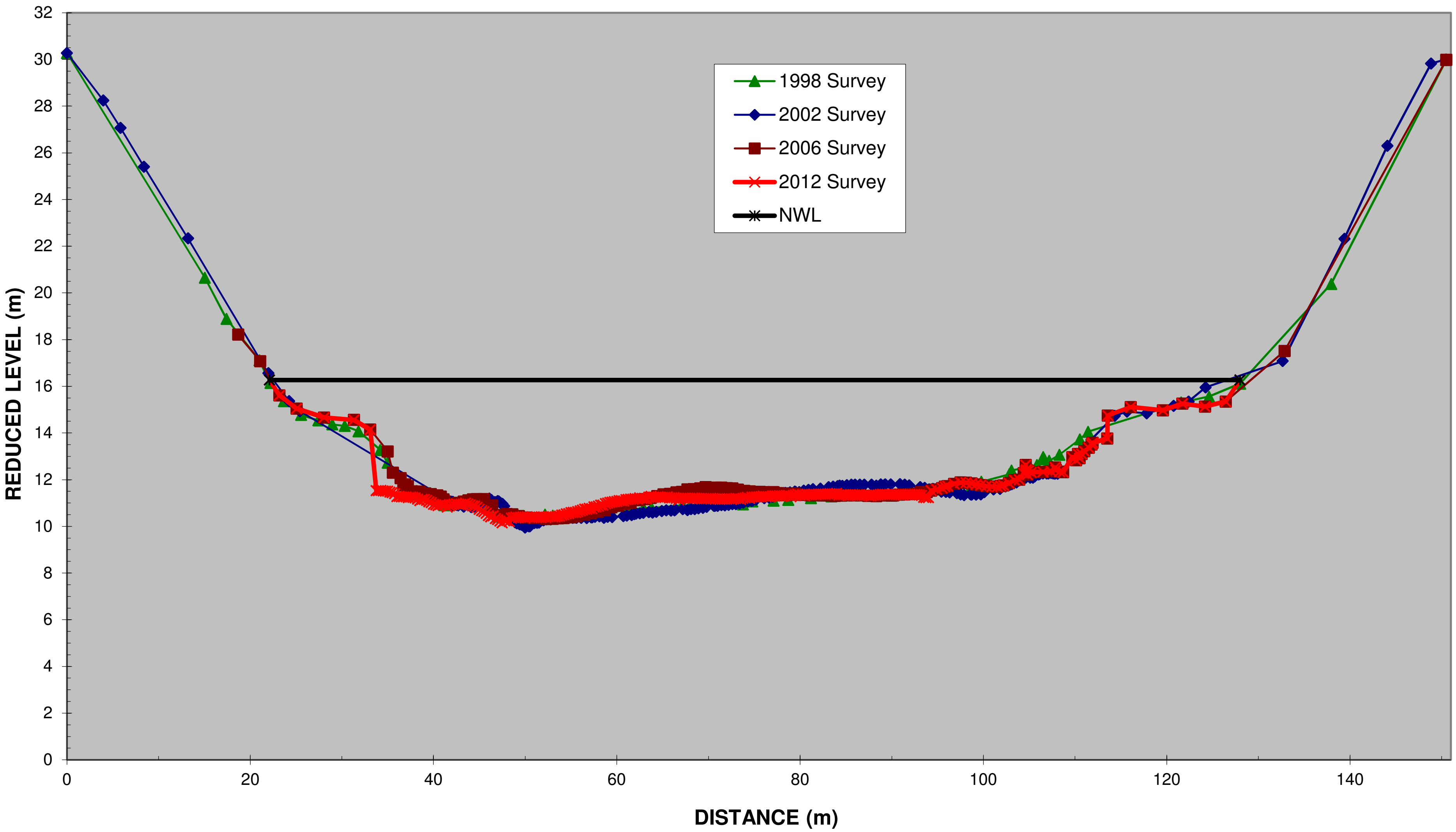

Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 158G
REDUCED LEVEL (m)
DISTANCE (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
0
20
40
60
80
2006 Survey
2012 Survey
NWL


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 159A
1998 Survey
2002 Survey
2006 Survey
2012 Survey
NWL
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
20
40
60
80
100

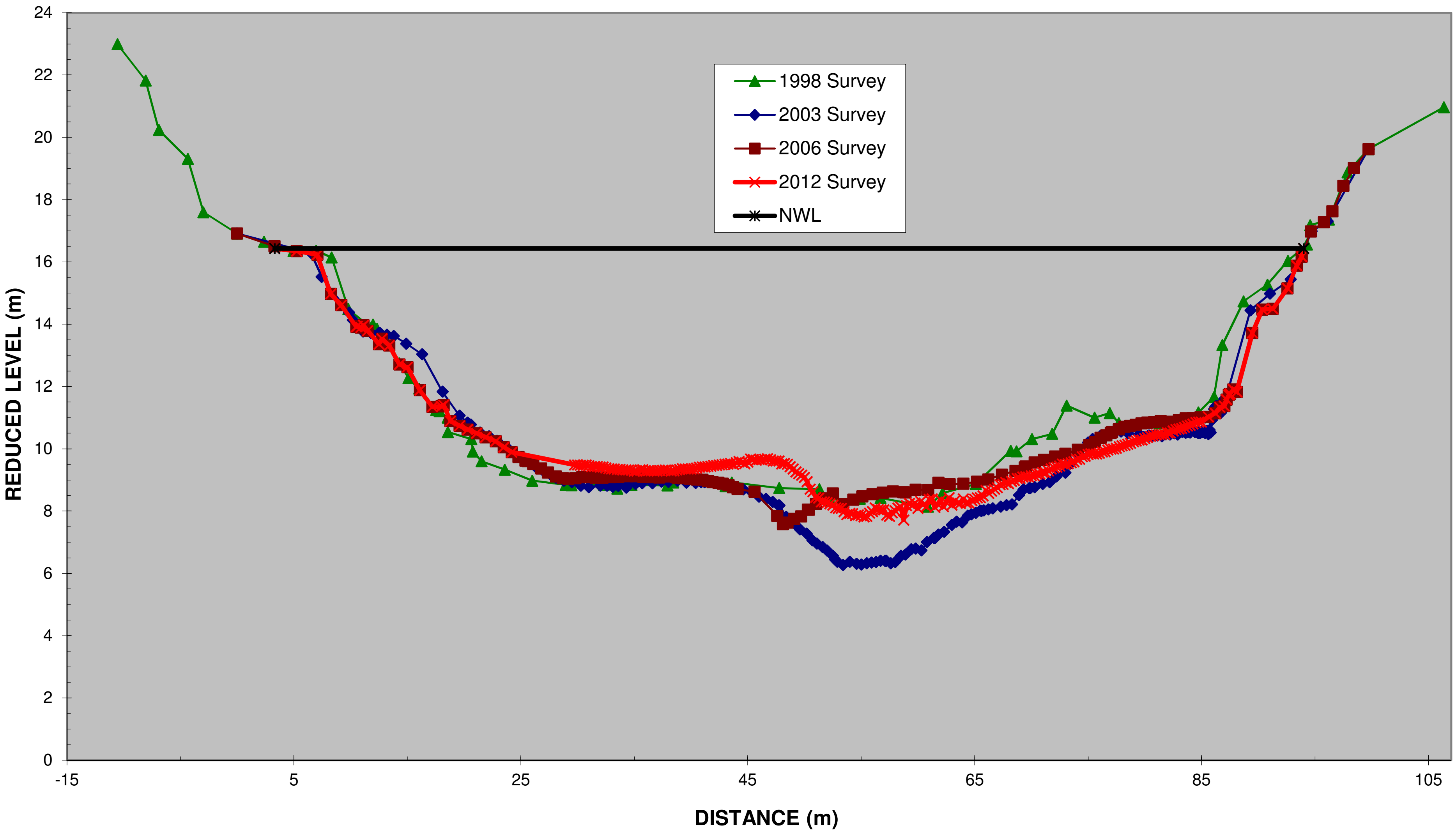
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 159



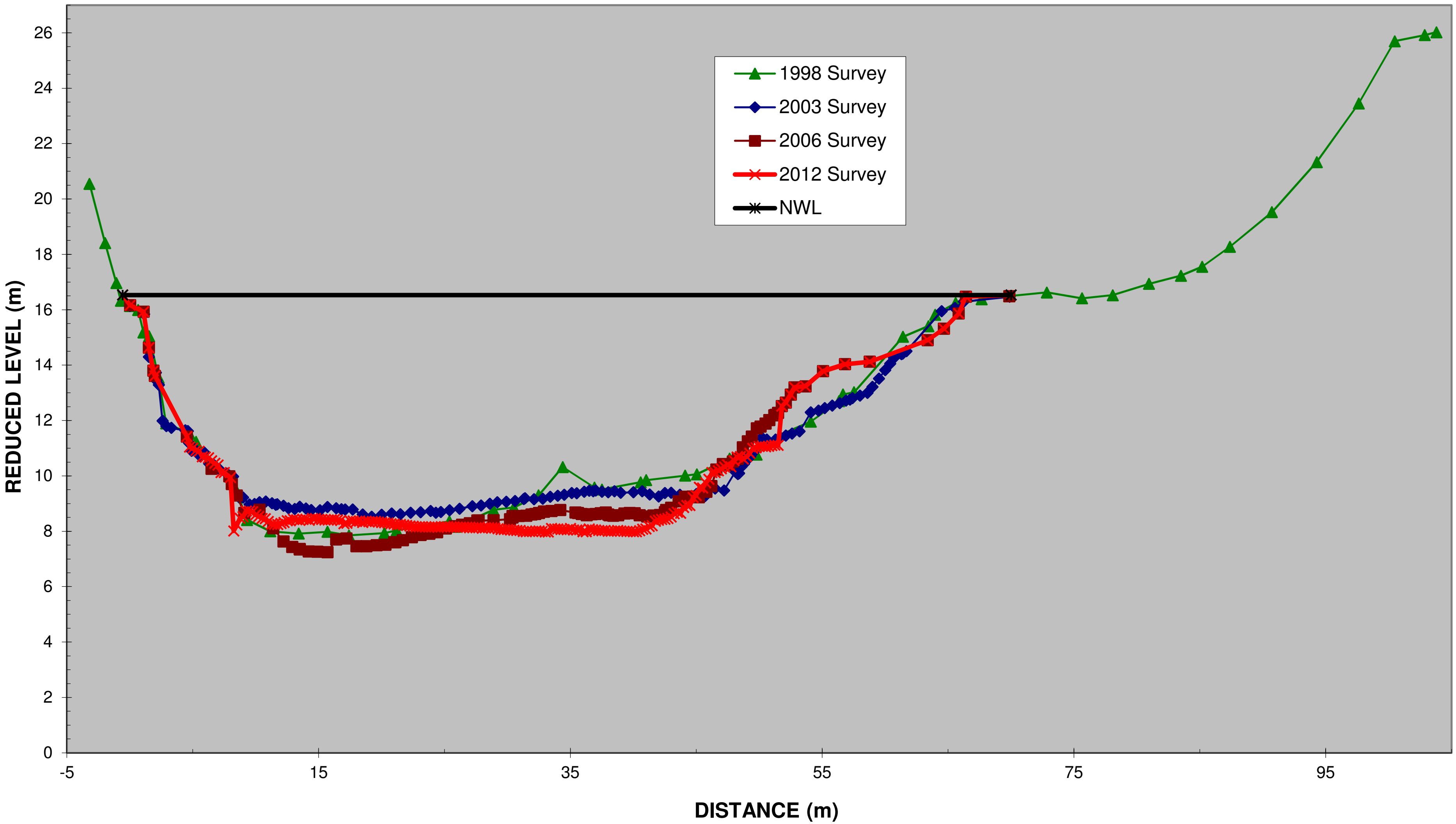
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 160



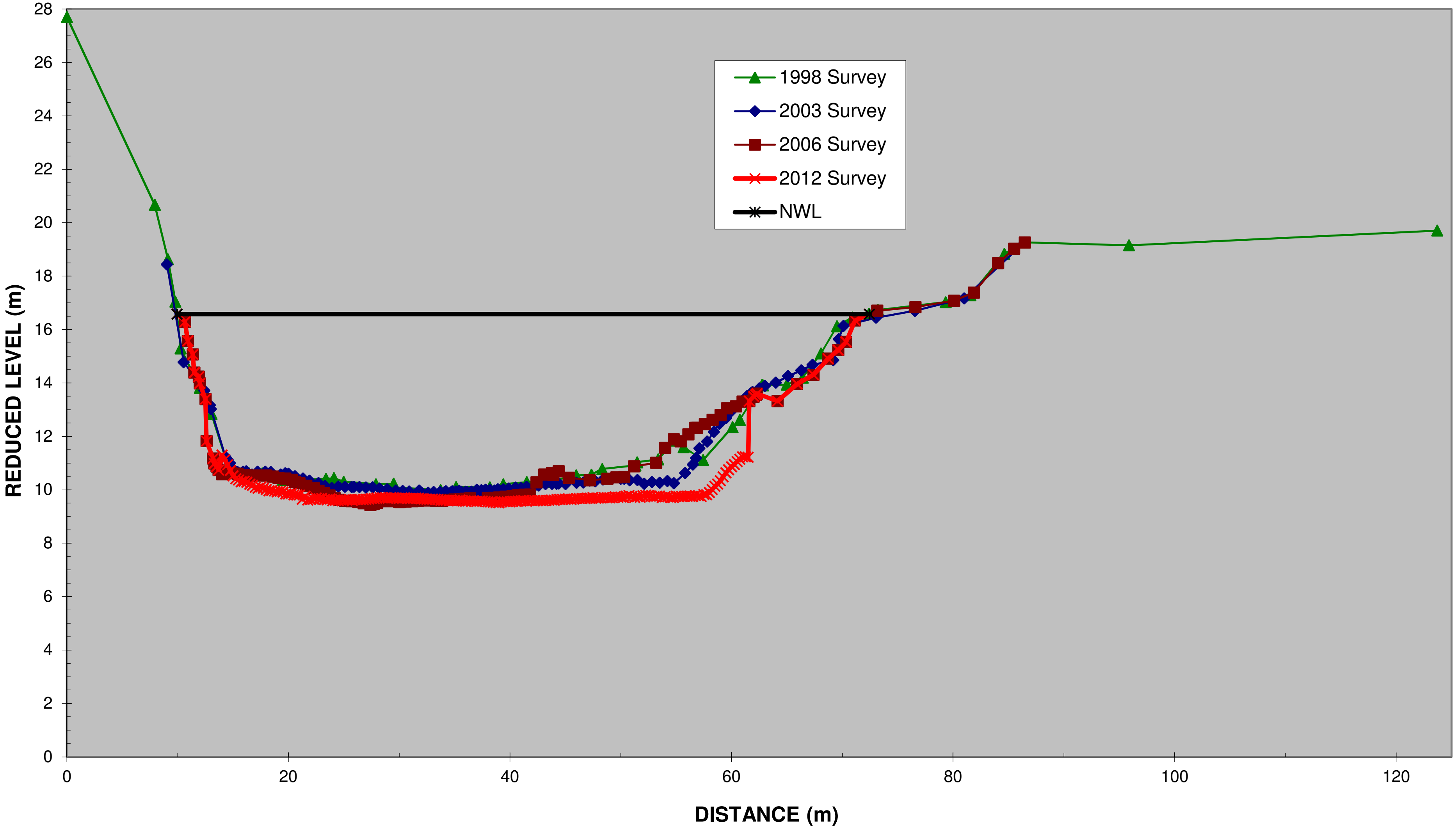
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 161A



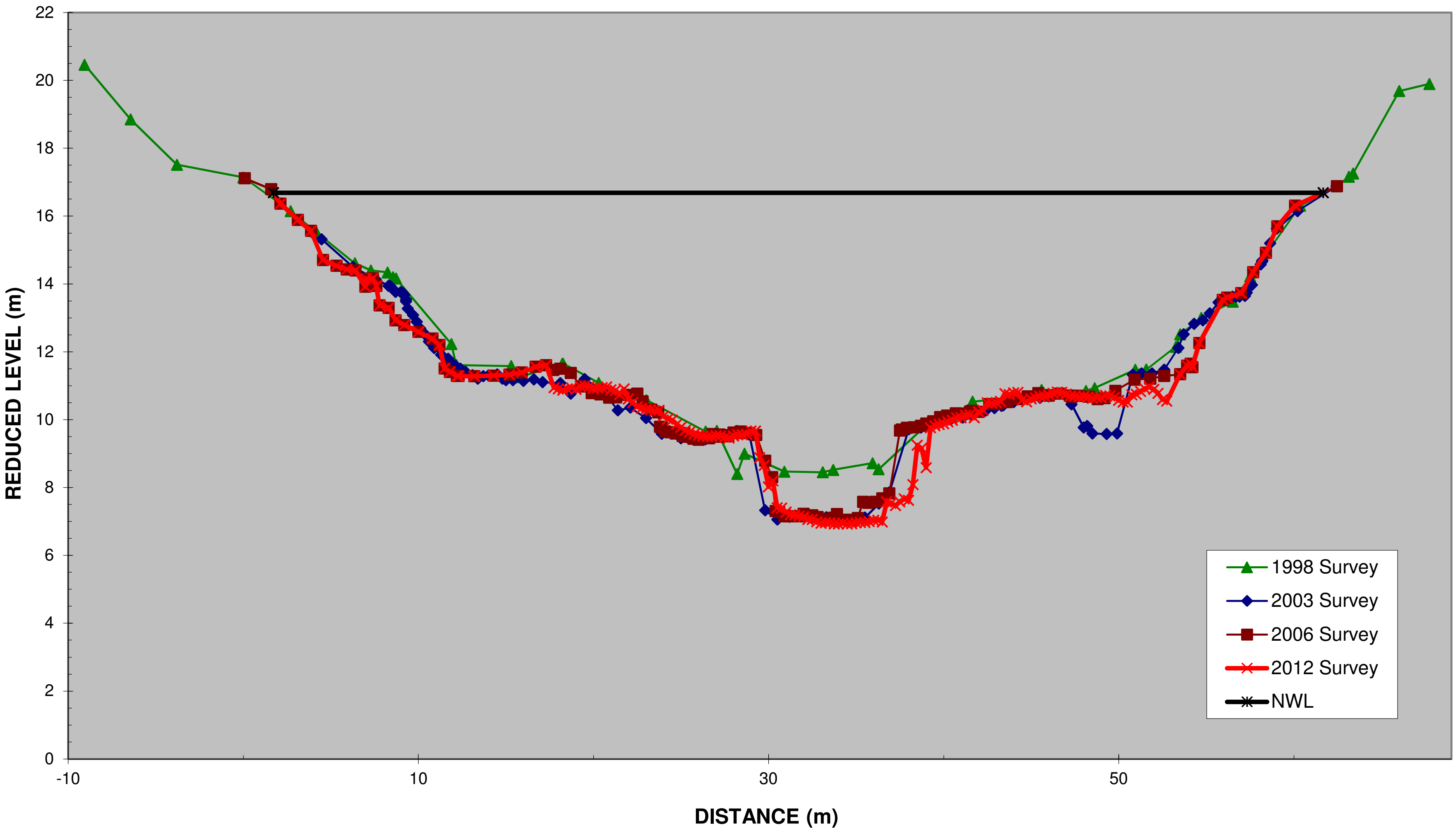
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 161B



