Channel morphology and sedimentation in the Lower Clutha River

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Foreword

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

To help maintain the integrity of the region's gravel resources, the Otago Regional Council undertakes scheduled cross-section surveys as part of the natural hazards programme. This information is utilised to understand the dynamic fluvial processes of each watercourse and general state of the gravel resource.

This report explores how the morphology and sedimentation of the Lower Clutha has changed over the surveyed periods, while providing a synthesis of the study's results to guide management strategies into the future.

Executive summary

Changes in channel morphology and sedimentation in the Lower Clutha were examined using historical cross-sections. The cross-sections date from 1865 (at Balclutha) to 2007 and originate from design surveys for bridges and ferries, monitoring sections for hydrology and monitoring sections for cross-sectional changes.

Cross-sections were completed at many Clutha River/Mata-Au bridges in 1948 by the Ministry of Works for the purpose of hydrological monitoring and design for the Roxburgh power scheme. A further extensive survey was completed in 1982 by the then Ministry of Works and Development for the proposed further development of hydro-electric schemes on the Lower Clutha River/Mata-Au. Monitoring cross-sections were initiated in the early 1990s, downstream of Beaumont, by the Otago Regional Council (ORC) for the purposes of bed level change monitoring. New cross-sections were added in 2007 to duplicate some of the 1948 and 1982 cross-sections.

Land use changes in the Clutha Catchment that may have impacted the bed levels of the river include: clearing for agriculture, general gold mining, hydraulic sluicing, dredging in the rivers and hydro-electric dam construction. The Rivers Commission (1920) estimated that 300 million cubic yards of sediment had been moved by mining activities, with about 60 million cubic yards in the river and 40 million cubic yards already washed out to sea. The remaining 200 million cubic yards had not yet reached the river at the time. This sediment input was estimated to have caused 10 feet of bed level aggradation in the upper reaches and three feet of aggradation in the lower reaches (Rivers Commission, 1920).

The early bridge and ferry cross-sections confirm a trend of aggradation, although the magnitude of aggradation is more extreme than the assessment made by the Rivers Commission. About 5m of aggradation occurred from 1875 to 1919 at Roxburgh bridge and an equivalent amount at Beaumont bridge from 1885 to 1948.

Nineteenth century aggradation at Balclutha was probably the result of the deposition of suspended sediment, which moves more rapidly through the catchment. Since the cessation of extensive mining activities in the 1920s, the trend has been falling bed levels: post-1919 at Roxburgh bridge, post-1940 at Millers Flat bridge and post-1948 at Beaumont bridge.

In 1954, the closure of the Roxburgh dam on the Clutha River/Mata-Au is associated with significant bed level degradation of 5m immediately downstream of the dam from 1948 to 1982 and a further 2m from 1982 to 2007. There has been 4m of degradation at Roxburgh bridge from 1948 to 2007.

The timing of bed level aggradation and degradation appears to indicate that changes in bed material supply take time to work through the catchment. The reduction in bed material supply from upstream caused by the Roxburgh dam may be made up in part by further erosion from the bank and bed of the river downstream of the dam. However, the bed material supply reduction signal from the dam is also likely to gradually work downstream. It is anticipated that it is currently being experienced around Beaumont, although the configuration of the Beaumont bar by gravel extraction activities means the signal may not readily be distinguished. The trend of bed degradation following reduction in gold mining activity may reach Balclutha in the next 10-15 years.

Despite this trend of bed level lowering and bank erosion upstream of Clydevale, gravel continues to accumulate at Roxburgh and Beaumont bars. This is potentially due to both locations acting as natural bed material deposition basins, with the volume of gravel here less sensitive to changes in total bed material supply in the river. However, the volume of bed material transported through these reaches is likely to be reduced significantly following the reduction in bed material supply from upstream.

In the future, further significant bed degradation and bank erosion is likely to take place between Roxburgh and the Roxburgh Dam as the deficit in bed material transport caused by the dam is made up by bed and bank erosion.

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1. Introduction

Channel morphology and sedimentation in the Lower Clutha has previously been monitored using cross-section surveys at a limited number of sites from Beaumont bar downstream to the sea. Cross-section monitoring points are introduced here to extend the analysis of gravel resources upstream from Beaumont bar to Roxburgh dam. Although these are recent additions to the Otago Regional Council (ORC) cross-section monitoring program, previous surveys have been undertaken at many of these sites and this historical information has been collated and assessed in this report.

The main source of information on historical changes in the Clutha River/Mata-Au channel is observations of channel cross-section changes. Descriptions of the condition of the river catchment are also available from historical reports and photographic archives. Limited information is available on the nature of sediment in the catchment and the rates of sediment transport in the channel. These were reported on in 2005 by a previous ORC report.

2. Survey datums

The many surveys available of the Clutha River/Mata-Au are given in terms of various survey datums, usually depending on the age of the survey and the purpose for which the survey was undertaken. In some cases, the cross-section plan does not indicate which datum has been used.

To allow effective comparison of various types and ages of cross-section survey, the survey datums were converted into Otago datum. This was completed by two methods:

1) Where the original datum was known and could be related to Otago datum through known conversion factors, simple arithmetic was used to convert the levels.
2) Where the datum was known, but could not be related to Otago datum or where the survey information did not identify the datum used, features common to the unknown cross-sections and more recent cross-sections were used as reference marks for conversion purposes.

Most of these common reference points were bridge features. Usually, the elevation of features such as bridge piers will not have changed significantly over time. However, features such as bridge deck levels may have altered as a result of bridge maintenance.

The known conversion factors between Otago datum and other datums are listed in Table 2.1**Error! Reference source not found.**. All datums and survey values obtained in feet were converted to metres through multiplication by a factor of 0.3048. The surveys where a reference mark has been used for datum conversions are identified in the following discussions. From the 1982 survey onwards, the levels were obtained in Otago or Dunedin metric datums and have not required further conversion.

Table 2.1 Selected survey datums used on the Clutha River/Mata-Au

Datum	Year	Level	Sea level (ft)	Sea level (m)	Note
Otago	1958	MSL		100.00	From LINZ
Dunedin	1958	MSL		0.00	From LINZ
NZ Railways		MHWS	47.00	14.33	From Robert Storm, Ontrack
Balclutha Railway		MHWS	47.00	14.33	Assumed to be equivalent to NZ Railways
Tuapeka Mth Railway		MHWS	47.00	14.33	Assumed to be equivalent to NZ Railways
Alexandra		MSL	-3.03	-0.92	
Rivers Commission	1920	MSL	44.88	13.68	From Plan X788, ORC archives
Roxburgh Hydro		MSL	-3.03	-0.92	Equivalent to Alexandra datum
Lower Clutha River Trust		MSL	43.49	13.26	From “Clutha Conversion” – Otago Catchment Board tables

MSL=Mean Sea Level; MHWS=Mean High Water Springs

3. Cross-sections

Cross-section surveys of the Clutha River/Mata-Au may be separated into bridge/ferry design surveys and cross-section surveys undertaken for hydrological or bed level monitoring. The former are mostly older than the latter but the latter are more numerous. Since the eight bridge surveys are relatively well spaced from Roxburgh Dam to Stirling, these may record gross changes in sediment conditions in the river. More localised changes can be identified in the more closely spaced monitoring cross-sections.

Design drawings of ferry crossings on the Clutha River/Mata-Au provide the earliest information on river bed levels (Figure 3.1). Cross-section information is available from National Archives for the ferry crossing at Balclutha on 24 May 1865. The earliest bridges for which bed level information is available are the bridges at Stirling on the Clutha delta (section surveyed 1875) and the first Roxburgh bridge (1875). Data are also available for the Commissioners Flat swing bridge, Millers Flat (opened 1899), Island Block/Horseshoe Bend (constructed 1913), Beaumont (opened 1887), Clydevale (opened 1939), Balclutha (third bridge opened 1935) and Stirling (opened 1876). Cross-section data also exist for the Balclutha railway bridge which was opened in January 1878.

Cross-sections have also been surveyed on the Clutha River/Mata-Au for river control works and monitoring purposes. The earliest cross-sections for river management appear to be those surveyed in 1880s upstream of Balclutha roadbridge, where bank erosion was rife around this time. Additional surveys were undertaken on both branches of the Clutha on the delta during various schemes for flood control. Upstream, nineteenth century cross-sections are available at Tuapeka Mouth and Clydevale.

Many of the cross-sections at bridges along the Clutha River/Mata-Au were re-surveyed during investigations into the Roxburgh (Coal Creek) hydro-electric power scheme in 1948, particularly for hydrological investigations.

Further cross-section surveys of the Clutha River/Mata-Au were undertaken from Roxburgh Hydro to Clydevale, as part of the investigations into Clutha River/Mata-Au hydro-electric power schemes in 1982-1983 by the then Ministry of Works and Development (MWD).

Cross-sections have been surveyed by the ORC and its predecessors from the Beaumont River to the sea. The most recent re-surveying was in 2007, when cross-sections from Roxburgh Hydro to Clydevale were added to the survey program. From Roxburgh Hydro to Clydevale, 17 of the 1982 MWD cross-sections were re-surveyed and five bridge cross-sections were also re-surveyed.

All available survey information has been compiled into the ORC cross-section database XSect. This software allows comparison of net change in bed levels and cross-sectional areas through time. The wide range of survey datums have been converted to the standard Otago datum using a combination of known datum offsets and/or duplicate surveys of known reference points such as bridge decks and benchmarks.

The resulting dataset of information on cross-sectional changes in the Clutha River/Mata-Au is the most comprehensive ever assembled in one place. The data extend in time from 1865 to the present day and in space from Roxburgh Hydro to Stirling. Cross-section data above the Roxburgh dam and below the Balclutha bifurcation are not considered within this study.

Major floods in the Clutha River/Mata-Au are shown in Figure 3.1 (Opus, 2000). The largest flood recorded is the event in 1878. Other significant floods include the 1919, 1978, 1995, 1996 and 1999 floods.

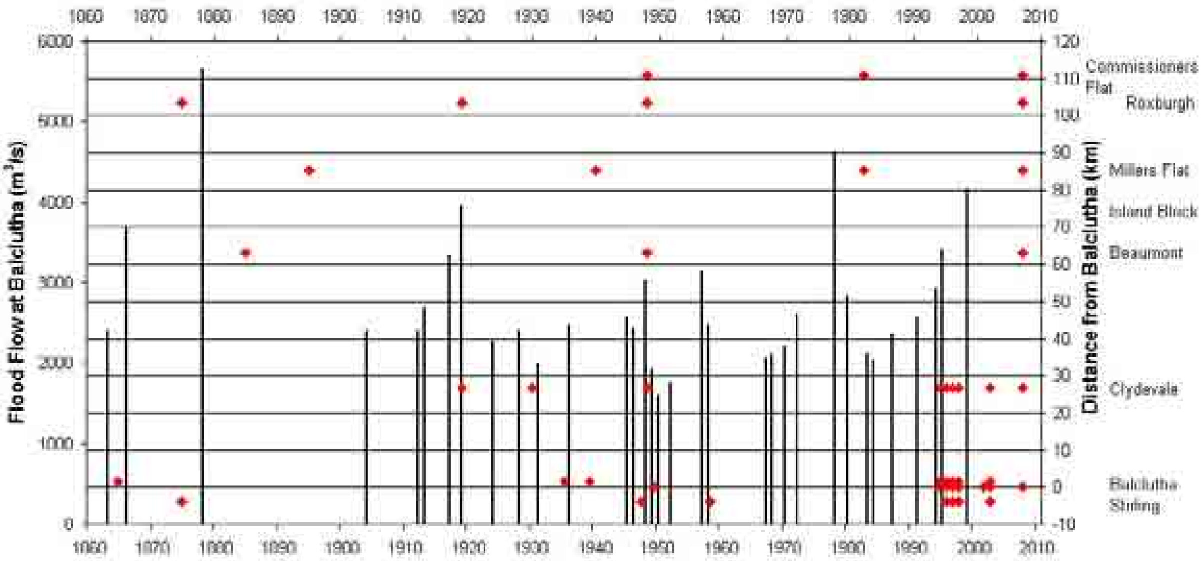

Figure 3.1 Bridge and ferry survey dates at various distances downstream from Roxburgh Hydro (right axis), shown with major flood flows (left axis) in the Clutha River/Mata-Au (1860-2007)

3.1 Bridge surveys

The Roxburgh dam is 112.6km from the Clutha River/Mata-Au bifurcation at Balclutha. The bridge closest to the Roxburgh dam which has repeat surveys available is the swing bridge at Commissioners Flat. Bridge surveys are also available for the Roxburgh bridges, Millers Flat bridge, Beaumont bridge, Clydevale bridge and Stirling bridge.

3.1.1 Commissioners Flat swing bridge

The swing bridge at Commissioners Flat is approximately 1.8km downstream of the dam face. The bridge was originally constructed around 1901 by W. Coulter and Party to convey water from Chasm Creek and Elbow Creek on the west (true right) side of the Clutha River/Mata-Au to a sluicing operation on the east side of the river (Stuart Edgecumbe, pers. comm. 2007). The bridge was later converted to a foot bridge. The 1948 survey was obtained at the bridge (ORC plan 5394), while the 1982 and 2007 surveys were obtained about 42m upstream.

Although cross-sectional area may have fluctuated over the 25-year period between 1982 and 2007, a lowering of the channel's thalweg (lowest point in the cross-section) by 1.5m indicates net degradation at this site. Observations of the 1948 section notes that the thalweg is 5m higher than the 2007 thalweg, located 42m upstream. The prevalence of a narrower channel at the 1948 site and observed differences in section bed levels, denotes an environment subject to net degradation.

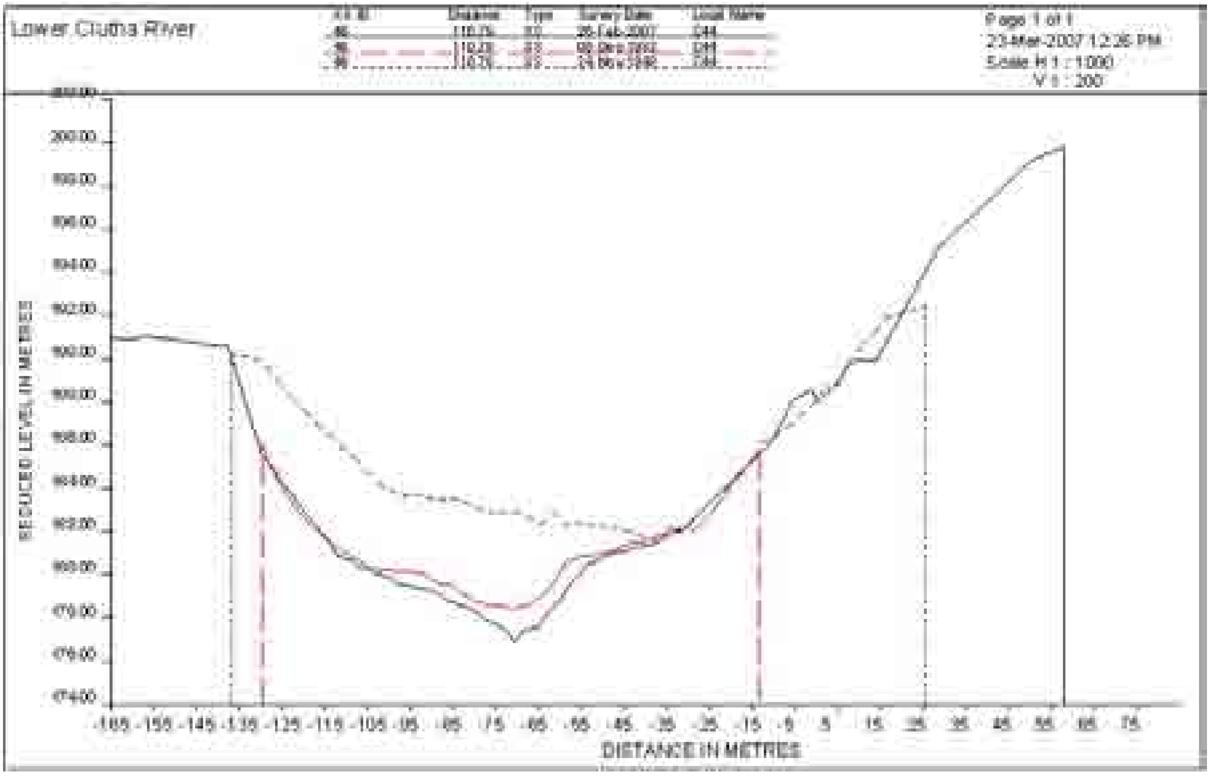

Figure 3.2 Commissioners Flat swing bridge, Roxburgh Hydro, 1948, 1982 and 2007

3.1.2 Roxburgh bridges

The original Roxburgh bridge was opened in 1875 (Figure 3.3), but was destroyed in the 1878 flood. The second Roxburgh bridge was installed 115m further downstream and opened in 1887. The third (current) bridge was opened 15m downstream of the second bridge in 1975 (Griffiths, 1978). The 1875 cross-section is the design section for the first bridge. The 1919, 1948 and 2007 cross-sections were obtained at the site of the second bridge. The 1875 (first bridge), 1919 and 1948 (second bridge) cross-sections were obtained from plan 5393 at the ORC.

Figure 3.3 Roxburgh bridge in 1875 looking upstream

Substantial changes in channel profiles from 1875 to 1919, even though the respective cross-sections are located 115m apart, are indicative of net change within this reach. Observations depicting bed level accumulation and a difference in thalweg of approximately 6m, denotes presiding aggradation along this reach. The comparison of profiles from the second bridge location shows a dominant degradational environment with net thalweg lowering of 1m from 1919 to 1948 and a further 4m from 1948 to 2007.

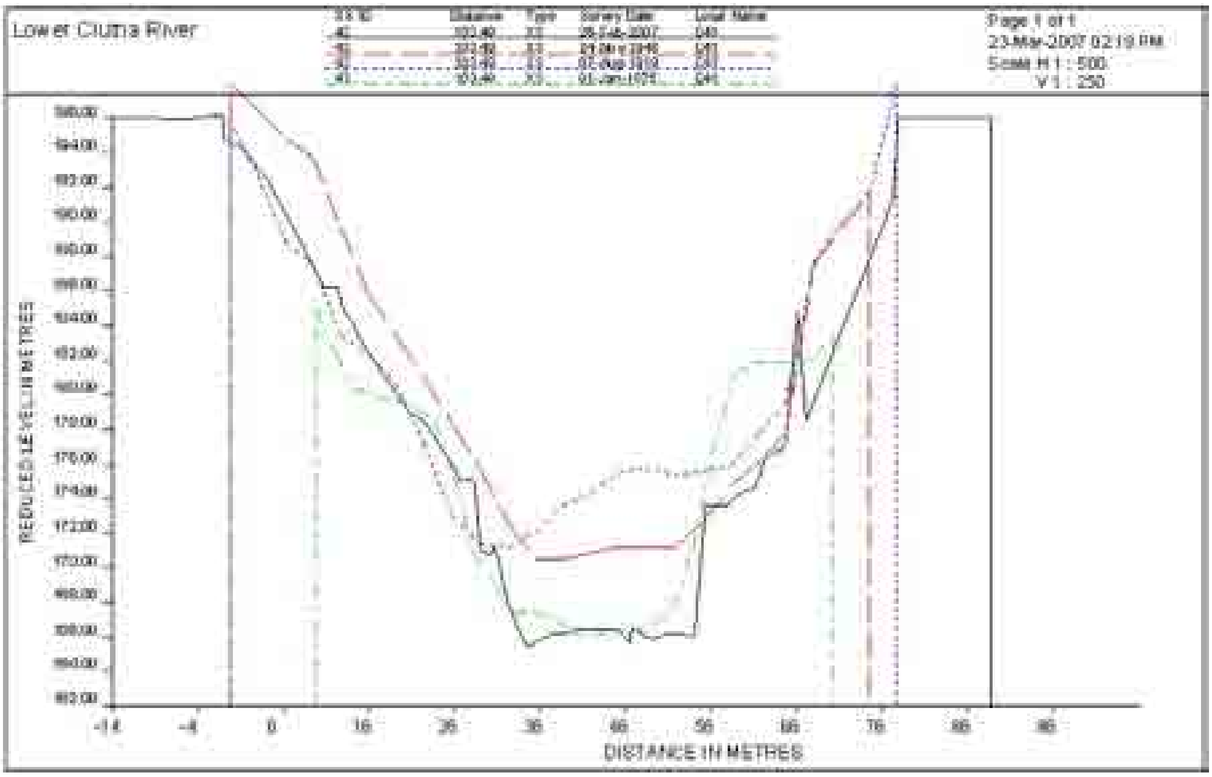

Figure 3.4 Roxburgh bridges, in 1875, 1919, 1948 and 2007

3.1.3 Millers Flat bridge

The cross-section at Millers Flat bridge was surveyed for design purposes in 1895, with the bridge opening in February 1899 (Griffiths, 1978). Cross-sections were obtained at the bridge site in 1895, 1914, 1940, 1948 (all from plan 5393), 1982 and 2007. Only the cross-sections from 1895, 1914, 1982 and 2007 are shown in Figure 3.5.

As all cross-sections for the Millers Flat bridge were taken at the same location, direct comparison of sections in determination of net aggradation or net degradation is valid. Sections from 1895 and 1914 show a location exhibiting accumulation on the true left and degradation on the true right, with the net change being aggradation. Although the reach may have varied between aggradation and degradation over the 68-year period between 1914 and 1982, sections show a net degradation of between 1.5 and 2m. From 1982 to 2007, net degradation also prevails at this location.

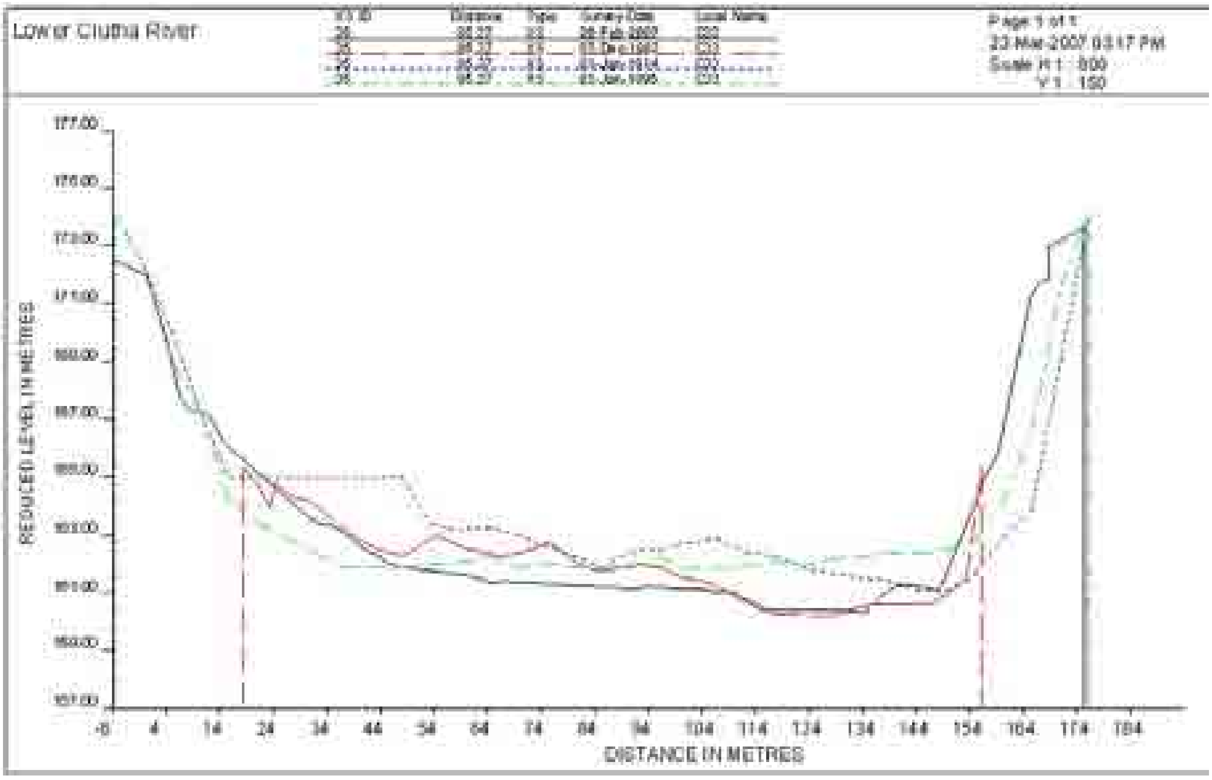

Figure 3.5 Millers Flat bridge in 1895, 1914, 1982 and 2007

3.1.4 Beaumont bridge

The Beaumont bridge was opened in March 1887, replacing a private bridge at the same location that was destroyed in the 1878 flood (Griffiths, 1978). The earliest survey at this site is the design cross-section of 1885 for the second bridge (plan 5395). The bridge was resurveyed in 1948 as part of the investigations into the Clutha valley hydro-electric power scheme. Located 100m downstream of the bridge, the 1982 cross-section is not directly comparable with the 1885, 1948 and 2007 cross-sections.

Two primary channels exist at the location of the bridge cross-sections, with the river bed being comprised of both bedrock and unconsolidated alluvium. The period from 1885 to 1948 yielded net thalweg aggradation of approximately 5m, with sediment accumulations virtually infilling the secondary channel. Between 1948 and 2007, net degradation of approximately 2-3m prevailed at this location.

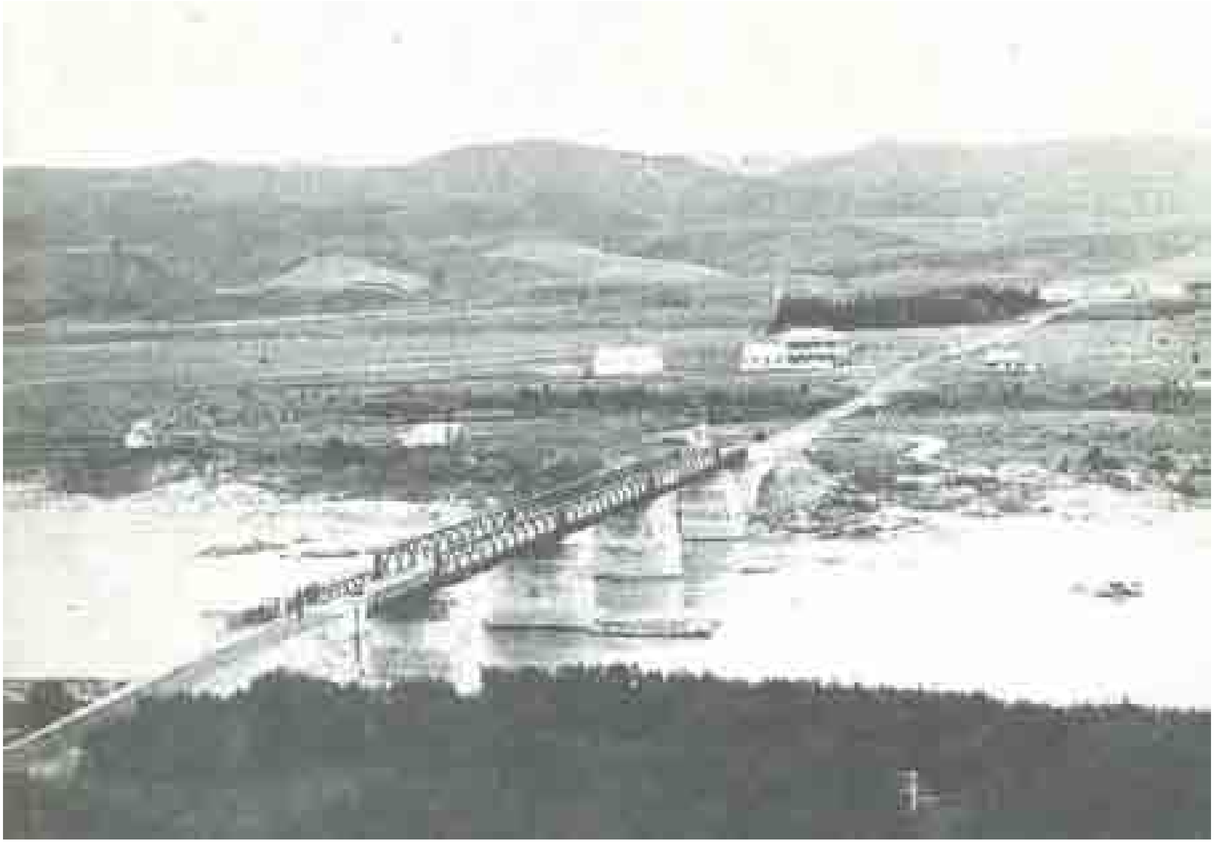

Figure 3.6 Beaumont bridge c. 1887. Downstream is to the left of the photograph

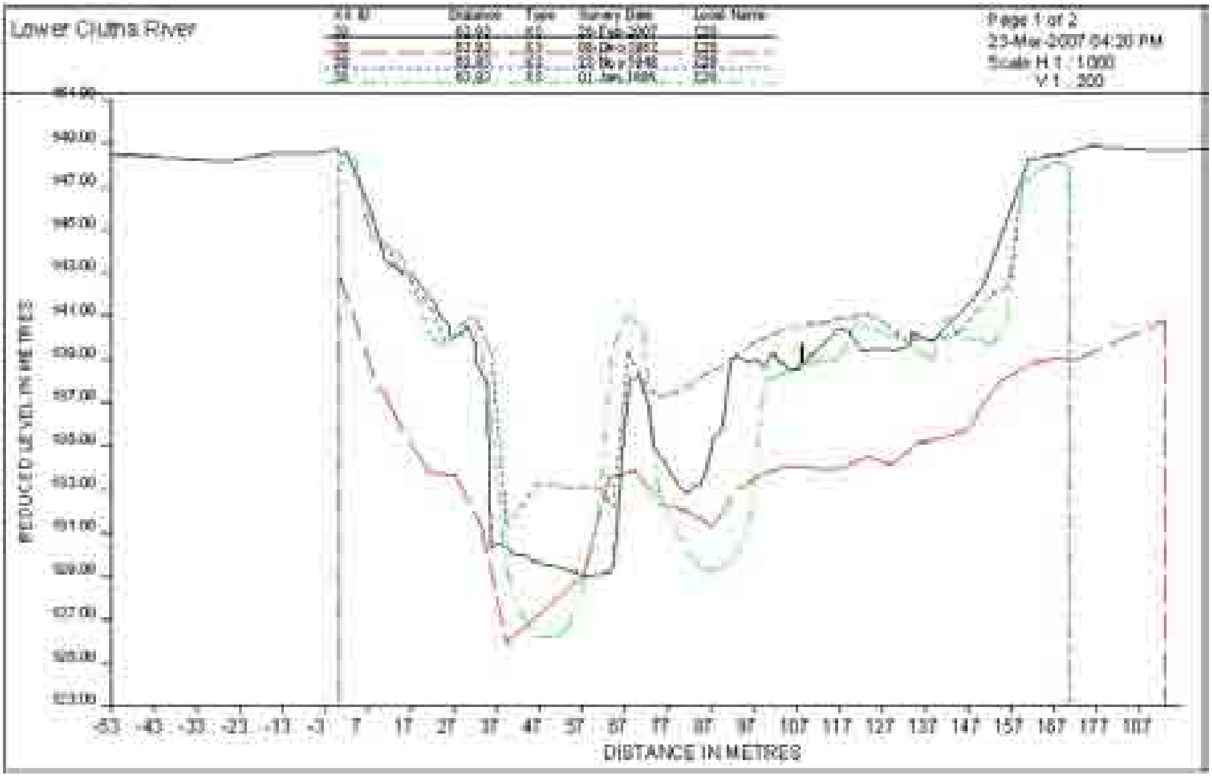

Figure 3.7 **Beaumont bridge in 1885, 1948, 1982 and 2007**

3.1.5 Clydevale bridge

The Clydevale bridge was opened in March 1939. Two earlier surveys available are of the ferry crossing at Clydevale approximately 75m upstream of the present bridge. The 1920 survey was obtained from Lower Clutha River Trust plan R/1/1, 2 & 3 (ORC plans 5583 and 5585) and the 1930 and 1948 surveys were obtained from ORC plan 718. Cross-sections also exist further upstream of the bridge from 1920 (plans 5583 & 5585), 1948 (plan 718) and 1978 (plan 9050), but these have not been repeated since that date.

