Channel morphology of the Shag River, North Otago

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Technical summary

Changes in the channel morphology of the Shag River/Waihemo have been assessed using visual inspections, aerial and ground photography, and cross-section data collected in April 2009 and October 2013. This assessment provides an update on changes in channel morphology that have occurred since the last catchment-wide analysis of long term trends in 2009. This report describes the nature of those changes where they have been significant and is intended to inform decisions relating to the management of the Shag River/Waihemo, including gravel extraction, floodwater conveyance, and asset management.

Cross-section analysis of the Shag River/Waihemo indicates that between April 2009 and October 2013 there was an overall increase in mean bed level (MBL) at 16 of the 22 surveyed cross-sections (as shown on Figure 5), and a decrease in MBL at 6 cross-sections. This indicates that (in the short term) the Shag River/Waihemo is showing signs of changing from a state of overall degradation (as described in the previous analysis of channel morphology in 2009) to one of aggradation/stability. However, the Shag River/Waihemo has not returned to a state of excess gravel accumulation and is still experiencing areas of ongoing bank erosion and channel incision.

This latest assessment shows that channel degradation was more prominent between Craig Road and Munro Road, while there was aggradation or minimal change in MBL from Munro Road downstream to Palmerston, and also from Craig Road upstream to McLew Road.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Overview

The physical processes that have shaped the Shag River/Waihemo catchment in North Otago (Figure 1) are still at work today. These processes include landslides and land instability, gold mining, alluvial fan activity, flood events, bank erosion, sediment transport, and sediment deposition. This report identifies what effects these processes have had on the channel morphology[1] of the Shag River/Waihemo, particularly over the short term (since 2009), and also places these recent changes within the context of longer-term trends. Changes in channel morphology are primarily determined by comparing changes in surveyed cross-sections collected in October 2013 with earlier surveys completed in April 2004, and April 2009.