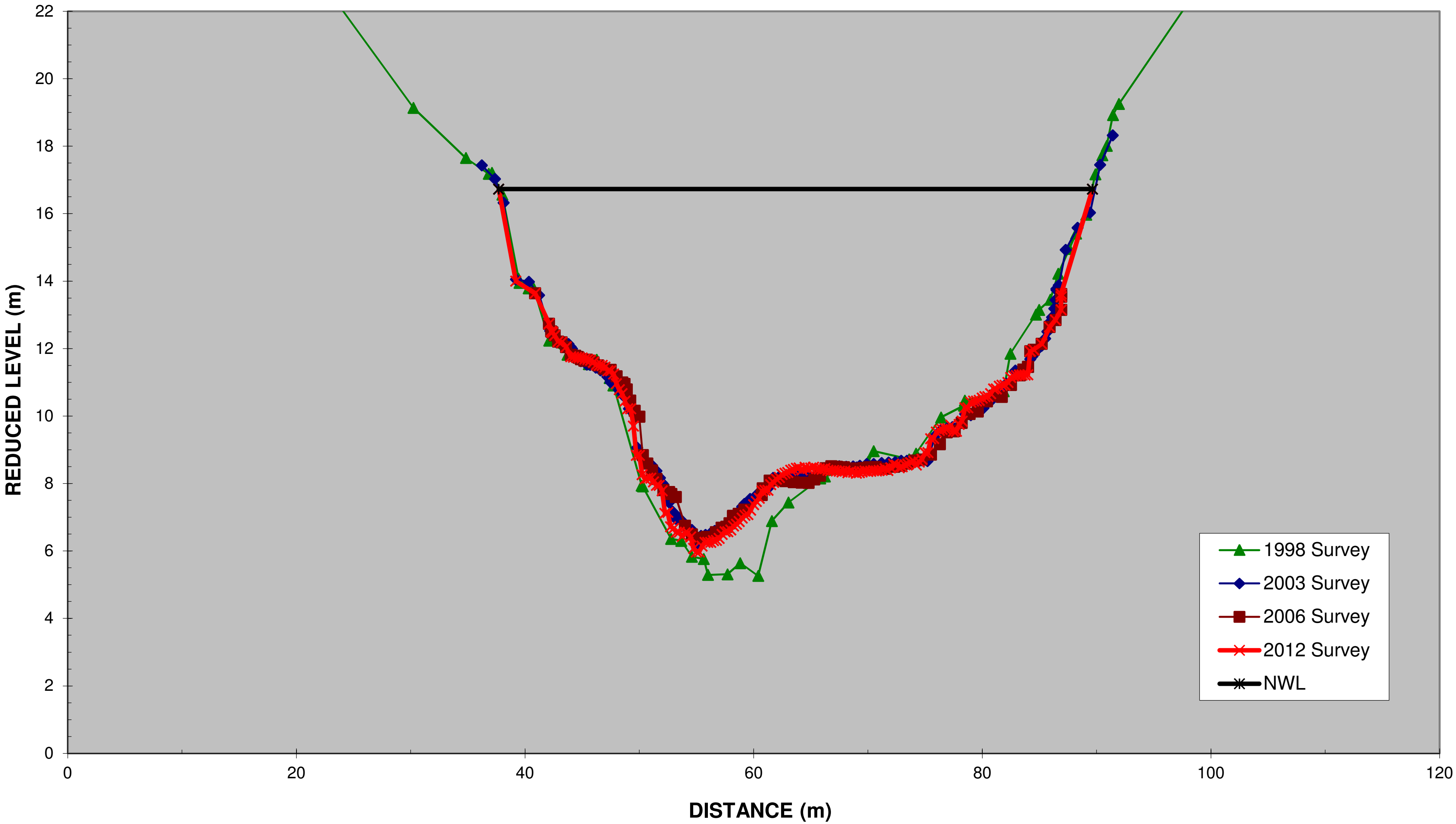
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 162



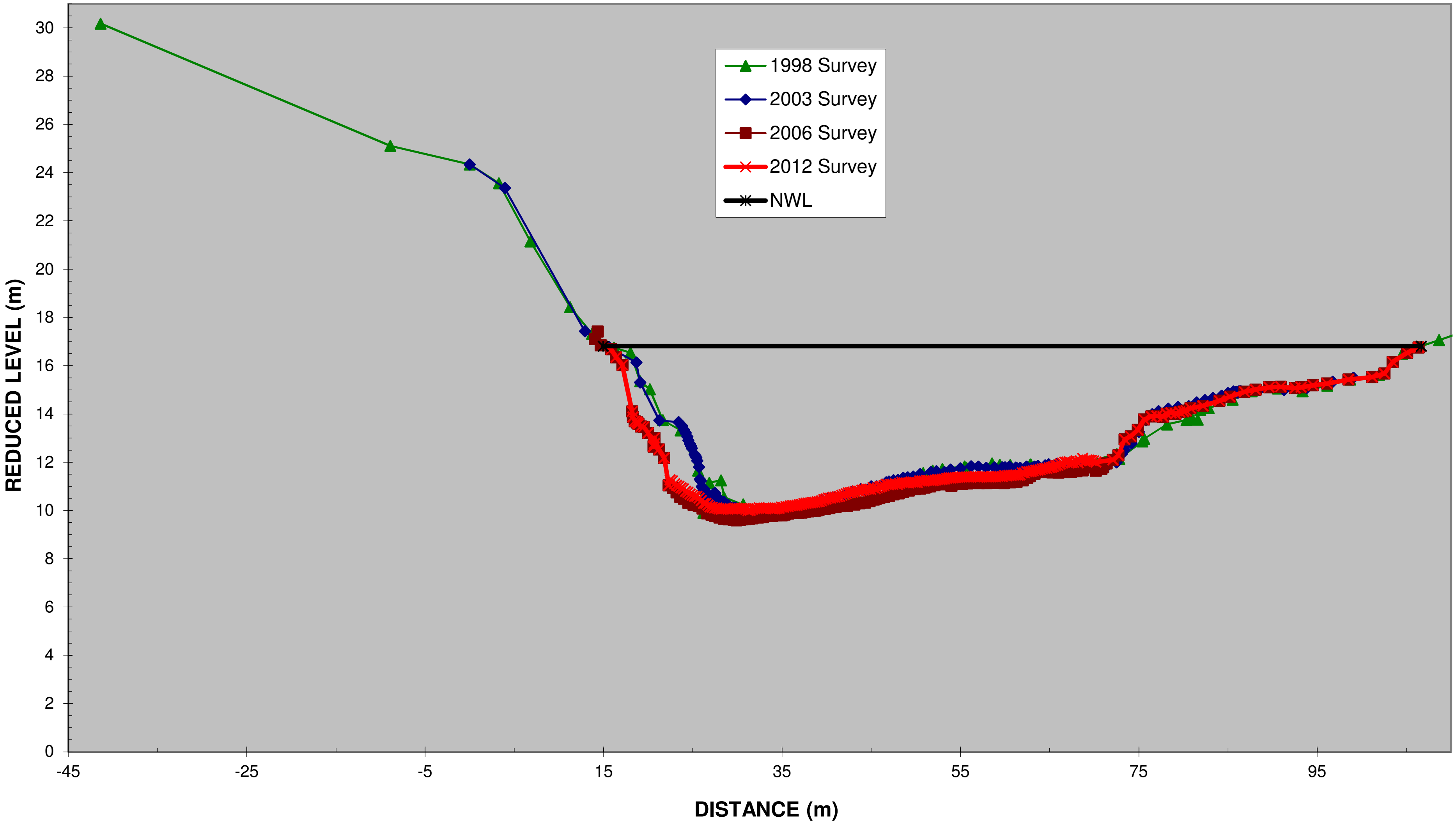
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 162A



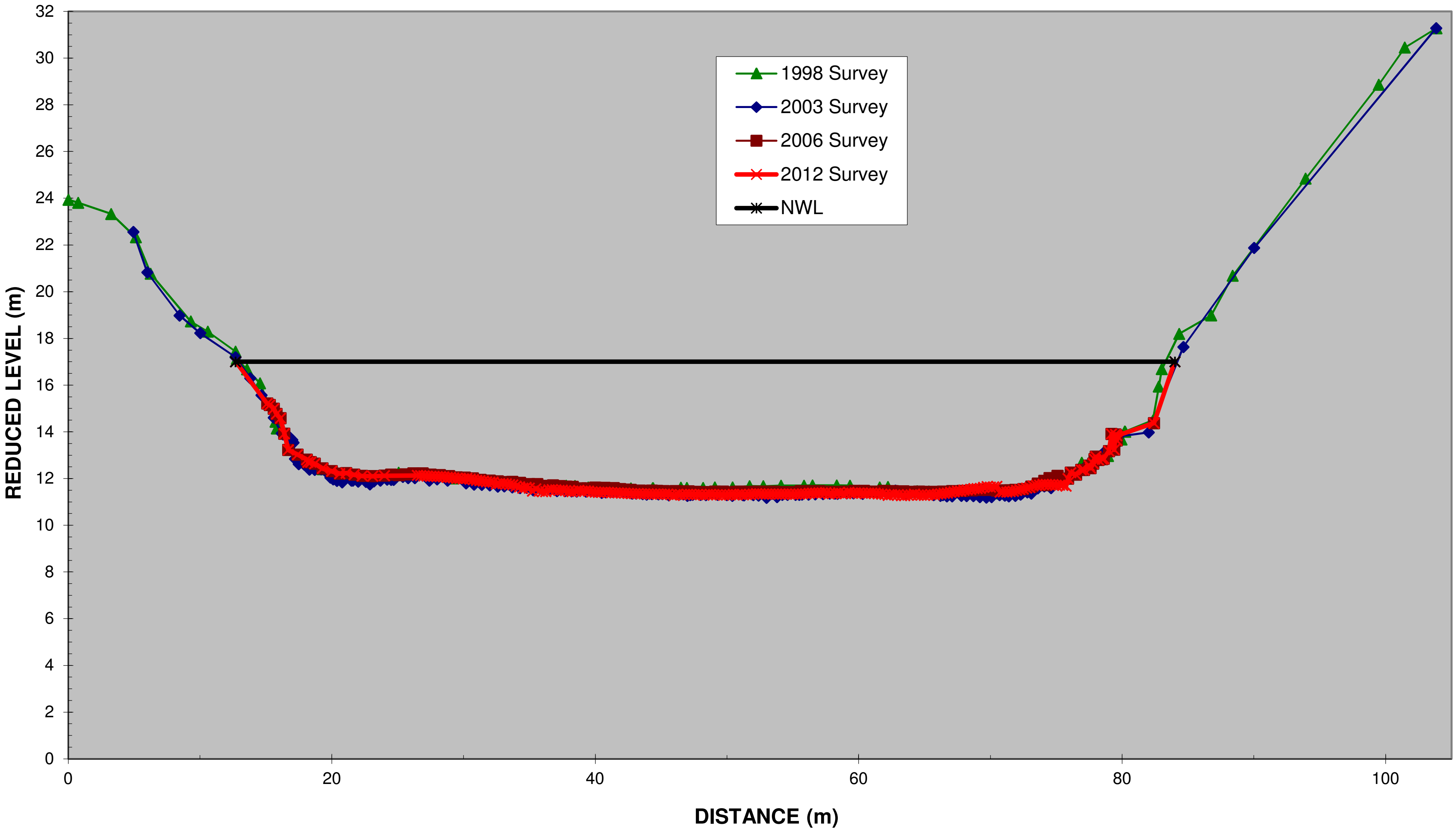
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 163



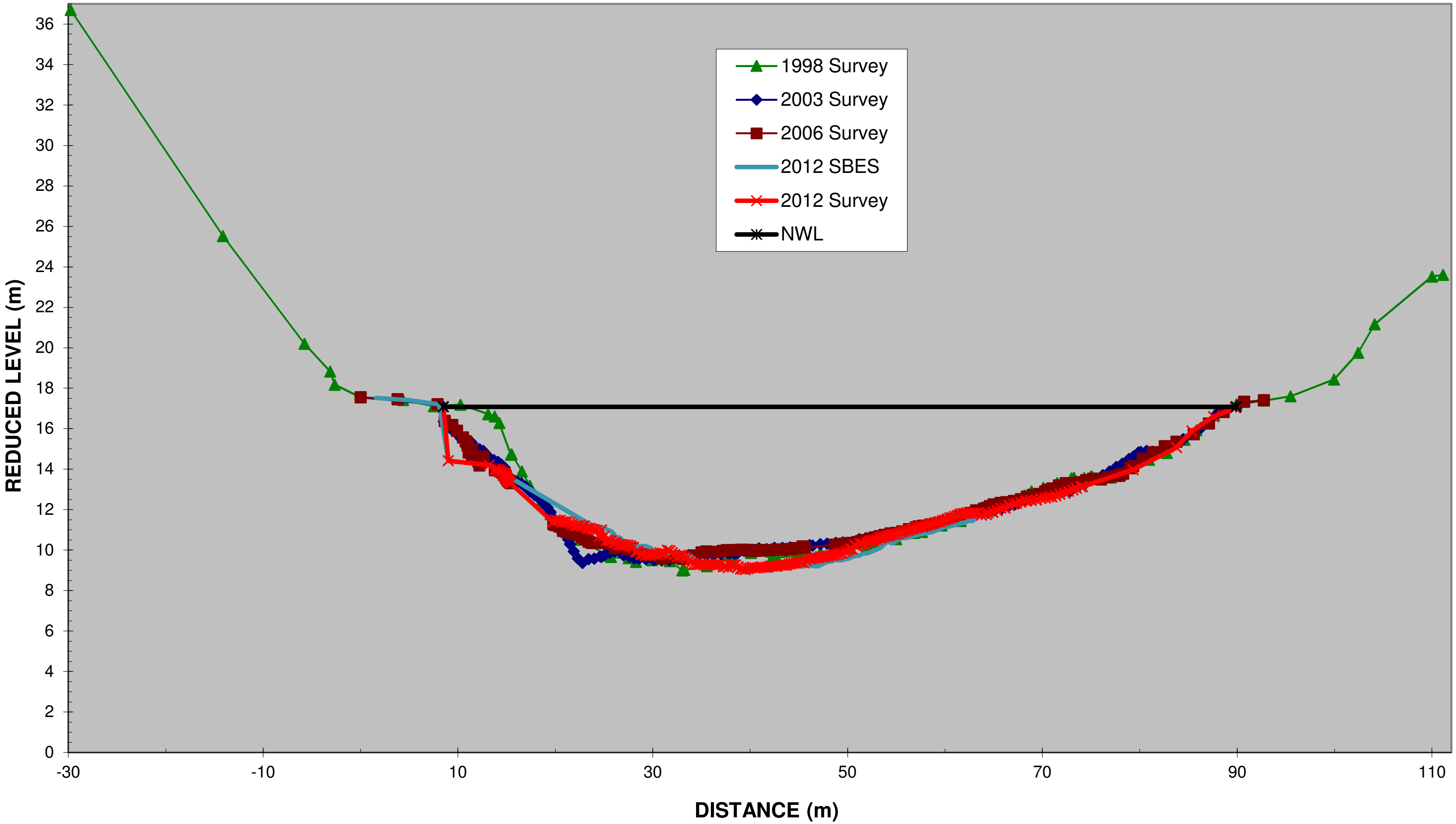
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 164



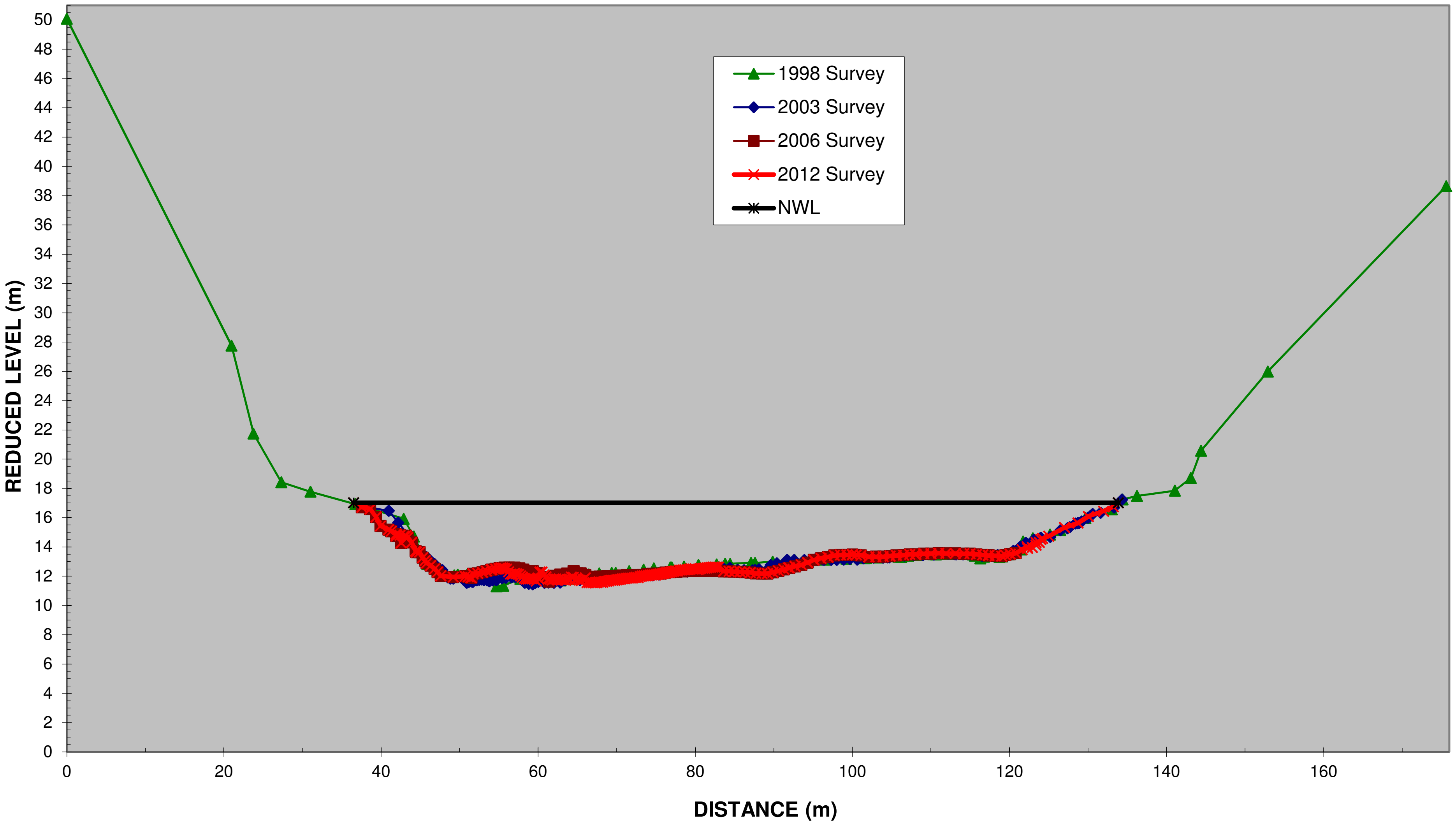
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 165