For the period from 1920 to 1930, the true right side of the Clydevale ferry/bridge showed net aggradation, while the true left showed extensive bank erosion. While periods of aggradation and degradation may have been present between 1930 and 1948, net degradation of up to 2.5m occurred during this period. Between 1948 and 2007, net aggradation occurred up to similar bed levels seen in 1930.

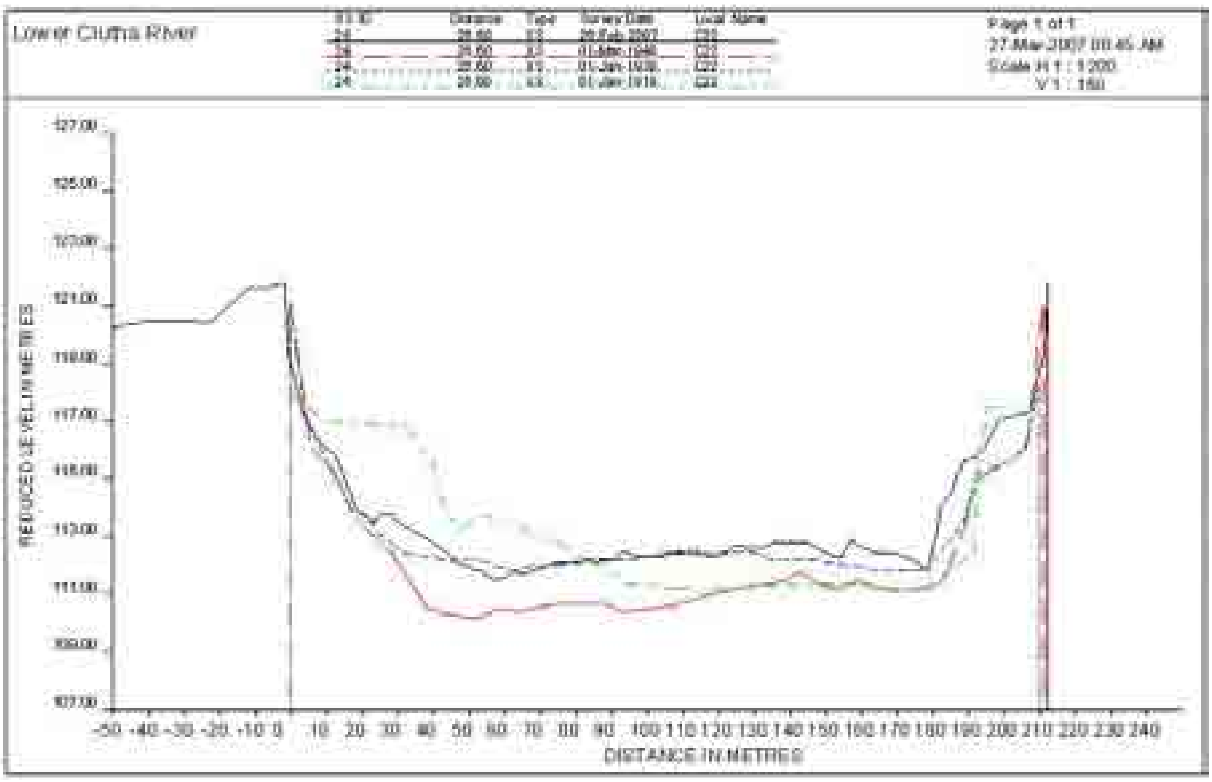

Figure 3.8 Clydevale bridge in 1920, 1930, 1948 and 2007

3.1.6 Balclutha railway bridge

The Balclutha railway bridge was constructed from 1875 to 1878 and opened in January 1878, prior to the floods of that year. Surveys are available from 1878, 1893, 1919, 1939 (plan 929) and modern surveys from 1994 to 2002.

For the 15 year period from 1878 to 1893, net aggradation of up to 2m across the width of the channel occurred at this location. While there is evidence to suggest periods of aggradation and degradation over the timeframe 1893 to 1939, the true left of the channel exhibited net degradation while the true right of the channel experienced net aggradation. Net degradation was dominant during the periods from 1939 to 1994 and from 1994 to 2002.

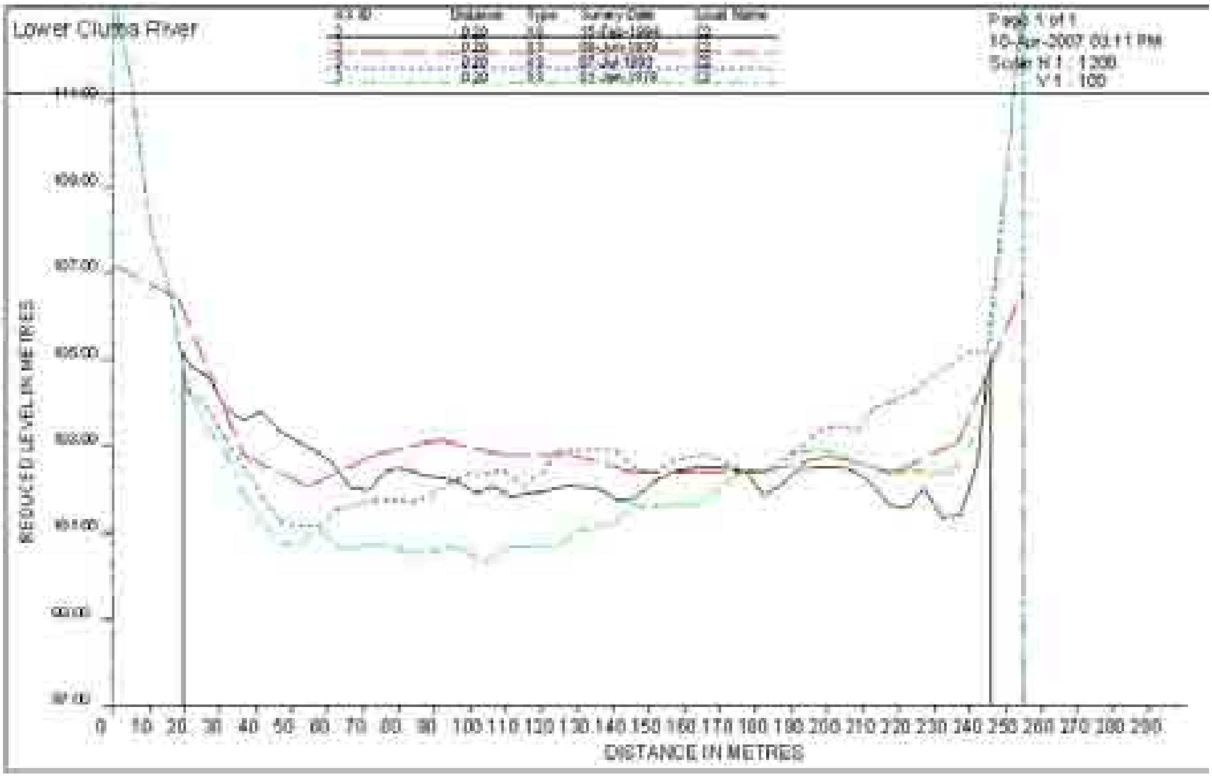

Figure 3.9 **Balclutha railway bridge in 1878, 1893, 1939 and 1994**

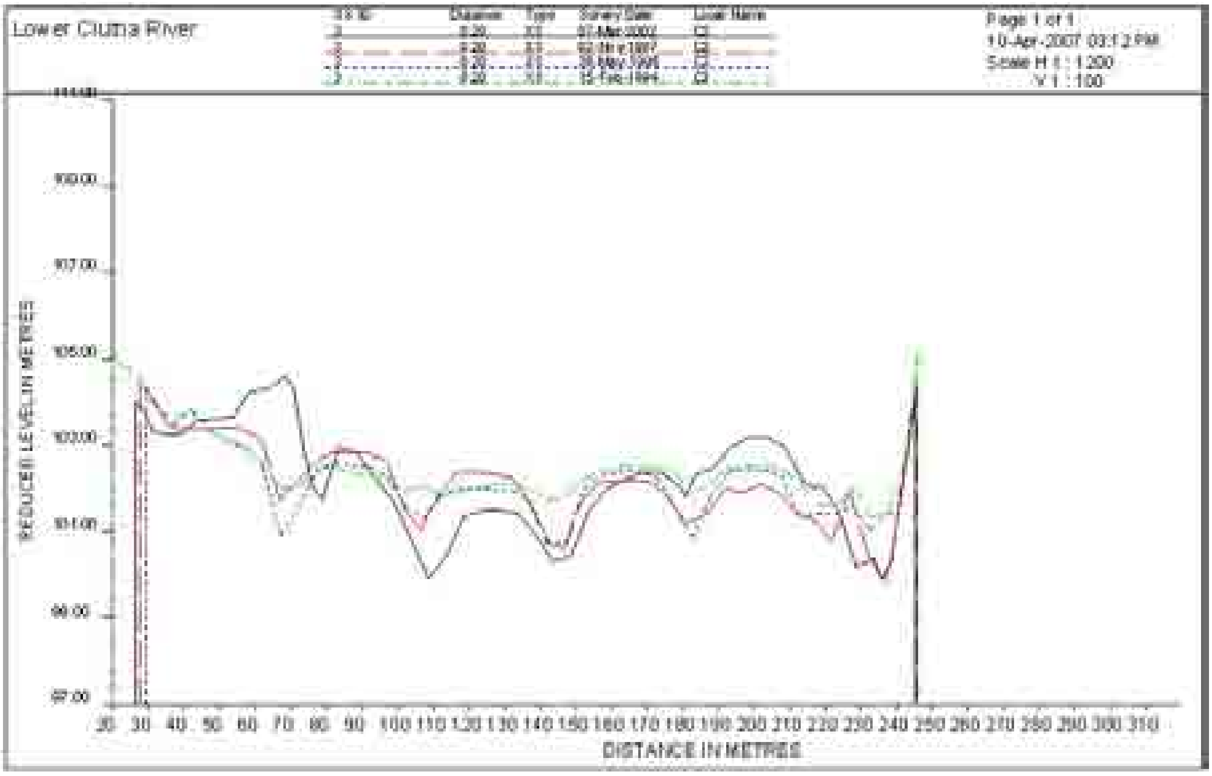

Figure 3.10 **Balclutha railway bridge in 1994, 1995, 1997 and 2002**

3.1.7 Stirling bridge

Stirling bridge, located on the Matau branch, opened in 1876 with the design survey dating from 1875 (plan 718). The bridge was replaced in the early 1960s. Between 1875 and 1947 significant net aggradation occurred resulting in up to 12m of sediment deposition in places. The aggradation during this period may have been a response to the 1878 flood (Figure 3.1), when the Matau branch of the Clutha River/Mata-Au enlarged to carry significantly more flow. Between 1947 and 2002, periods of aggradation and degradation have been prevalent, with net aggradation being dominant, particularly on the true left of the channel.

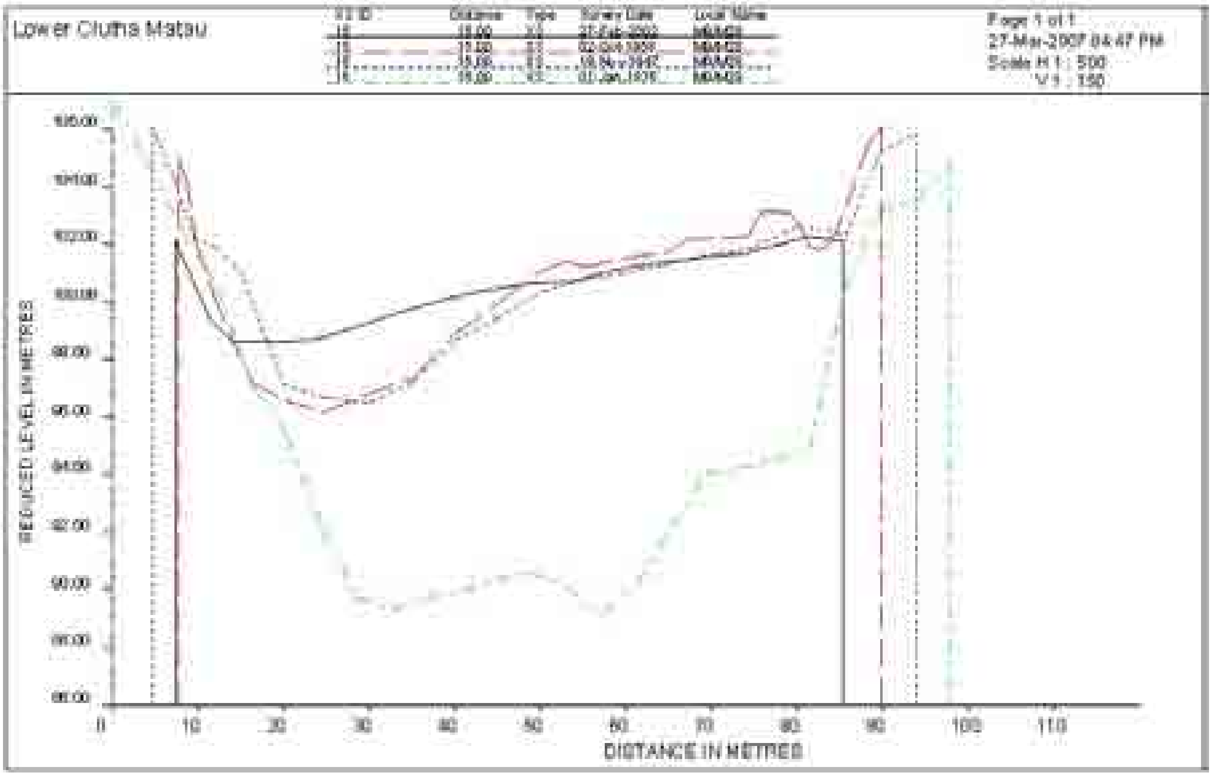

Figure 3.11 Stirling bridge in 1875, 1947, 1958 and 2002

3.2 Monitoring cross-sections

The cross-sections from Roxburgh Hydro to Clydevale were initially surveyed for the hydro-electric scheme investigations in 1982 and 1983. Most of these cross-sections were resurveyed in January 2007 and a few additional cross-section surveys were included at bridges. Cross-sections at ferry sites and bridges have been discussed in section 3.1.

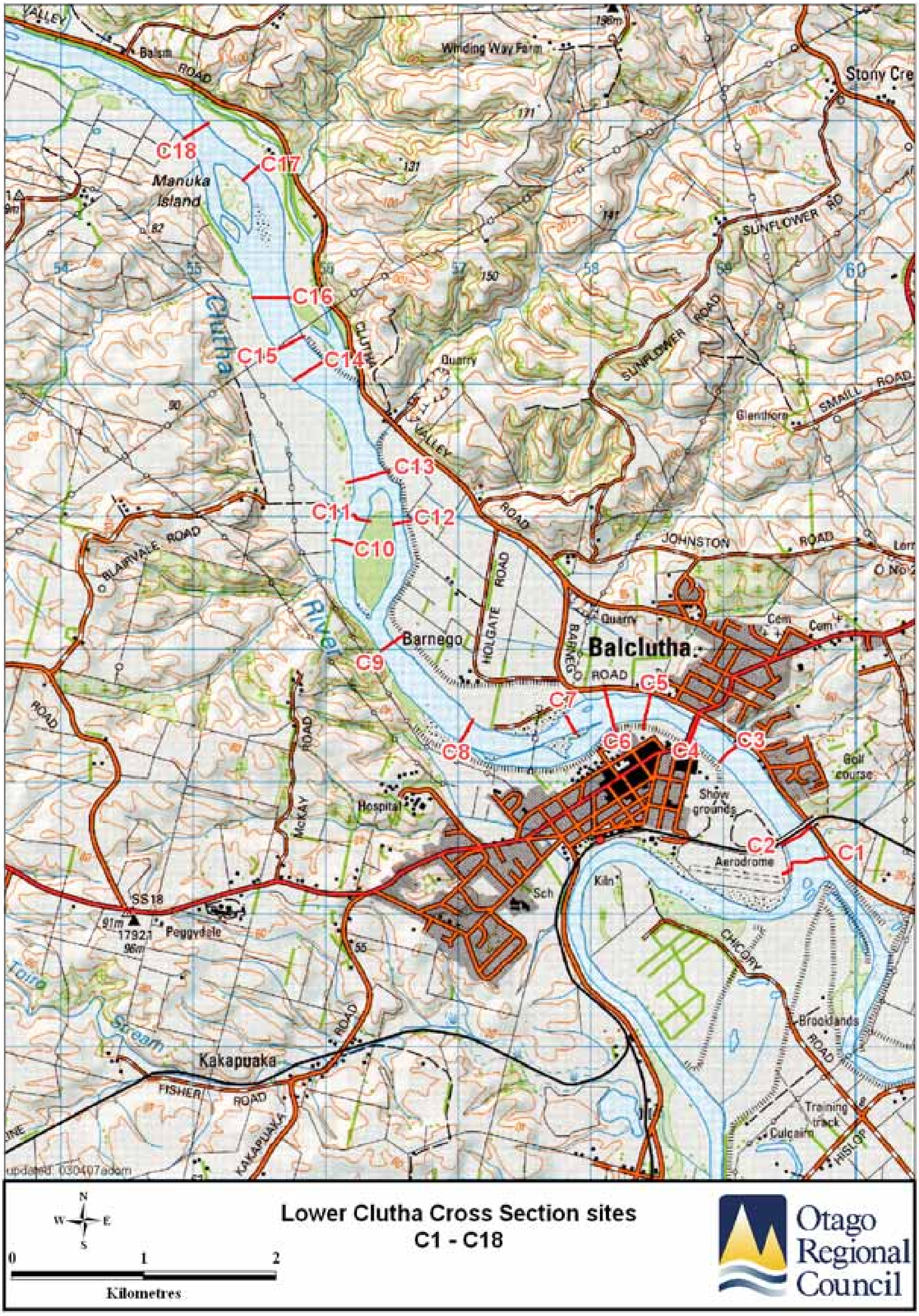

Figure 3.12 Location of cross-sections C1 to C18

Figure 3.13 **Location of cross-sections C18 to C28**

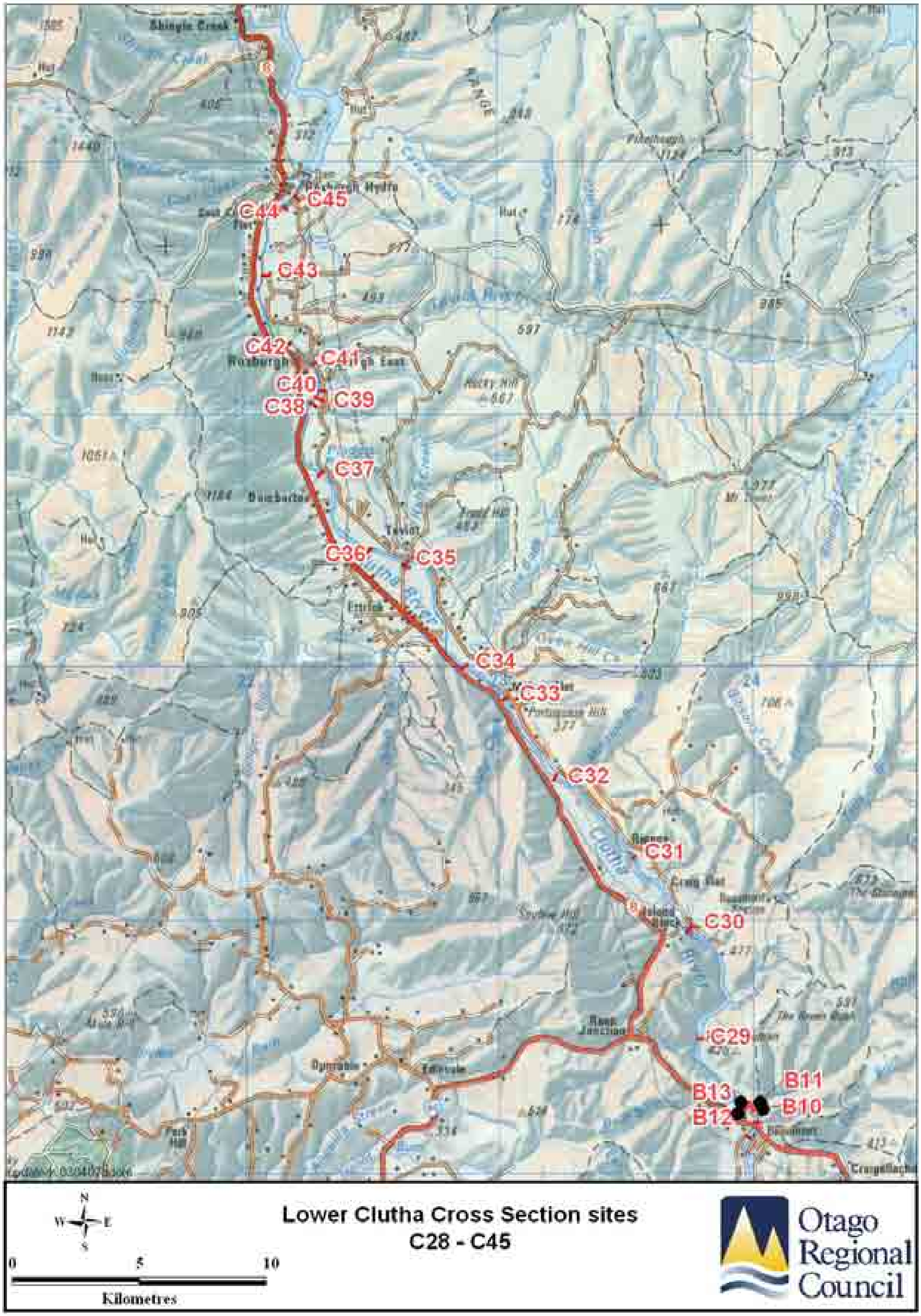

Figure 3.14 Location of cross-sections C28 to C45 and B10 to B13

Forty-nine cross-sections exist from Roxburgh Hydro to Balclutha, including four located at Beaumont bar (Figure 3.12, Figure 3.13 and Figure 3.14). It is not feasible to examine all sections (Appendix 1) in detail, therefore notable trends are highlighted in the following section.

Cross-sections C28-C45 (Figure 3.14*)*
Between 1982 and 2007, the majority of cross-sections in the reach downstream of Roxburgh Hydro (C45) to Beaumont bar (B10) experienced net degradation. Exceptions to this are:

- (C40) Roxburgh East – bedrock channel has experienced net aggradation.
- (C30) McCunn's Beach – significant bank erosion on the true-left and minor net aggradation.

At Beaumont bar (B10-B13), survey data was taken in 1996, 2003 and 2007. While periods of aggradation and degradation may have occurred between 1996 and 2003, the four cross-sections at Beaumont bar have experienced net degradation. From 2003 to 2007, these cross-sections have experienced net aggradation of the thalweg, whereas the bank/beach proximities, except section B13, have experienced net degradation. The net change for these sections has been one of degradation.

Cross-sections C18-C28 (Figure 3.13)
Between 1982 and 2007, sections C26 and C25 through the Rongahere Gorge, experienced variation in bed and bank position with little net change in cross-sectional area. Cross-sections from Tuapeka Mouth to Clydevale bridge (C24-C22) indicate net degradation from 1994 to 2007, with net aggradation dominating at Clydevale (C22) prior to 1994. Management objectives at the Mayor Island sites (C21 and C20) between 1994 and 2007 have influenced the sediment storage capabilities of these channels. The right channel (C21) has experienced widening while the left channel (C20) has narrowed, consistent with works undertaken in this area.

Cross-sections C1-C18 (Figure 3.12)
Between 1994 and 2007, the reach from Whitelea (C19) to upstream of the Training Works (C14) has endured periods of shifting bars and channels, with evidence of shoaling in some locations (C14) and channel deepening in others (C15). This morphology is consistent with bank erosion and concomitant bar development. Evidence for bank erosion is present on the true right of C17, at Manuka Island and the true right bank upstream of the Training Works (C15 and C14).

Four cross-sections (C13-C10) are located within the vicinity of Gull Island. Cross-section C13, upstream of Gull Island, experienced net aggradation between 1994 and 1997 and net degradation from 1997 to 2002. Channel widening due to the erosion of Gull Island between 1997 and 2002 has contributed to net aggradation at location C12. C11 and C10, in the true right channel, experienced net degradation from 1997 to 2002, primarily due to gravel extraction activities.

Extensive bank erosion at cross-section C9 between 1994 and 2002 has led to channel migration and net aggradation on the true right. Substantial channel migration is also evident at Bottings Island (C8), where net degradation has led to the establishment of a channel while net aggradation has prevailed on the true left. Downstream, cross-sections C7 and C6 have experienced net degradation during the period 1994 to 2002.

From the Balclutha Cement Works (C5) to the channel's bifurcation (C1), minimal net change in cross-sectional area is evident, even though significant changes in the depth and position of the thalweg have occurred in some sections (C1, C2 and C4). The position of the bifurcation separation point (C1) has shifted to the left (east) between 1997 and 2002.

It is extremely important to note that, while interpretations of change have been made over large temporal scales, periods of morphological change have occurred between measured periods. With this concept in mind, any statements made in the previous two sections relate purely to the **net change** of channel morphology and/or cross-sectional area.

4. Land use change in the Clutha Catchment

Land use change within the Clutha River Catchment has had implications on the sediment supply regime of the channel. The morphological and sedimentation characteristics of the channel can provide an indication of the possible influence this change has had. Land use changes in the Clutha River/Mata-Au Catchment have included:

- Clearing for agriculture.
- Deforestation.
- General gold and coal mining.
- Hydraulic sluicing.
- Dredging in the rivers and on alluvial flats.
- Hydro-electric dam construction.

4.1 Clearing for agriculture

Sheep farmers first arrived in the Alexandra district in 1857-8 (Moore, 1953) and clearance of the country by fire was practised. For example, in the late 1850s the land between Beaumont and the present Roxburgh dam was fired in one large conflagration (Webster, 1948, 14).

Rabbits arrived in New Zealand in 1838 but were only released in the wild by 1844. Forty years later they had reached plague proportions. For example, in five months in 1902 about 250,000 rabbits were killed on the Earnscleugh Station (Moore, 1953, 11).

By 1920, the Rivers Commission on the Clutha River/Mata-Au reported that "agricultural and pastoral operations, including burrowing by rabbits and burning off, has . . . enabled the natural denuding agencies to carry increased quantities of detritus into the rivers and its tributaries" (Rivers Commission 1920, pp5).

However, general assessment of the contribution of sediment to the river from accelerated land erosion caused by changing land management practices since the nineteenth century suggests that it was small compared to natural land erosion (Hicks et al. 2000).

4.2 Deforestation

The Rivers Commission (1920, pp5) also reported that "within the watershed below the lakes [Lakes Wakatipu & Wanaka] there never was very much large timber, what there was has been almost entirely cut out, especially for mining timber".

4.3 General gold mining

Despite earlier successful prospecting, gold mining in the Clutha Catchment only became a significant enterprise following publication of the discoveries of Gabriel Read at Lawrence in 1861. From that point, gold discoveries in much of the Clutha Catchment resulted in the impacts of gold mining being felt widely.

Initially, gold was extracted from alluvial gravels by washing the dirt in boxes using naturally-available or piped water. However, in 1862 gold was obtained by ground sluicing – running water across ditches in the ground to wash the dirt through sluice boxes. This was closely followed by the use of explosives to break up the conglomerate on Blue Spur in

Gabriel's Gully (Mayhew, 1949, 20ff.). By the 1880s, the original township in Gabriel's Gully had been covered by 50ft (17m) of tailings from these various operations. "A large proportion of these found their way to the Molyneux [Clutha]" (Mayhew, 1949, 42).

In the Teviot (Roxburgh-Millers Flat), similar developments took place through this period, with much mining activity on the Teviot Creek (the first claim), Horseshoe Bend, Millers Flat and Hercules Flat (Webster, 1948, 44ff.).