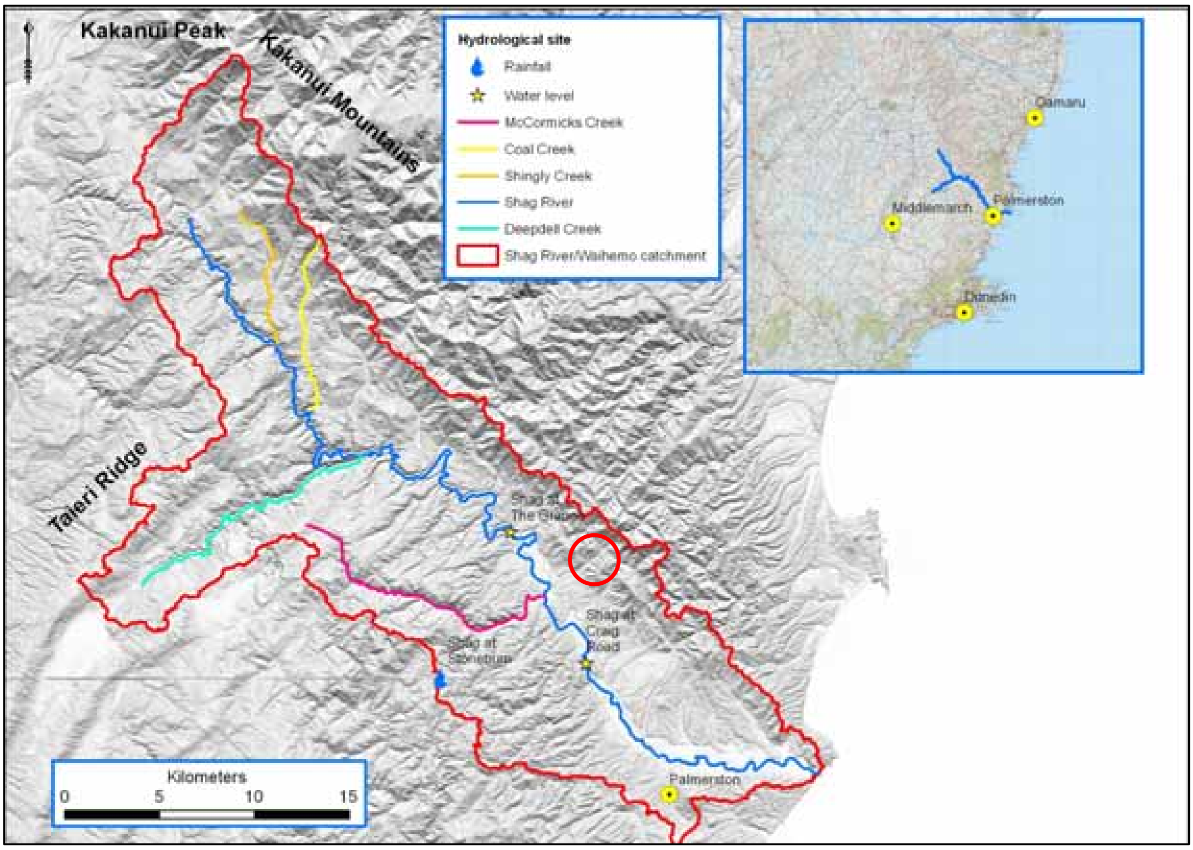

Figure 1. Shag River/Waihemo catchment, the red circle indicates the approximate location of the image shown in Figure 2.

[1] The form or structure of topographical features within the river channel

Figure 2. Evidence of land instability in an unnamed tributary of the Shag River (red circle on Figure 1), imagery date: April 2007 (Google Earth).

This report is intended to inform decisions relating to the management of the Shag River/Waihemo, including gravel extraction, floodwater conveyance, and asset management. A previous report (ORC, 2009)[2] describes the geology and geomorphology of the Shag River/Waihemo catchment and describes changes within the river channel up to 2009. Although this information is not reproduced in detail, where appropriate, earlier records have been used to help describe and understand changes in channel morphology (section 2.3). A description of the Shag River/Waihemo catchment is provided below, and a summary of the most recent changes in channel morphology in the Shag River/Waihemo is provided in Section 2, including visual observations made by ORC staff. A more detailed description of the changes that have occurred at each section since they were last surveyed in 2009 is provided in Appendix 2. Appendix 3 describes the methods used to collect and analyse morphological data.

1.2 Catchment description

The Shag River/Waihemo catchment has an area of 544km^2 and is bounded by the Taieri Ridge to the south and the Kakanui Mountains to the north. Kakanui Peak is the highest point in the catchment at an elevation of 1528m above mean sea level. For most of its course the Shag

[2] ORC. 2009: *Channel morphology and sedimentation, Shag River/Waihemo, North Otago.*

River/Waihemo parallels the Waihemo fault system (Forsyth 2001).[3] The geology of the Shag River/Waihemo catchment is dominated by varying grades of quartzofeldsparthic sandstone interbedded with mudstone and igneous rocks of the Dunedin volcanics group. This generally takes the form of greywacke deposits on the true right side of the catchment, argillite on the true left of the catchment, and igneous rocks to the south of the Waihemo fault system (Forsyth, 2001).

The main tributaries of the Shag River/Waihemo include Deepdell, McCormicks, Coal, and Shingly Creeks. The upper Shag River/Waihemo catchment (upstream from Dunback) consists of schist uplands covered in tall tussock grassland and pine plantations. The lower catchment consists of flat, high producing grassland along the valley floor, with lower producing grassland on the steeper valley sides. For much of its course the Shag River/Waihemo flows through confined, meandering channels, with a bed of mixed gravel, boulder, and bedrock. Sediment in the Shag River/Waihemo is sourced from slope instability in the upper catchment, reworking of bank and bed material, and from post-gold-mining tailings. Black et al (2004)[4] estimate that discharged mine tailings between 1890 and1946 contributed one hundred times (at least 85,000 tonnes) more sediment to Deepdell Creek than would naturally have occurred over this period. Most of the mine tailings have been moved through the Shag River/Waihemo system since gold mining ceased in the Deepdell Creek catchment in 1946 (Black et al, 2004) and the river now exhibits a more natural form (ORC, 2009).