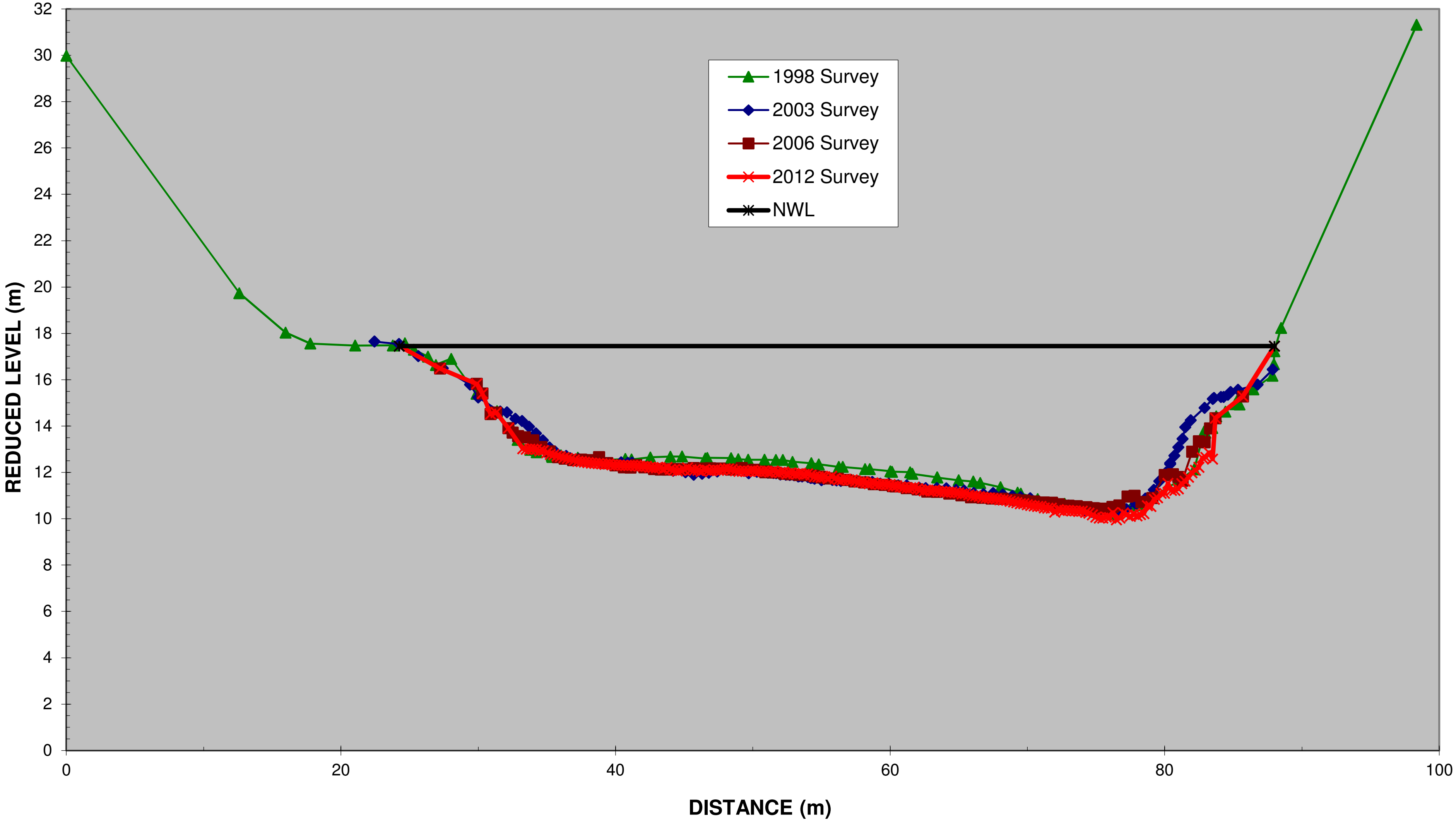
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 165A



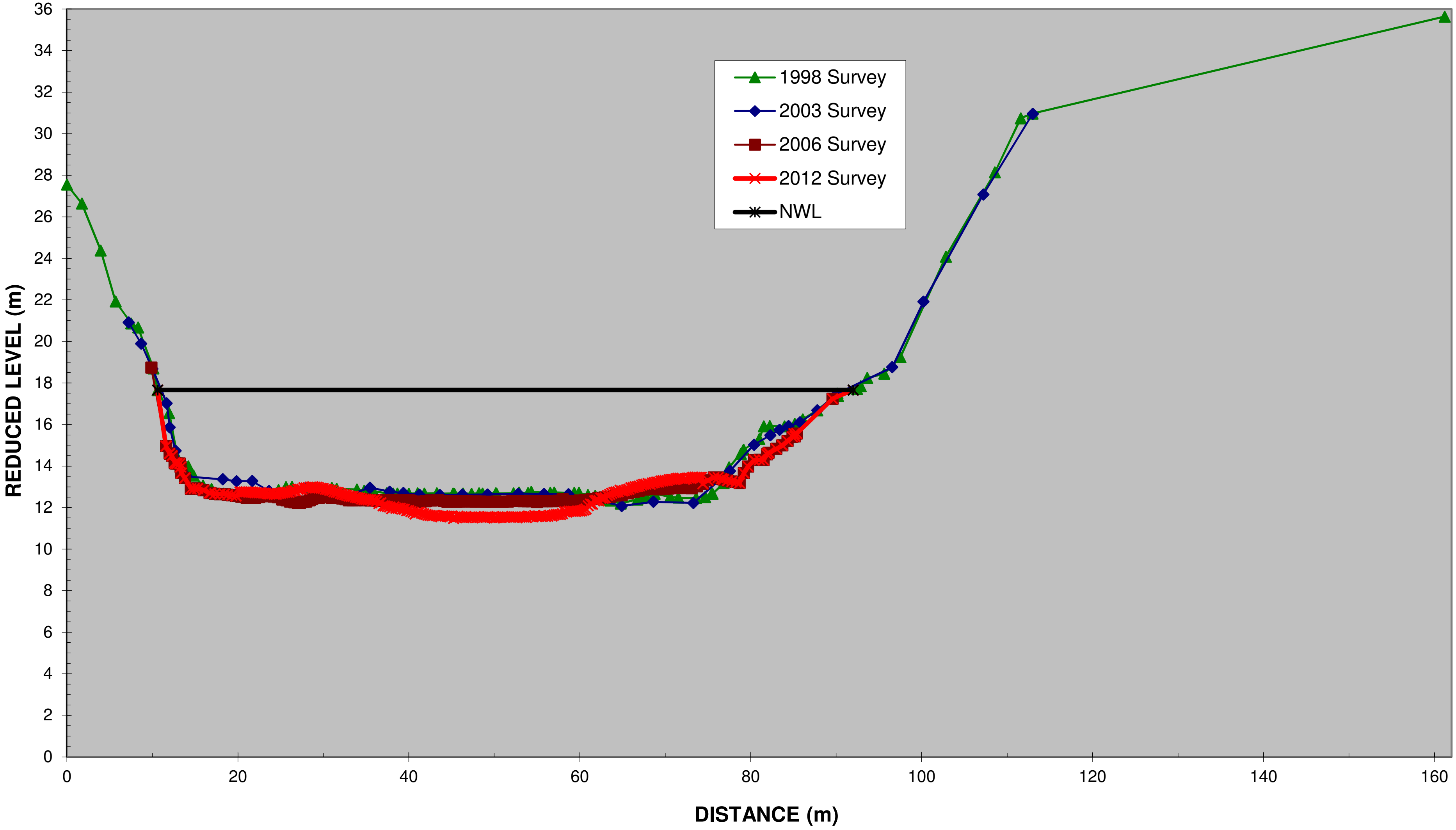
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 166



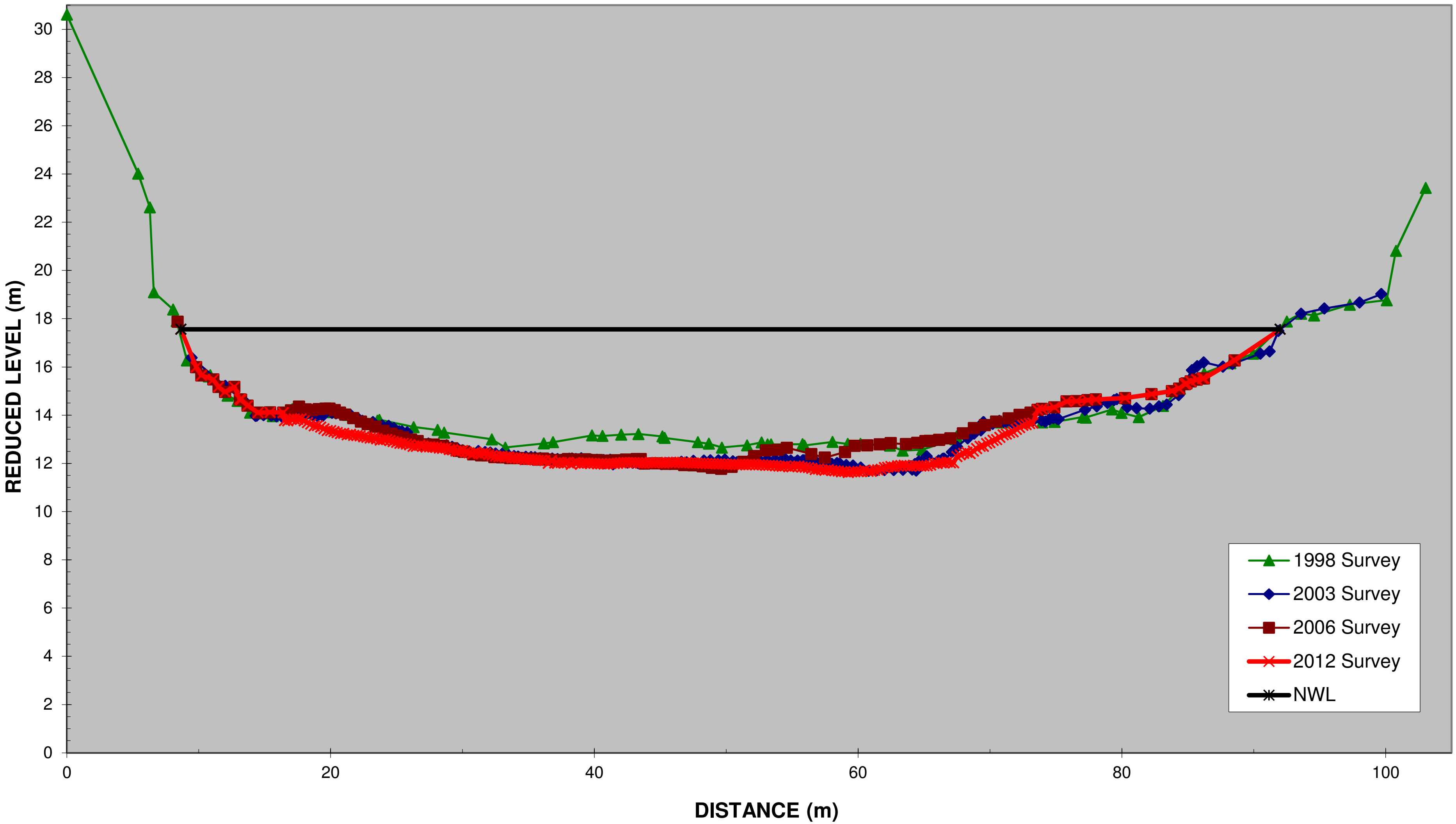
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 167



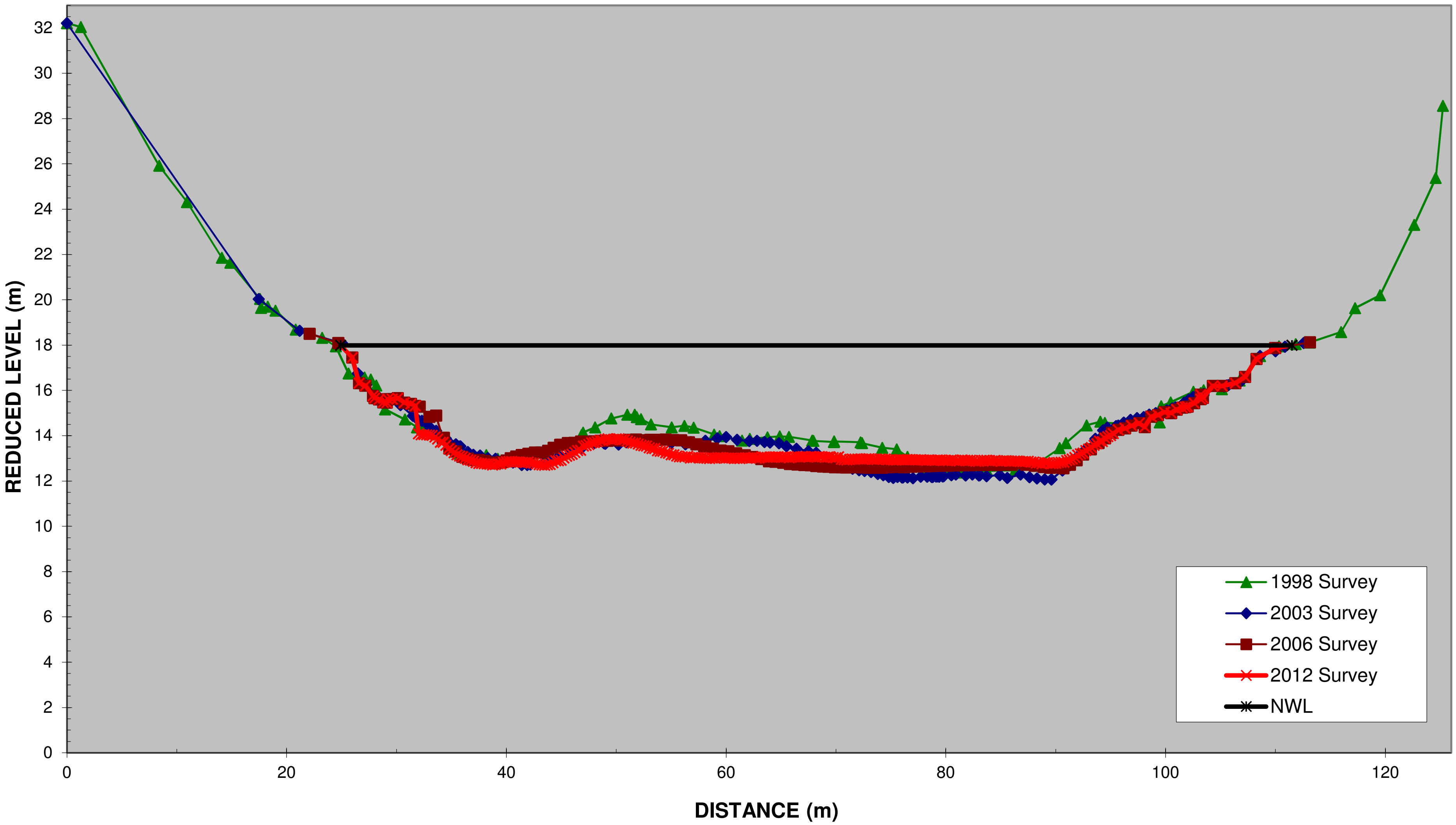
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 168



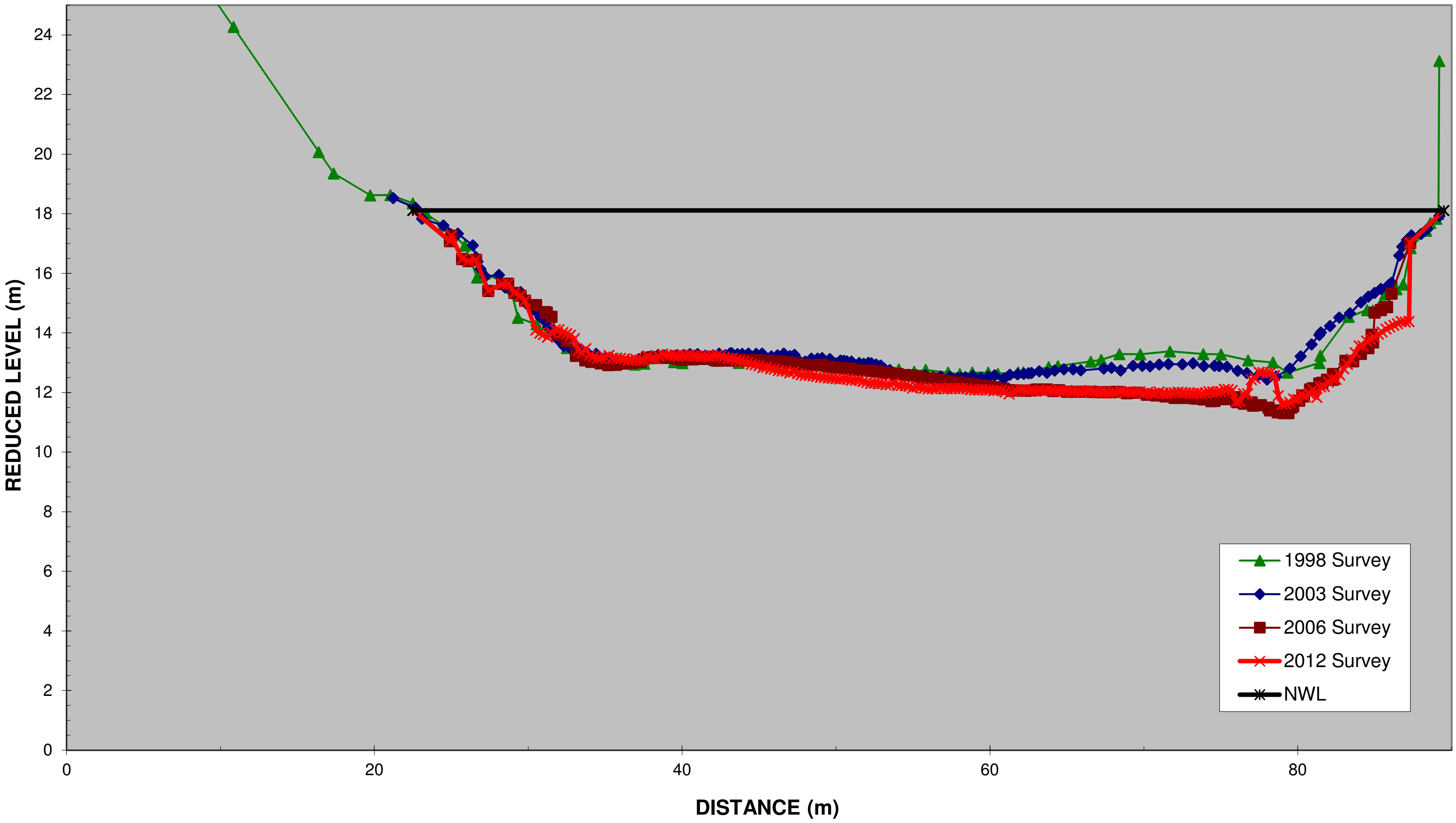
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 169