Figure 4.1 Hydraulic sluicing in the Clutha Catchment

4.4 Hydraulic sluicing

In 1880, the technique of hydraulic sluicing and elevating was introduced to the Tuapeka area and used shortly afterwards in the Teviot district. This technique used jets of water to wash sediment away from alluvial deposits, for collection and processing (Figure 4.1). Sluicing left a significant amount of loose material lying in gullies and channels on the margins of the river (Rivers Commission, 1920, 7).

4.5 Dredging in rivers and on alluvial flats

Dredging of gold from the Clutha River/Mata-Au and the alluvial flats around the river commenced with spoon dredges in the 1860s. By 1881, four current-wheel dredges were working in the Teviot area. In 1882, a steam dredge was launched at Alexandra and by 1892 ten stream dredges were working in the river between Horseshoe Bend and Coal Creek (Webster, 1948, 56ff.).

Beginning in 1889, dredges were adapted to work the alluvial flats, which they did by floating in a pond of their own making and shifting gravel from in front of the dredge to behind (Figure 4.2 and Figure 4.3). The tailings were soon being stacked high behind the dredge with the invention of the tailings elevator (Webster, 1948, 58ff.).

The distribution of gold dredging claims in the Clutha River/Mata-Au below the Roxburgh gorge in 1900 is shown in Figure 4.4. There are 88 separate gold mining claims shown on the map, with 62 dredging in the rivers (including the Clutha River/Mata-Au, the Tuapeka River and the Teviot River), 23 dredging on the banks, 23 dredging on the river beaches and 12 dredging on the alluvial flats. Some claims were being operated using more than one method. Although this is a dredging map, two sluicing claims are also shown.

Further dredging and sluicing operations were present in the reaches of the Clutha River/Mata-Au upstream of Alexandra and in its tributaries such as the Manuherikia River. The Rivers Commission (1920) indicated that approximately two-thirds of the sediment supply from mining activities was delivered to the river upstream of the Roxburgh dam site and about one-third below (Ministry of Works, 1948).

Figure 4.2 Dredge tailings in the Clutha River/Mata-Au at Benger Burn, about 1903

Figure 4.3 Dredges working from Ettrick (at left) to Millers Flat (at right), about 1903

Figure 4.4 Map of dredging claims from Tuapeka Mouth to north of Coal Creek, 1900

4.6 Hydro-electric dam construction

In 1948, the trapping of sediment behind the Roxburgh dam was recognised in the preliminary design report (Ministry of Works, 1948). When the Roxburgh dam was constructed between 1949 and 1954, it stopped the delivery of coarse grained bed material from the Upper Clutha to the Lower Clutha. Hicks et al. (2000) suggest that prior to the construction of the dam, about 214.3 kt/yr of bed material (i.e. gravel) would have arrived at the Roxburgh dam site. With contributions from tributaries downstream of the dam and losses to abrasion, they suggest about 228.2 kt/yr would have arrived at Balclutha in the Clutha River/Mata-Au. After dam construction, Hicks et al. (2000) estimate that 24.5 kt/yr of bed material should arrive at Balclutha, supplied by tributaries and river channel erosion.

The signal of reduced coarse sediment supply from upstream is likely to take decades to work through the Clutha River/Mata-Au system downstream of Roxburgh dam. Hicks et al. (2000) anticipated that with the 90 percent reduction in gravel supply to the Lower Clutha River/Mata-Au, an average of 0.2m of bed level degradation would occur downstream of the Roxburgh dam within 50 years.

The gravel starvation signal appears to be much more significant close to the dam, with the effect yet to be felt fully downstream. This is to be anticipated, as the gravel starvation signal is not felt immediately at all points in the river; it takes time for the deficit to work downstream. As the volume of gravel readily available to be entrained from the river bed and banks is reduced in upstream locations, it will be obtained by the river from the bed and banks, further and further downstream. The trend of bed degradation may strengthen at Balclutha in the next 10-15 years. The timing of this will depend on how much additional material is eroded from the reach from Clydevale to Balclutha to make up the deficits.

The estimates of Hicks et al. (2000) suggest a bed material deficit of 214.3 kt/yr at Roxburgh dam. This equates to about 107,000 m^3 per annum (assuming 2 tonnes per m^3 of bed material). In the 53 years since Roxburgh dam was closed, this equates to a 3m bed level drop over a 90m wide river for a distance of 400m downstream. The actual bed level drop at Commissioners Flat bridge (1.7 km downstream of the dam) averages about 3m across a width of 100m, suggesting the bed material deficit is more severe than a simple loss of the average bed material load since 1954. The cause of this additional sediment volume loss from the river bed may be that fine-grained sediment (silt) has been entrained from the river downstream of the dam without adequate replacement from upstream of the dam. It is known that each year from 1954 to 1992 about 1.42 million m^3 of sediment filled Lake Roxburgh (Fairless et al., 2000). Hicks et al. (2000) estimated that from 1994 to 1999 0.13-0.77 million m^3 of sediment per annum was flushed from Lake Roxburgh to the Clutha River/Mata-Au.

4.7 Combined effects of land use change

The Rivers Commission report (1920) suggested that 300 million cubic yards of material may have been moved in the Clutha Catchment since the onset of mining. This is equivalent to about five million cubic yards per annum to 1920. The Rivers Commission estimated in 1920 that 200 million cubic yards had not yet reached the Clutha, with 60 million cubic yards of the remainder on the bed of the river and 40 million cubic yards having been already delivered to the sea.

In 1956, the Otago Catchment Board published its Scheme of Control for the Lower Clutha River/Mata-Au. This report noted the enormous volume of sediment contributed to the river during the mining boom, but remained equivocal about the impact of this sediment on rates of erosion and aggradation. The report noted, however, that there did appear to be a general increase in height, length and volume of the gravel bars in the Koau, Clutha and upper reaches of the Matau.

5. General trends in cross-sections

A general trend of aggradation is seen from Roxburgh to Balclutha, starting in 1875. This trend in the upper part of the catchment from Roxburgh to Beaumont may be related to increased input of coarse sediment to the river from gold mining operations, which peaked in intensity around 1900. At Balclutha, the bed levels began to rise from the 1870s onwards, most likely in response to the deposition of suspended sediment in the delta area.

The rate of transmission of this increase in sediment supply downstream probably reflected two processes – the movement of suspended sediment at a rapid velocity and the movement of bed material at a slower velocity. In 1920, the Rivers Commission (page 8) reported that “the river… is now, especially in the Koau Branch [of the Clutha delta], full of shingle-bars, always muddy and generally very much shallower than it was, say, in 1860”.

Starting in the 1920s and 1930s, the bed levels at Roxburgh bridge started to degrade by several metres, followed in the 1940s by similar bed lowering at the Millers Flat and Beaumont bridges downstream. Since the 1990s, this degradation signal may have reached Clydevale. Large scale gold mining in the river largely ceased in the period of the 1920s and 1930s. The general trend of degradation working downstream from Roxburgh from this time is most likely related to this reduction in bed material supply to the river.

Between 1948 and 1982, bed degradation of approximately 5m was recorded at Commissioners Flat, just downstream of the Roxburgh dam. This is undoubtedly due to coarse material being trapped behind the dam, resulting in erosion of the bed downstream. A similar fall in bed levels occurred between 1948 and 2007 at Roxburgh, while a trend of bed level decline occurred at Millers Flat from 1940 to 1982 and at Beaumont between 1948 and 1982.

6. Conclusions

Following the cessation of significant levels of gold mining, the trend in the Clutha River/Mata-Au below Roxburgh dam has been one of bed degradation as the sediment supply rates reduced again. However, in 1954 the closure of the Roxburgh dam resulted in a much greater reduction in sediment supplied to the Lower Clutha.

In the reach of the river between Clydevale and Balclutha, where the impacts of the sediment supply increase signal may now just be ending, gravel extraction is assisting to manage the unstable channel alignment. This unstable alignment has persisted for many decades, as shown by the large number of islands in the centre of the river. The unstable alignment may be a result of this part of the catchment acting as a sediment deposition centre, particularly of finer-grained material transported through steeper reaches upstream. The magnitude of any future sediment supply reduction signal may be greatly reduced in this reach of the river.

However, upstream of Clydevale it is likely that the sediment supply reduction signal following the cessation of gold mining activities is now being experienced. In these reaches, any gravel extraction will probably exacerbate the bed level degradation being experienced.

Despite this, gravel continues to accumulate at particular points in the channel, including the Roxburgh bar and Beaumont bar. These areas may be natural deposition basins for gravel; the bed level changes in these locations may not reflect the general trend of bed level changes elsewhere in the catchment. Gravel extraction from these reaches may appear to be tapping a readily-available resource, but the volume of sediment transported through these reaches is likely to be reducing significantly as the effects of the Roxburgh dam sediment starvation signal are expressed.

Between Roxburgh dam and Roxburgh, the impact of the damming of the river at Coal Creek is being felt with significant levels of bed degradation. The impacts of this degradation appear to include high levels of bank erosion. The future impacts of a generally lowering river bed will probably include further bank erosion in these reaches.

7. References

Griffiths G. 1978. The Great Flood of ’78 – An Illustrated Commemorative. John McIndoe, Dunedin.

Hicks DM, Walsh JM and Duncan MJ. 2000. Clutha River Sediment Budget. NIWA Client Report CHC00/45.

Mayhew WR. 1949. Tuapeka – The Land and Its People. Otago Centennial Historical Publications.

Ministry of Works 1948. Report on the Preliminary Investigations of the Roxburgh Power Development, Otago Central.

Ministry of Works and Development 1986. Lower Clutha Hydro-Electric Investigations. Comprehensive Report ‘Clean Draft, prepared by Power Directorate (MWD) for Electricity Division Ministry of Energy.

Moore CWS 1953. The Dunstan – A History of the Alexandra-Clyde Districts. Otago Centennial Historical Publications.

Opus 2000. Flood History in the Clutha Catchment.

Otago Catchment Board 1956. Scheme of Control for the Lower Clutha River/Mata-Au.

Otago Regional Council 2005. Clutha River/Mata-Au Below Roxburgh Dam Gravel Resource Assessment, prepared by SEJ Swabey, Manager, Natural Hazards.

Rivers Commission 1920. Clutha River/Mata-Au – Report of the Rivers Commission on Clutha River.

Webster AHH 1948. Teviot Tapestry – A History of the Roxburgh-Millers Flat District. Otago Centennial Historical Publications.