Within the surveyed reaches of the Shag River/Waihemo there are several assets of critical importance for the local communities. These assets include roads, bridges, power lines and poles, water intakes, and water pipes. Some of these assets are located in elevated positions above the floodplain, and its associated flood hazard area (Figure 4), however some are located in close proximity to the active channel. One notable location is on the true left bank near cross-section S28 (Figure 47) where a power pole and associated power line is located on an actively eroding bank in the flood hazard area.

Figure 3. Flooding of the Shag River/Waihemo at SH85 near Palmerston on 5 June 1980.

[3] Forsyth, P. J. 2001: Geology of the Waitaki Area, Institute of Geological and Nuclear Sciences 1:250,000 geological map 19, *Institute of Geological and Nuclear Sciences*, Lower Hutt.

[4] Black, A., Craw, D., Youngson, J. H., Karubaba, J. 2004: Natural recovery rates of a river system impacted by mine tailing discharge: Shag River, East Otago, New Zealand, *Journal of Geochemical Exploration*, 84, p. 21-34.

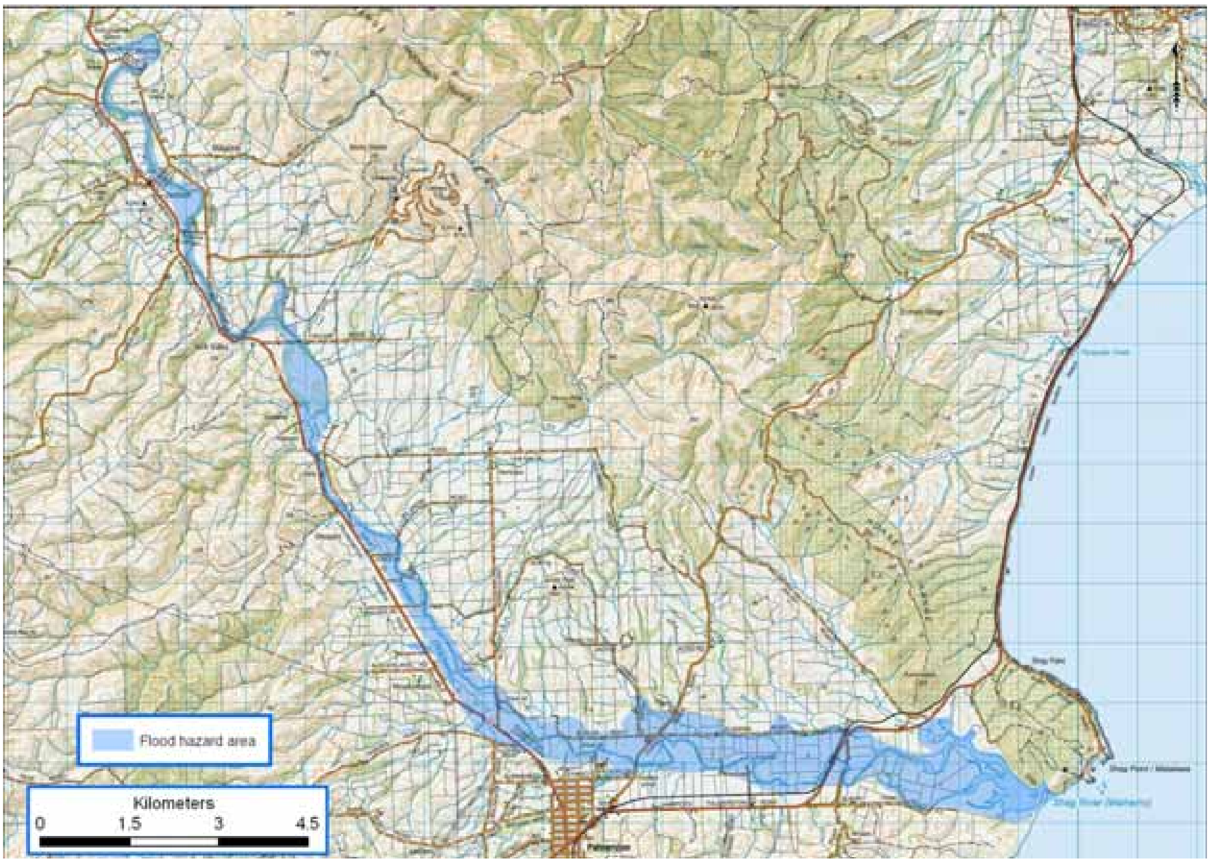

Figure 4. Flood hazard area for the lower Shag River/Waihemo (ORC, 2002).[5]