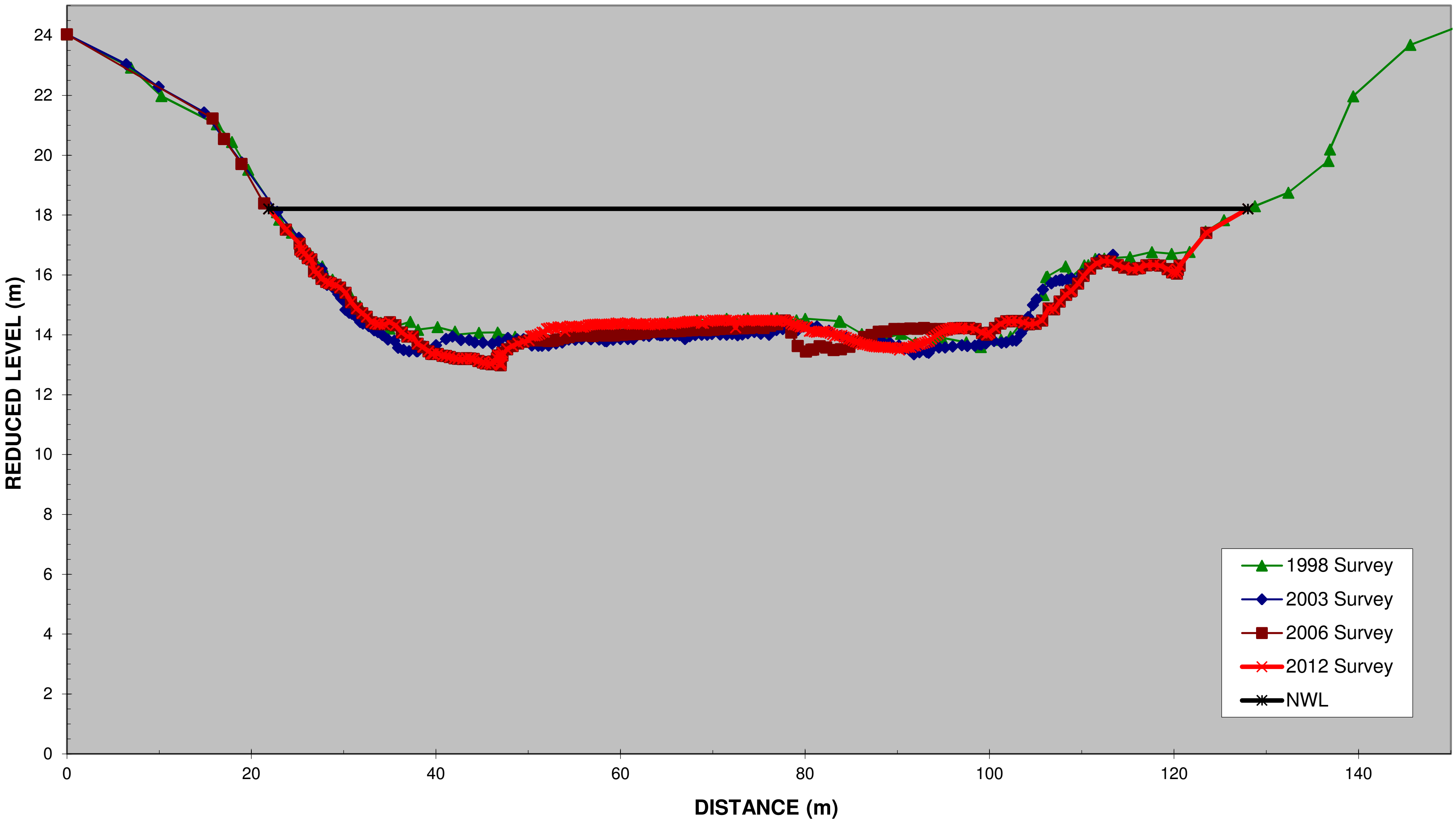
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 169A



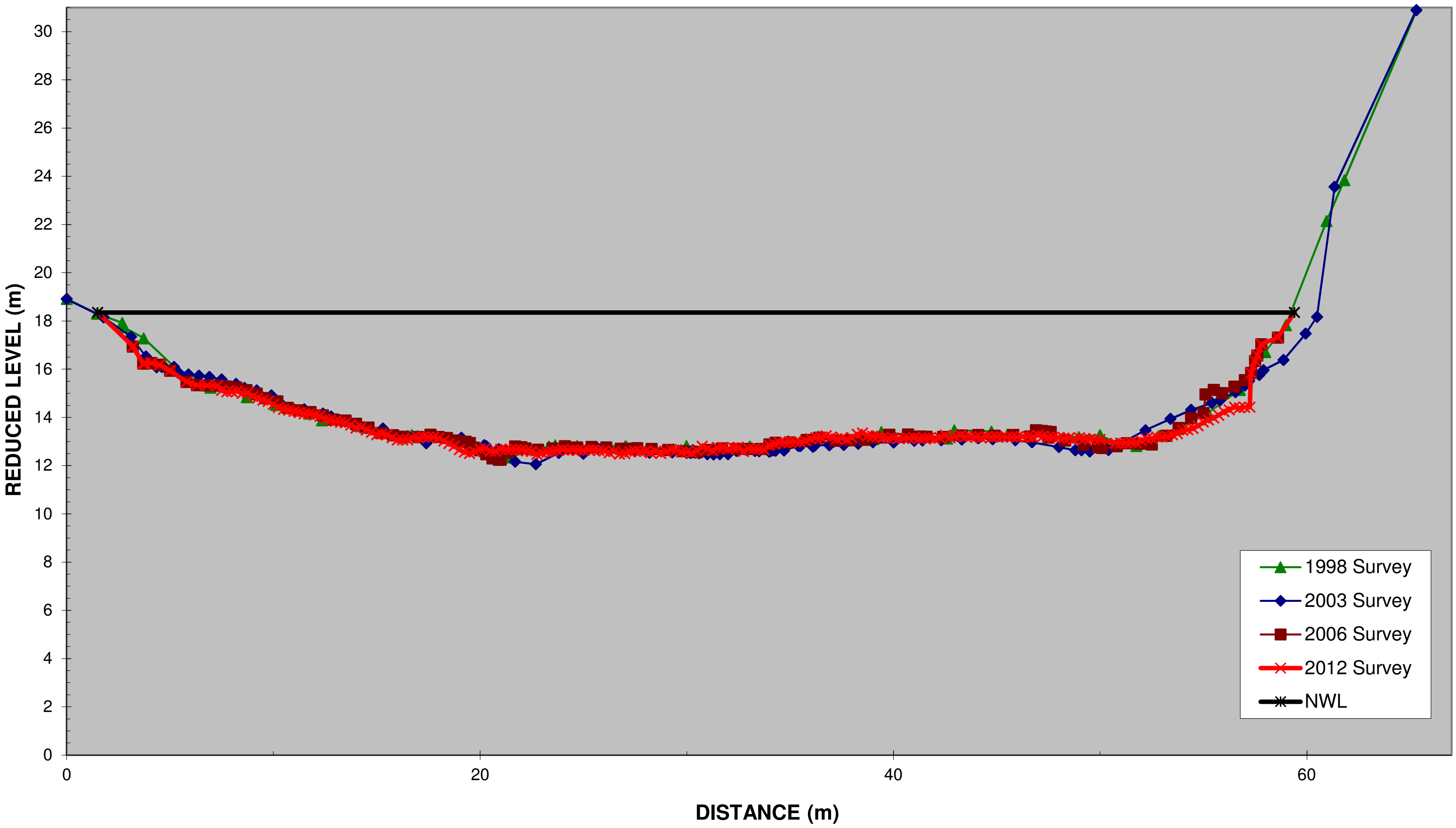
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 170



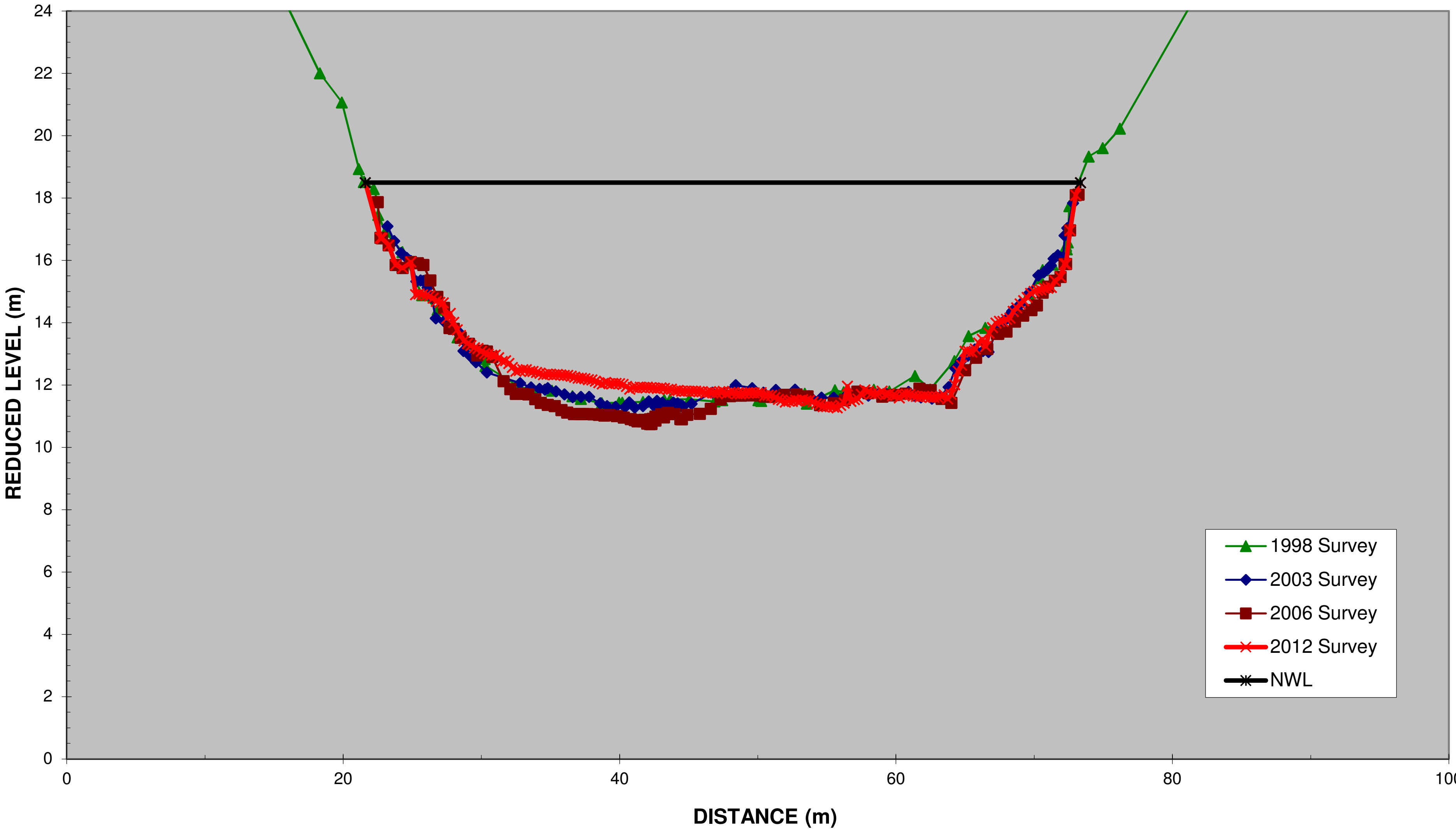
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 171

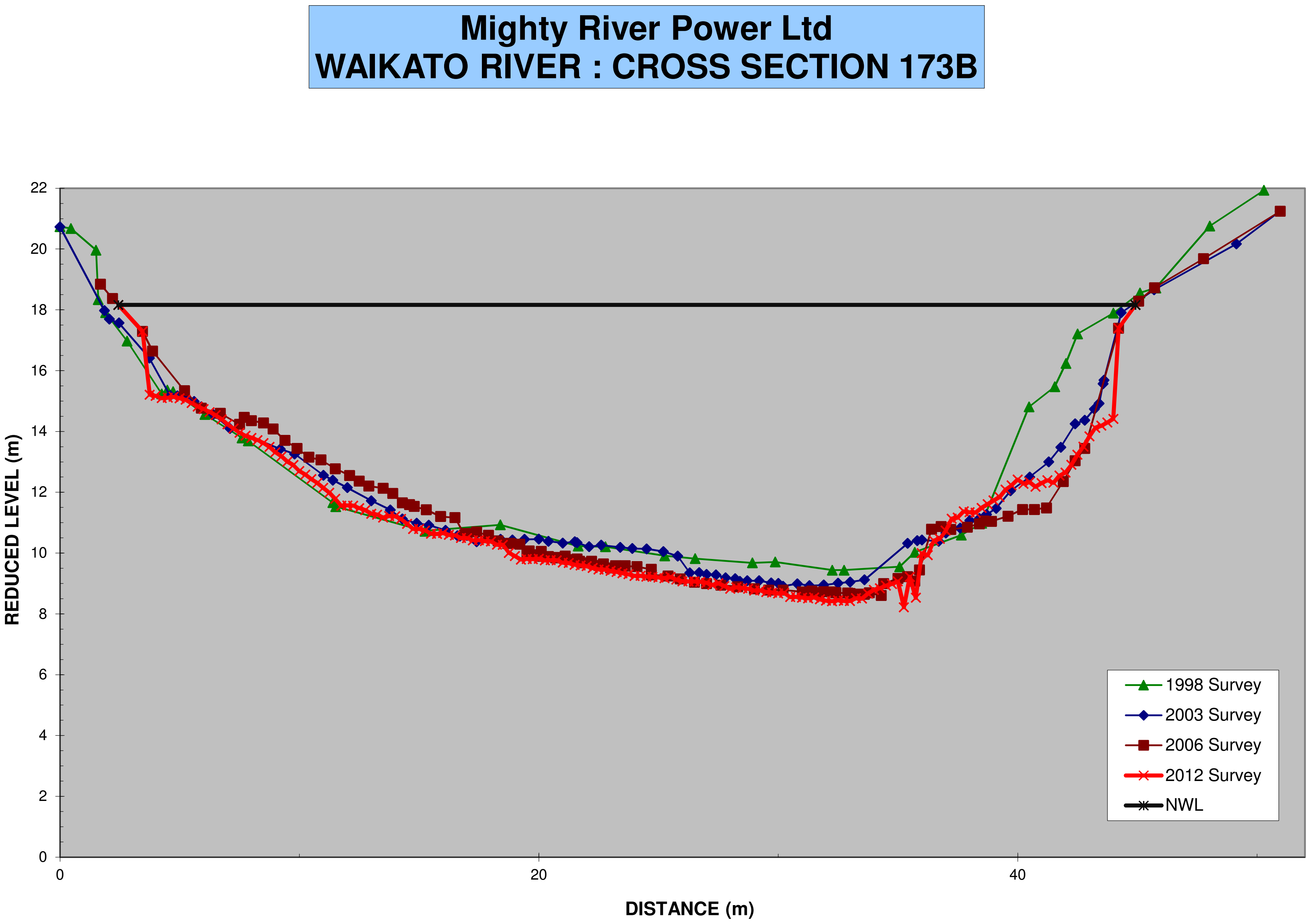


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 172A



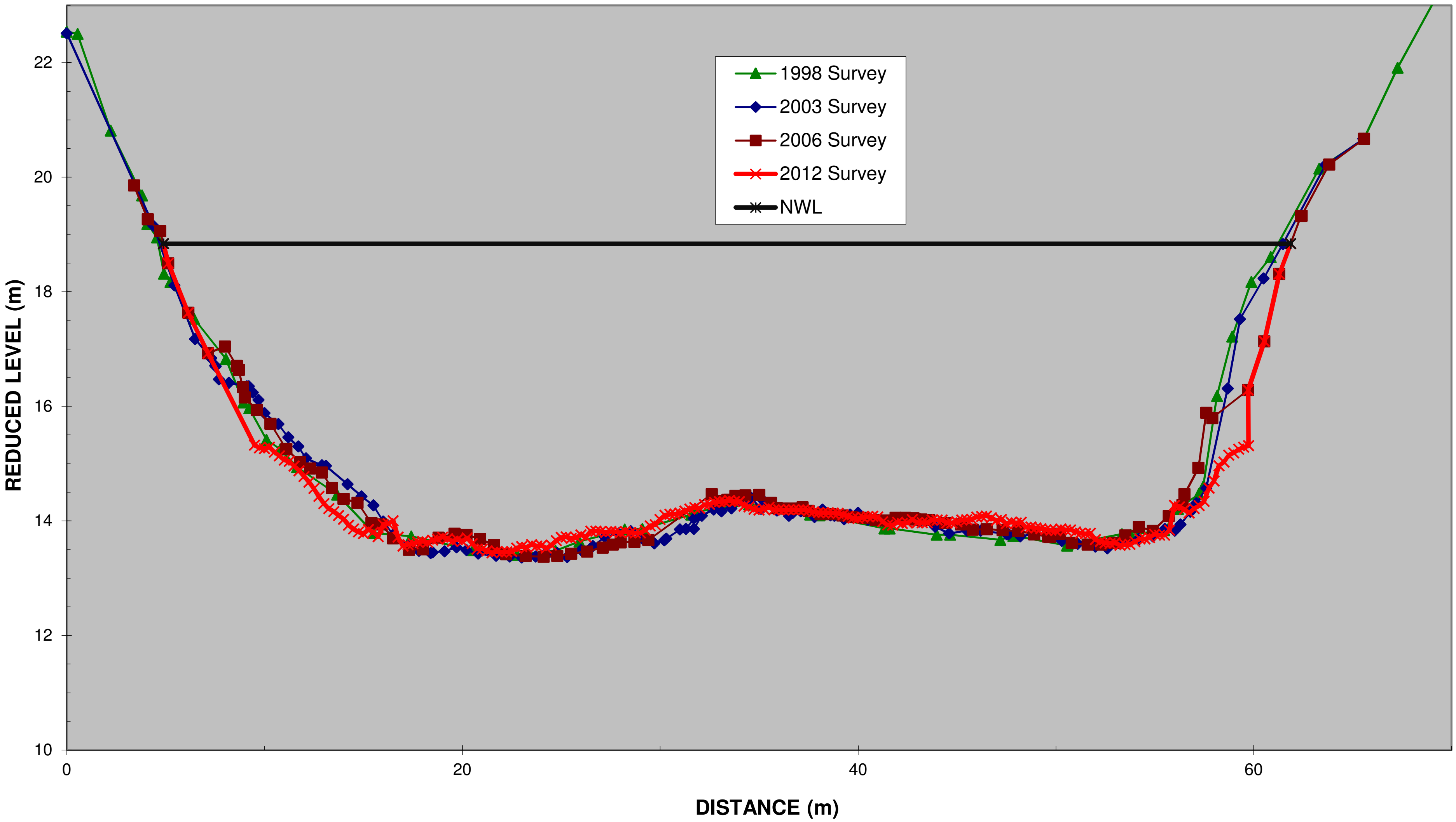
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 173