Appendix 1: Cross-section diagrams

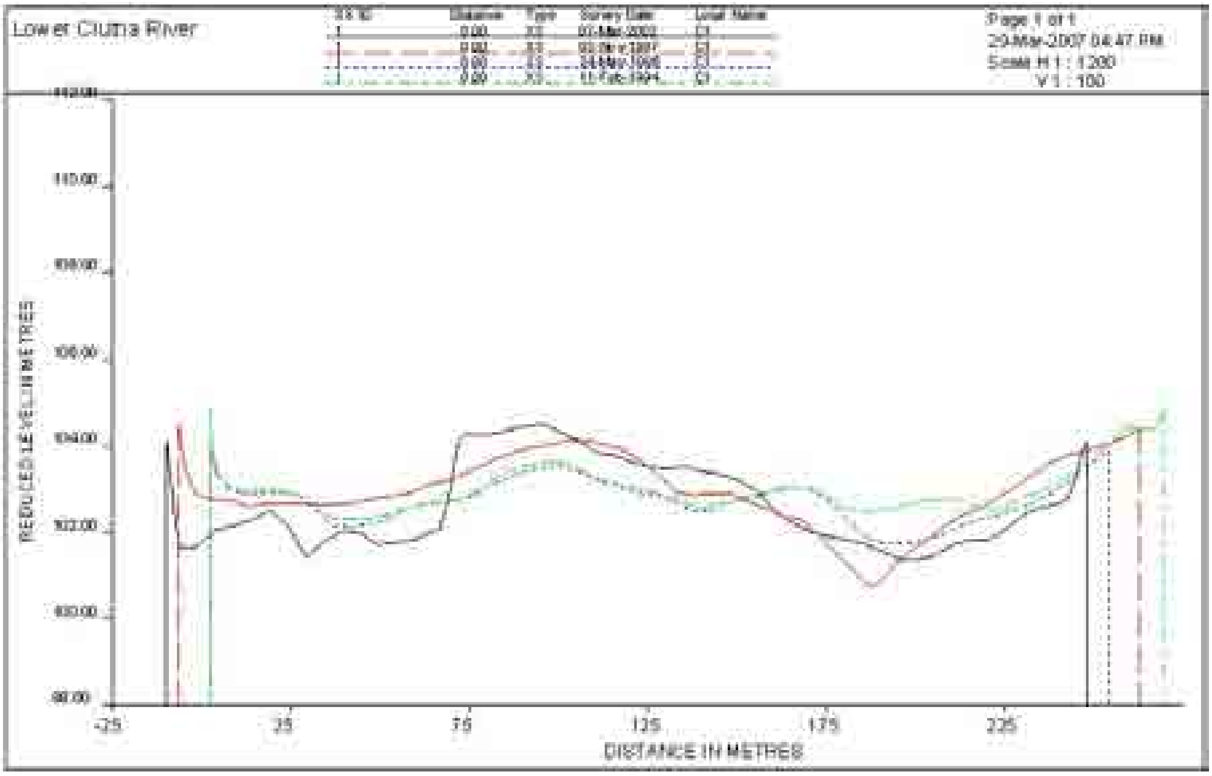

Figure A. 1 **Cross-section C1 – Balclutha bifurcation**

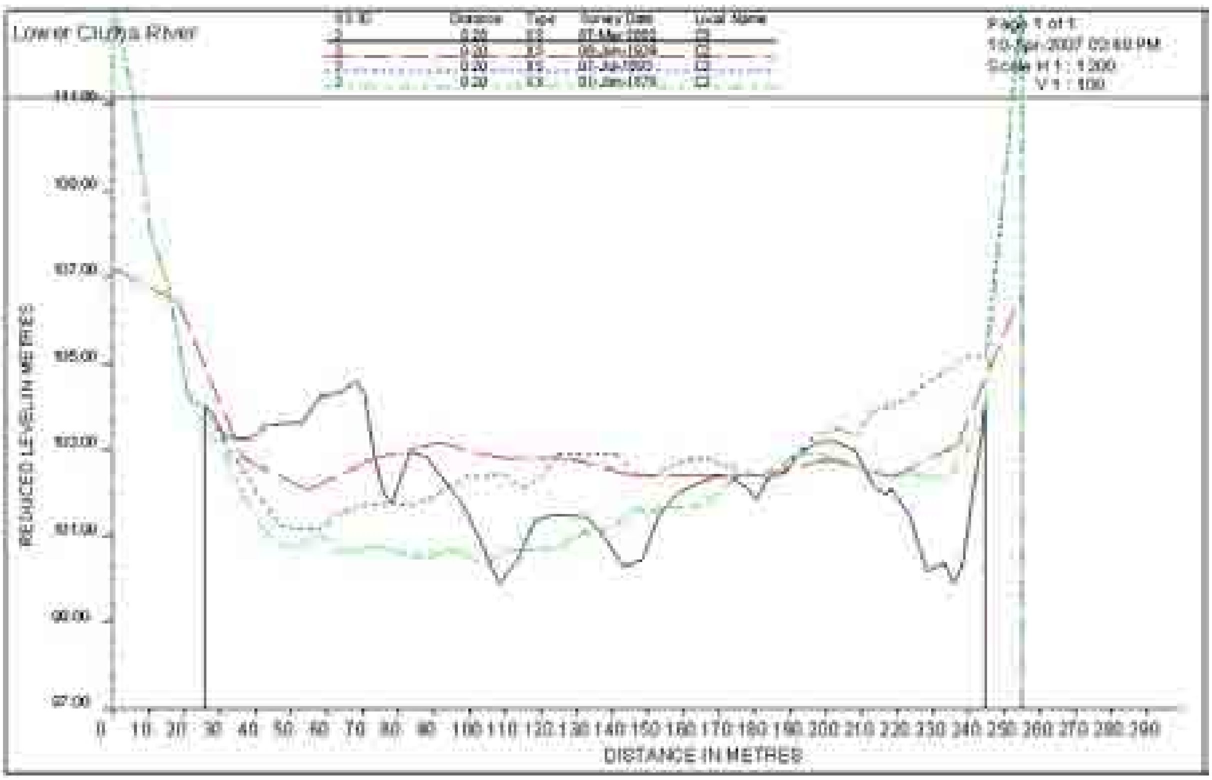

Figure A. 2 **Cross-section C2 – Balclutha railway bridge**

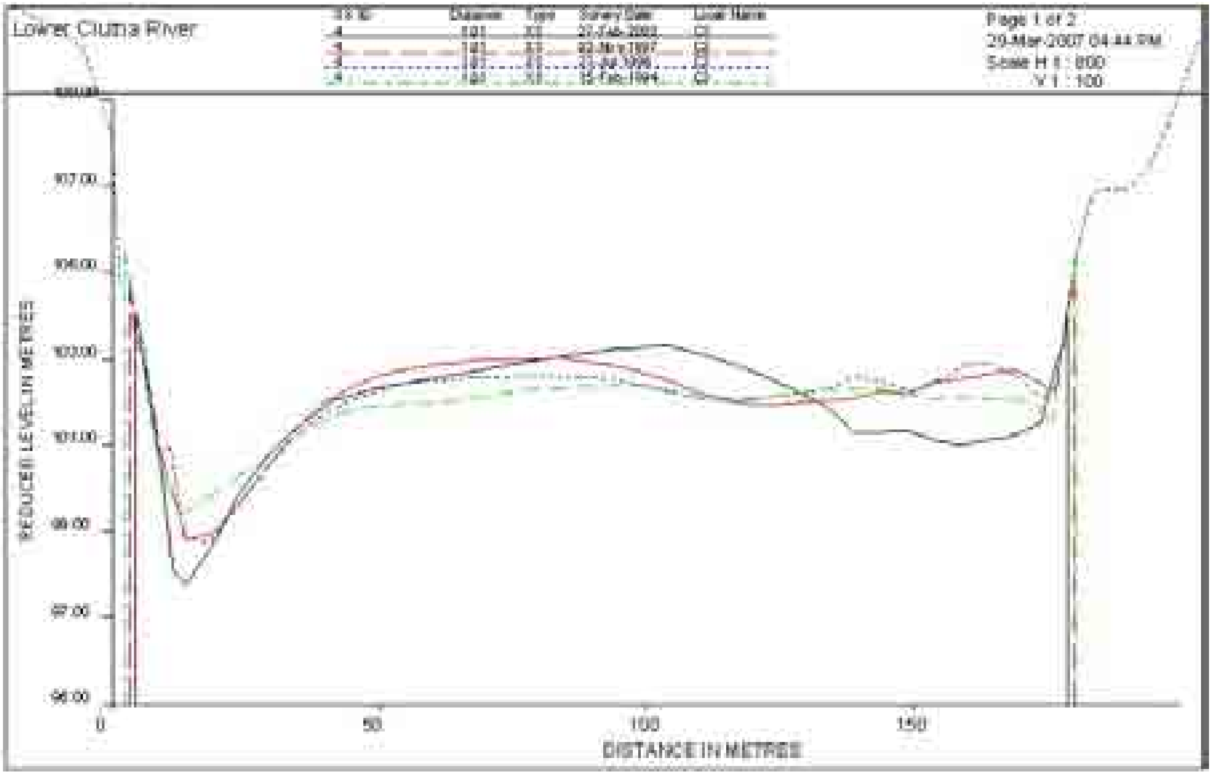

Figure A. 3 Cross-section C3 – ORC depot, Balclutha

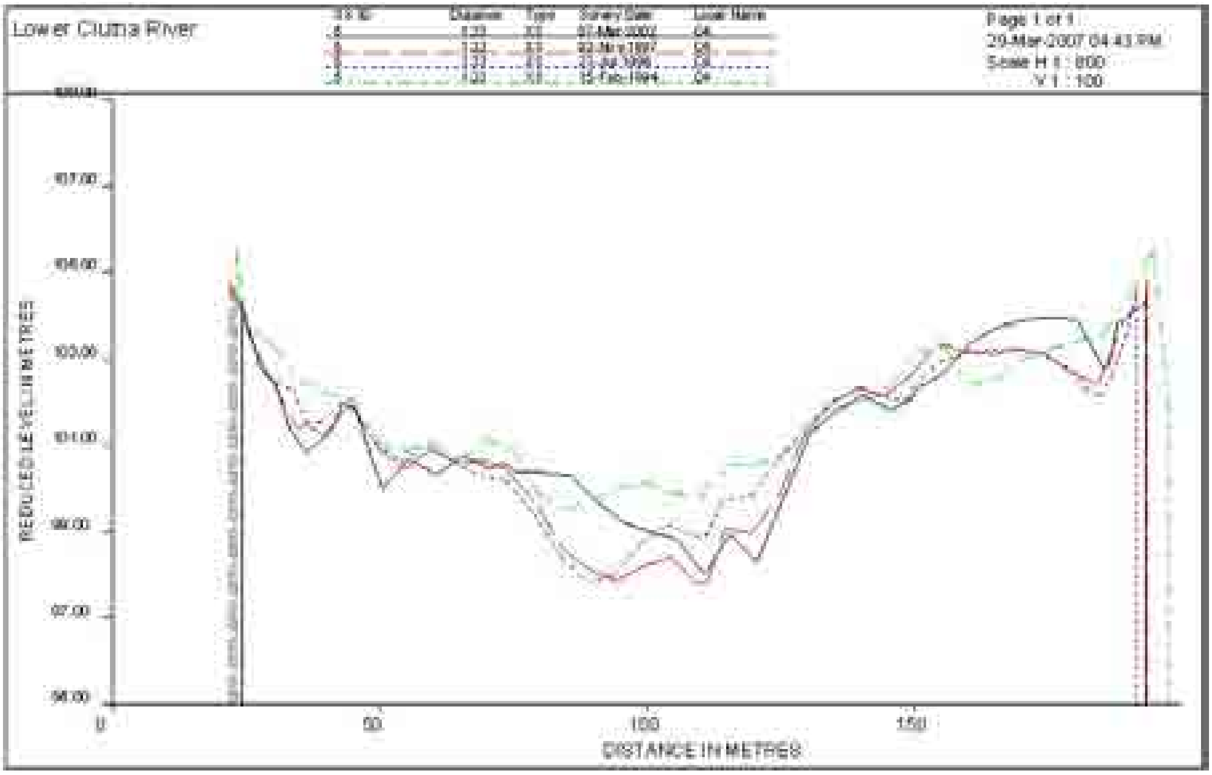

Figure A. 4 Cross-section C4 – Balclutha State Highway 1 bridge

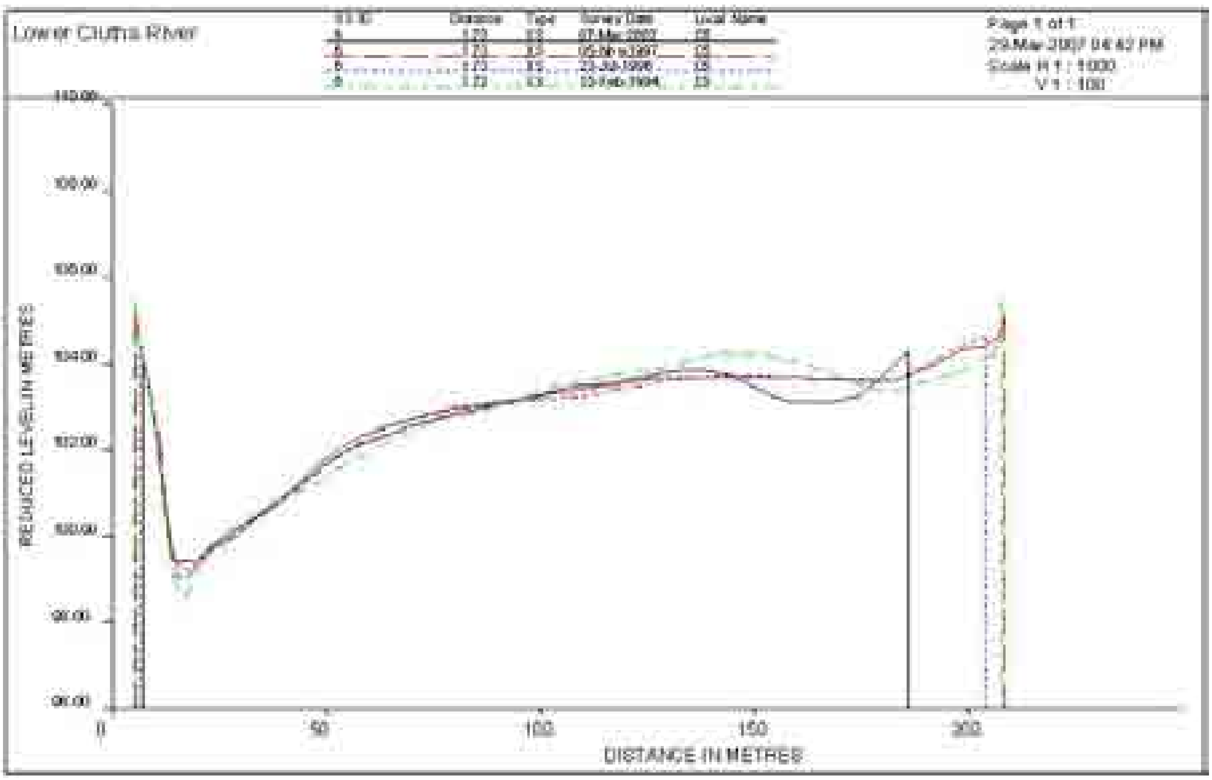

Figure A. 5 Cross-section C5 – Balclutha Cement Works

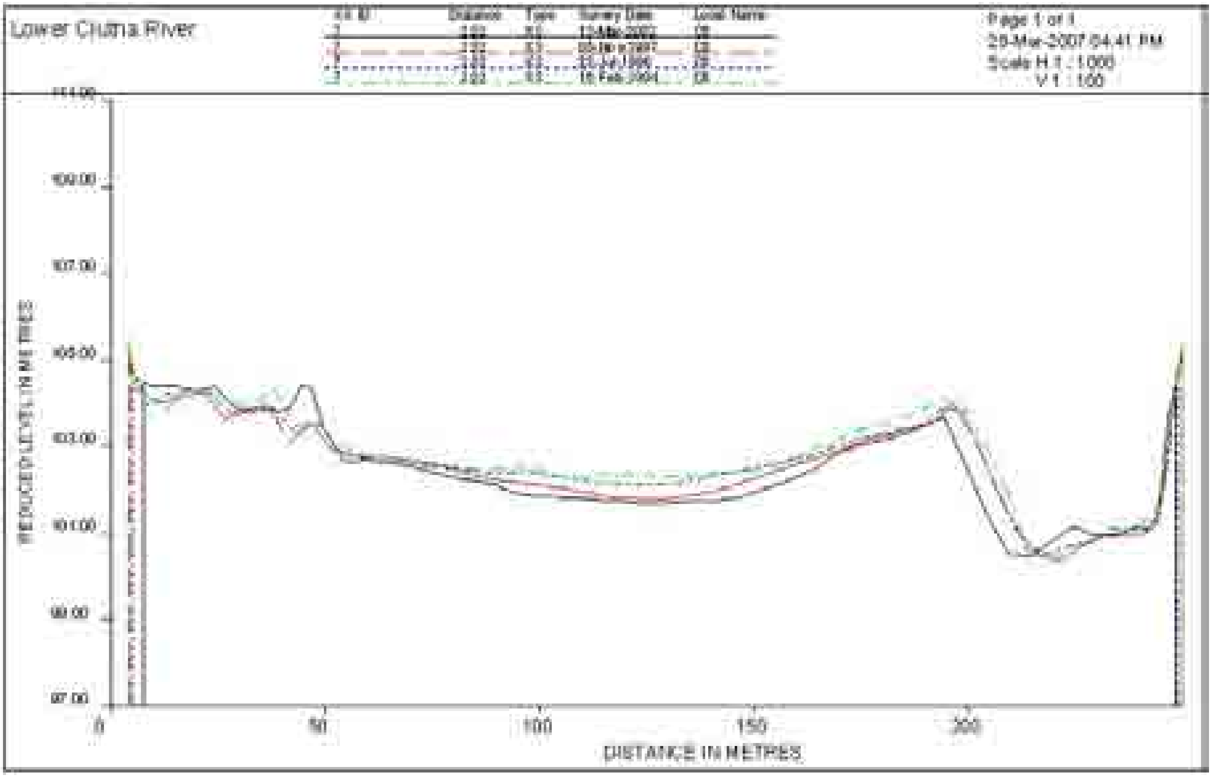

Figure A. 6 Cross-section C6 – Barnego Road

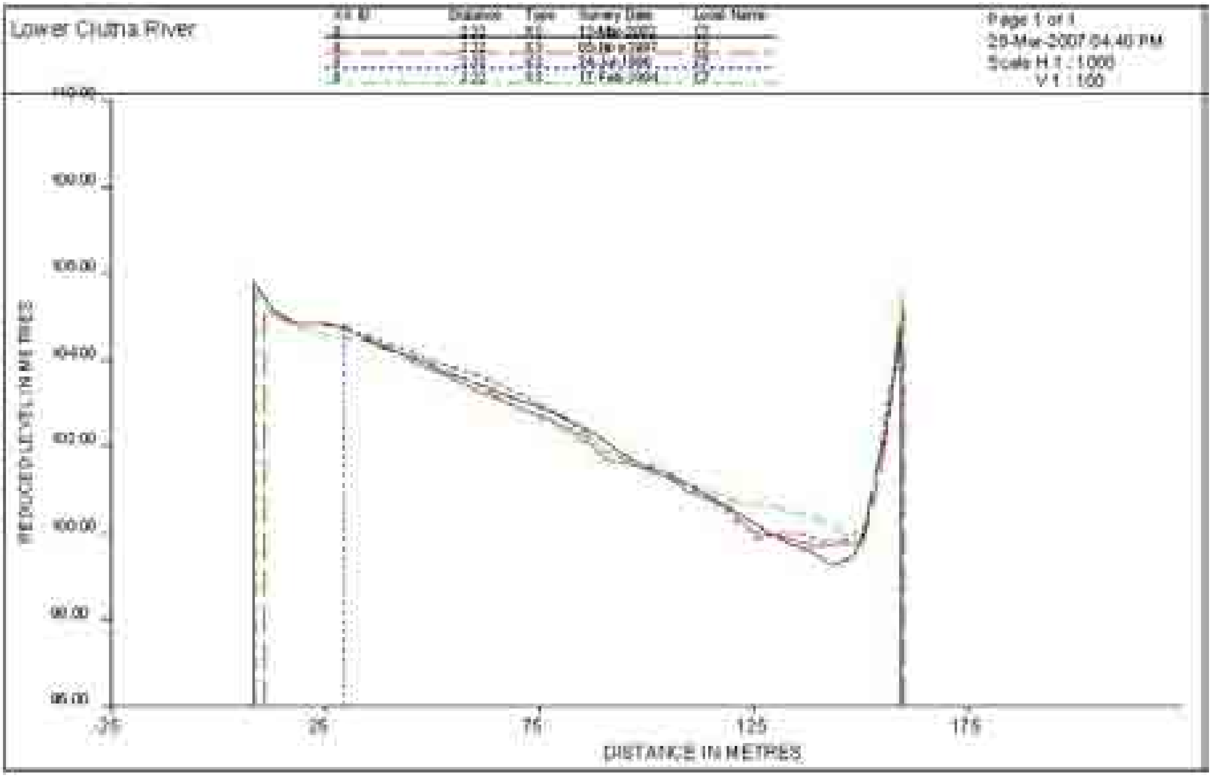

Figure A. 7. **Cross-section C7 – Hospital Bend**

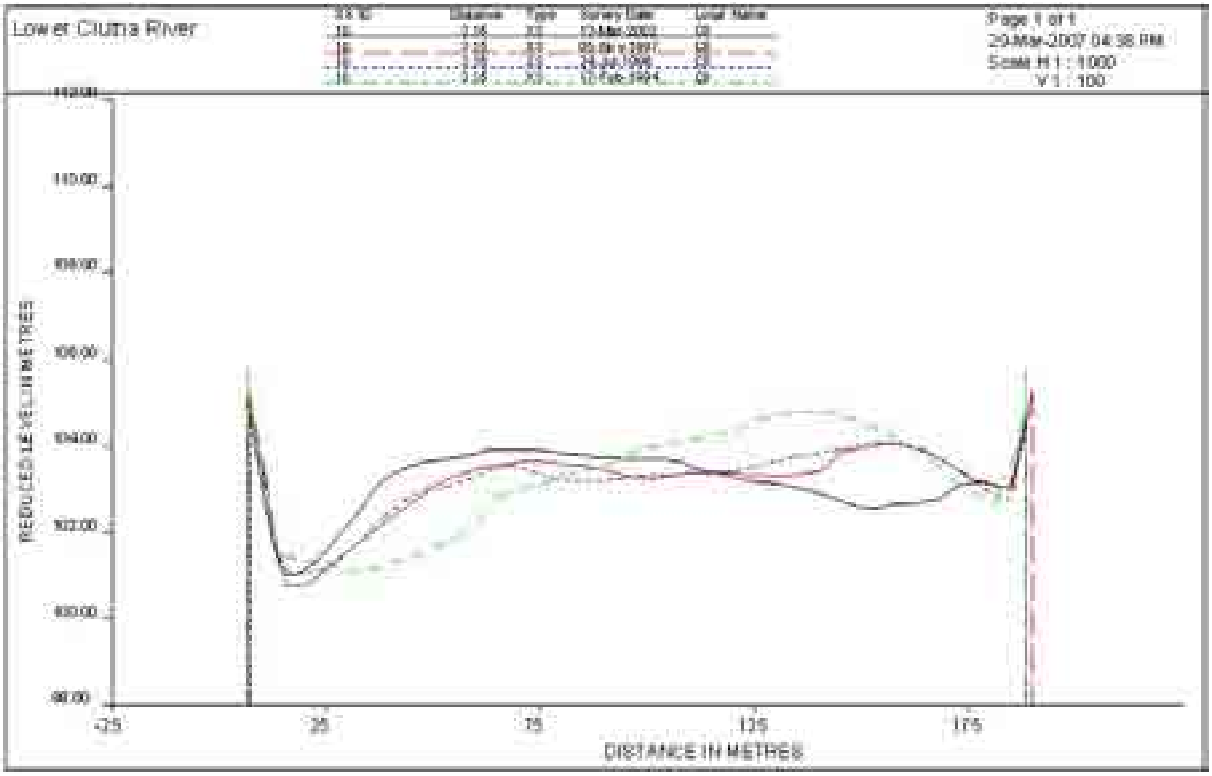

Figure A. 8 **Cross-section C8 – Bottings Island**

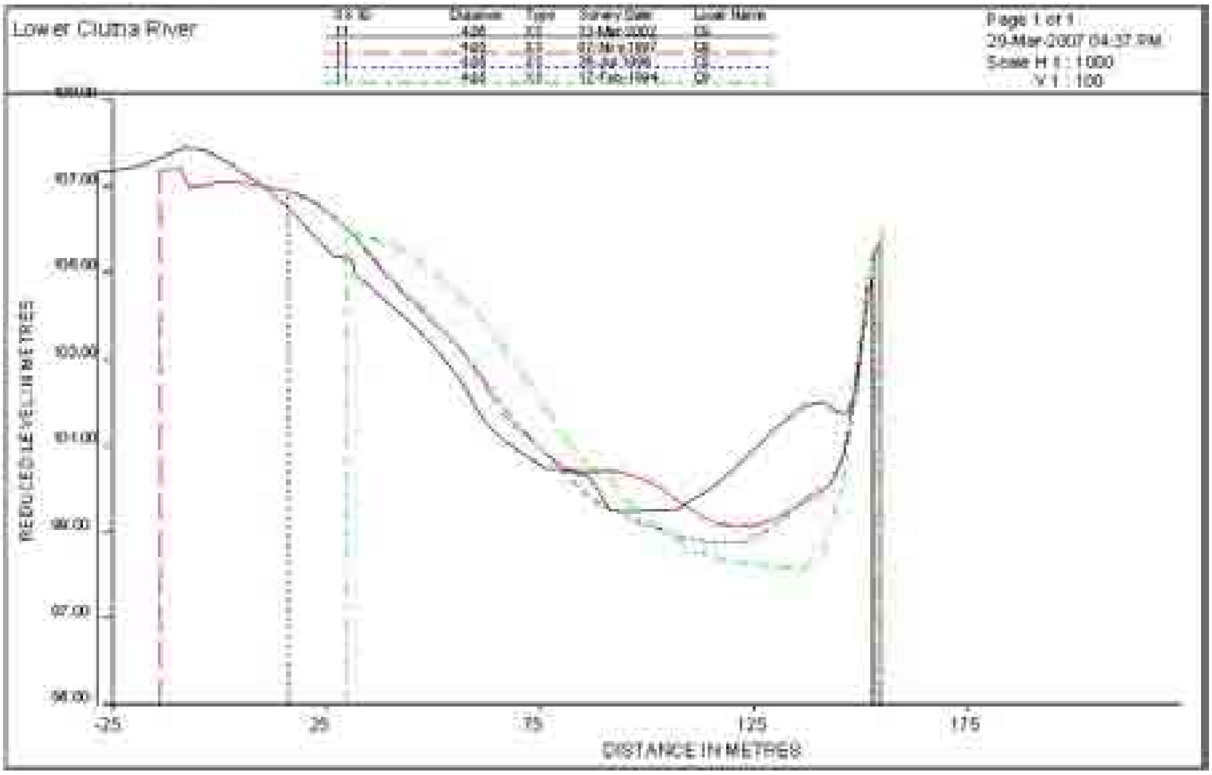

Figure A. 9 Cross-section C9 – Bottings Island

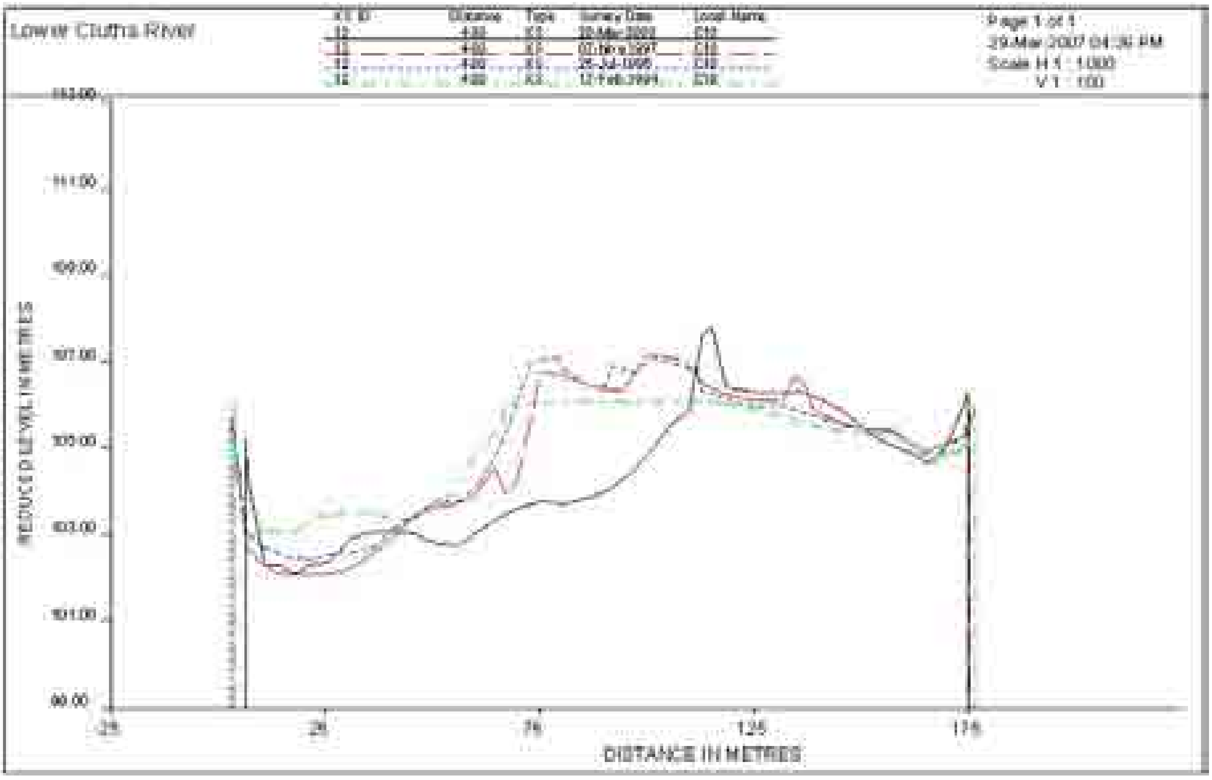

Figure A. 10 Cross-section C10 – Downstream end of true right channel of Gull Island

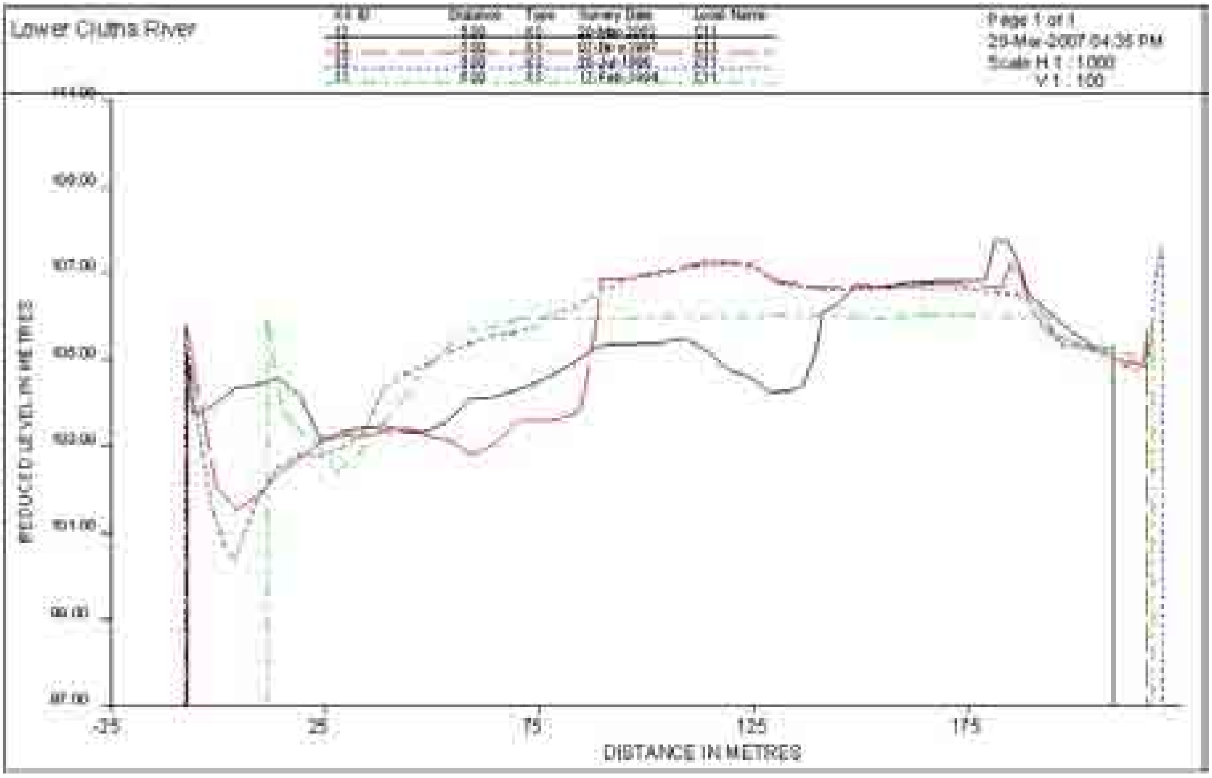

Figure A. 11 Cross-section C11 – Upstream end of true right channel of Gull Island