[5] Otago Regional Council. 2002. *Waitaki District Floodplain Report (DRAFT).*

2 Results

The active channel of the Shag River/Waihemo is a dynamic system where flood events and sediment movement regularly cause changes in channel morphology. Changes in the longitudinal profile and morphology of the river bed are occurring due to the effects of aggradation and degradation along the channel as well as lateral bank erosion. This report summarises the changes that have occurred since the last survey in 2009, and places these changes within the context of trends identified in an earlier report (ORC, 2009).

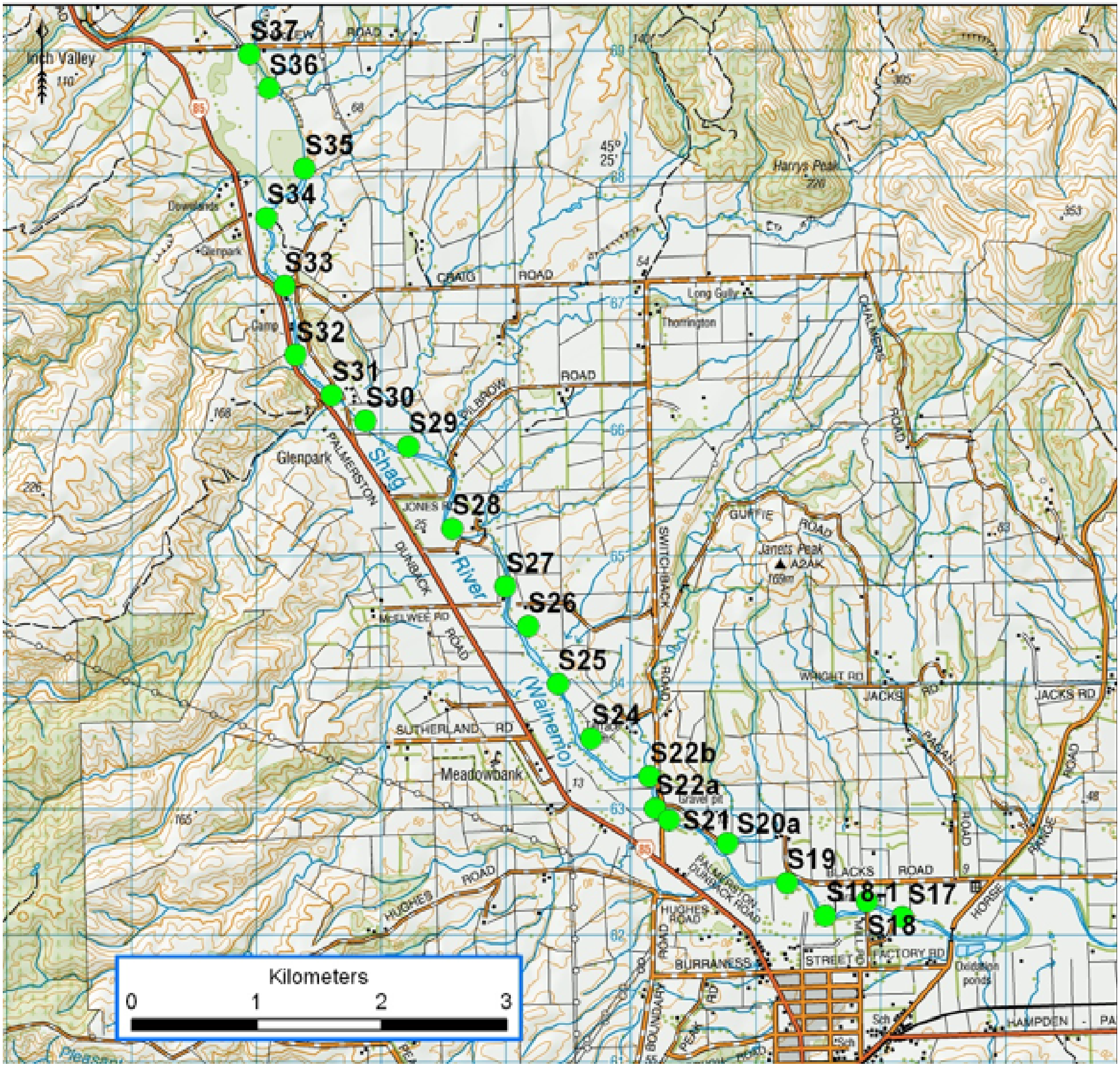

Figure 5. Location of surveyed cross-sections on the Shag River/Waihemo, as described in this report.