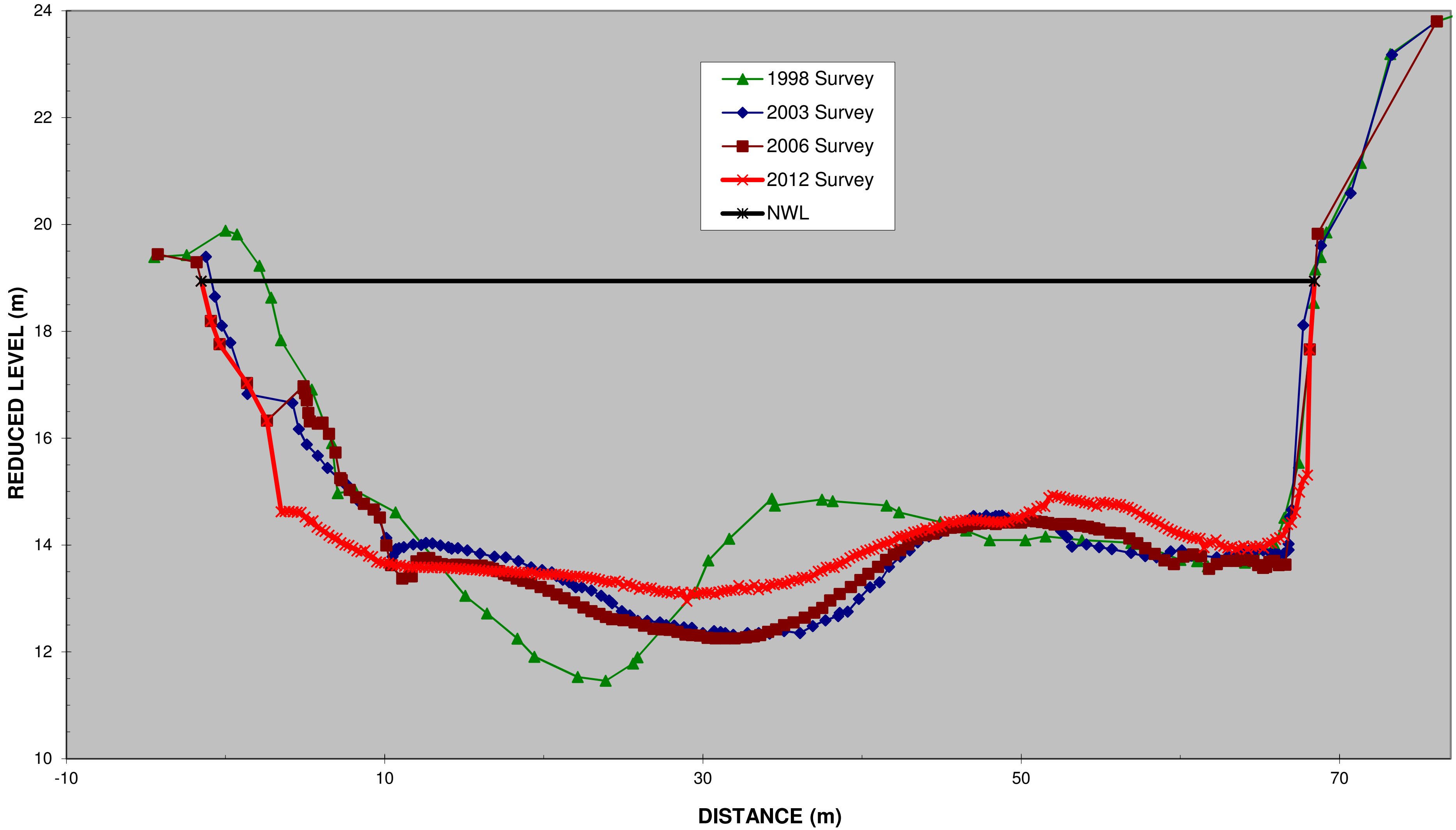


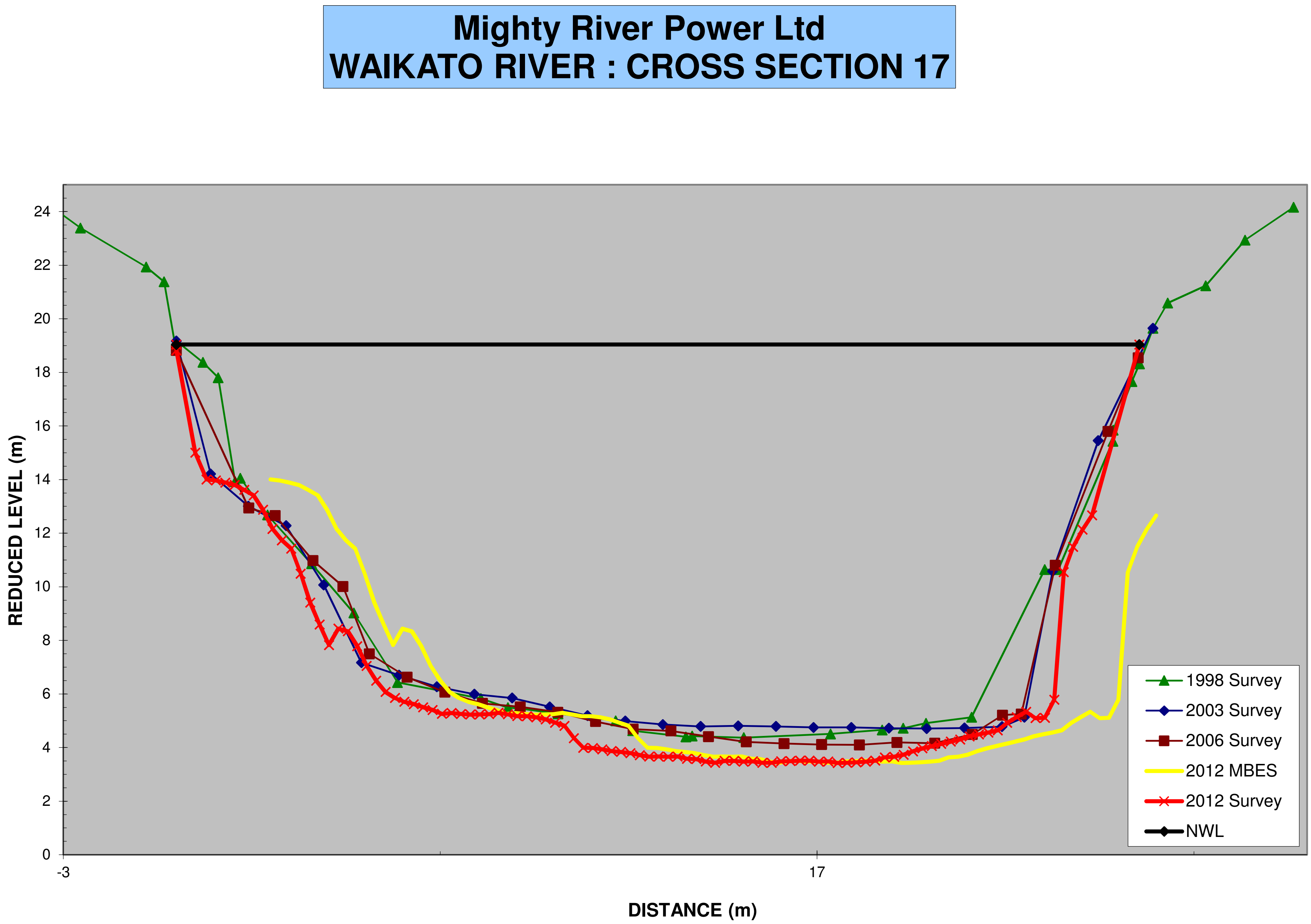
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 173B
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
14
16
18
20
22
0
20
40
1998 Survey
2003 Survey
2006 Survey
2012 Survey
NWL

Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 174

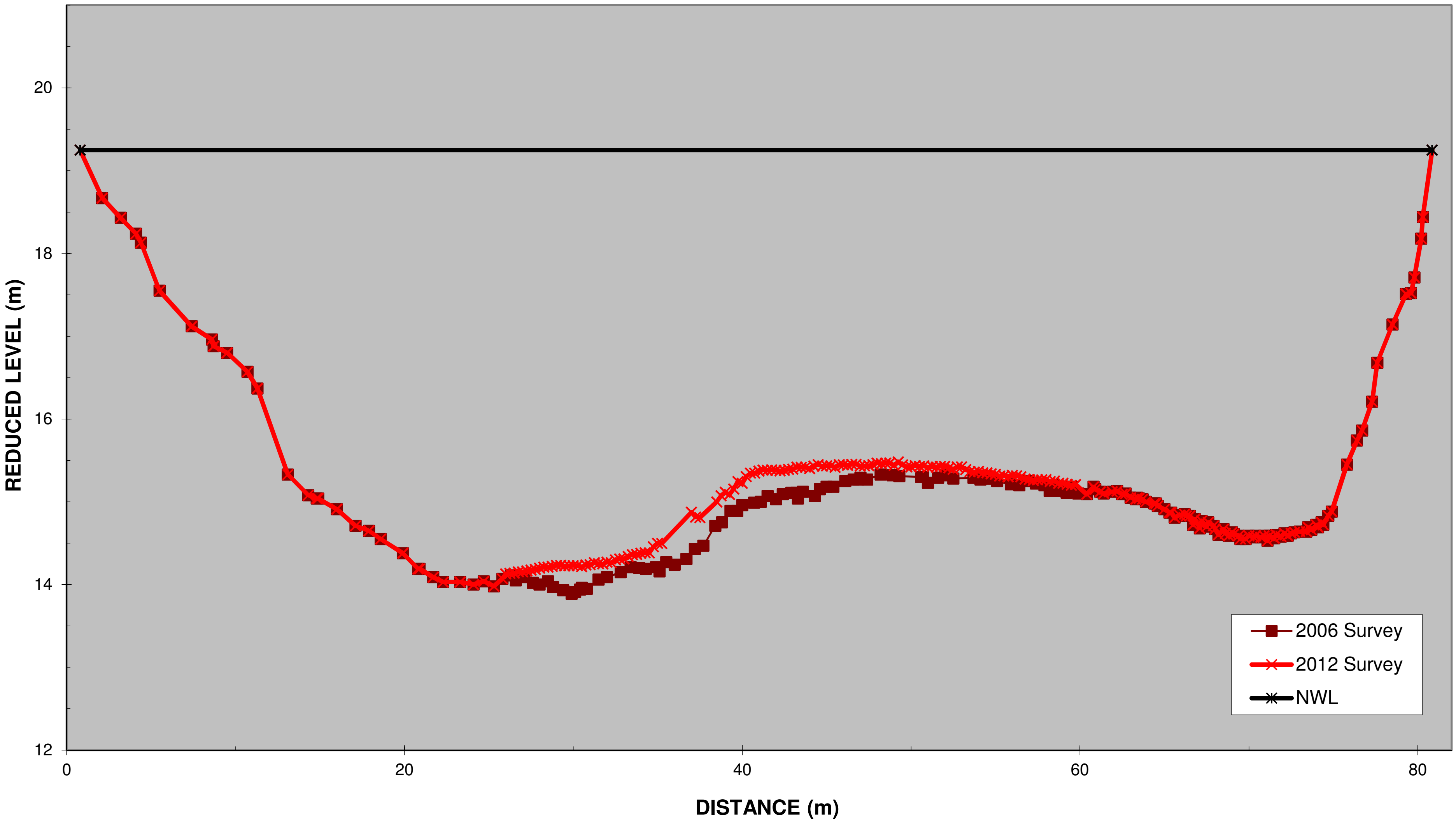


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 174A

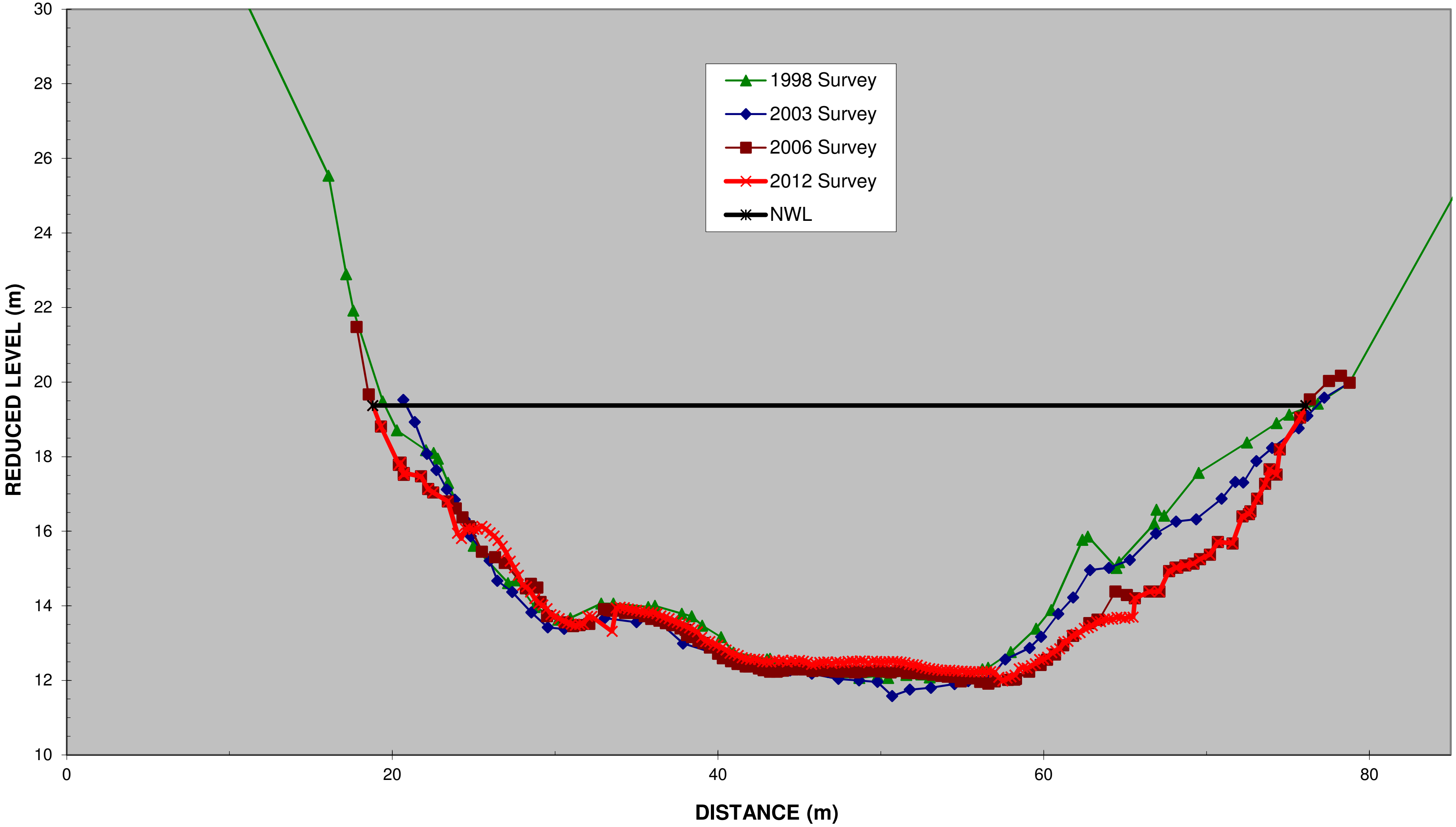



Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 17
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
-3
17
1998 Survey
2003 Survey
2006 Survey
2012 MBES
2012 Survey
NWL

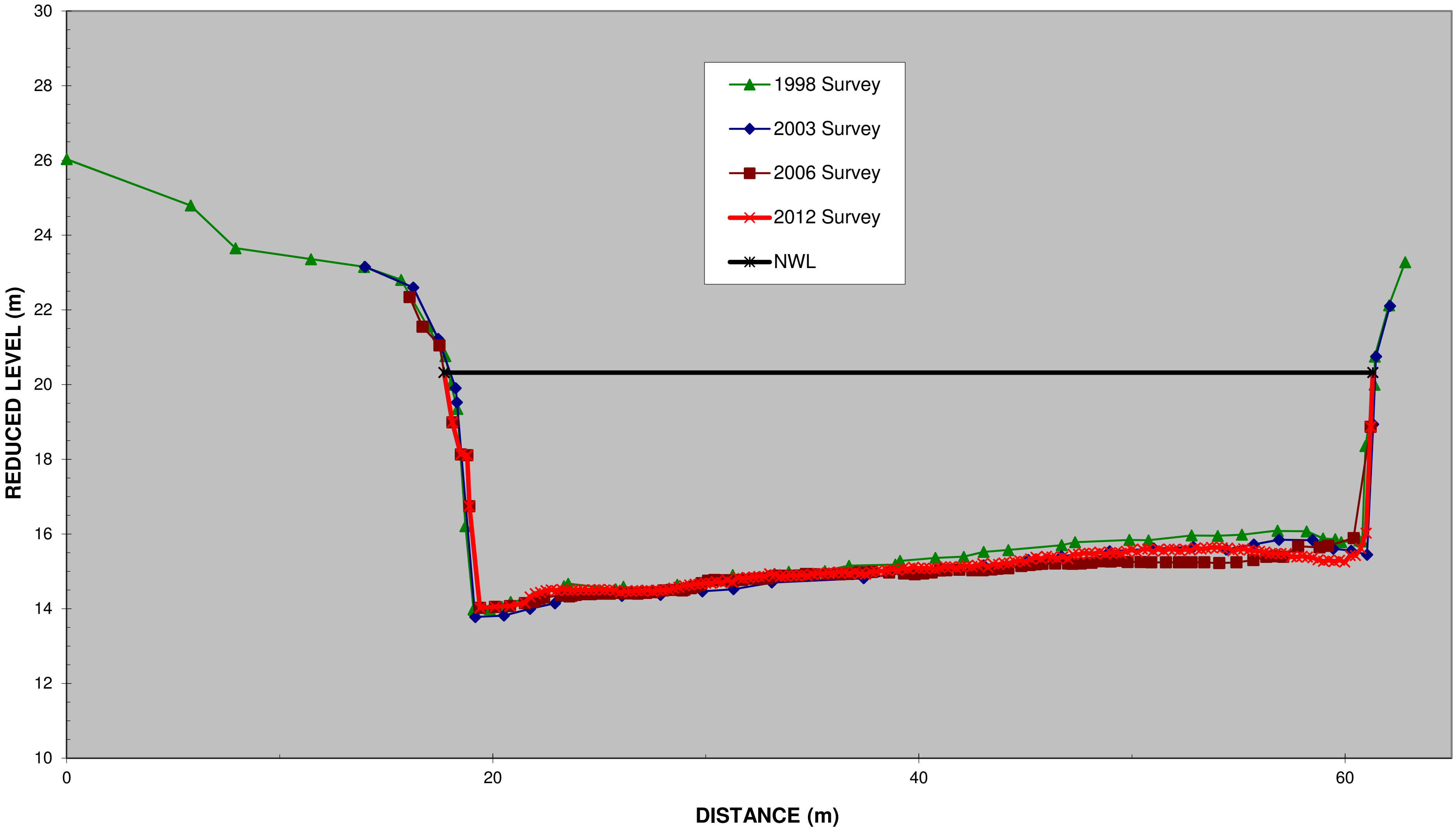
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 16G