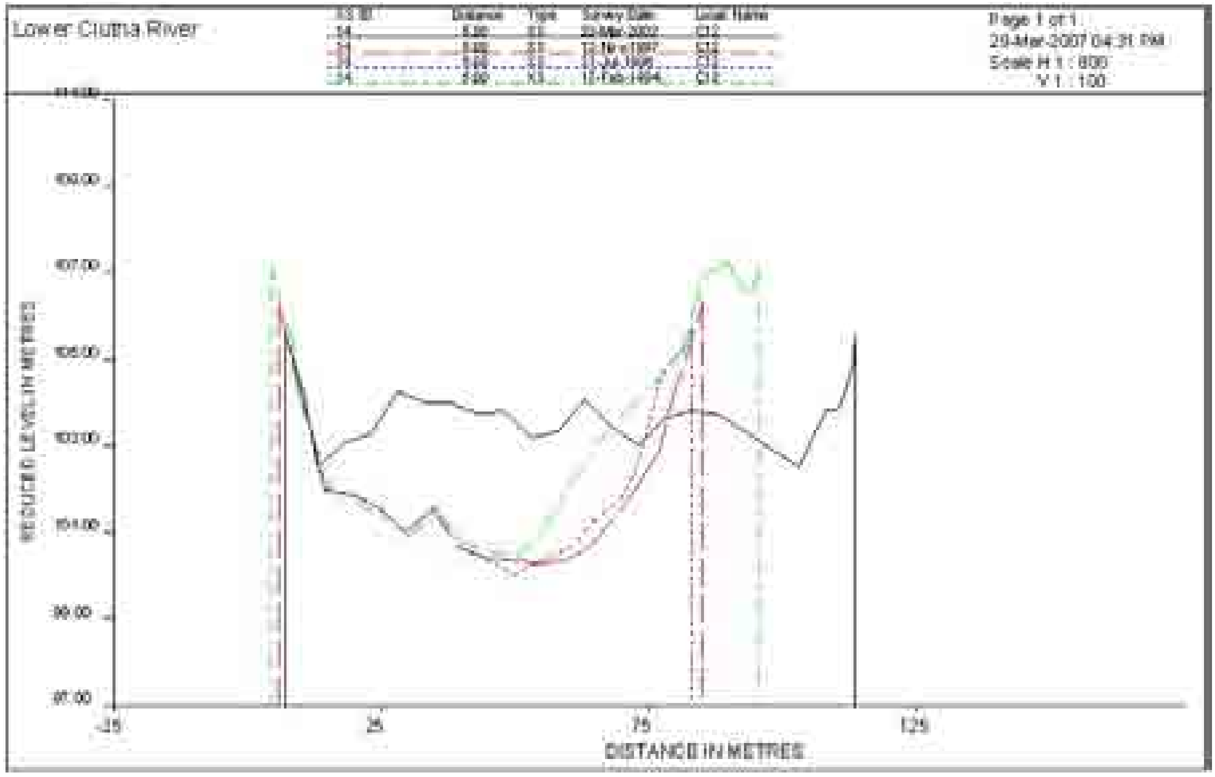

Figure A. 12 Cross-section C12 – True left channel of Gull Island

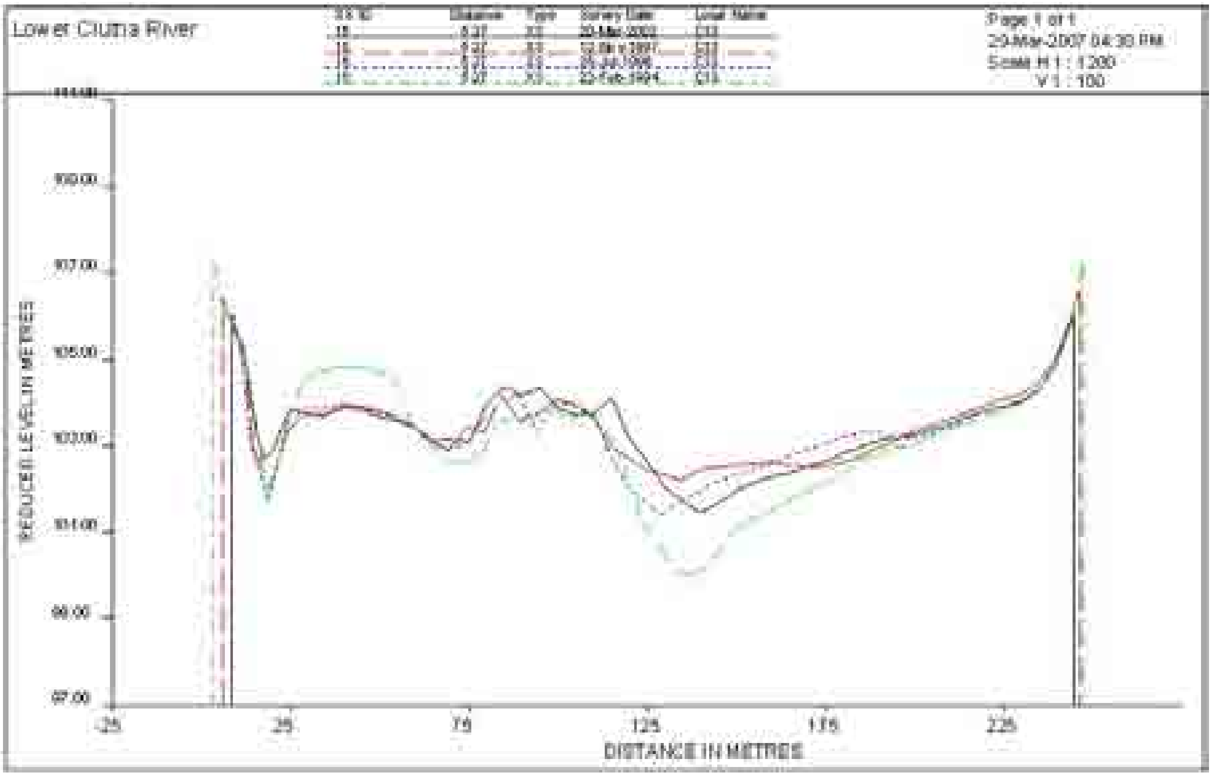

Figure A. 13 Cross-section C13 – Upstream of Gull Island

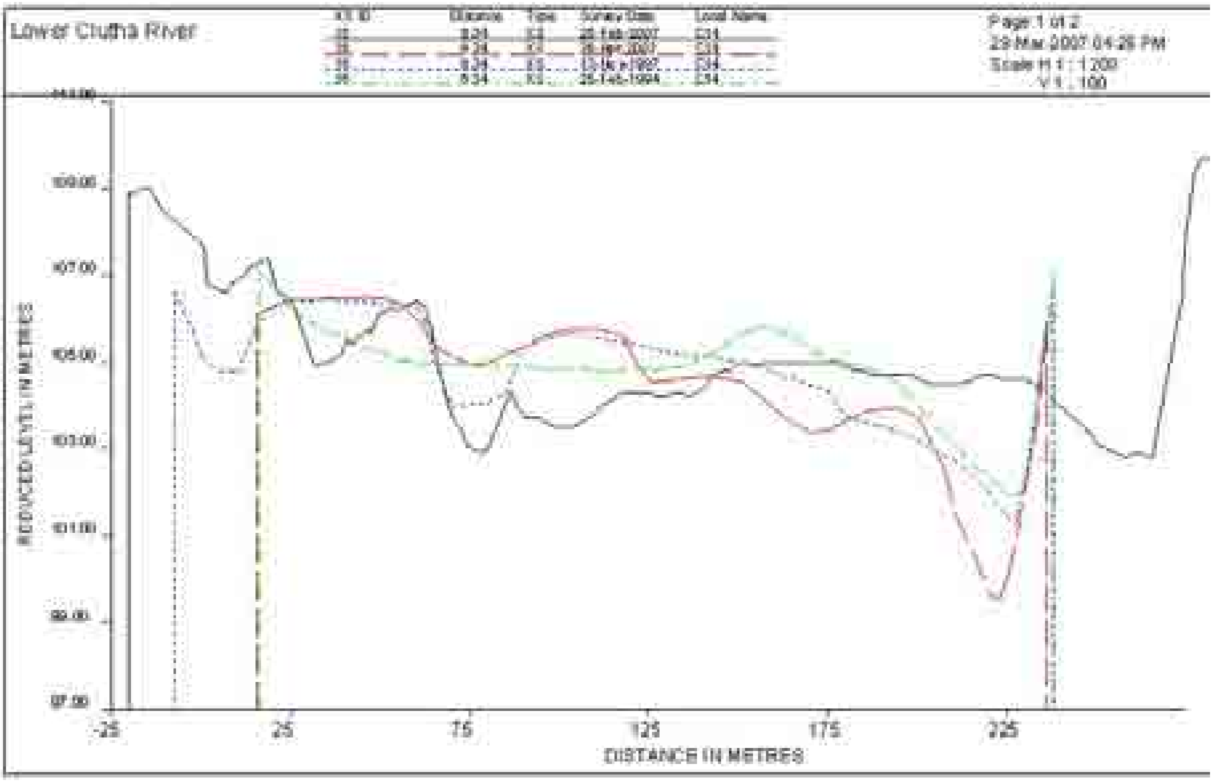

Figure A. 14 Cross-section C14 – Upstream of Training Works

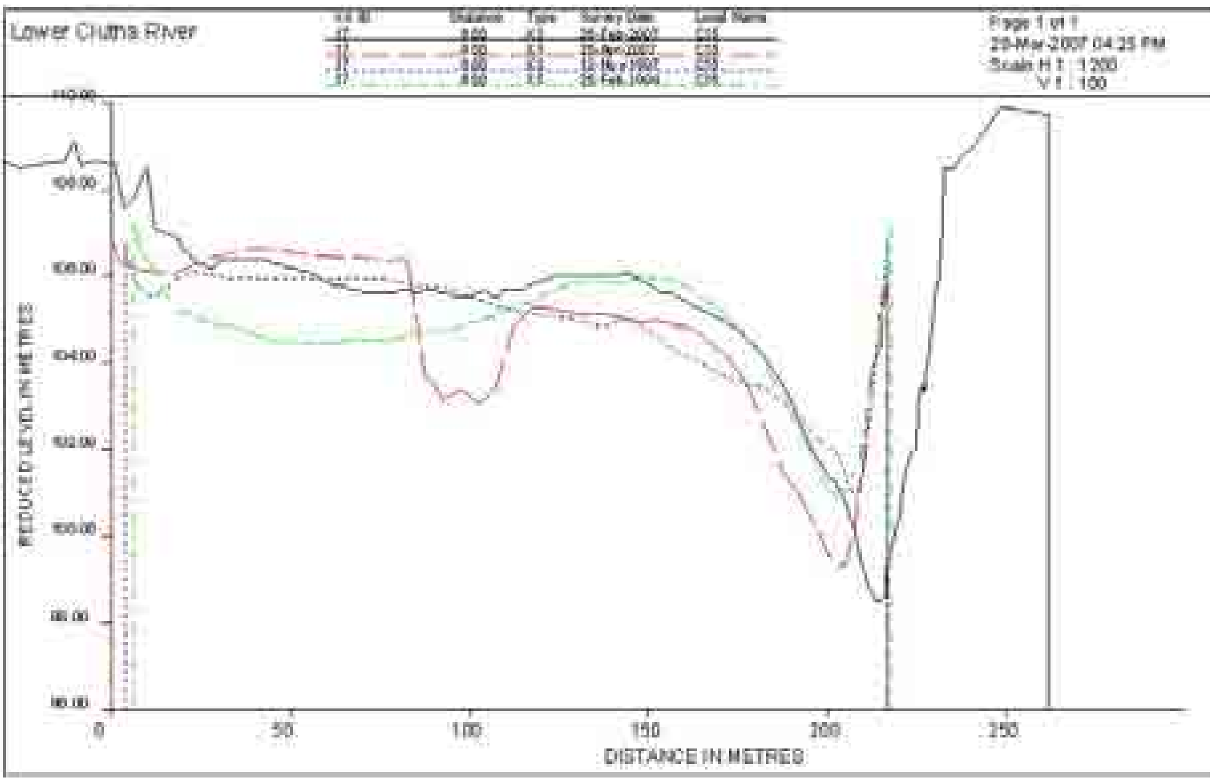

Figure A. 15 Cross-section C15 – Upstream of Training Works

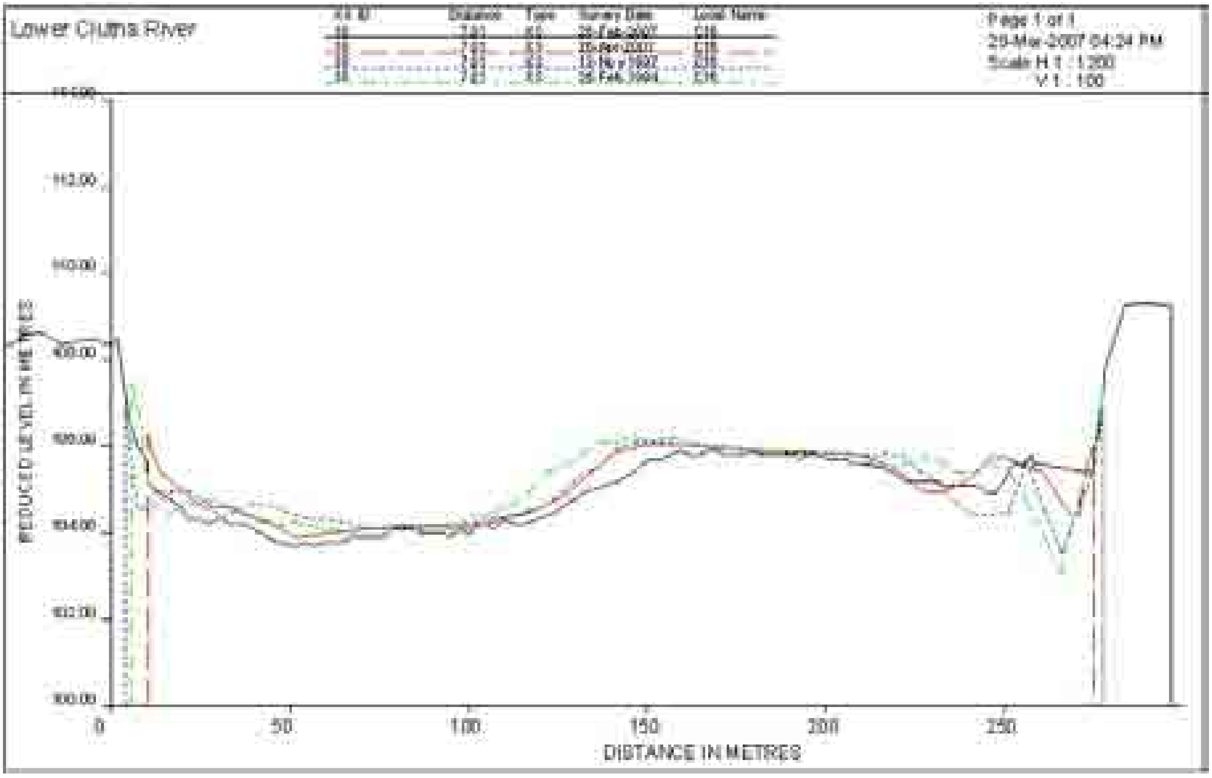

Figure A. 16 Cross-section C16 – Upstream of Training Works

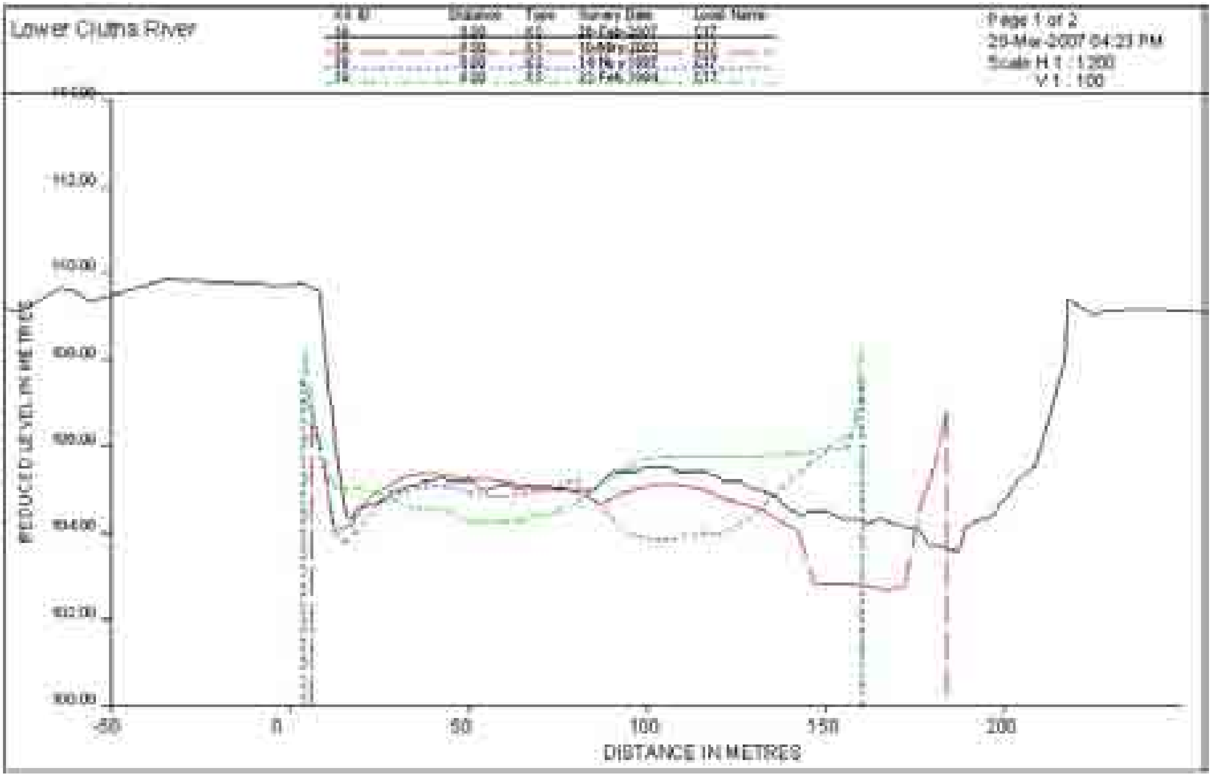

Figure A. 17 Cross-section C17 – Manuka Island

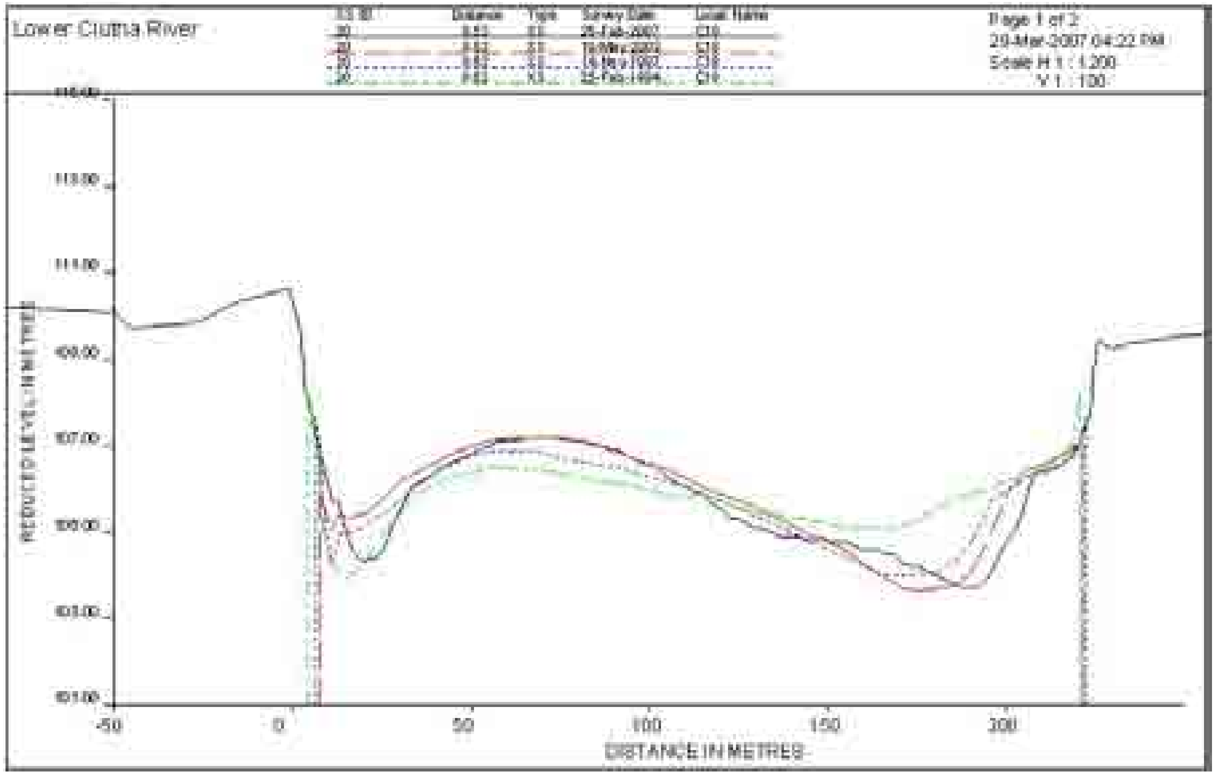

Figure A. 18 Cross-section C18 – Manuka Island

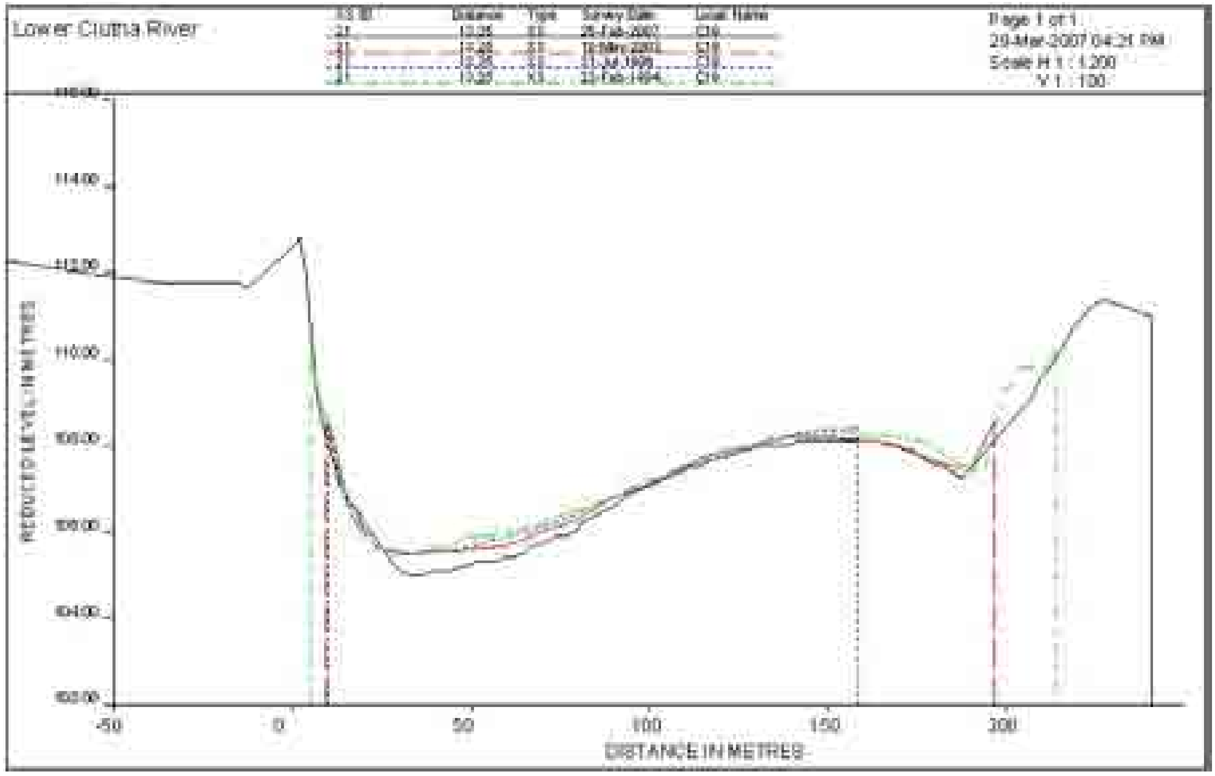

Figure A. 19 Cross-section C19 – Whitelea

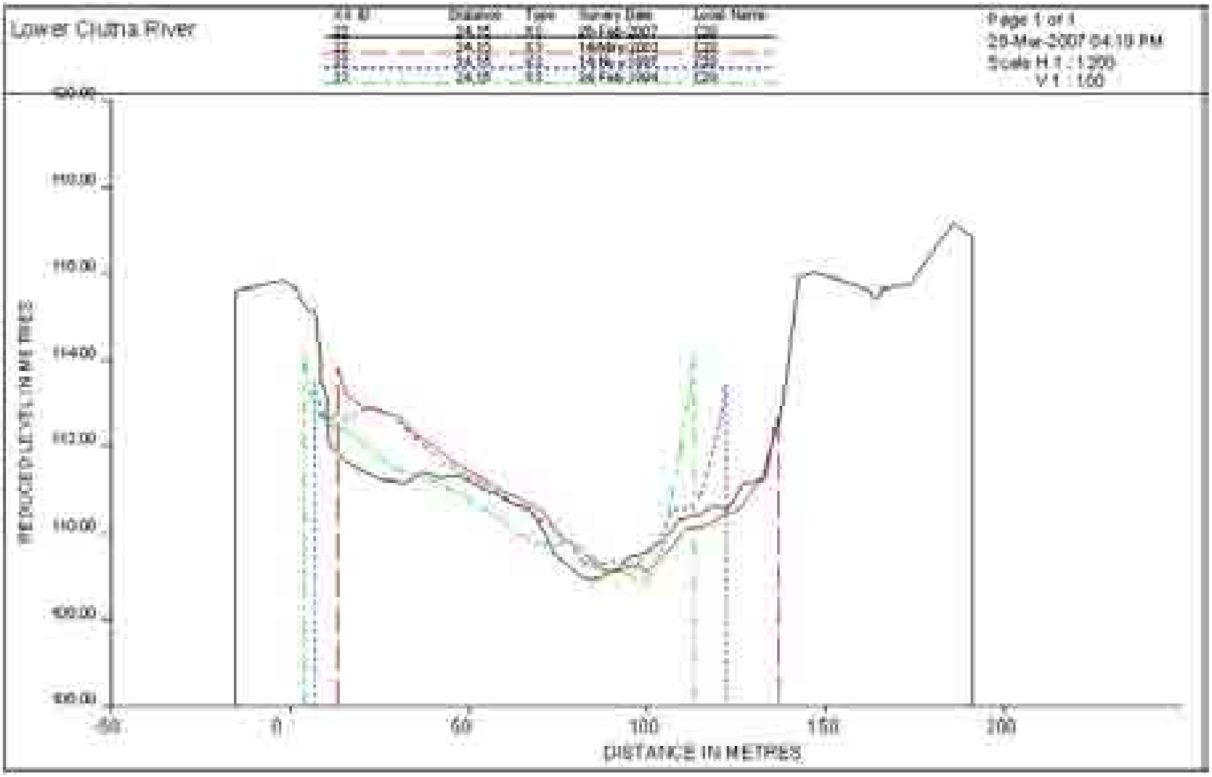

Figure A. 20 Cross-section C20 – Mayor Island, right channel downstream

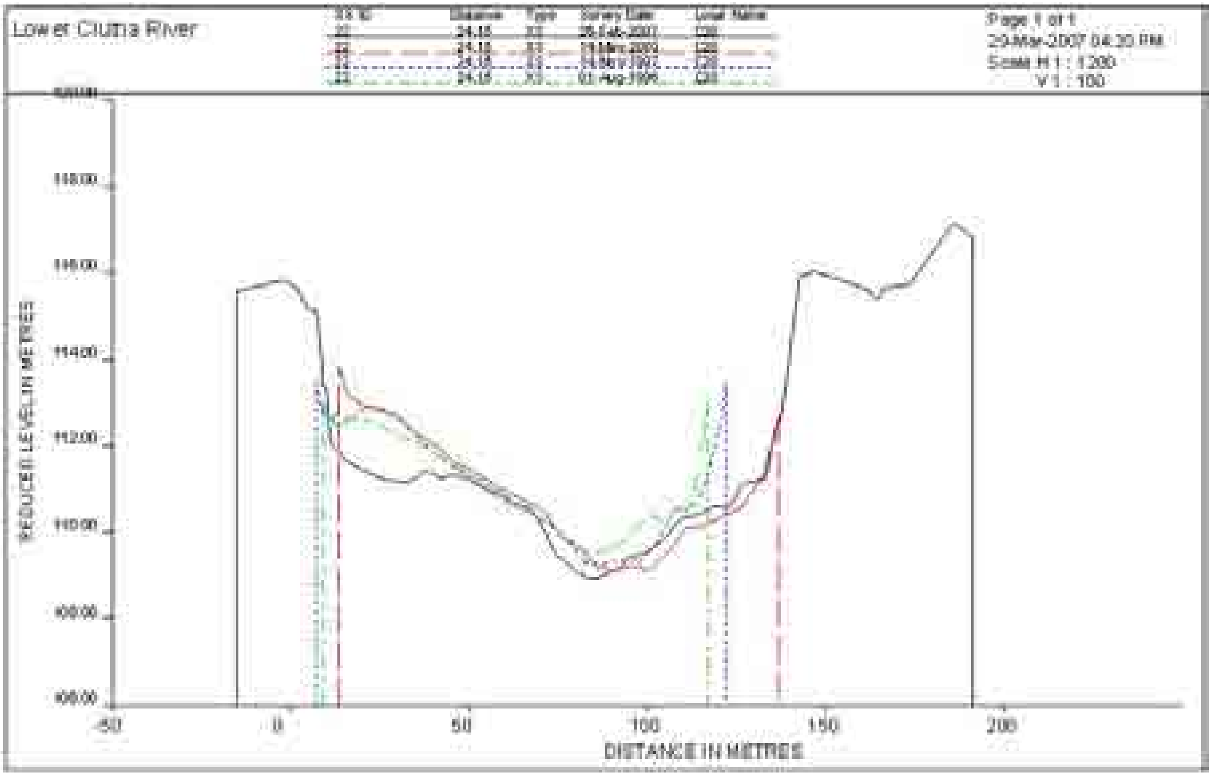

Figure A. 21 Cross-section C20 – Mayor Island, right channel downstream

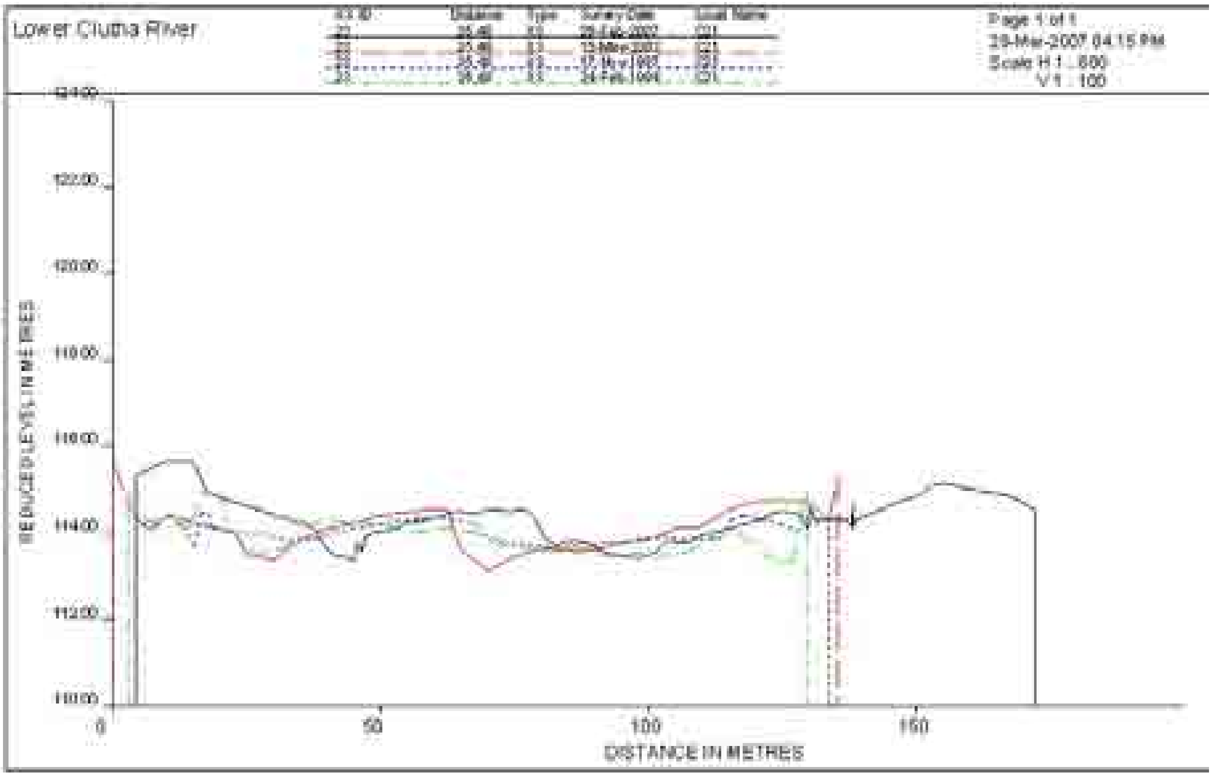

Figure A. 22 Cross-section C21 – Mayor Island, left channel upstream