2.1 Changes in mean bed level

Figure 6 shows changes in mean bed level (MBL) at each cross-section from April 2004 to April 2009, April 2009 to October 2013 and the net change during the period April 2004 to October 2013. Cross-section locations, the magnitude of MBL changes between April 2009 and October 2013, areas of bank erosion, and areas where gravel has historically been extracted are shown in Figure 7 to Figure 9.

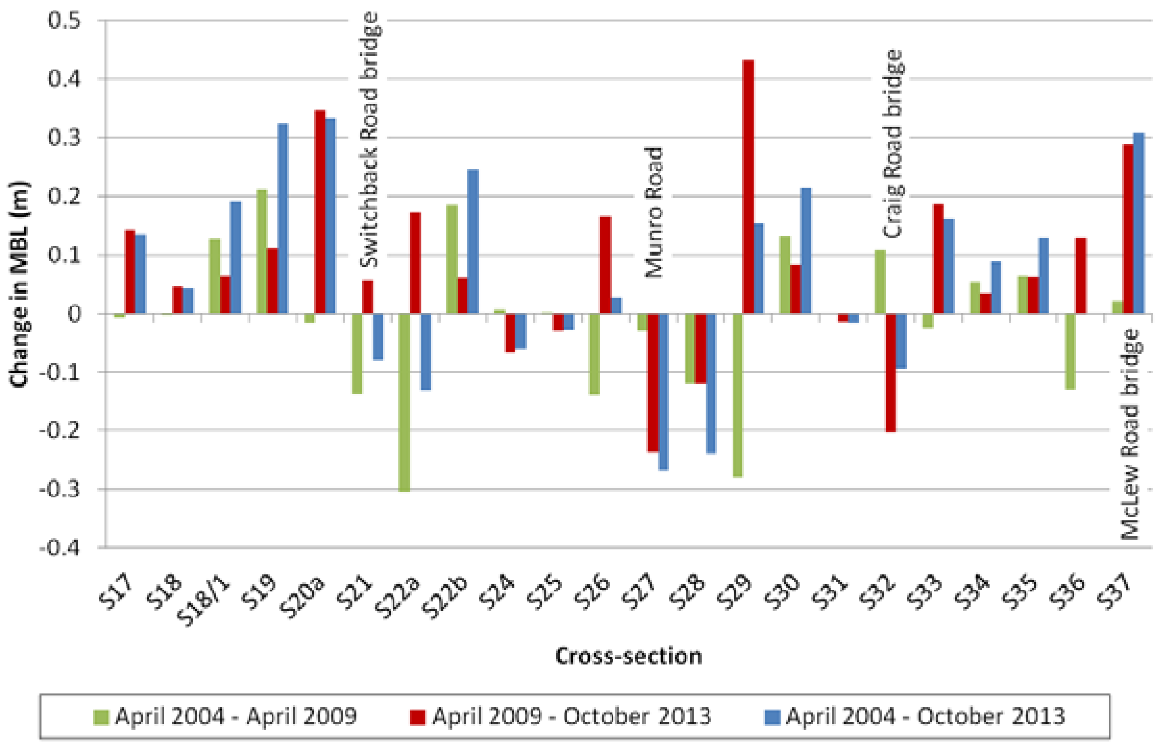

Figure 6. Changes in MBL at cross-sections on the Shag River/Waihemo between April 2004 and April 2009, and April 2009 to October 2013. The net change in MBL over the entire period is also shown. The location of each cross-section is shown in Figure 7 to Figure 9.