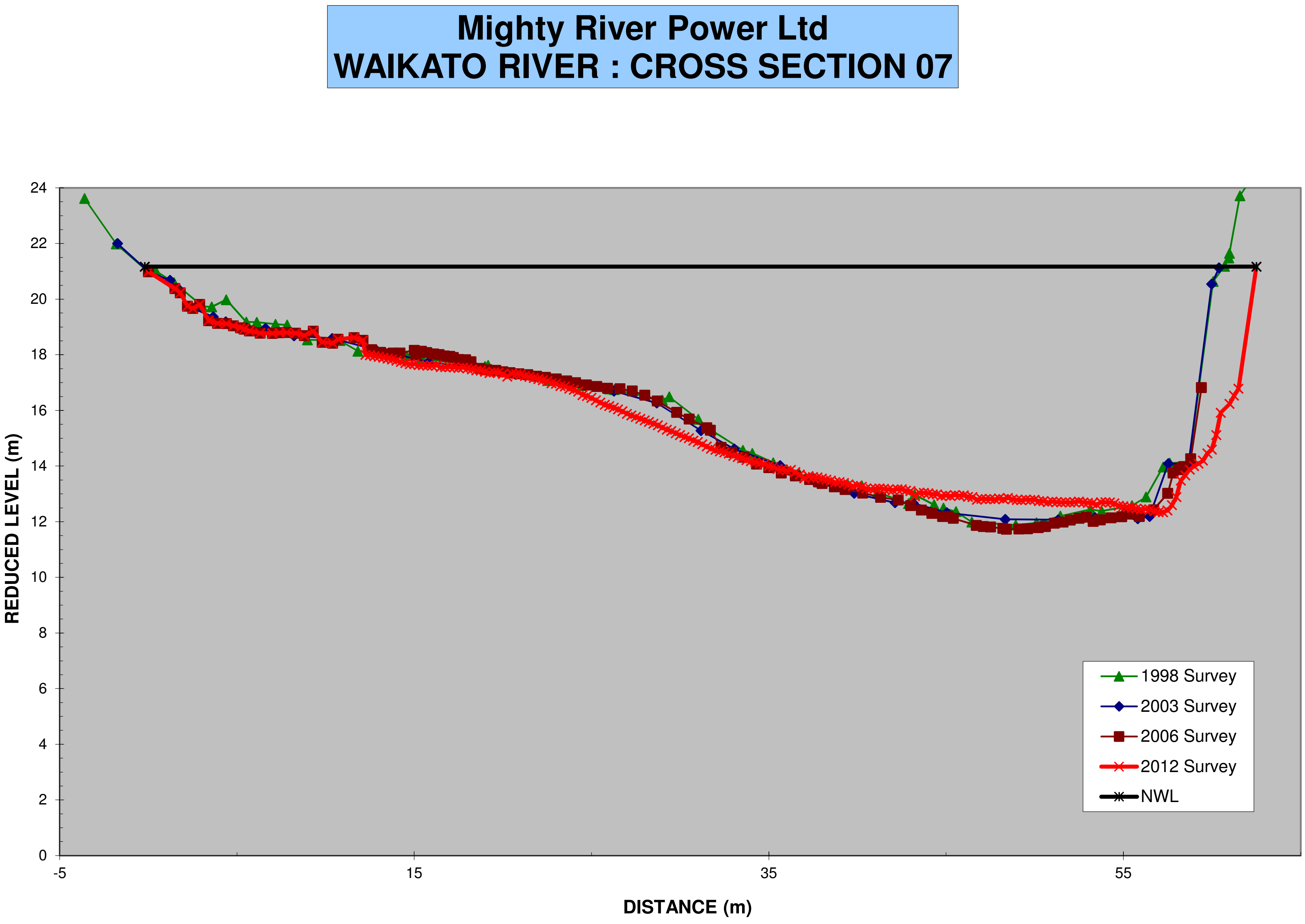


Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 16



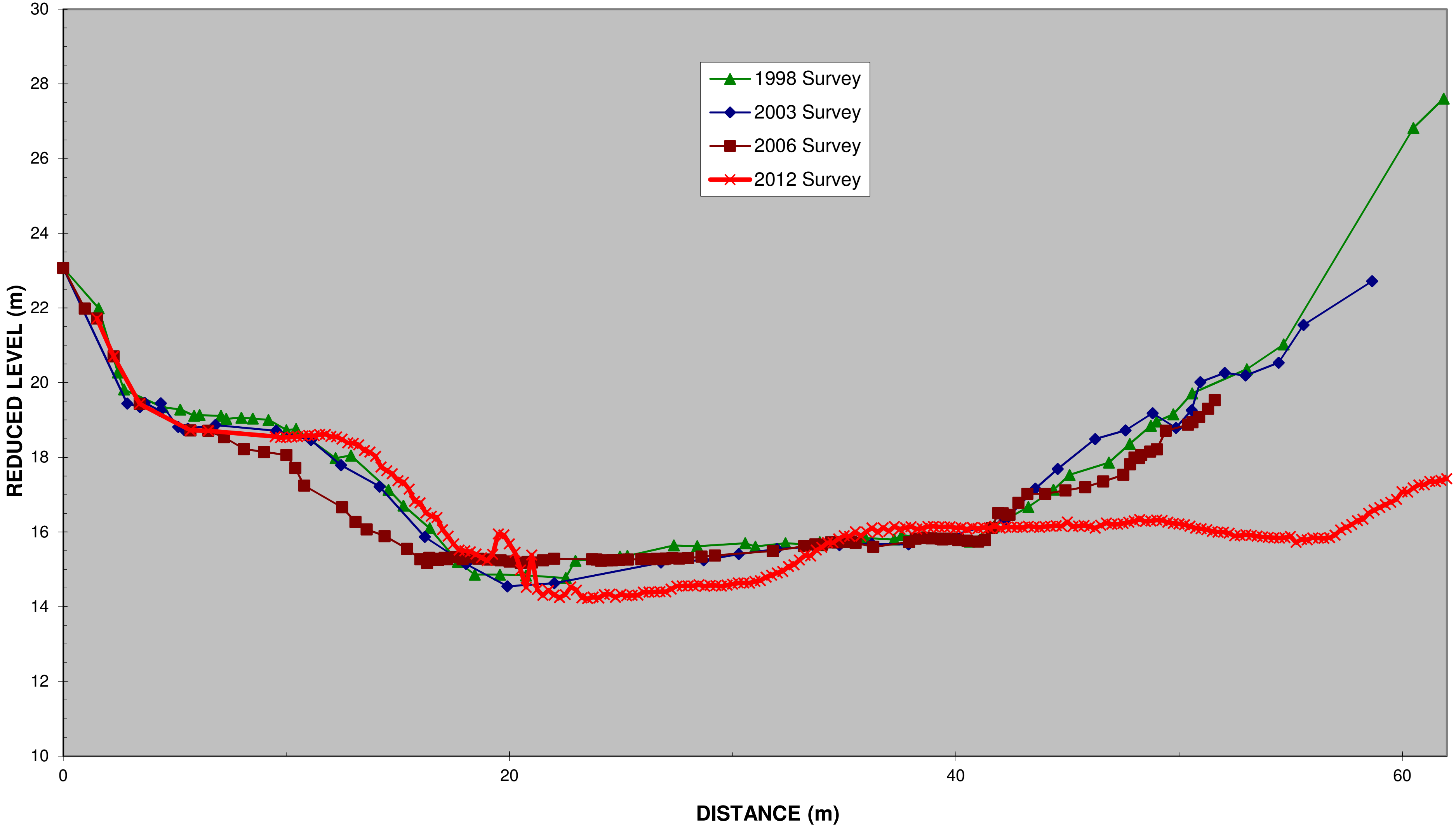
Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 10

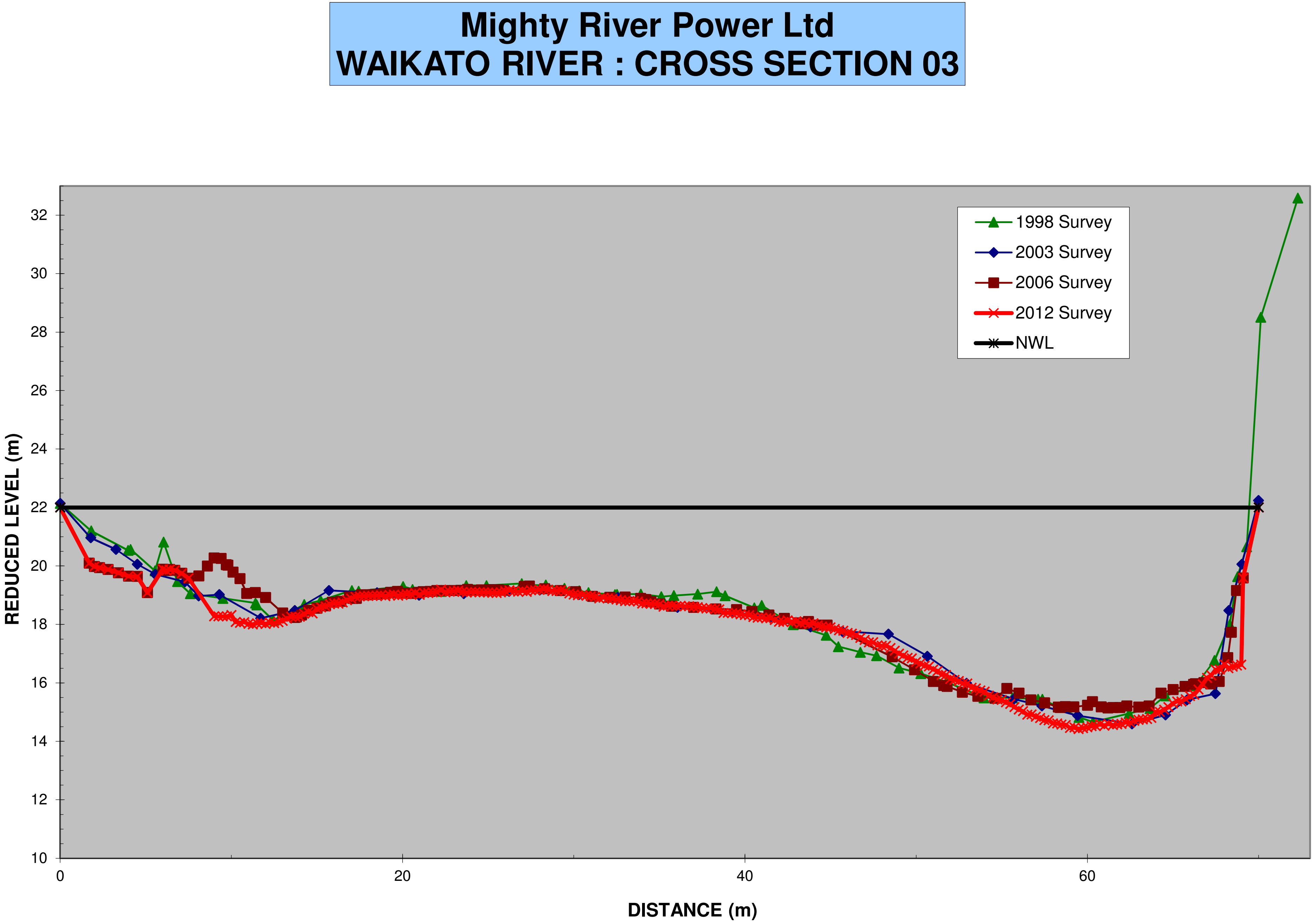




Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 07
REDUCED LEVEL (m)
DISTANCE (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
-5
15
35
55
1998 Survey
2003 Survey
2006 Survey
2012 Survey
NWL

Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 05




Mighty River Power Ltd
WAIKATO RIVER : CROSS SECTION 03
1998 Survey
2003 Survey
2006 Survey
2012 Survey
NWL
REDUCED LEVEL (m)
DISTANCE (m)
32
30
28
26
24
22
20
18
16
14
12
10
0
20
40
60

Appendix C Key infrastructure sites

See separate volume.

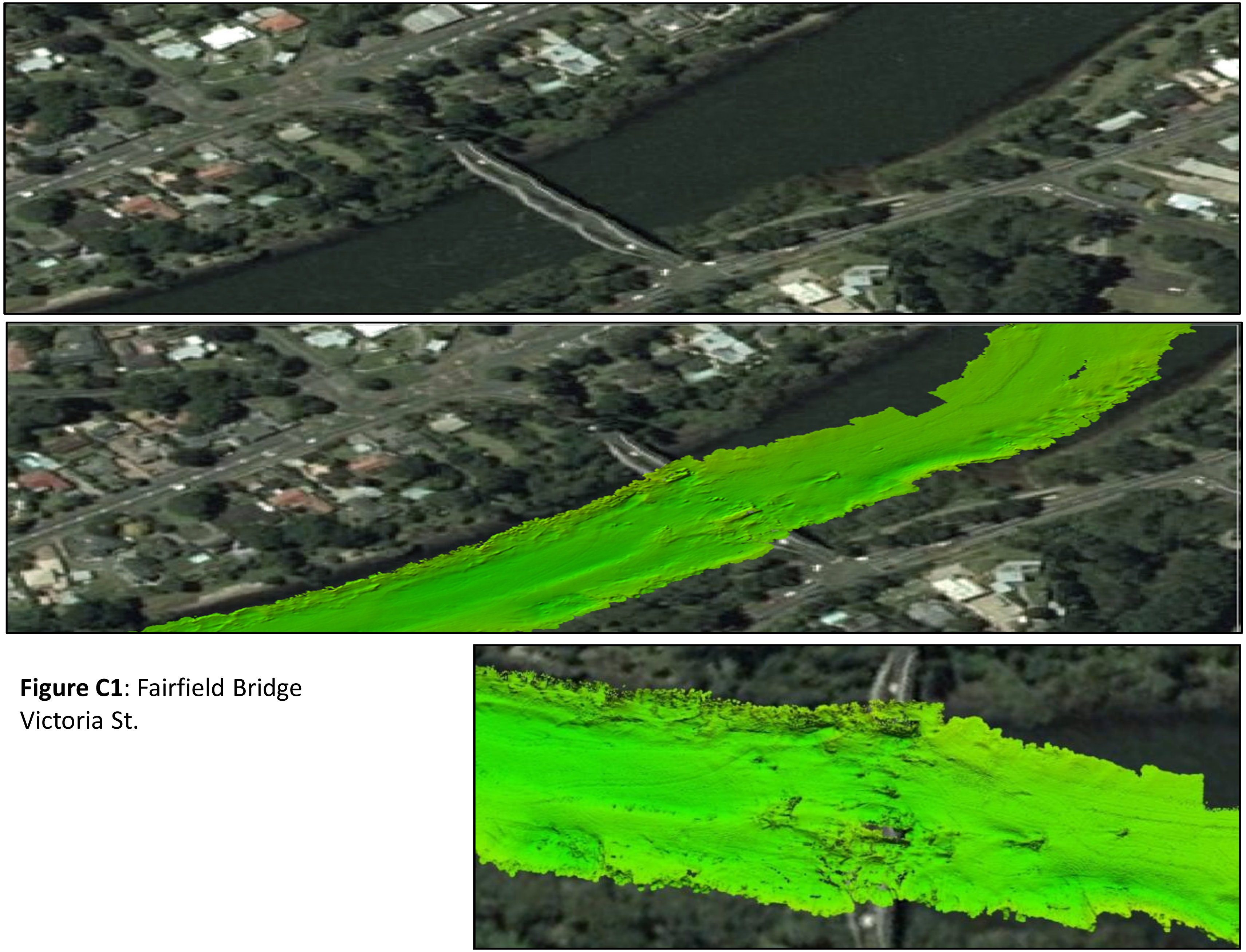


Figure C1: Fairfield Bridge
Victoria St.

Figure C2: Hamilton East Water Treatment Plant – Intake (section 154)