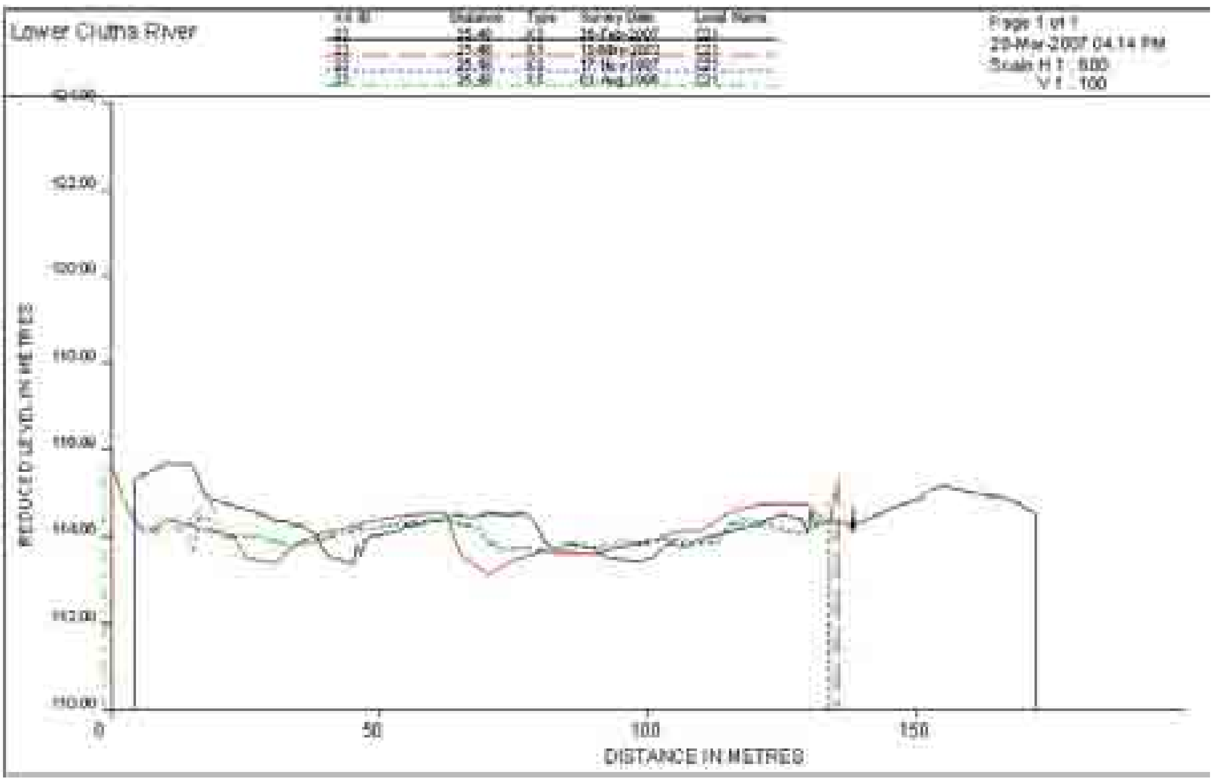

Figure A. 23 Cross-section C21 – Mayor Island, left channel upstream

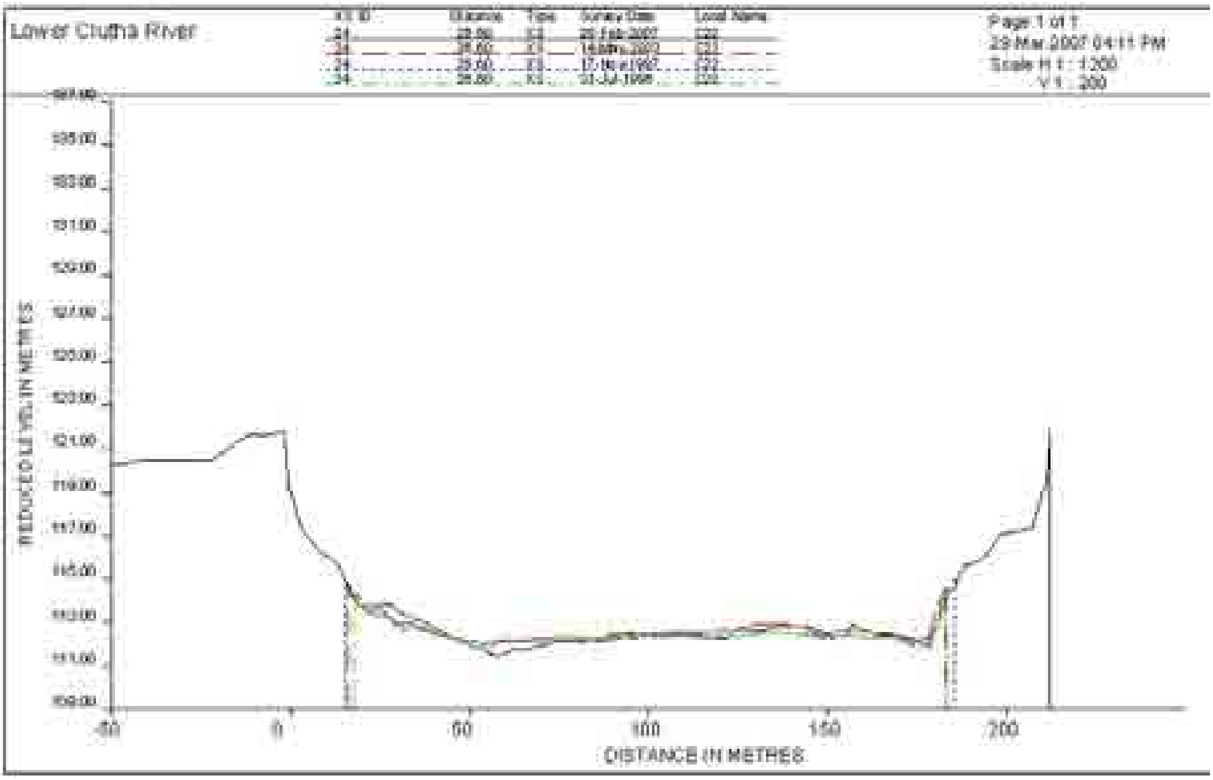

Figure A. 24 Cross-section C22 – Clydevale bridge

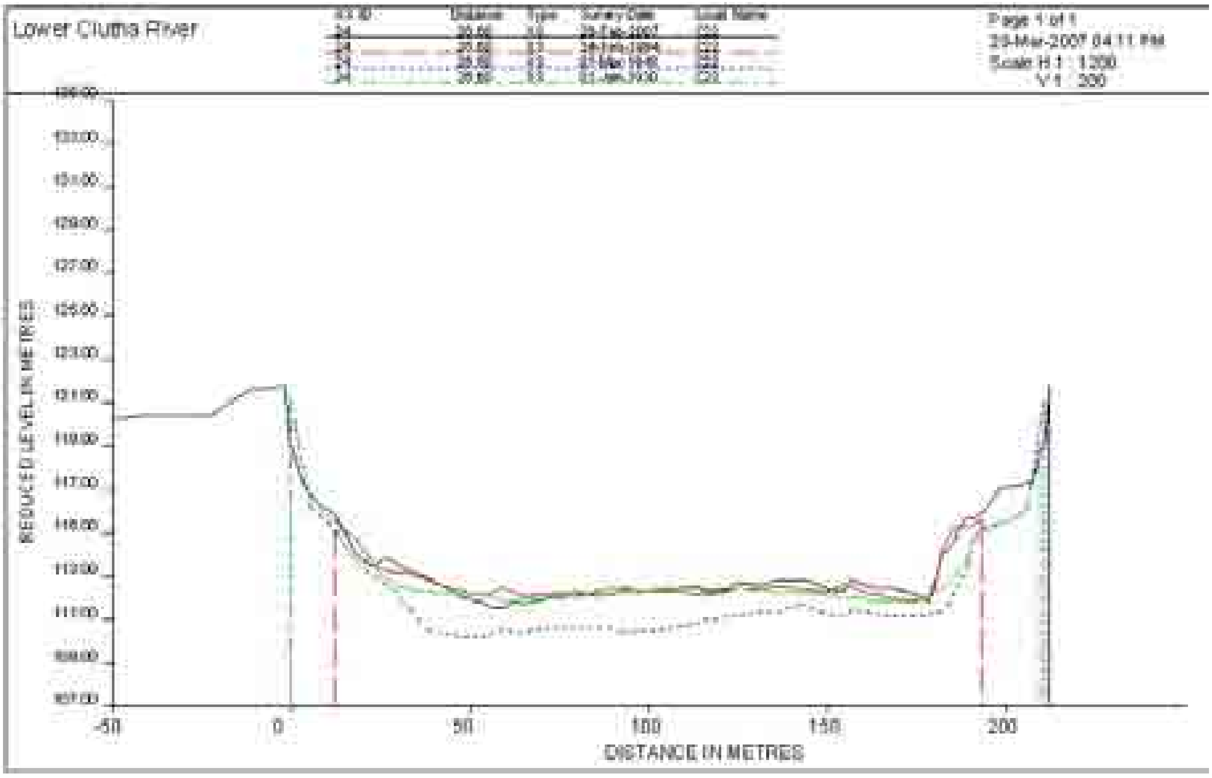

Figure A. 25 Cross-section C22 – Clydevale bridge

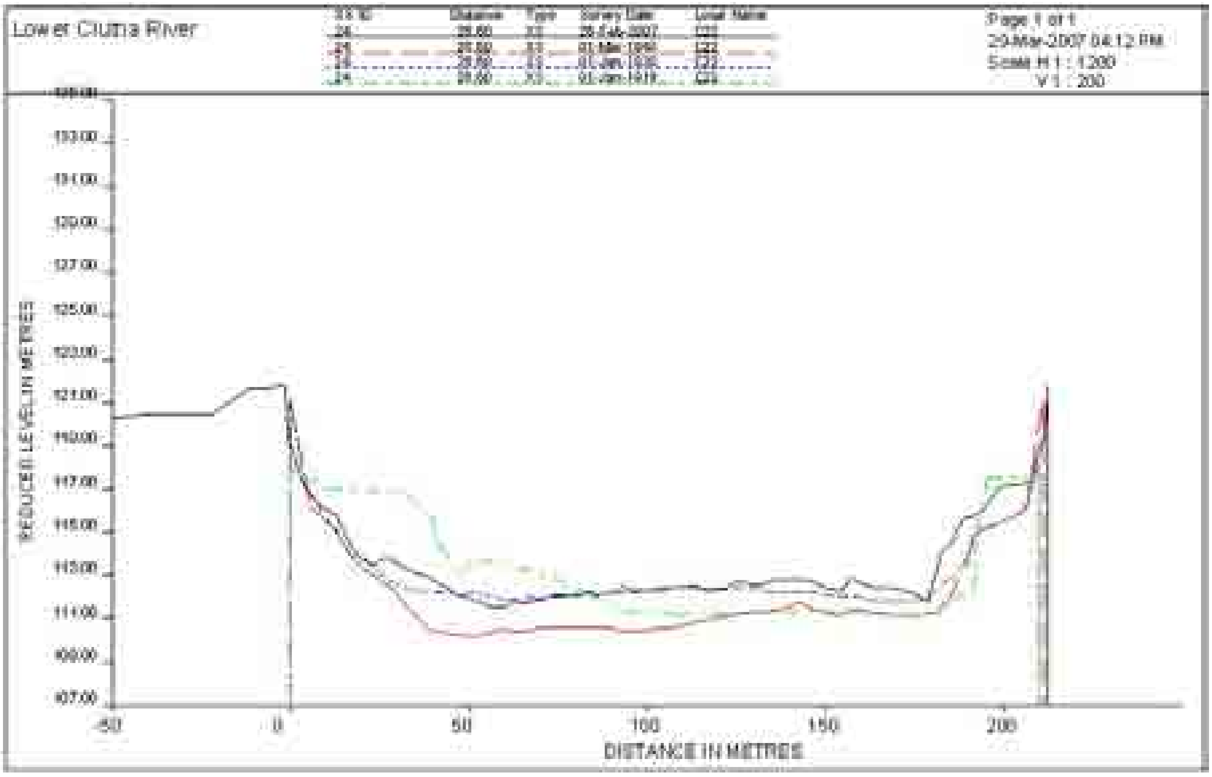

Figure A. 26 Cross-section C22 – Clydevale bridge

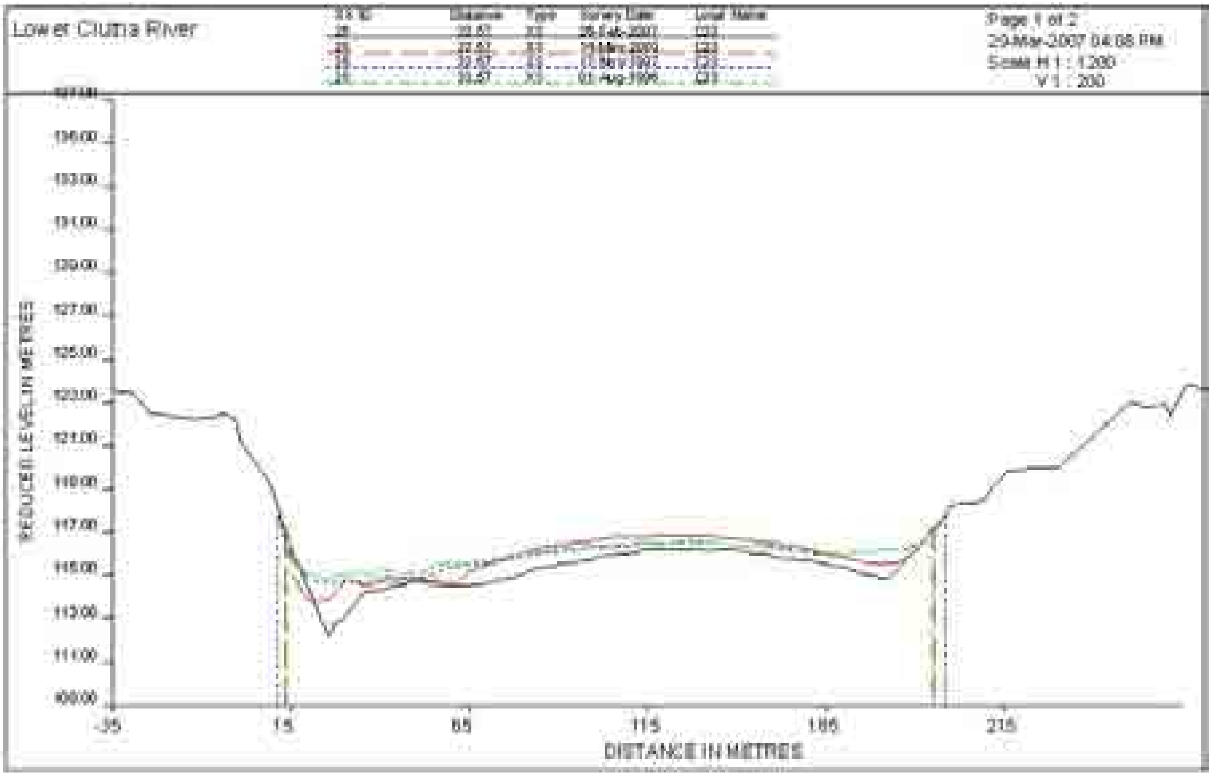

Figure A. 27 Cross-section C23 – Moor Farm

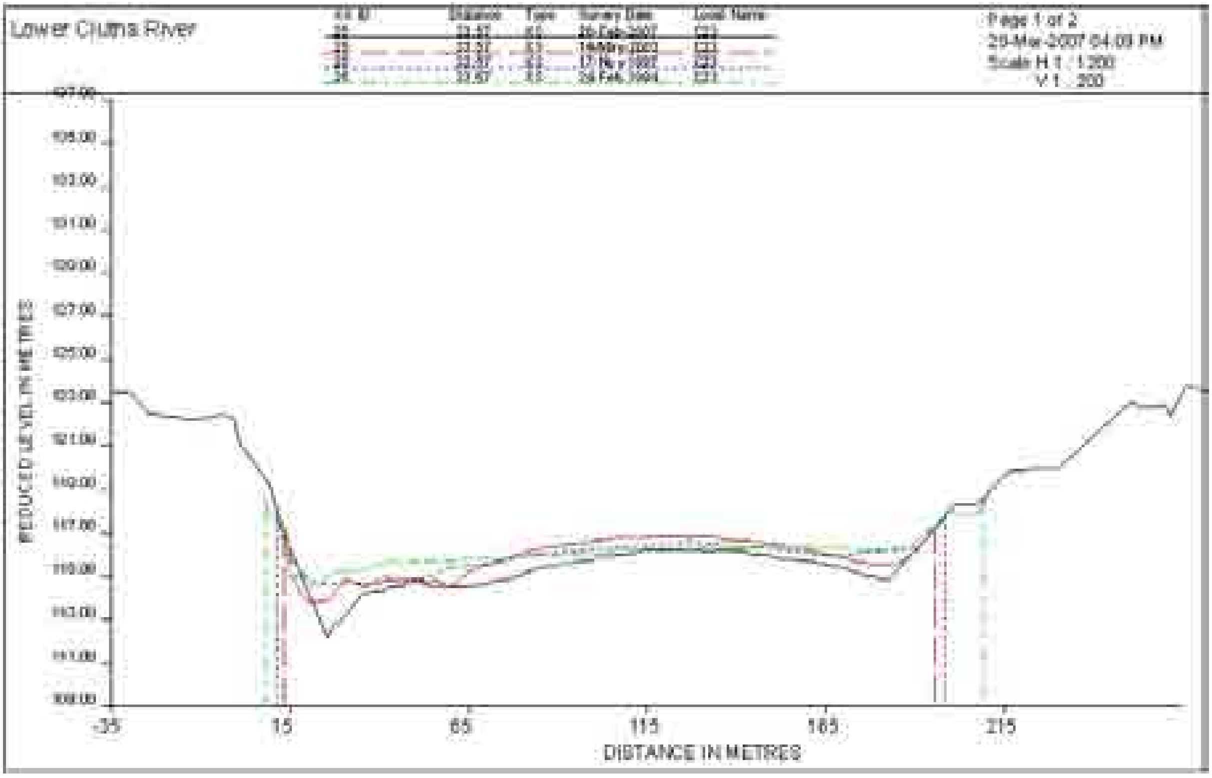

Figure A. 28 Cross-section C23 – Moor Farm

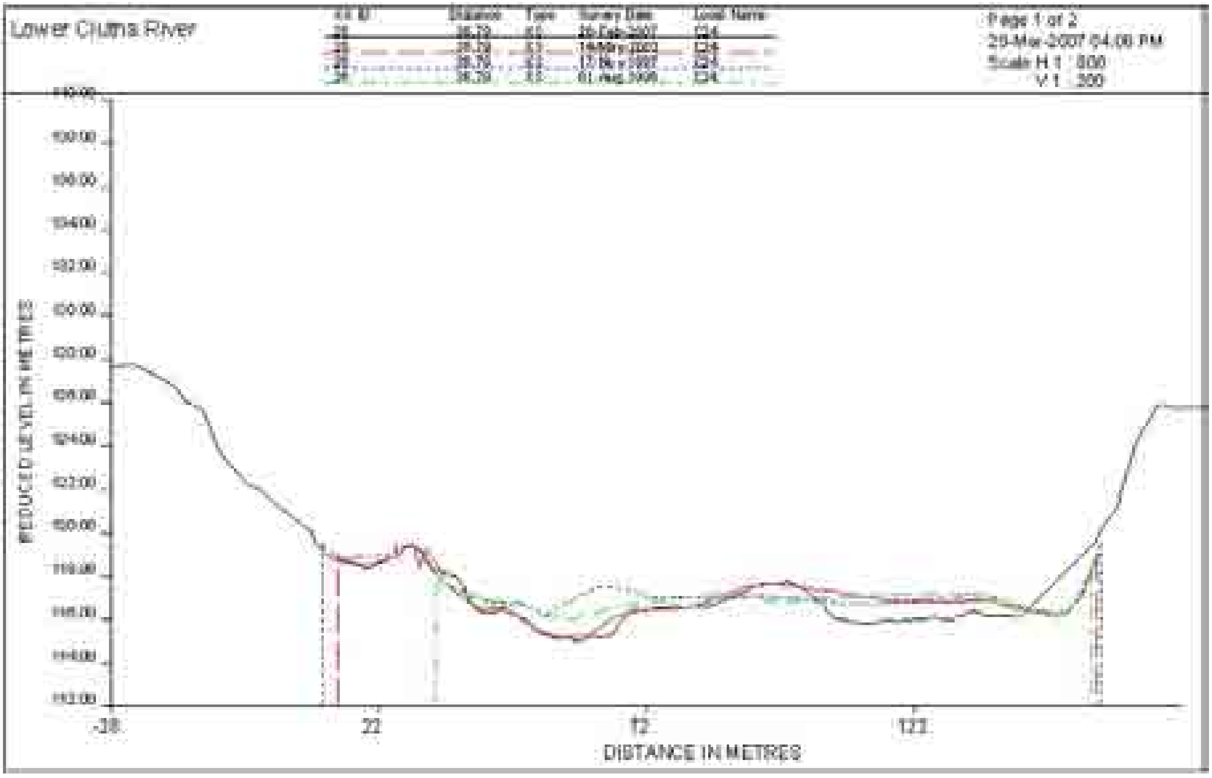

Figure A. 29 **Cross-section C24 – Tuapeka Mouth punt**

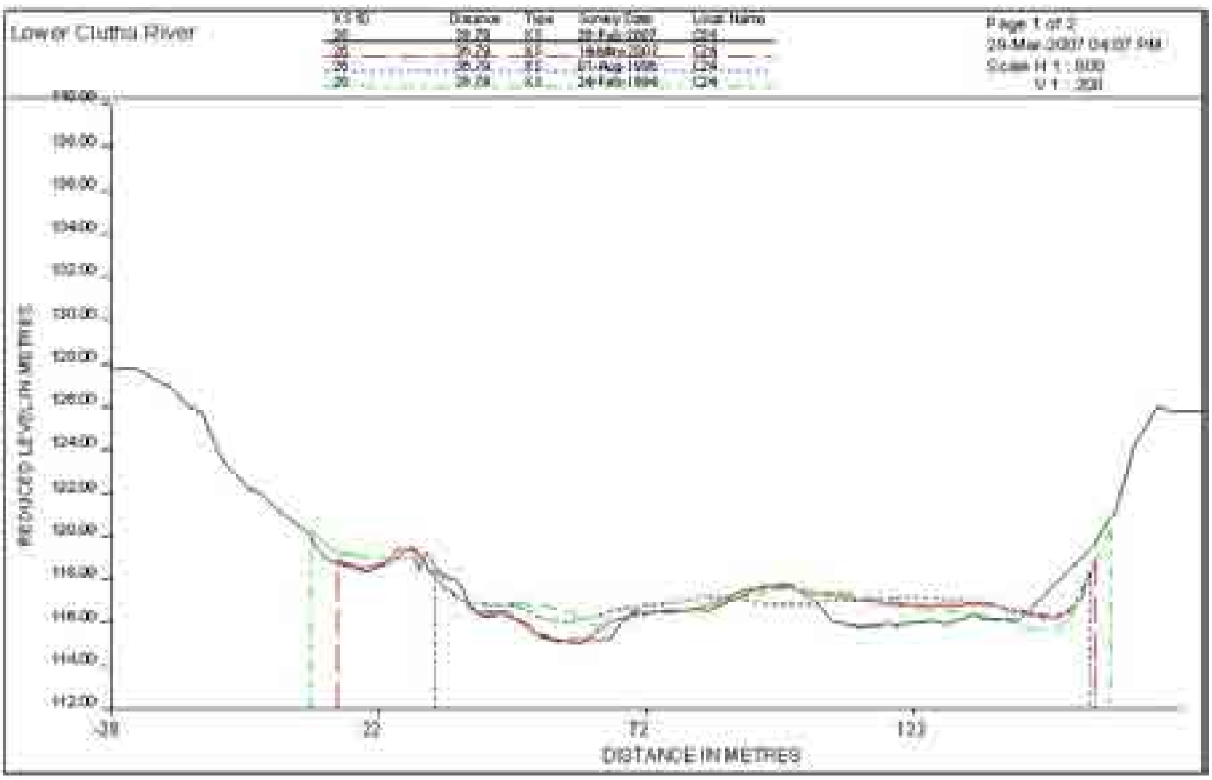

Figure A. 30 **Cross-section C24 – Tuapeka Mouth punt**

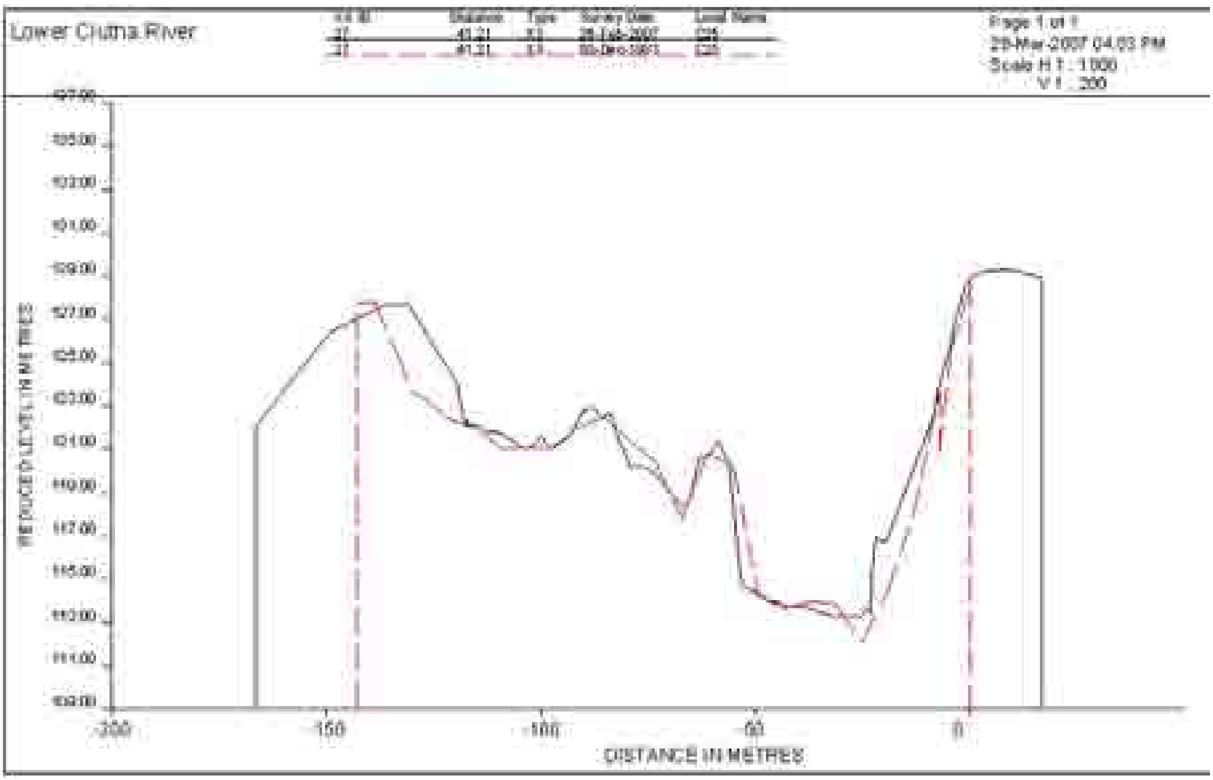

Figure A. 31 **Cross-section C25 – Rongahere**

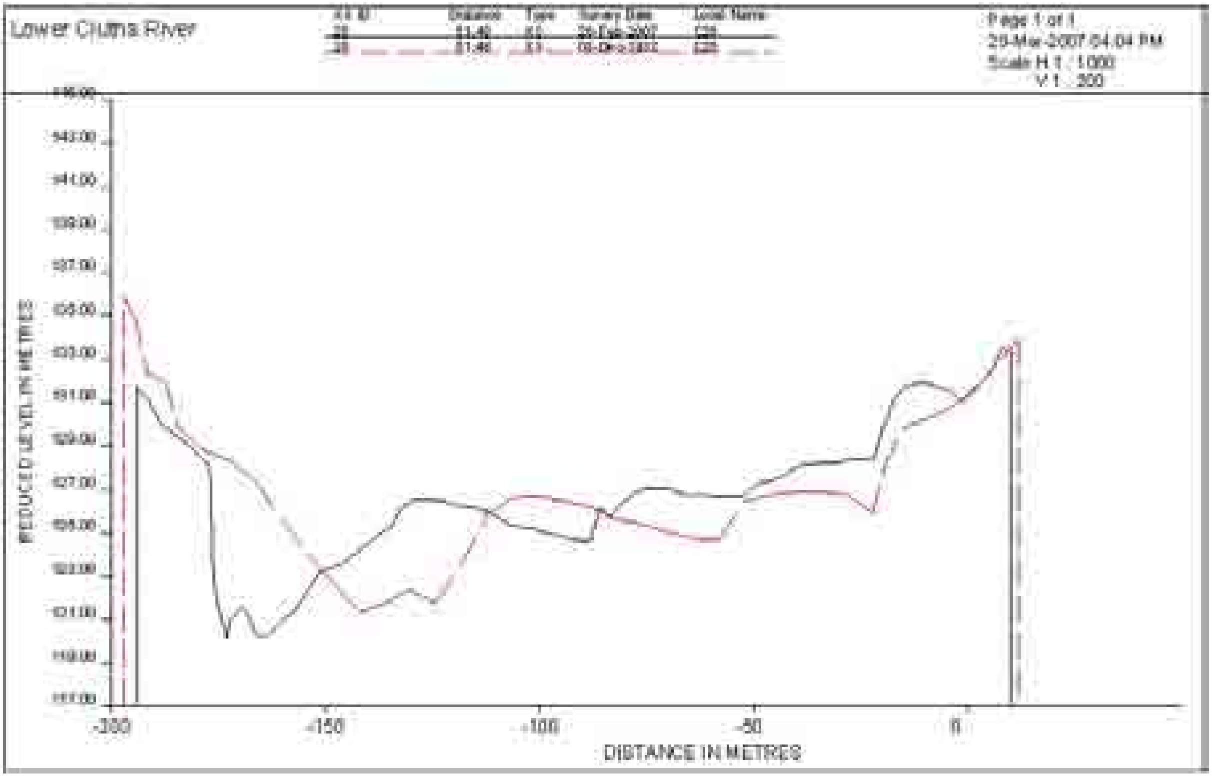

Figure A. 32 **Cross-section C26 – Upstream of Birch Island, Rongahere Gorge**

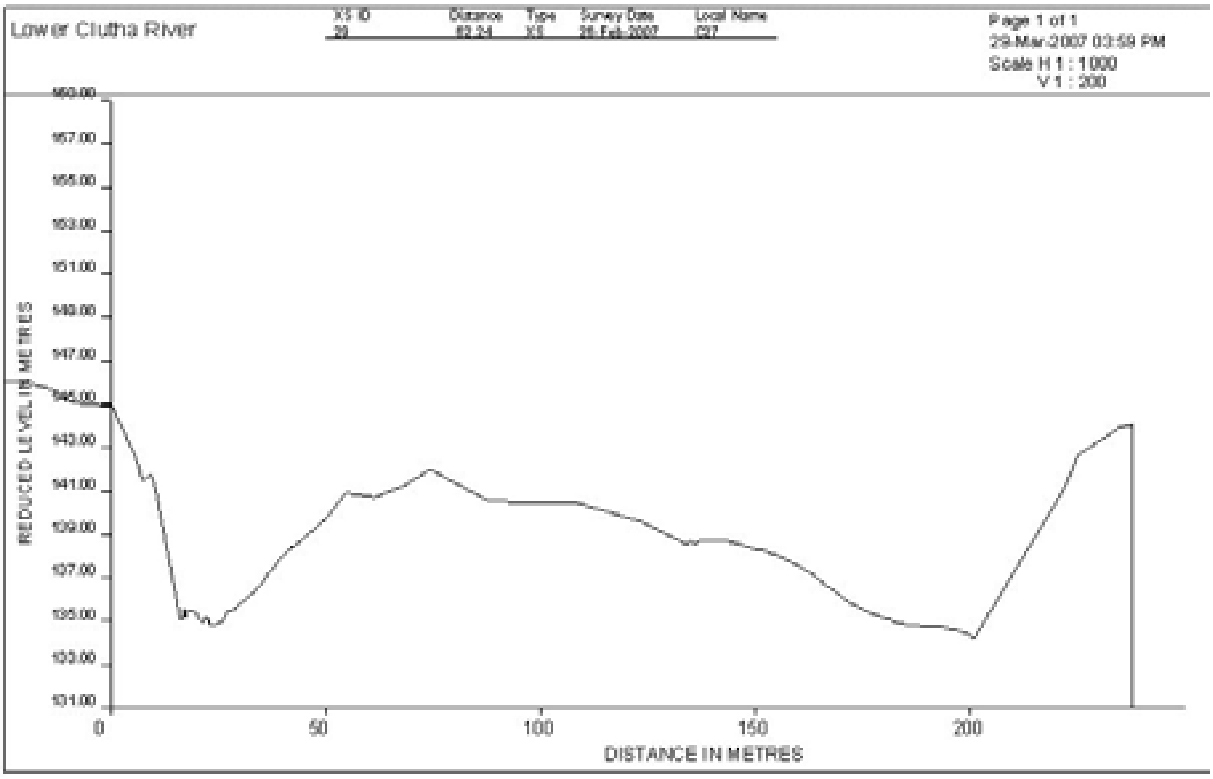

Figure A. 33 Cross-section C27 – Beaumont race course

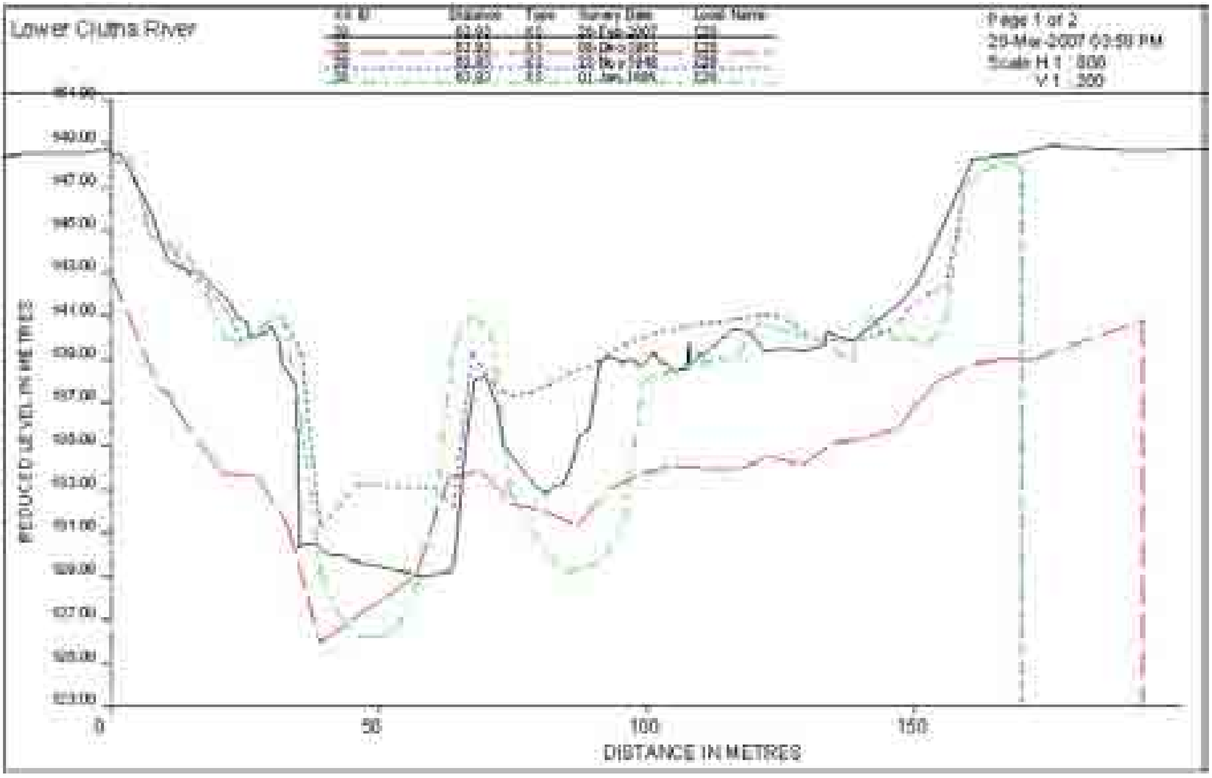

Figure A. 34 Cross-section C28 – Beaumont bridge

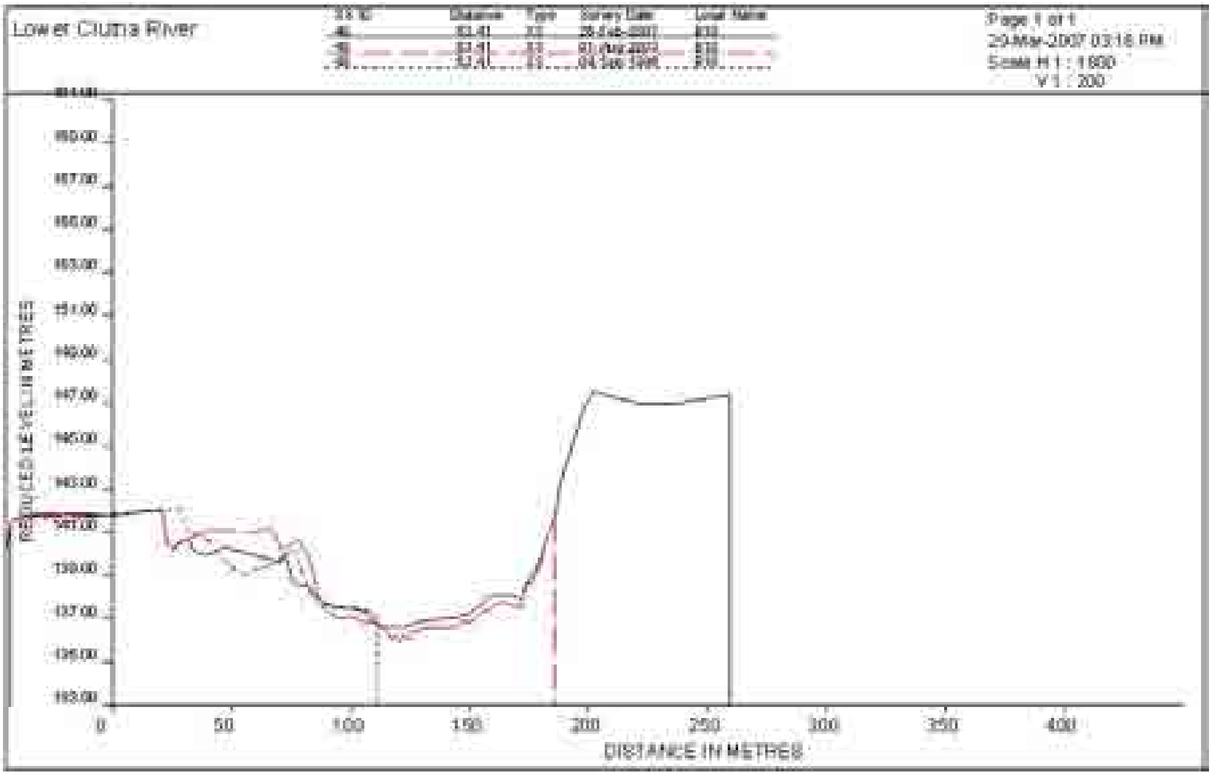

Figure A. 35 Cross-section B10 – Beaumont bar

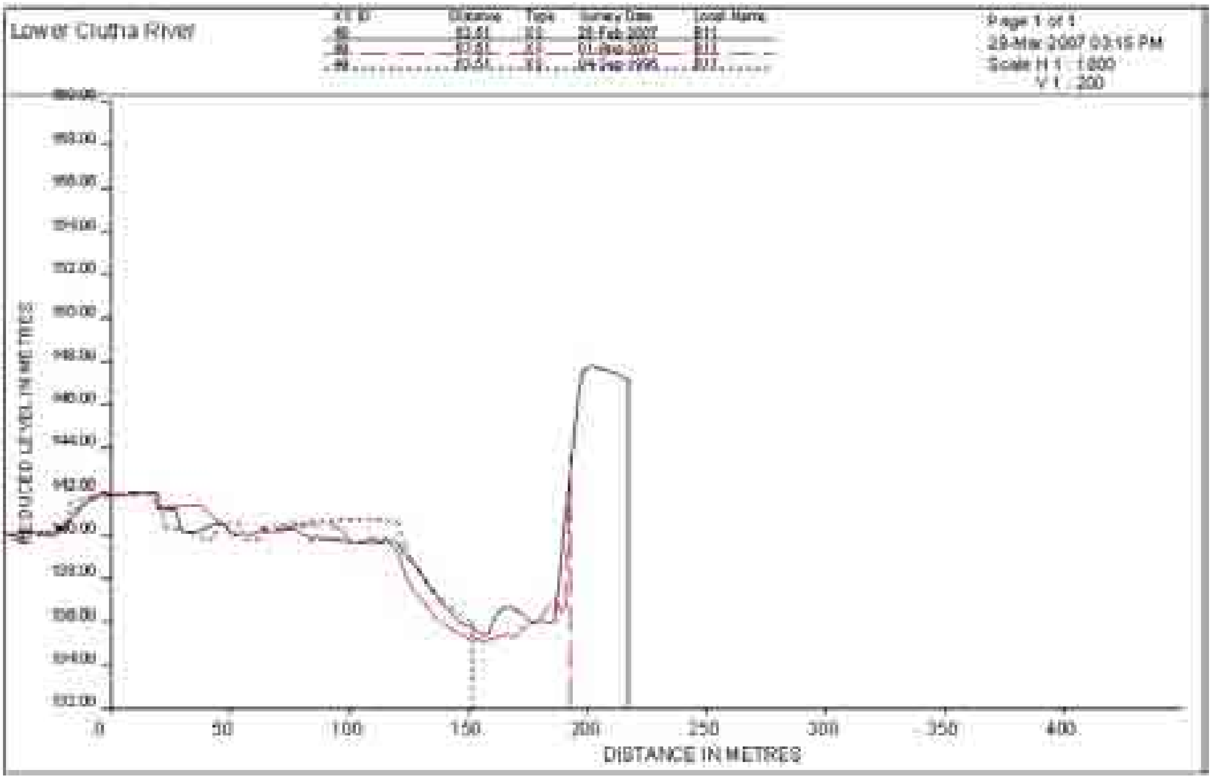

Figure A. 36 Cross-section B11 – Beaumont bar

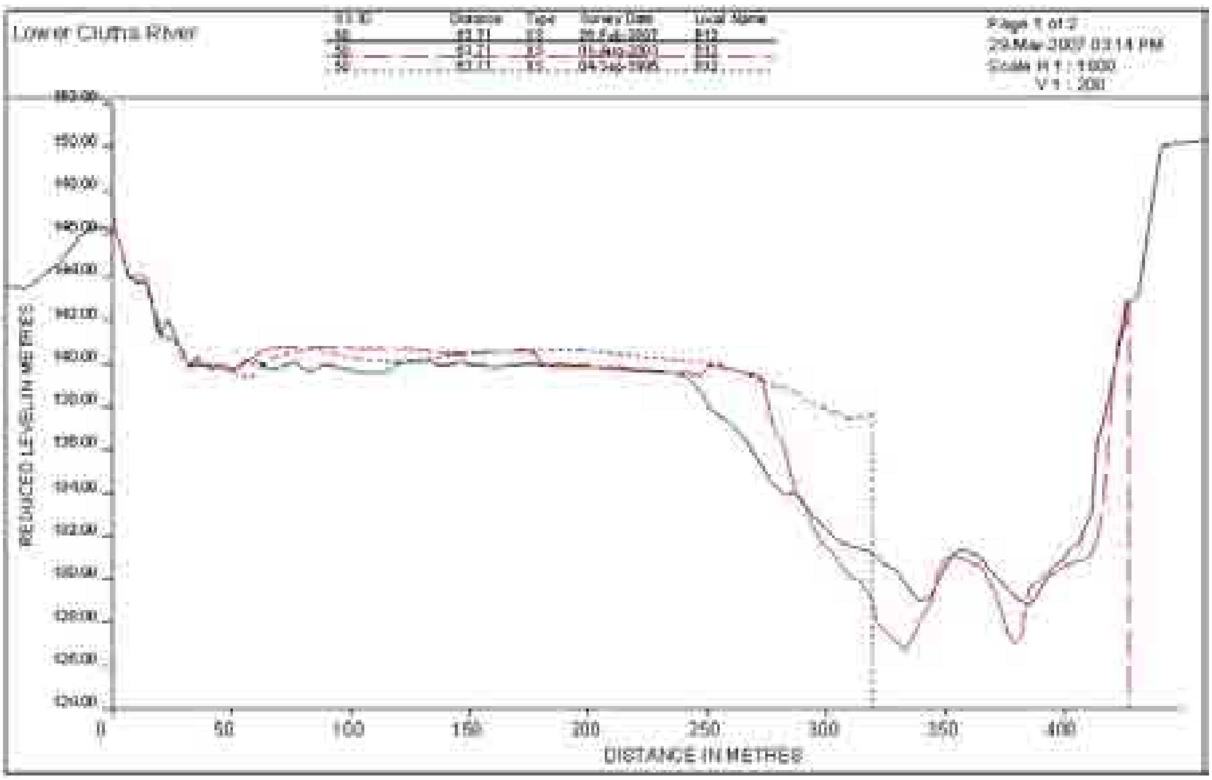

Figure A. 37 **Cross-section B12 – Beaumont bar**

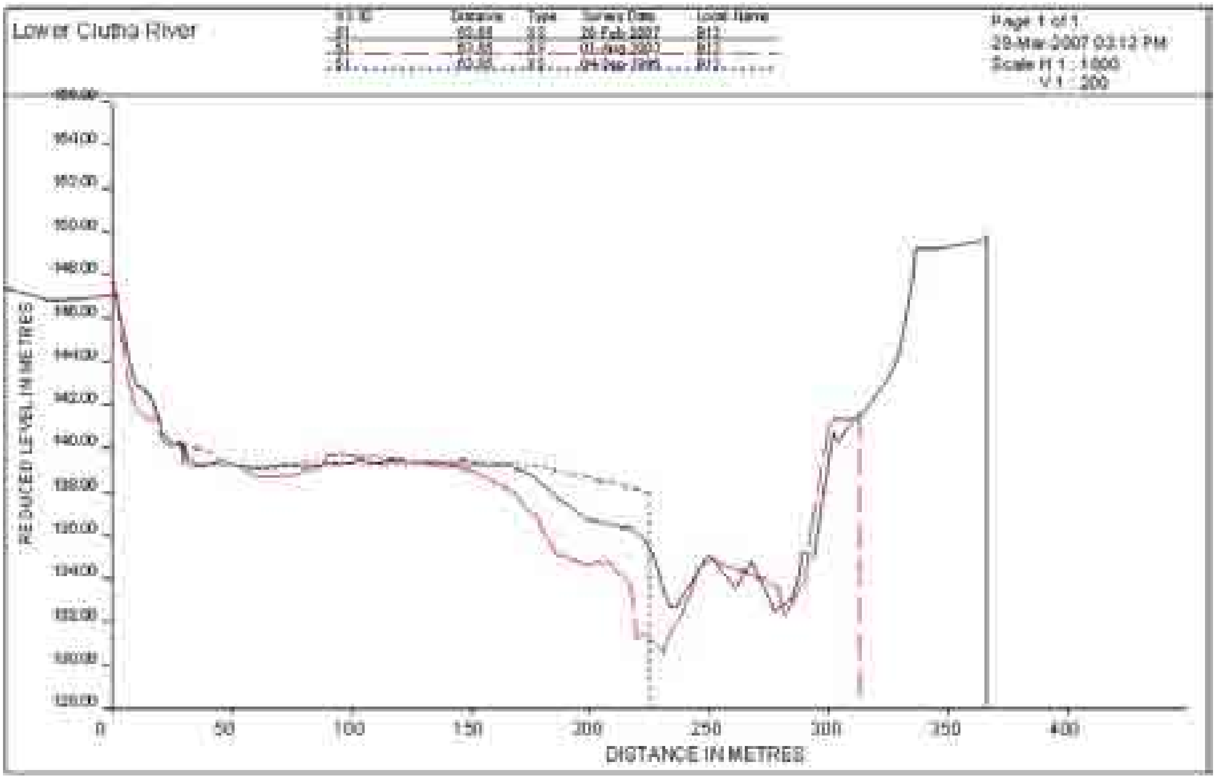

Figure A. 38 **Cross-section B13 – Beaumont bar**

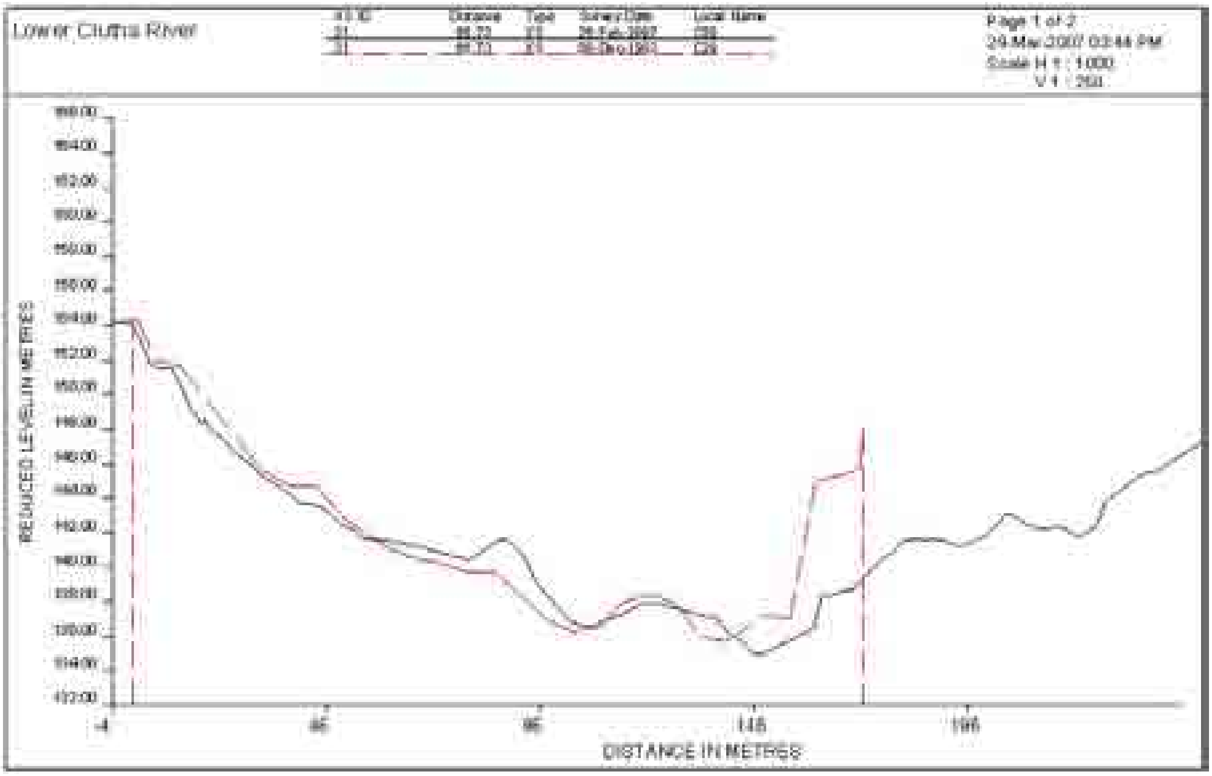

Figure A. 39 Cross-section C29 – Beaumont Gorge

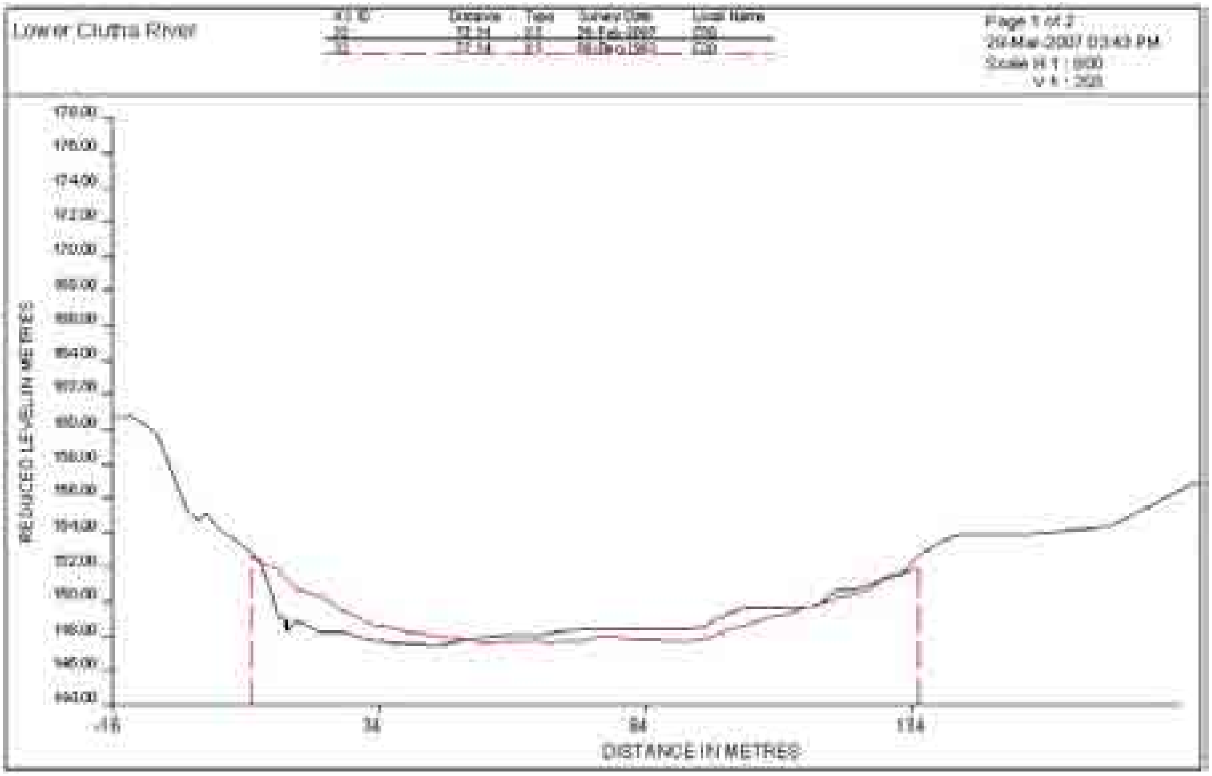

Figure A. 40 Cross-section C30 – McCunn's Beach

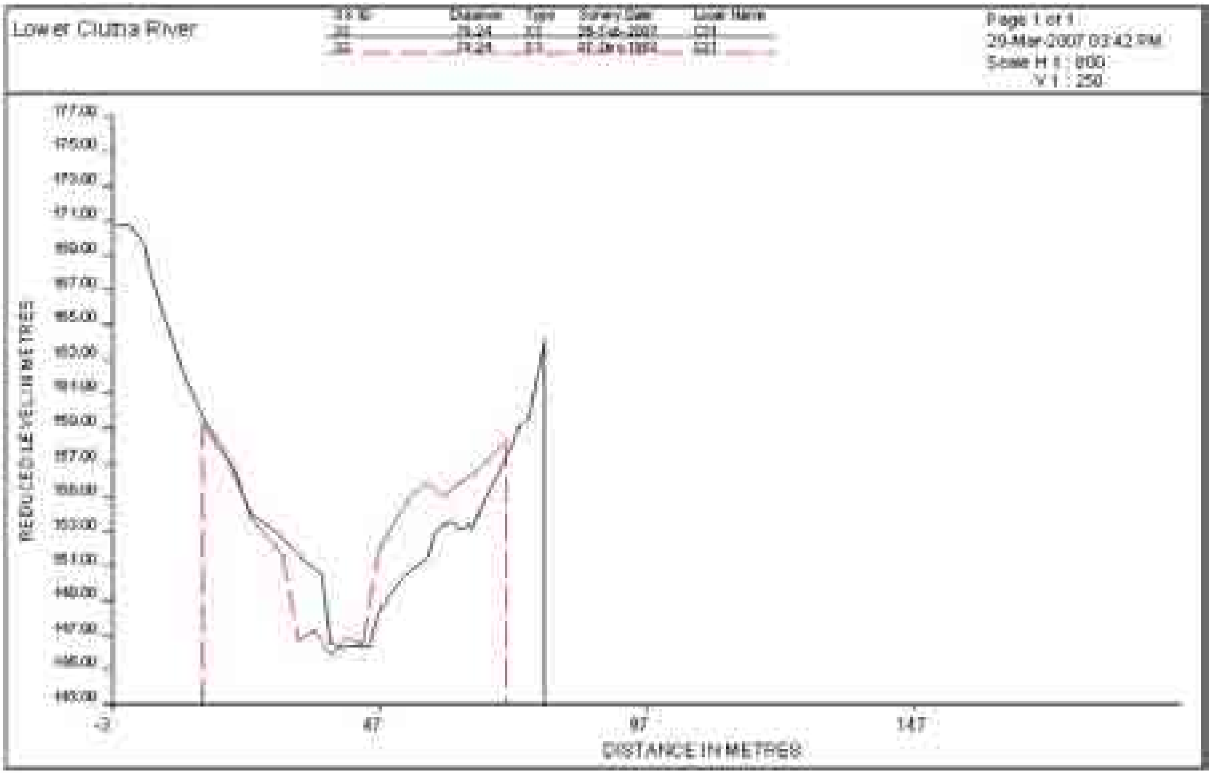

Figure A. 41 Cross-section C31 – Upstream of Rigney

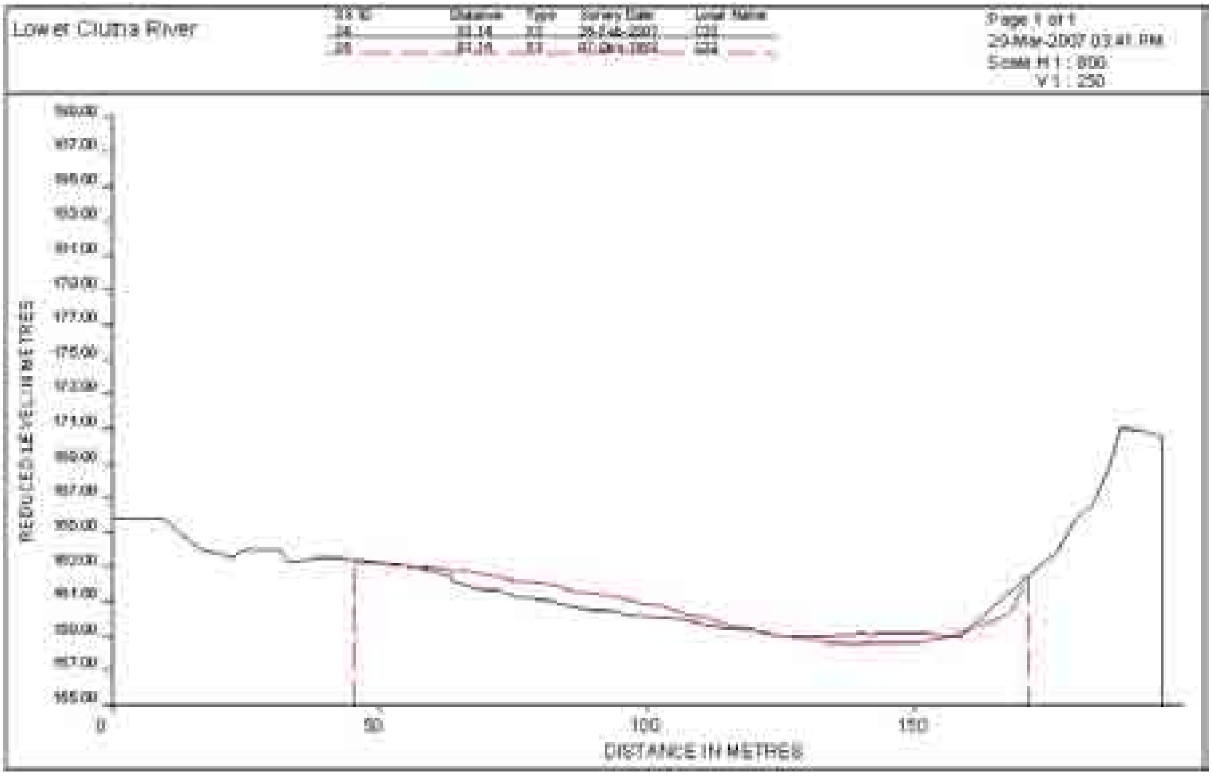

Figure A. 42 Cross-section C32 – Mayor Island

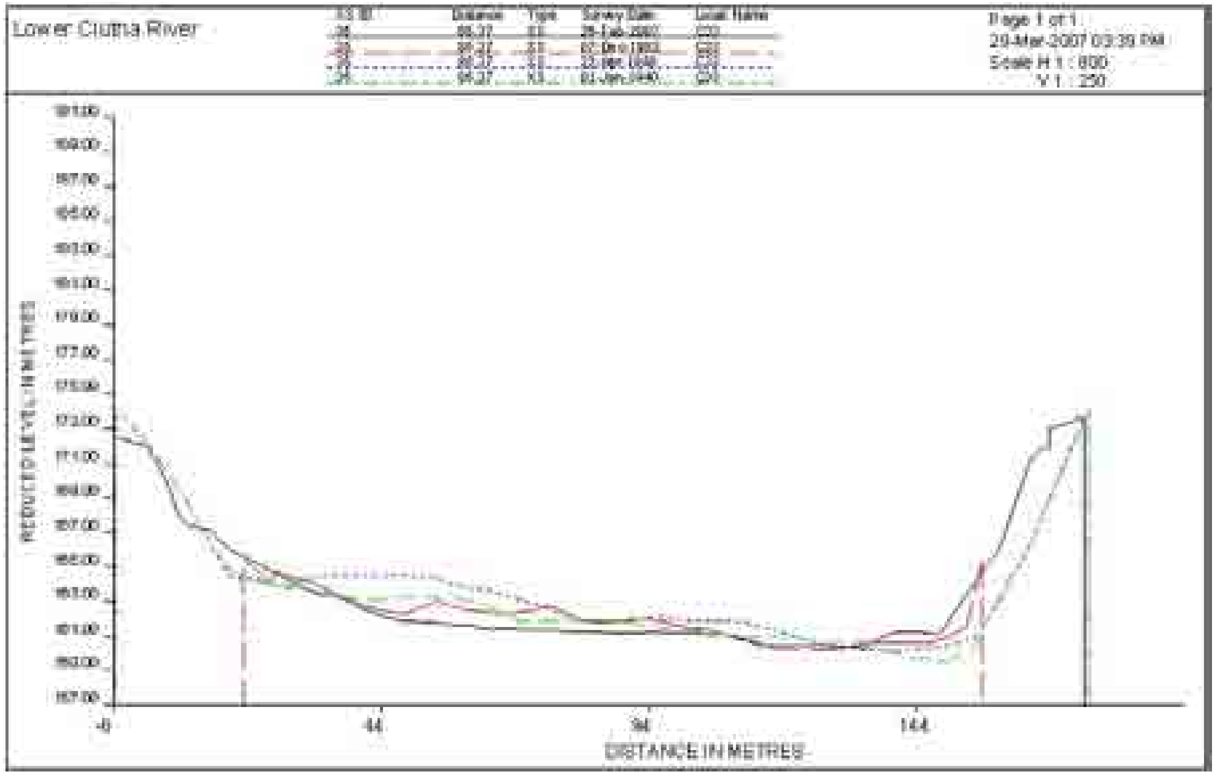

Figure A. 43 Cross-section C32 – Millers Flat bridge

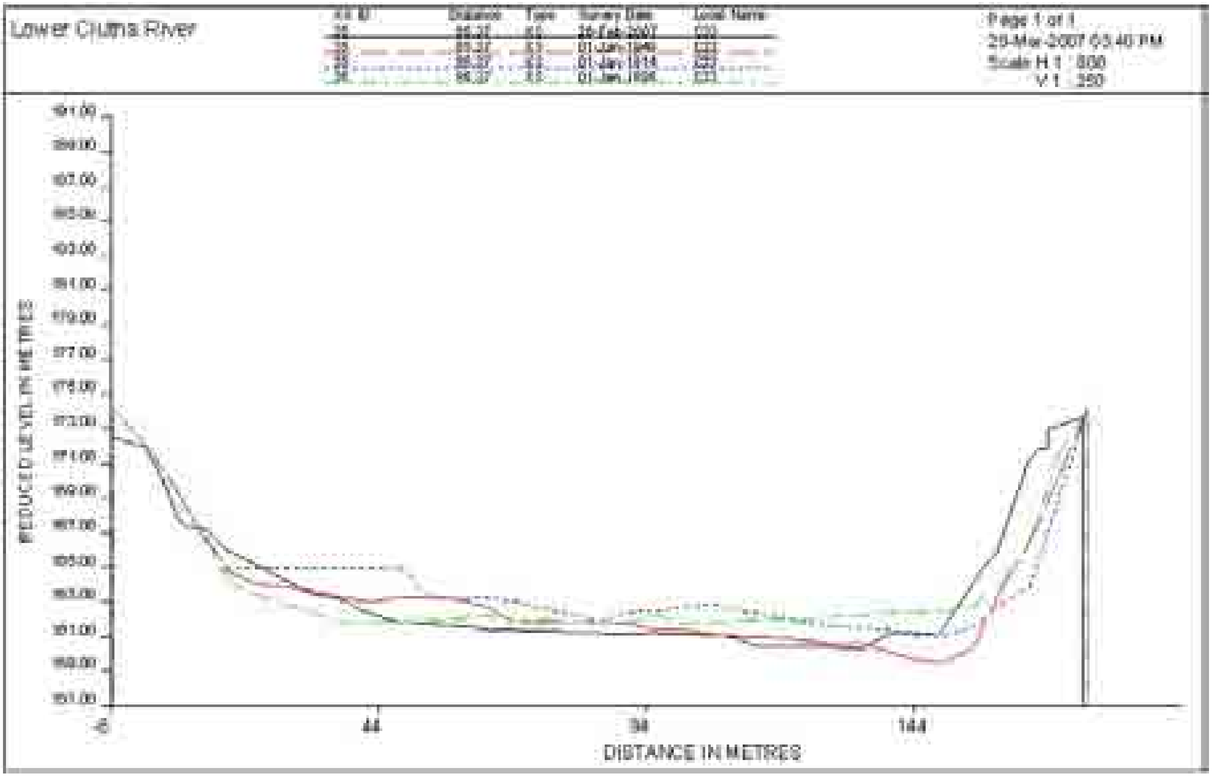

Figure A. 44 Cross-section C33 – Millers Flat bridge

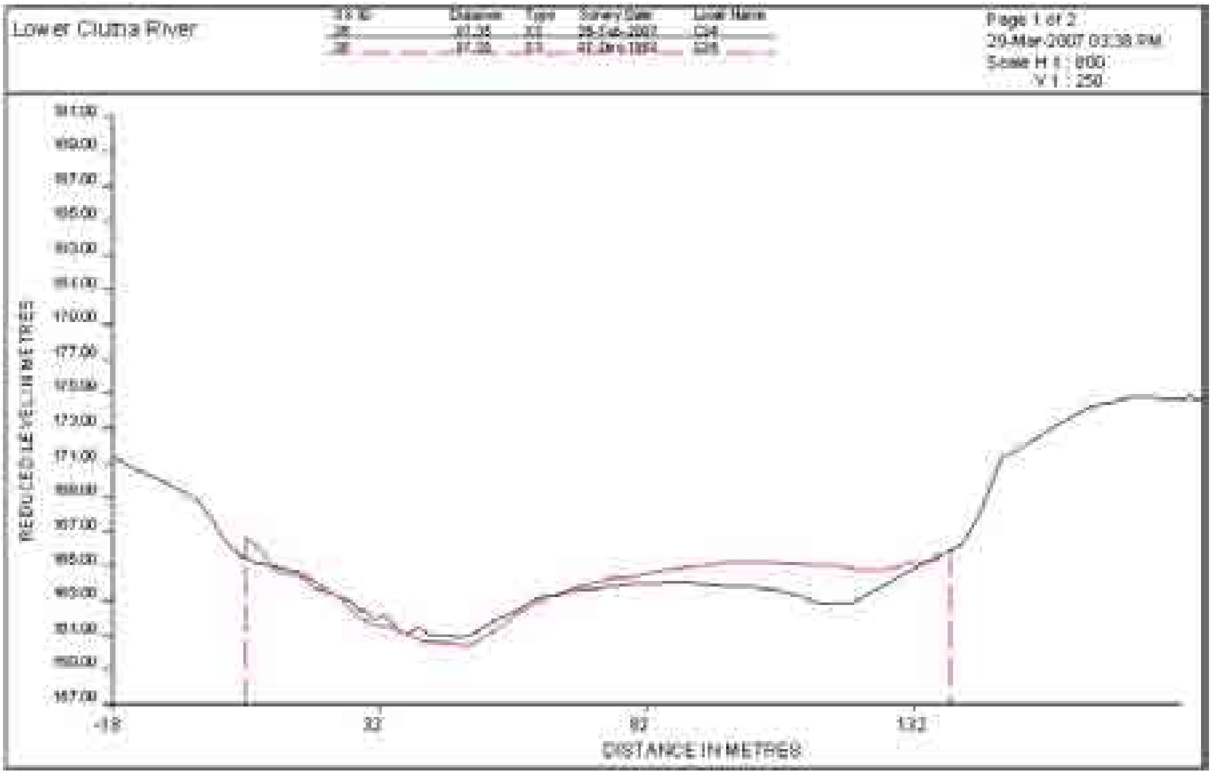

Figure A. 45 Cross-section C34 – Minzion