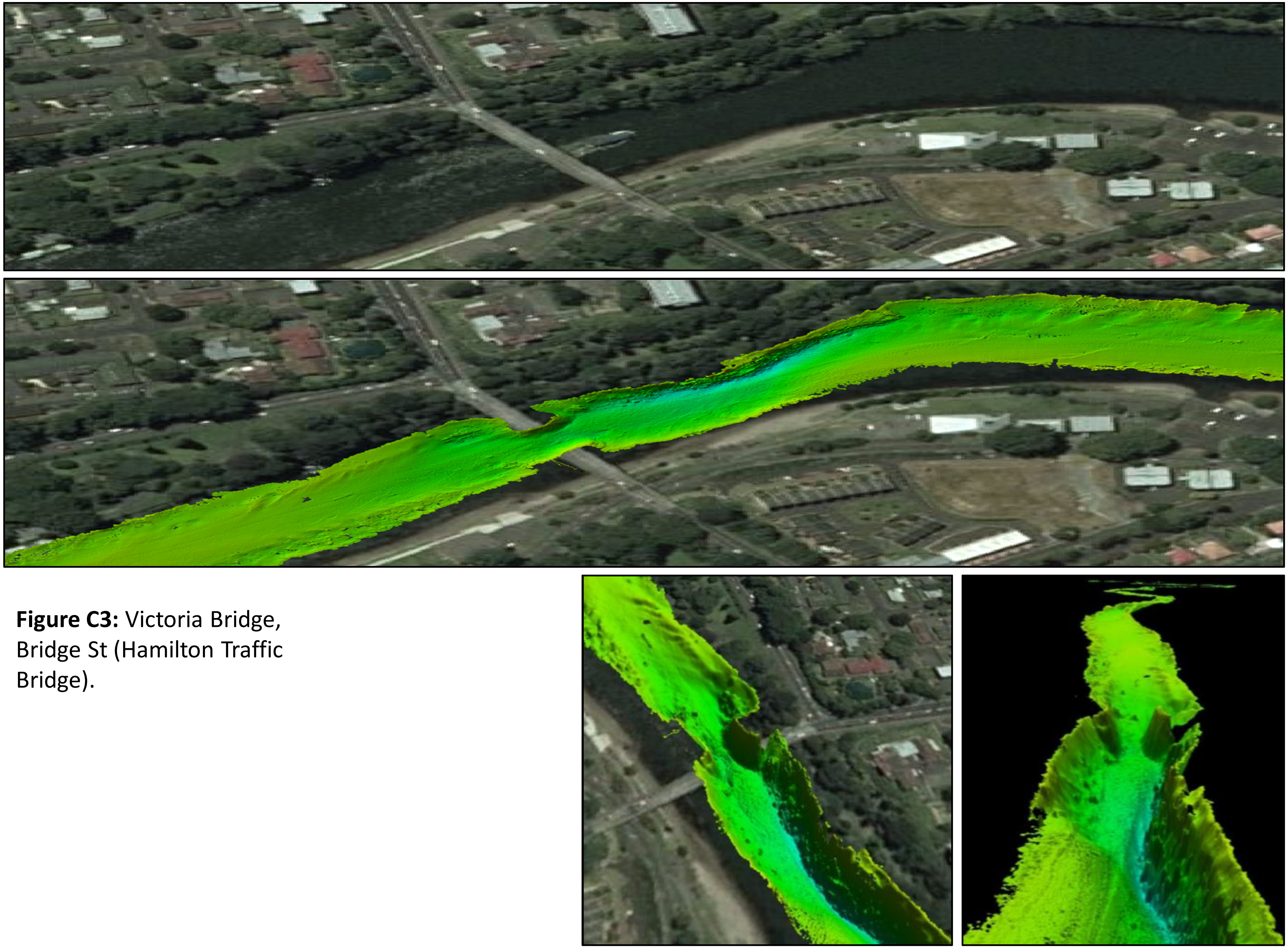
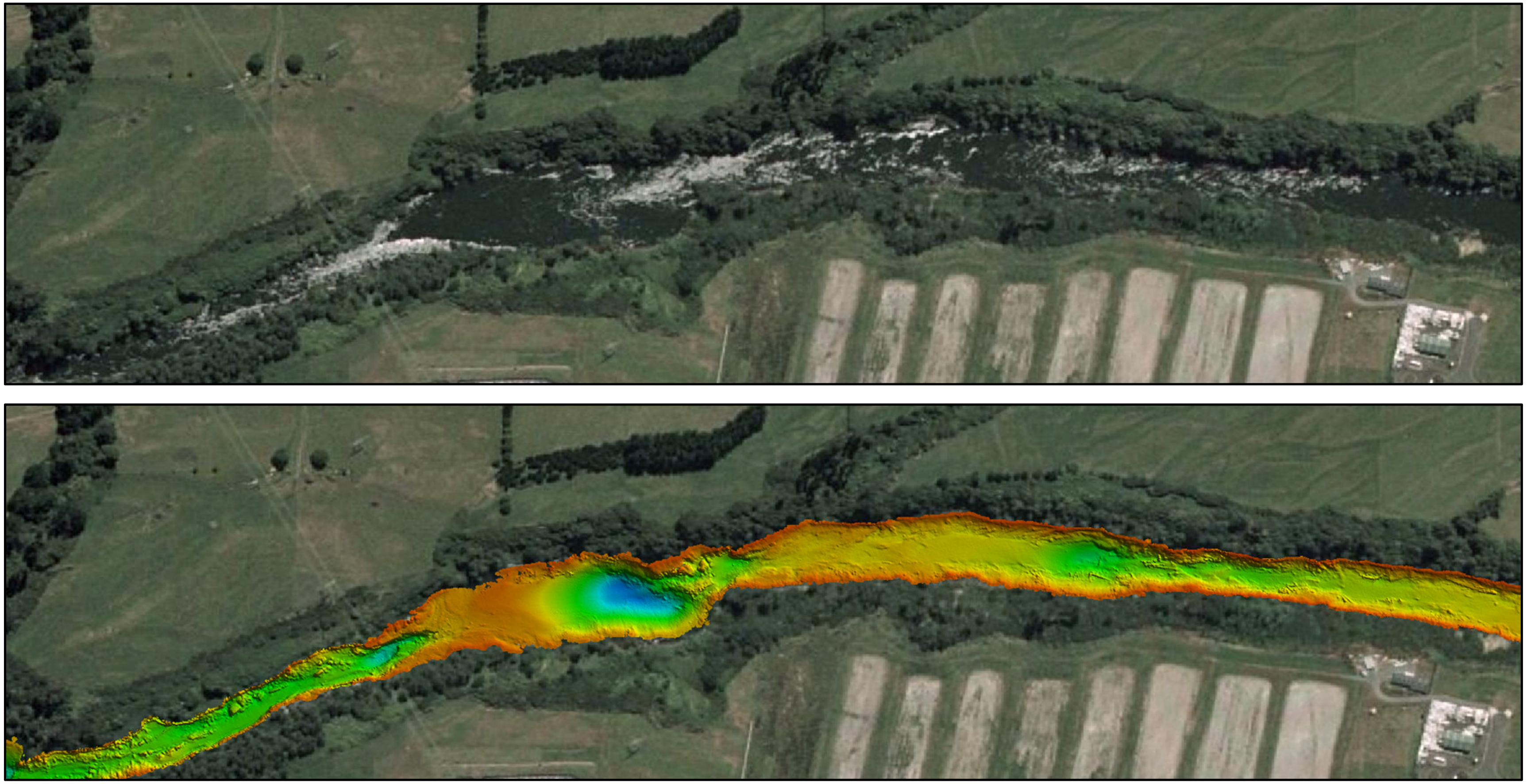


Figure C3: Victoria Bridge, Bridge St (Hamilton Traffic Bridge).

Appendix D Representative river bed types

See separate volume.



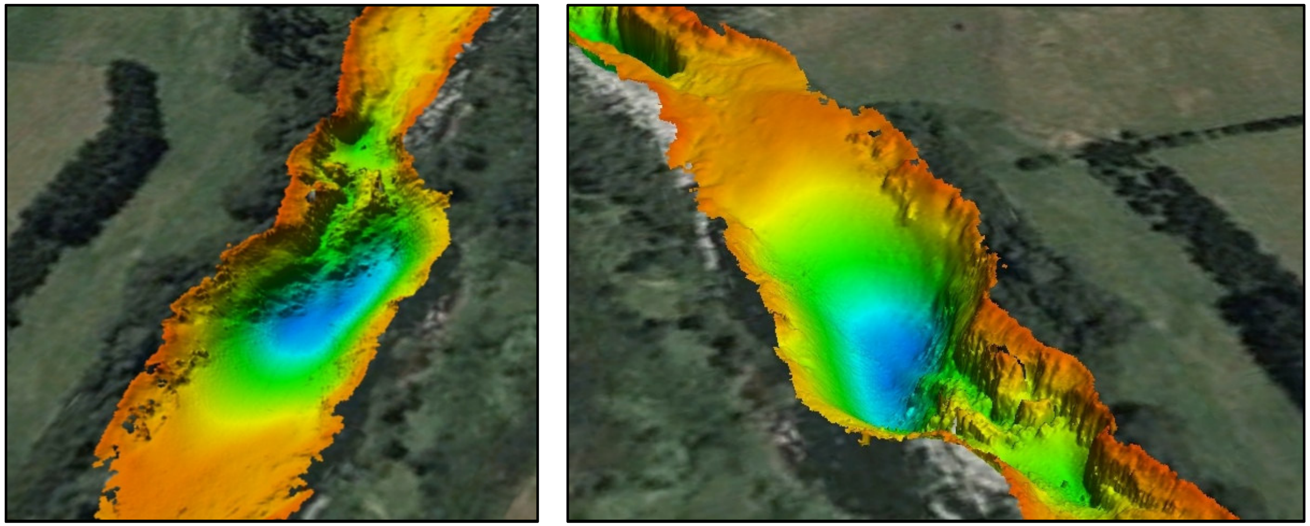


Figure D1:
10m+ deep hole at chainage 139.01km (140m upstream of section 172A)

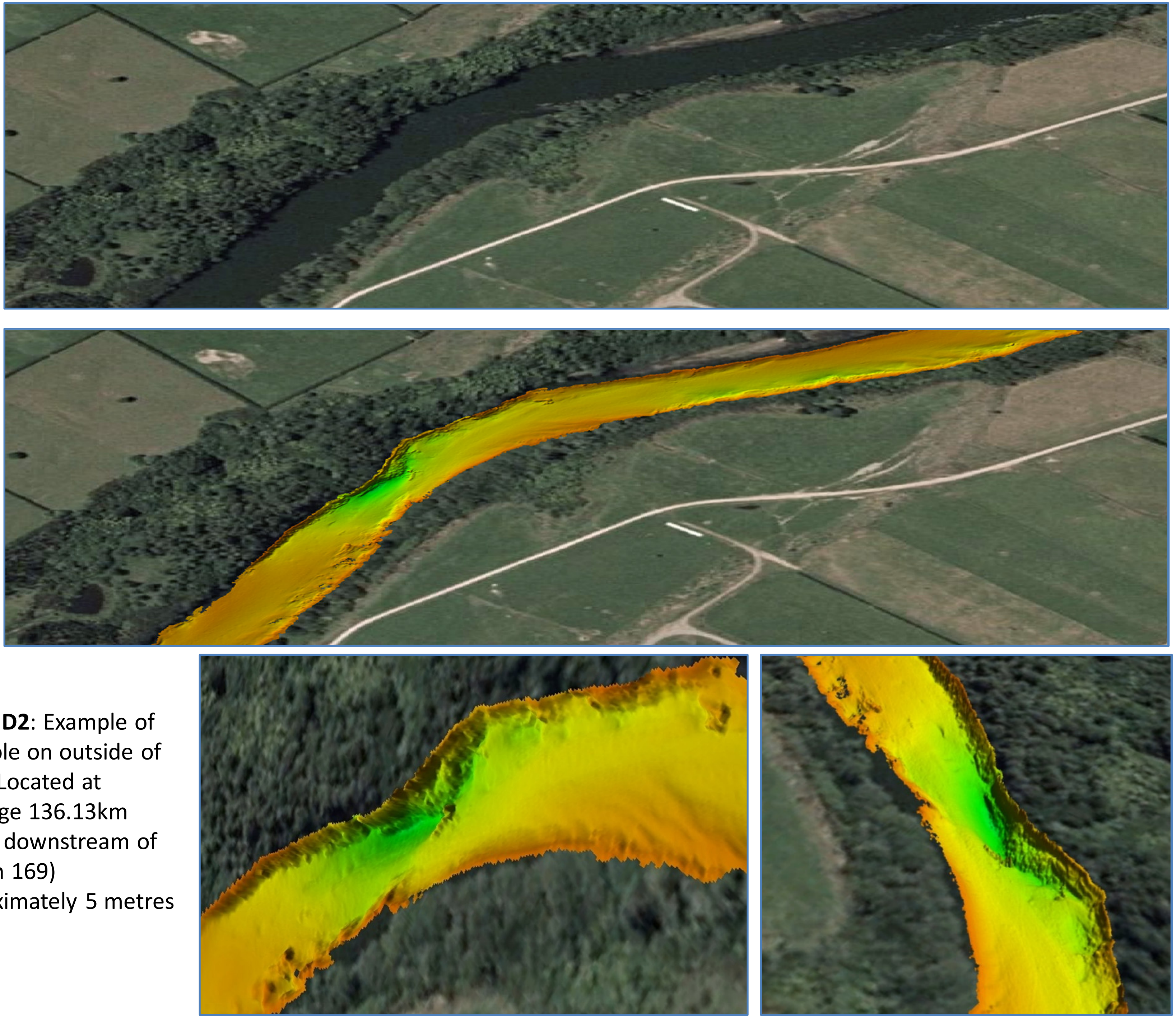


Figure D2: Example of bed hole on outside of bend. Located at chainage 136.13km (160m downstream of section 169) Approximately 5 metres deep

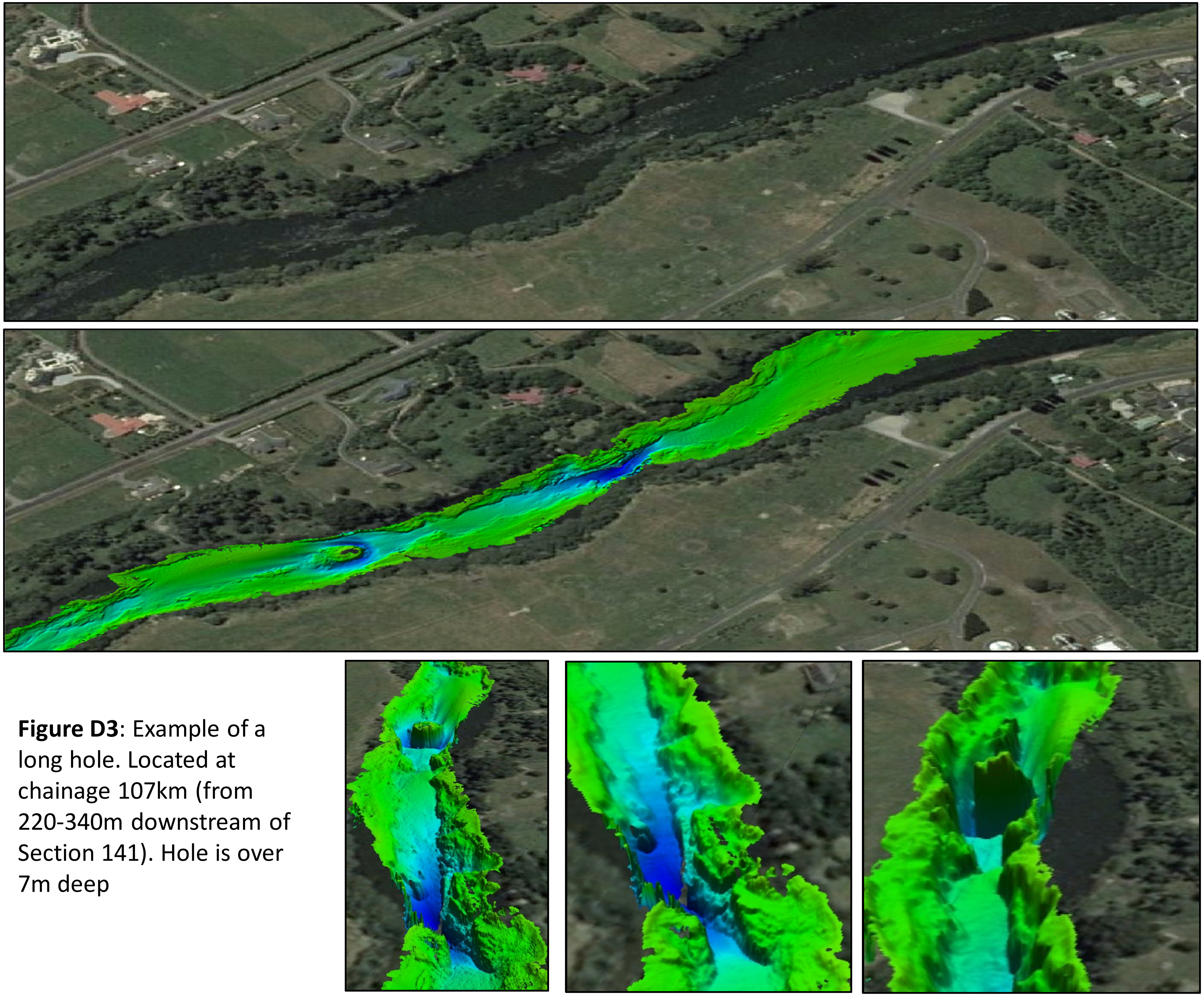
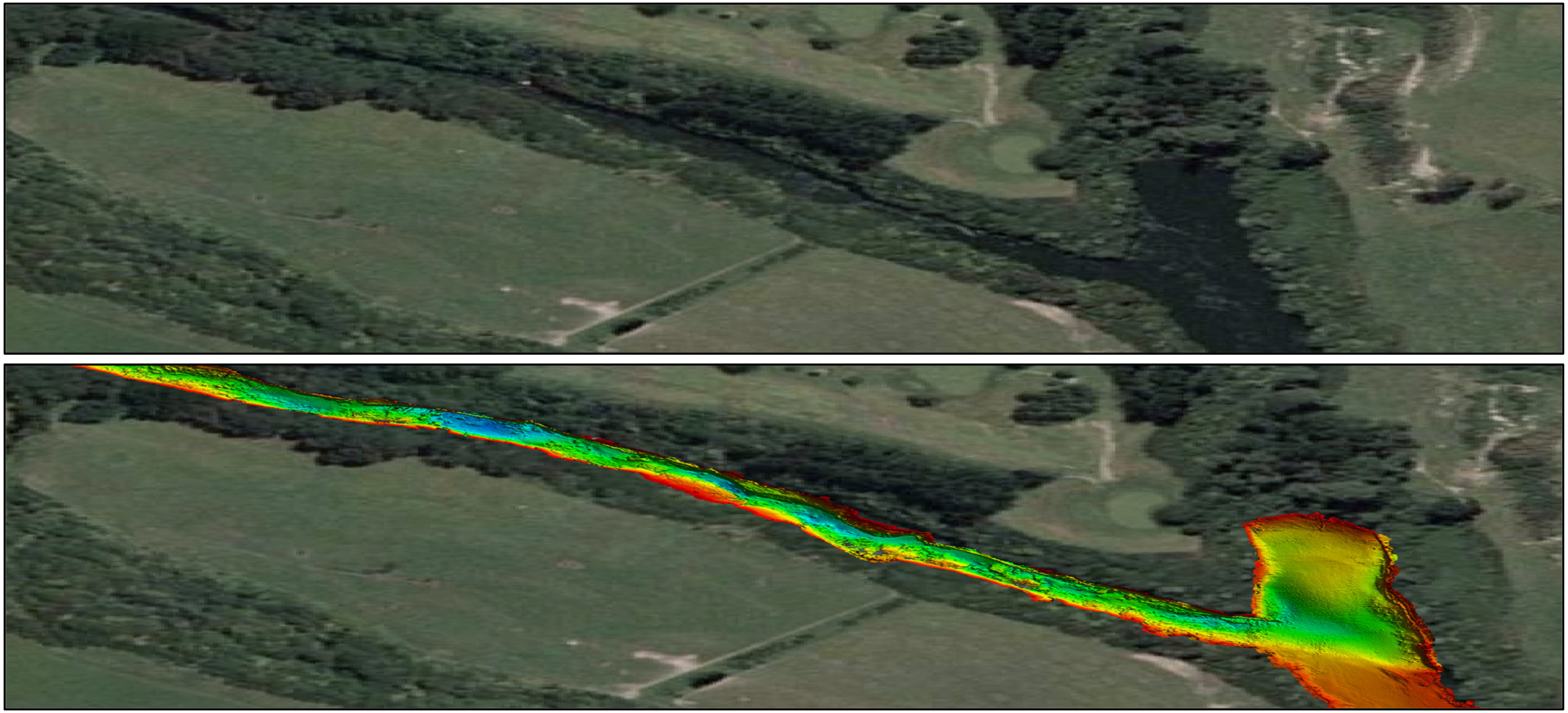


Figure D3: Example of a long hole. Located at chainage 107km (from 220-340m downstream of Section 141). Hole is over 7m deep

Figure D4: Example of a planar bed. Section is located at approximate chainage 101.5km (between sections 136 and 136A).