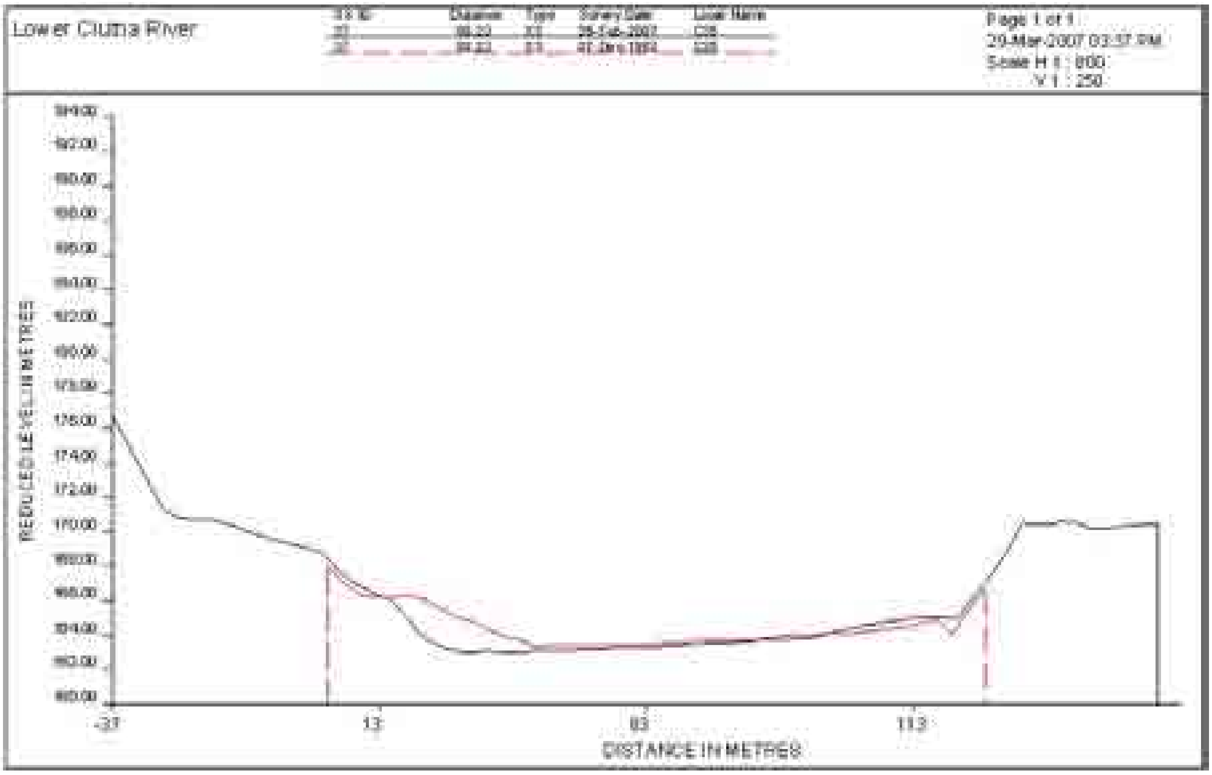

Figure A. 46 Cross-section C35 – Clutha Road, Ettrick

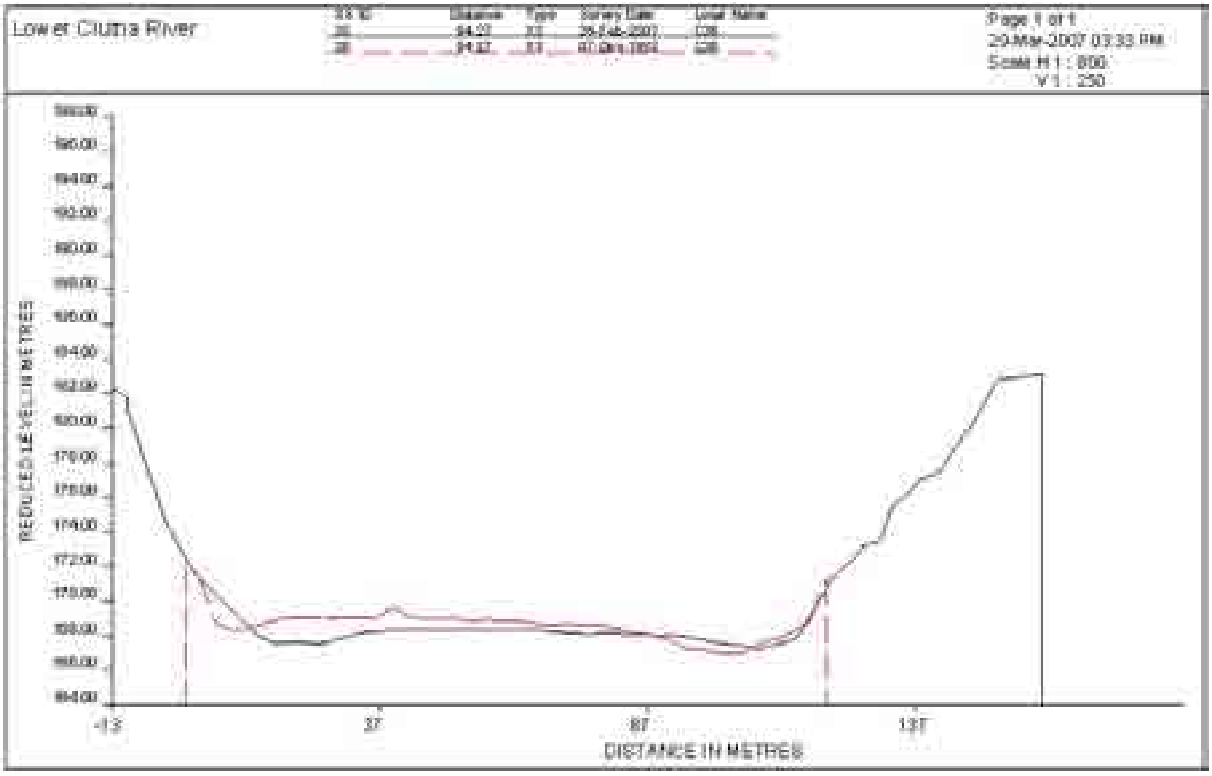

Figure A. 47 **Cross-section C36 – Frames Lane, Ettrick**

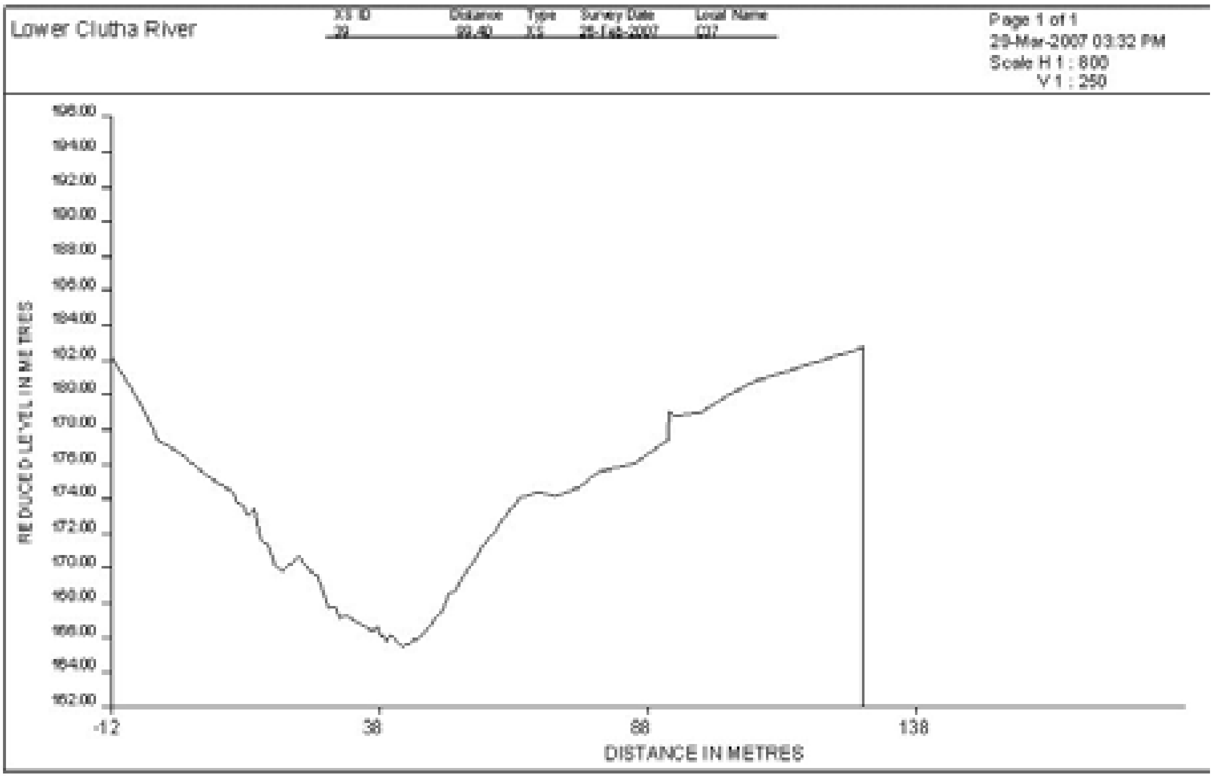

Figure A. 48 **Cross-section C37 – Jacks Creek**

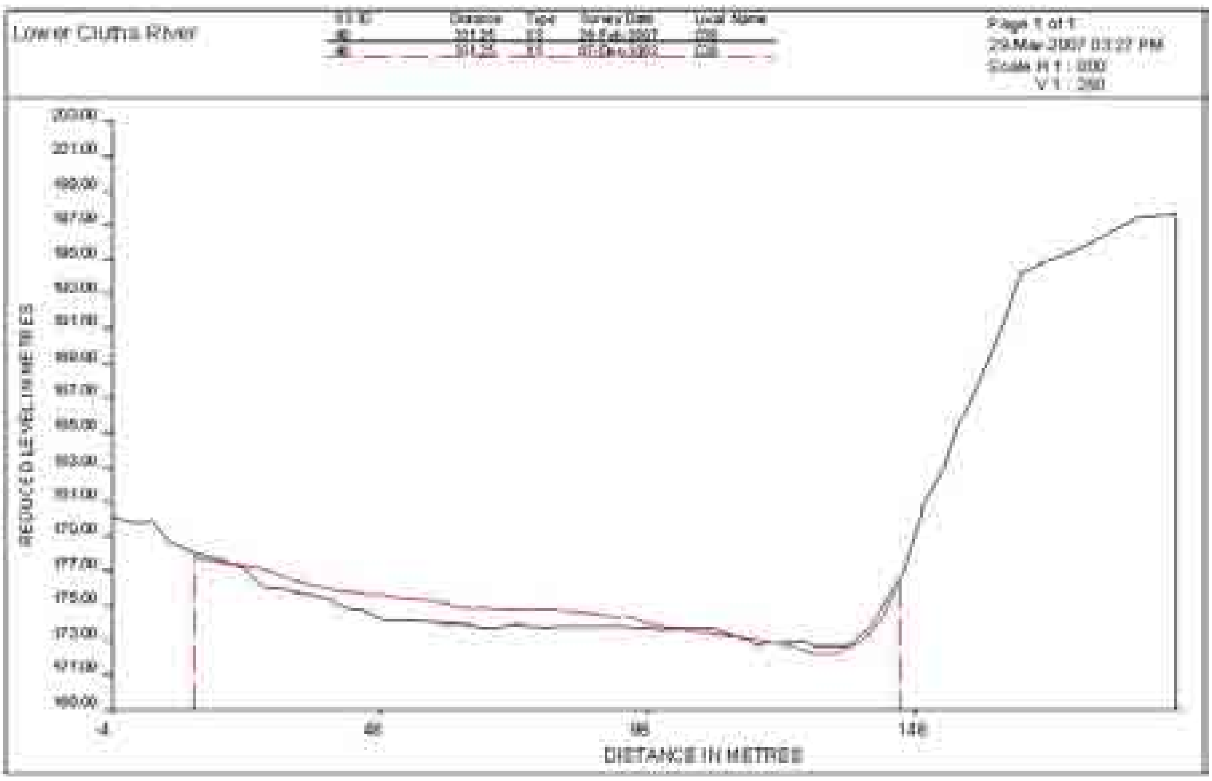

Figure A. 49 **Cross-section C38 – Hercules Flat**

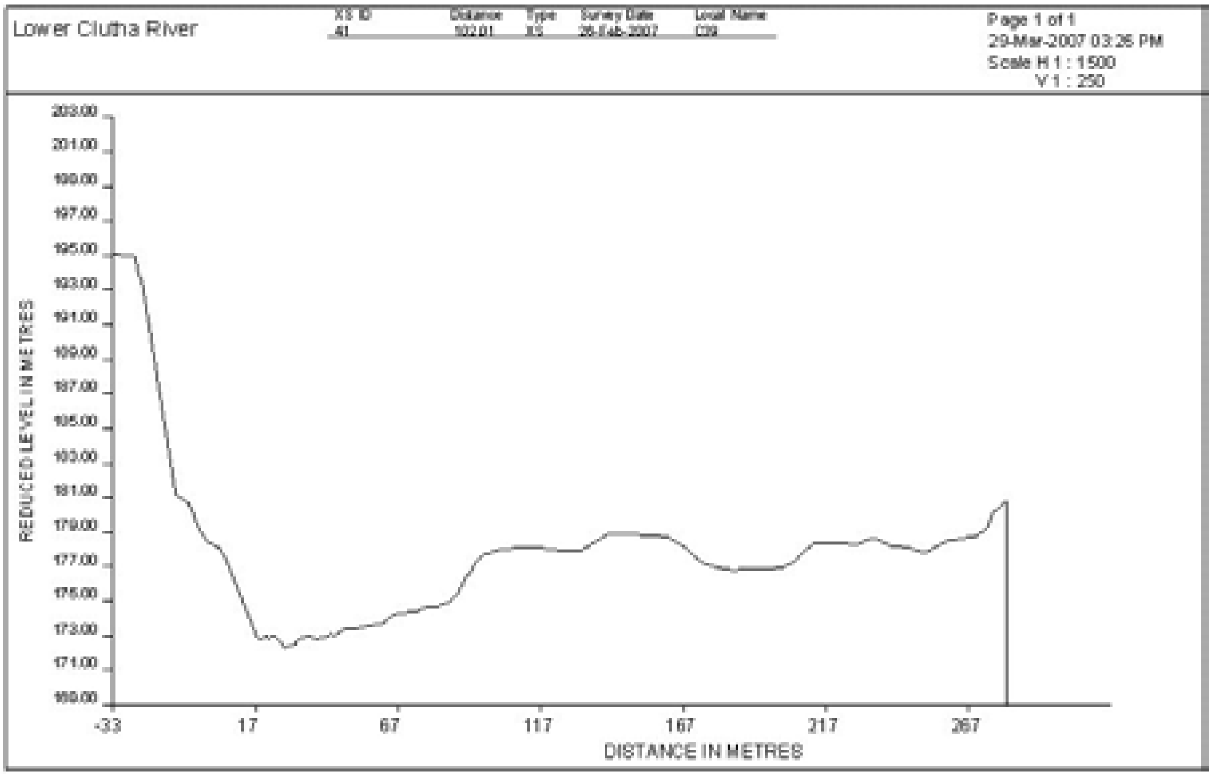

Figure A. 50 **Cross-section C39 – Roxburgh bar**

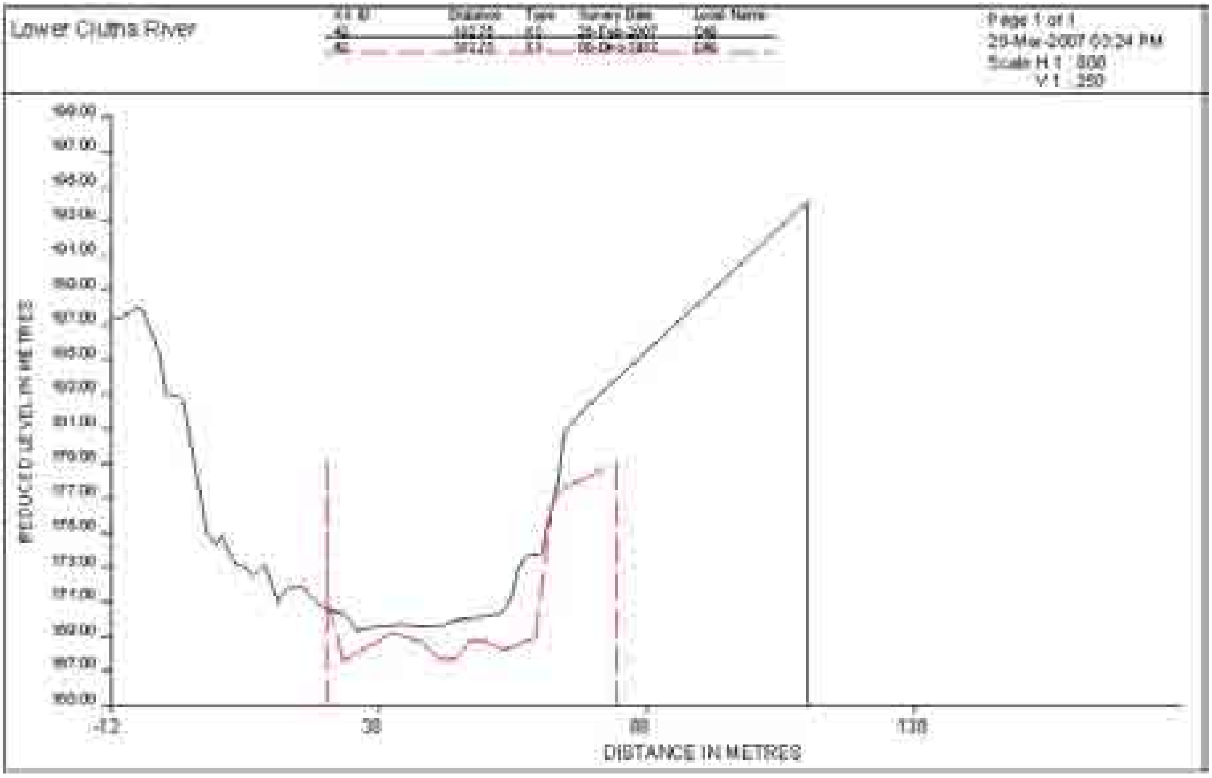

Figure A. 51 **Cross-section C40 – Roxburgh East**

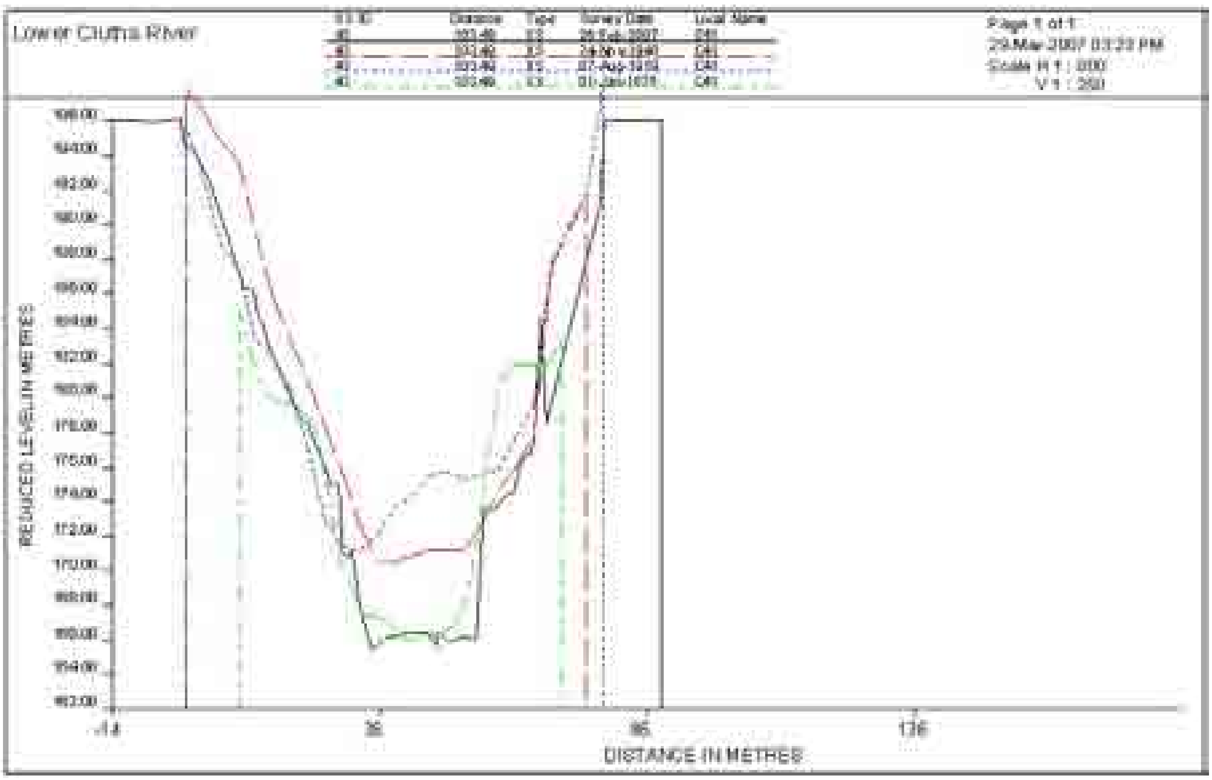

Figure A. 52 **Cross-section C41 – Roxburgh bridge**

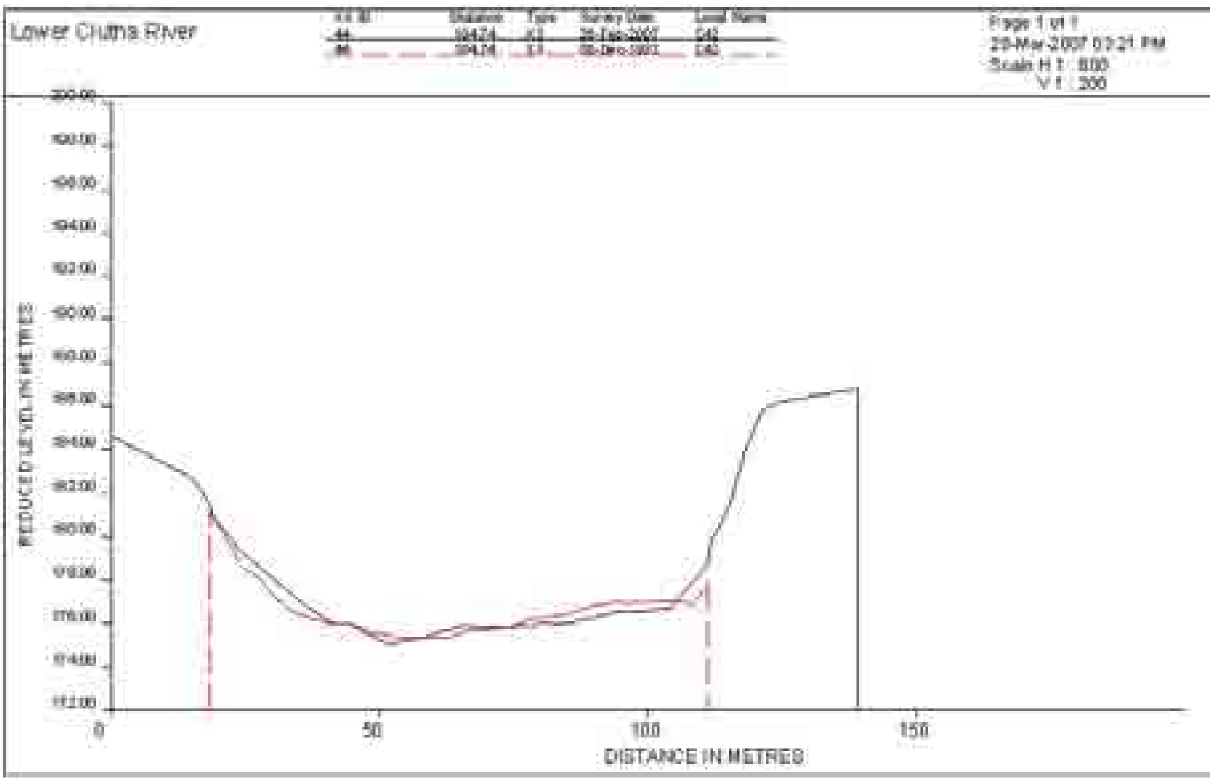

Figure A. 53 Cross-section C42 – Tweed Street, Roxburgh

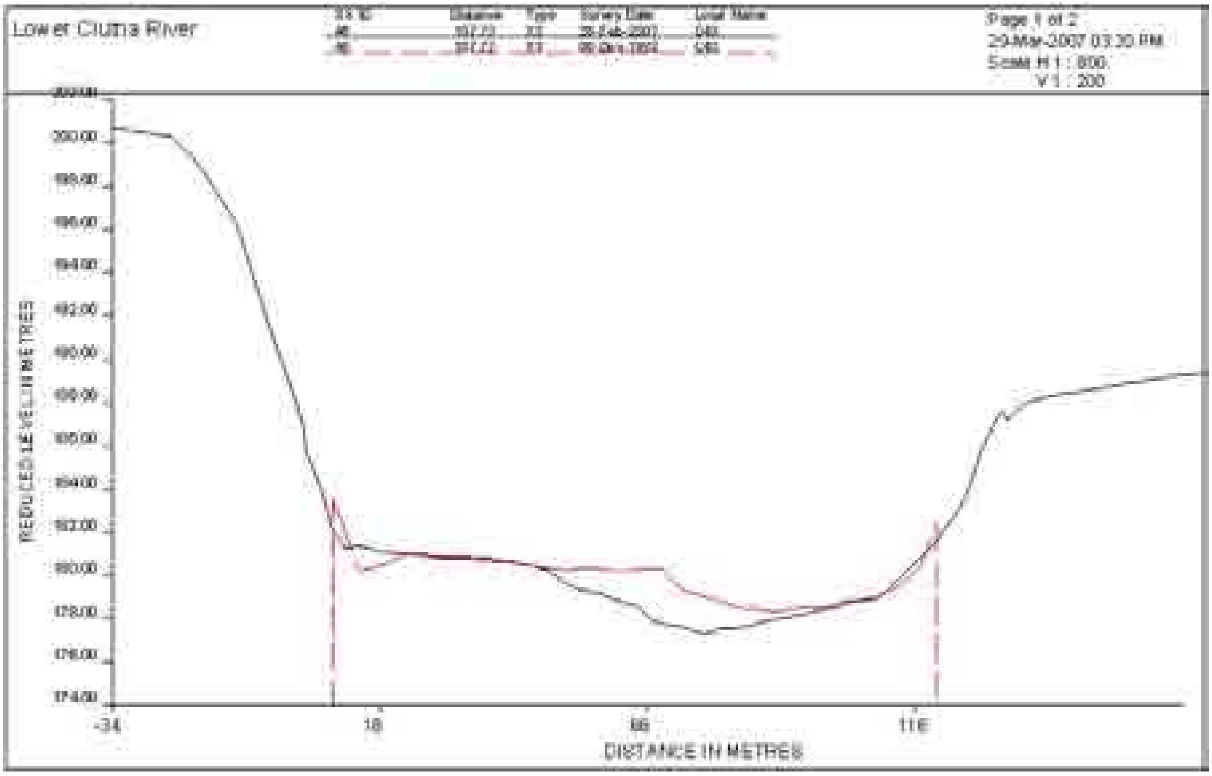

Figure A. 54 Cross-section C43 – Old hydro investigation gauging station

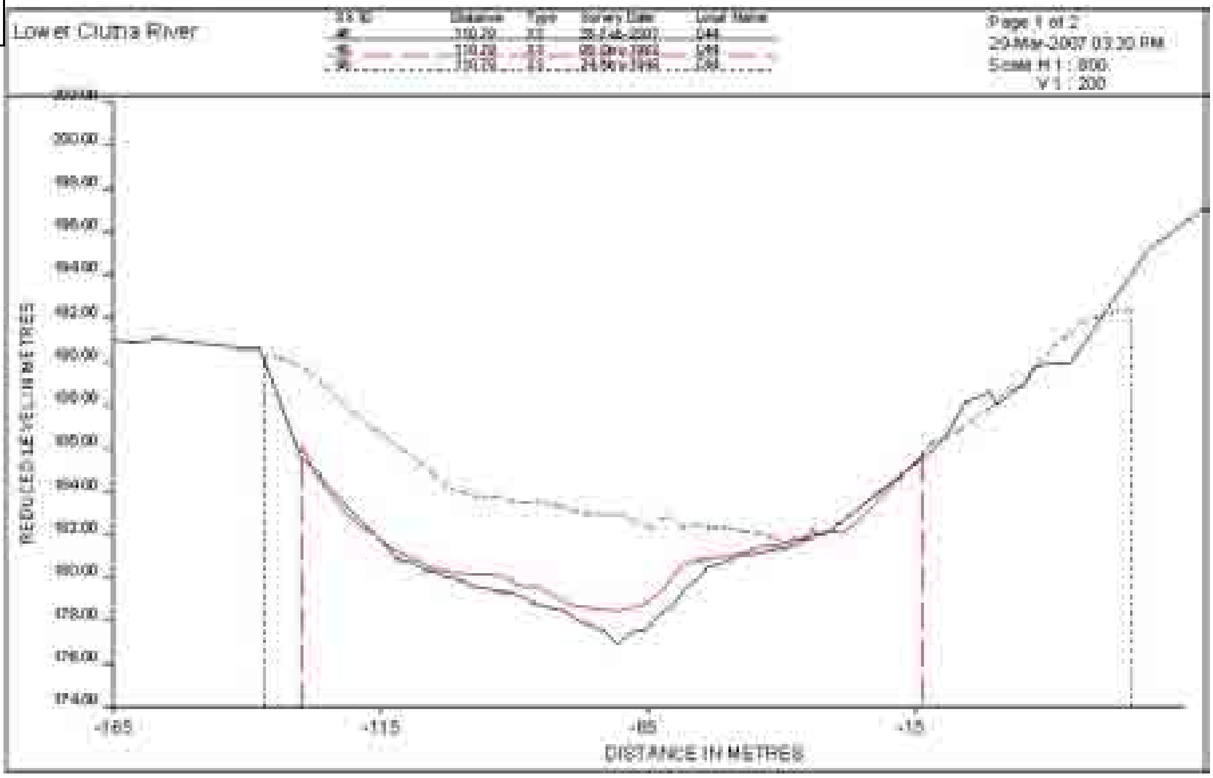

Figure A. 55 Cross-section C44 – Commissioners Flat bridge

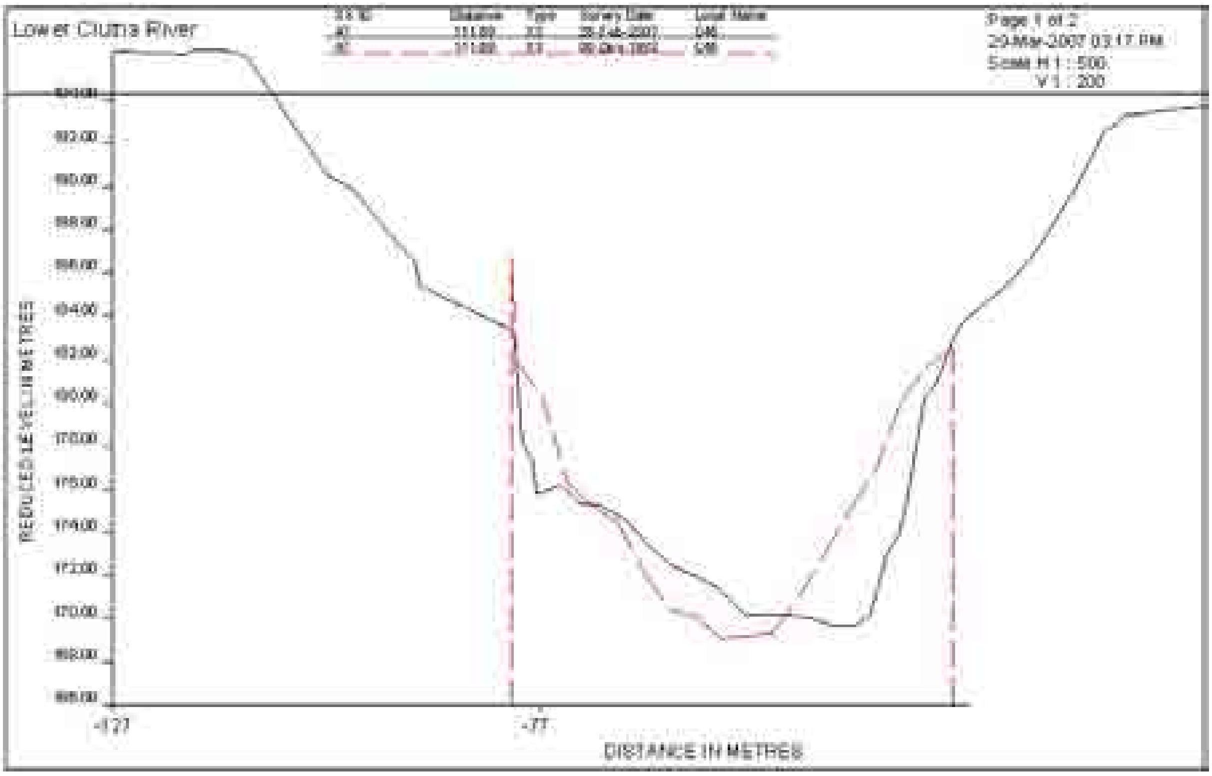

Figure A. 56 Cross-section C45 – Downstream of Roxburgh dam (present gauging station)