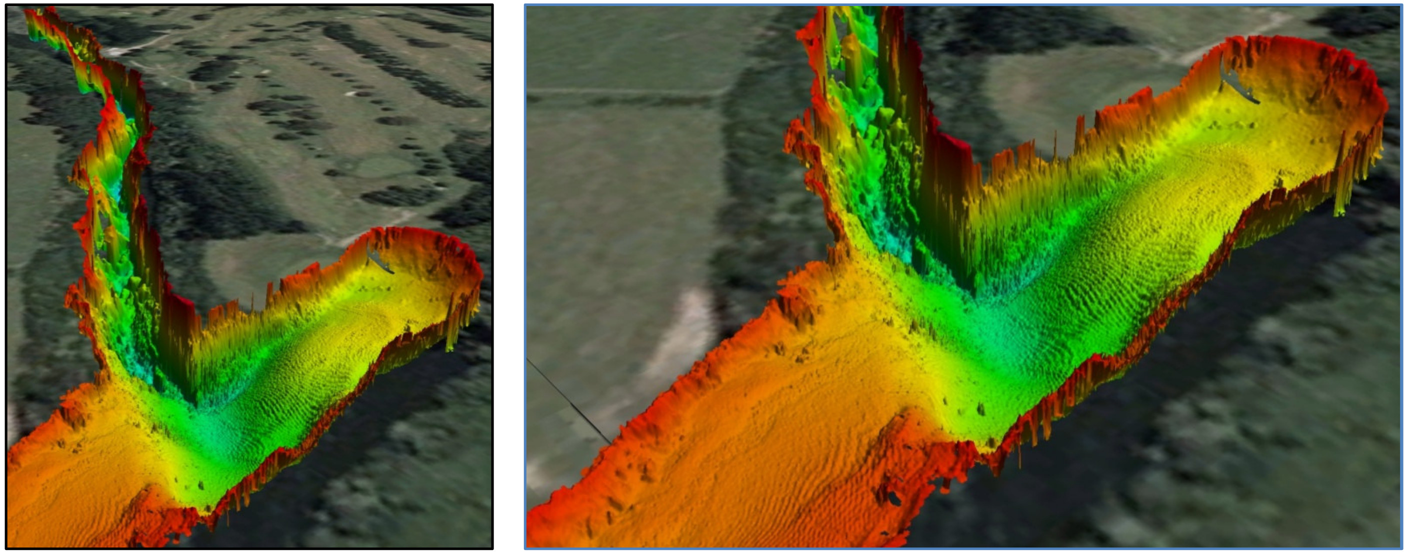


Figure D5: Example of a fault forming a sill. Located at chainage 144.65. The bed level drops by 8m, with individual holes a further 1.5 metres deep.

Appendix E Cross section data

See separate volume.

				Year 2012				Year 2006				Year 2002/2003				Year 1998			
Section	Chainage	NWL (m)	Width of NWL (m)	WMBL (m)	Thalweg (m)	XS area (m2)	TI	WMBL (m)	Thalweg (m)	XS area (m2)	TI	WMBL (m)	Thalweg (m)	XS area (m2)	TI	WMBL (m)	Thalweg (m)	XS area (m2)	TI
133	95.881	10.33	88.98	6.05	3.11	388.4	0.69	6.16	3.46	371.33	0.647	6.11	3.23	375.2	0.68	6.18	3.37	367.2	0.68
133A	96.071	10.35	146.70	7.19	5.61	466.8	0.39	7.31	5.87	445.20	0.473	7.26	5.96	454.5	0.42	7.48	6.22	429.5	0.44
133B	97.031	10.48	115.25	6.94	3.99	413.6	0.83	7.13	4.27	385.75	0.853	7.19	4.41	383.2	0.85	7.25	4.34	376.8	0.90
134	97.542	10.55	201.03	7.92	5.44	536.1	0.94	8.03	5.86	506.88	0.858	8.26	6.26	472.1	0.87	8.41	6.68	439.6	0.81
134A	98.042	10.62	71.35	5.44	0.58	373.1	0.94	0.92	5.76	345.75	-0.498	1.28	5.93	333.2	1.00	1.11	5.92	334.7	1.03
134B	98.622	10.71	176.67	7.49	6.17	574.2	0.41	7.61	6.41	546.72	0.388	7.71	6.16	535.0	0.52	7.84	5.85	508.4	0.69
135	99.152	10.78	132.60	7.21	5.33	479.3	0.53	7.54	5.28	428.67	0.698	7.62	5.83	415.5	0.56	7.97	5.98	371.4	0.71
135A	99.972	10.89	119.05	7.35	5.79	425.8	0.44	7.57	5.83	399.21	0.521	7.62	5.82	392.3	0.55	7.60	5.88	394.9	0.52
135B	100.710	11.00	112.60	7.18	6.00	433.3	0.31	7.35	6.00	409.35	0.369	7.48	6.34	394.0	0.32	7.34	6.32	409.3	0.28
136	101.356	11.09	130.10	7.57	6.00	464.2	0.45	7.78	6.31	430.88	0.444	8.09	6.81	391.0	0.43	8.23	7.21	381.5	0.36
136A	102.026	11.18	150.40	8.13	6.41	481.7	0.56	8.18	6.39	452.59	0.595	8.40	6.60	425.4	0.65	8.36	6.81	431.3	0.55
137	102.660	11.28	45.40	3.07	-0.13	383.4	0.40	3.31	-0.08	361.65	0.425	3.75	-0.04	344.2	0.50	4.15	0.81	304.8	0.47
137A	103.290	11.39	64.60	5.24	2.64	402.1	0.42	5.42	2.38	383.25	0.510	5.27	2.30	393.2	0.49	5.95	2.32	384.7	0.67
138	104.028	11.53	134.92	8.02	6.70	485.0	0.38	8.12	6.96	460.64	0.339	8.31	7.14	427.2	0.36	8.51	7.39	400.8	0.37
138A	104.368	11.59	107.60	7.76	6.40	415.9	0.35	7.84	6.50	403.89	0.358	7.78	6.28	403.9	0.39	7.88	6.64	413.0	0.33
139	105.235	11.75	80.47	6.90	1.83	396.0	1.05	7.04	1.52	379.22	1.172	7.18	2.33	379.2	1.06	7.40	2.15	361.1	1.21
139B	105.705	11.89	115.05	8.20	5.84	430.7	0.64	8.17	5.81	427.28	0.636	8.16	5.93	427.3	0.60	8.35	6.04	427.9	0.65
140	106.506	11.98	97.97	7.37	4.66	456.0	0.59	7.35	4.70	453.98	0.572	7.28	4.61	454.0	0.57	7.67	4.98	458.1	0.62
141	107.279	12.12	111.58	8.63	6.72	394.0	0.55	8.35	6.33	421.09	0.536	8.45	6.53	421.1	0.52	8.98	6.95	398.5	0.64
141A	107.449	12.15	92.75	8.38	4.93	352.7	0.91	8.24	4.80	362.28	0.879	8.08	5.90	362.3	0.53	8.18	5.53	380.7	0.67
142	108.116	12.27	131.10	8.89	6.96	450.2	0.57	8.87	6.87	445.88	0.586	9.09	7.30	445.9	0.56	9.19	7.88	417.7	0.43
143	108.759	12.38	84.05	7.33	4.91	428.7	0.48	7.55	5.89	405.88	0.343	7.59	5.81	405.9	0.37	7.79	5.81	399.0	0.43
143A	109.479	12.51	86.50	7.63	5.92	426.1	0.35	7.75	6.20	413.20	0.325	7.78	6.12	413.2	0.35	7.99	6.34	418.7	0.36
144	110.111	12.62	122.40	9.09	7.80	437.7	0.37	9.18	7.91	420.65	0.370	9.39	8.27	420.7	0.35	9.62	8.54	398.4	0.36
145	110.530	12.70	43.29	5.36	1.41	323.1	0.54	5.63	1.40	306.40	0.598	5.45	1.41	306.4	0.56	5.79	2.04	312.2	0.54
145Y	110.974	12.77	79.91	7.89	4.96	393.6	0.60	7.72	4.24	403.58	0.688	7.45	4.28	403.6	0.60				
146	111.173	12.81	84.50	8.28	6.10	391.7	0.48	8.07	5.98	392.51	0.441	7.93	6.04	392.5	0.39	8.35	6.28	401.5	0.46
146A	111.433	12.86	163.74	9.83	7.36	500.8	0.82	9.88	7.49	487.36	0.803	9.76	7.51	487.4	0.73	9.98	8.03	507.3	0.68
146B	111.803	12.93	80.39	8.53	4.97	357.8	0.81	8.46	4.99	359.47	0.778	8.39	4.74	359.5	0.81	8.49	5.08	363.7	0.77
147	112.429	13.04	87.65	7.78	4.87	465.5	0.55	7.67	4.77	470.75	0.539	7.64	4.44	470.8	0.59	8.30	4.78	471.3	0.74
148	113.523	13.24	111.20	9.21	7.40	470.7	0.45	8.95	7.18	469.27	0.412	9.23	7.11	469.3	0.53	9.34	7.60	443.2	0.45
148A	113.810	13.30	106.62	9.34	8.25	425.7	0.28	9.40	7.98	415.94	0.364	9.64	8.69	415.9	0.26	9.66	8.51	388.4	0.32
149	114.312	13.40	122.58	9.71	8.12	459.2	0.43	9.81	8.22	439.53	0.444	8.91	5.69	439.5	0.72	9.30	5.76	546.2	0.86
149A	114.737	13.49	90.72	9.01	7.72	410.0	0.29	8.79	7.36	426.25	0.304	8.68	7.15	426.3	0.32	8.91	7.18	431.8	0.38
150	115.342	13.63	86.37	9.54	8.10	360.0	0.35	9.41	8.08	361.12	0.317	9.61	8.22	361.1	0.35	9.62	8.17	349.2	0.36
150A	115.822	13.74	129.26	10.16	8.72	467.1	0.40	10.19	8.84	458.72	0.381	10.24	8.99	458.7	0.36	10.15	9.44	455.1	0.20
151	116.275	13.84	87.53	9.63	6.37	382.6	0.78	9.68	6.42	361.24	0.785	9.83	6.70	361.2	0.78	10.05	7.44	349.8	0.69
151A	116.375	13.94	124.54	10.36	9.09	452.0	0.35	10.29	8.80	454.31	0.407	10.29	8.78	454.3	0.41	10.41	8.94	451.5	0.42
152	117.257	14.05	56.61	6.58	1.21	389.6	0.72	6.74	1.64	377.16	0.698	6.66	1.42	377.2	0.71	6.63	1.63	383.8	0.67
152A	117.527	14.11	89.90	9.78	8.38	393.0	0.32	9.74	8.40	392.98	0.307	9.75	8.32	393.0	0.33	9.96	8.61	394.5	0.32
152B	117.727	14.16	46.71	6.87	1.32	345.1	0.76	7.36	1.53	318.15	0.858	7.02	1.13	318.2	0.82	7.88	2.20	321.8	0.90
152C	118.017	14.23	89.55	9.49	5.28	428.9	0.89	9.43	5.22	418.36	0.879	9.57	5.69	418.4	0.84	9.83	6.04	414.3	0.86
153	118.367	14.30	86.86	7.96	2.98	559.4	0.79	8.26	2.90	506.18	0.888	7.60	3.64	506.2	0.59	8.72	3.81	582.7	0.88
153A	118.577	14.35	128.29	10.84	8.78	457.7	0.59	10.60	8.98	442.31	0.432	10.80	9.16	442.3	0.46	10.89	9.36	442.1	0.44
153Z	118.748	14.38	97.27	9.44	7.40	485.2	0.41	9.93	7.87	432.72	0.463								
153B	118.882	14.41	64.15	8.94	5.54	355.7	0.62	8.91	5.45	352.29	0.628	8.91	5.20	352.3	0.68	9.15	6.16	349.5	0.57
154	119.213	14.48	65.10	8.21	6.34	318.1	0.30	8.29	6.45	403.96	0.297	8.43	6.82	404.0	0.27	8.79	7.06	396.2	0.30

				Year 2012				Year 2006				Year 2002/2003				Year 1998			
Section	Chainage	NWL (m)	Width of NWL (m)	WMBL (m)	Thalweg (m)	XS area (m2)	TI	WMBL (m)	Thalweg (m)	XS area (m2)	TI	WMBL (m)	Thalweg (m)	XS area (m2)	TI	WMBL (m)	Thalweg (m)	XS area (m2)	TI
154A	119.548	14.55	110.07	10.45	7.85	454.9	0.63	10.45	7.95	451.2	0.61	10.51	7.56	451.19	0.73	10.72	8.07	362.0	0.69
154B	120.068	14.66	77.12	10.00	6.43	363.3	0.77	9.93	5.69	364.0	0.90	9.90	6.53	363.96	0.71	9.82	6.31	443.5	0.72
155	120.486	14.76	64.82	8.52	4.80	406.4	0.60	8.31	4.51	418.8	0.59	8.39	4.91	418.76	0.55	8.43	5.11	410.6	0.53
155A	120.801	14.83	89.98	10.33	8.28	410.0	0.46	10.20	8.28	417.4	0.41	10.43	8.61	417.37	0.42	10.73	8.27	390.5	0.60
156	121.375	14.96	96.15	10.36	7.79	447.9	0.56	10.26	7.54	450.1	0.58	10.27	7.26	450.05	0.64	10.28	7.21	451.9	0.66
156A	121.995	15.09	85.39	10.62	9.52	385.4	0.25	10.61	9.69	379.9	0.20	10.45	9.58	379.92	0.19	10.70	9.89	394.0	0.19
157	122.442	15.19	97.69	10.86	8.98	427.6	0.43	10.66	8.73	426.3	0.43	10.99	9.13	426.28	0.44	11.06	9.35	409.6	0.41
157A	123.332	15.39	70.94	10.21	6.98	371.5	0.62	10.27	6.92	362.0	0.65	10.42	6.70	362.02	0.75	10.28	6.81	351.5	0.68
157G	123.741	15.50	83.56	9.95	4.43	467.3	1.00	10.22	4.54	440.9	1.07								
157B	124.352	16.52	98.50	11.60	10.16	399.5	0.36	11.89	10.58	367.4	0.28	11.56	10.05	367.35	0.31	11.81	10.42	398.8	0.30
158	124.868	15.73	76.70	10.50	6.56	403.6	0.75	10.55	8.09	359.8	0.47	10.83	7.65	359.76	0.65	10.97	7.76	373.9	0.67
158A	125.458	15.85	84.55	11.43	8.61	377.3	0.64	11.73	9.03	348.4	0.65	11.56	8.50	348.36	0.71	11.68	8.94	362.8	0.66
159A	125.951	15.95	69.26	11.01	5.41	349.5	1.14	10.76	5.42	362.7	1.03	10.75	5.17	362.67	1.07	11.32	5.76	350.2	1.20
159	126.326	16.05	26.70	5.51	4.00	284.8	0.14	5.88	4.10	271.2	0.17	5.75	3.44	271.21	0.22	5.79	3.86	274.8	0.19
160	126.364	16.27	105.90	12.26	10.15	432.7	0.52	12.39	10.31	415.0	0.54	12.19	9.95	415.01	0.55	12.31	10.38	424.7	0.49
161A	127.550	16.43	90.68	10.53	7.71	545.3	0.48	10.47	7.58	535.9	0.48	10.08	6.27	521.07	0.60	10.61	8.14	527.5	0.43
161B	128.120	16.53	70.58	10.68	7.97	421.0	0.46	11.32	7.25	411.5	0.78	11.02	8.53	395.84	0.45	10.96	7.85	392.9	0.56
162	128.399	16.58	62.51	10.89	9.52	358.6	0.24	11.39	9.43	324.4	0.38	11.65	9.84	311.98	0.37	11.57	9.99	312.9	0.32
162A	129.079	16.69	59.95	11.17	6.92	335.9	0.77	11.28	7.05	324.3	0.78	11.27	7.06	328.34	0.78	11.65	8.40	302.2	0.64
163	129.313	16.73	51.95	9.94	5.97	360.4	0.59	10.01	6.39	349.6	0.54	10.08	6.23	359.61	0.58	9.79	5.26	360.5	0.65
165	130.894	17.00	71.30	12.10	11.27	355.9	0.17	12.17	11.41	344.4	0.16	12.02	11.18	330.10	0.17	12.28	11.36	336.5	0.20
165A	131.384	17.08	81.40	11.87	9.03	435.9	0.55	12.09	9.56	407.7	0.51	12.04	9.37	409.78	0.53	11.89	9.00	422.1	0.56
166	132.100	17.02	97.37	13.22	11.55	374.4	0.44	13.28	11.64	365.9	0.44	13.27	11.46	366.58	0.48	13.39	11.32	353.3	0.57
167	133.573	17.45	63.75	12.43	9.96	328.5	0.49	12.51	10.44	314.2	0.42	12.82	10.25	299.77	0.55	12.70	10.19	302.6	0.53
168	134.802	17.66	81.40	13.05	11.47	379.6	0.34	13.10	12.24	367.4	0.19	13.34	12.08	342.45	0.29	13.46	12.20	342.2	0.30
169	136.282	17.56	83.36	13.27	11.62	361.6	0.39	13.53	11.78	335.8	0.44	13.38	11.69	319.40	0.40	13.73	12.53	319.3	0.31
169A	136.740	17.99	86.60	13.87	12.69	359.7	0.29	13.90	12.56	354.0	0.33	13.87	12.07	356.22	0.44	14.22	12.38	326.1	0.49
170	137.425	18.11	67.00	13.21	11.61	334.6	0.33	13.23	11.31	324.0	0.39	13.72	12.44	294.19	0.29	13.66	12.62	298.4	0.23
171	138.060	18.21	106.14	14.79	12.98	368.6	0.53	14.72	12.98	370.7	0.50	14.71	13.36	344.50	0.38	14.95	13.59	346.2	0.42
172A	138.878	18.35	57.90	13.68	12.46	275.3	0.26	13.83	12.24	267.3	0.35	13.76	12.06	271.90	0.37	13.81	12.34	263.1	0.32
173	139.707	18.49	51.75	12.90	11.26	293.7	0.29	12.61	10.74	304.8	0.32	12.74	11.27	290.94	0.26	12.85	11.40	291.9	0.26
173B	140.881	18.16	42.48	11.26	8.22	296.8	0.44	11.50	8.60	282.8	0.44	11.73	8.91	276.64	0.30	11.92	9.44	265.1	0.28
174	141.771	18.84	56.98	14.40	13.44	259.7	0.22	14.48	13.38	248.5	0.25	14.45	13.36	248.38	0.25	14.45	13.41	250.0	0.24
174A	142.361	18.94	69.96	14.15	12.95	340.2	0.25	14.00	12.25	345.6	0.35	14.01	12.32	341.51	0.34	14.03	11.46	343.5	0.52
174B/17	142.650	19.04	25.55	6.66	3.42	321.6	0.26	7.57	4.10	295.3	0.30	7.64	4.71	292.76	0.26	7.83	4.37	286.4	0.31
175/16G	142.937	19.25	80.05	15.37	13.98	317.5	0.36	15.20	13.89	316.6	0.32								
175A/16	143.267	19.37	57.30	14.14	11.99	304.0	0.41	14.07	11.91	303.9	0.41	14.23	11.58	287.76	0.51	14.67	12.07	269.1	0.55
177/10	145.100	20.32	43.59	15.16	14.02	227.7	0.22	15.11	14.02	227.8	0.21								
178/07	146.680	21.17	62.70	15.65	12.34	349.6	0.60	15.69	11.73	334.6	0.72	15.70	12.07	332.31	0.66	15.84	11.88	334.1	0.74
180/03	148.250	22.00	70.00	17.86	14.42	297.4	0.83	18.03	15.14	275.5	0.73	18.03	14.60	276.97	0.86	18.08	14.66	274.7	0.87

URS

URS New Zealand Limited
273 Cashel Street
Christchurch 8011
PO Box 4479, Christchurch 8140New Zealand

T: 64 3 374 8500
F: 64 3 377 0655

www.urscorp.co.nz