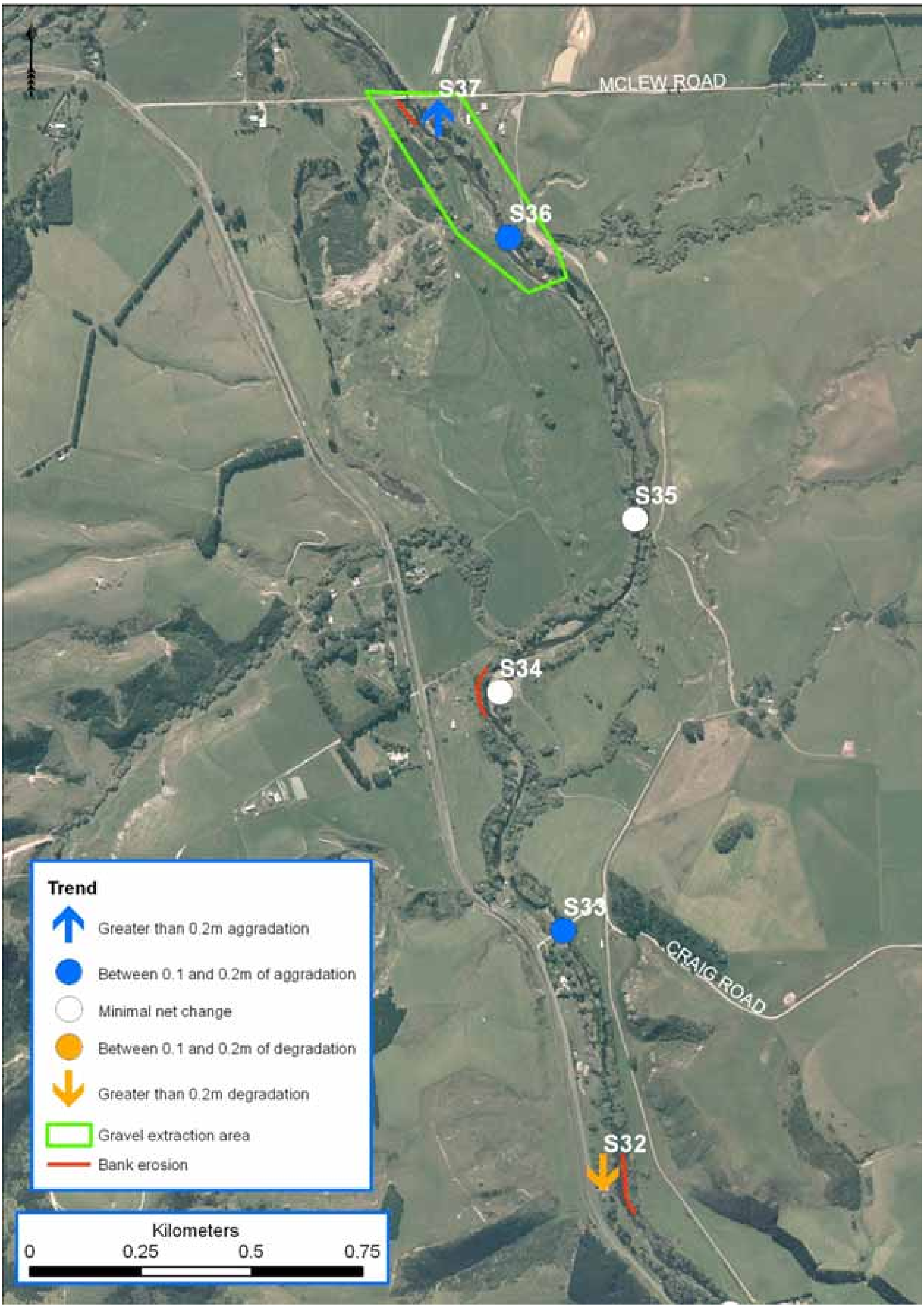

Figure 7. The location of cross-sections S37 to S32 on the Shag River/Waihemo. The white, orange, and blue symbols show the magnitude of MBL change at each cross-section between April 2009 and October 2013. Locations where significant bank erosion (>1m) was observed during this period are shown as red lines. Locations of historic gravel extraction are outlined in green.

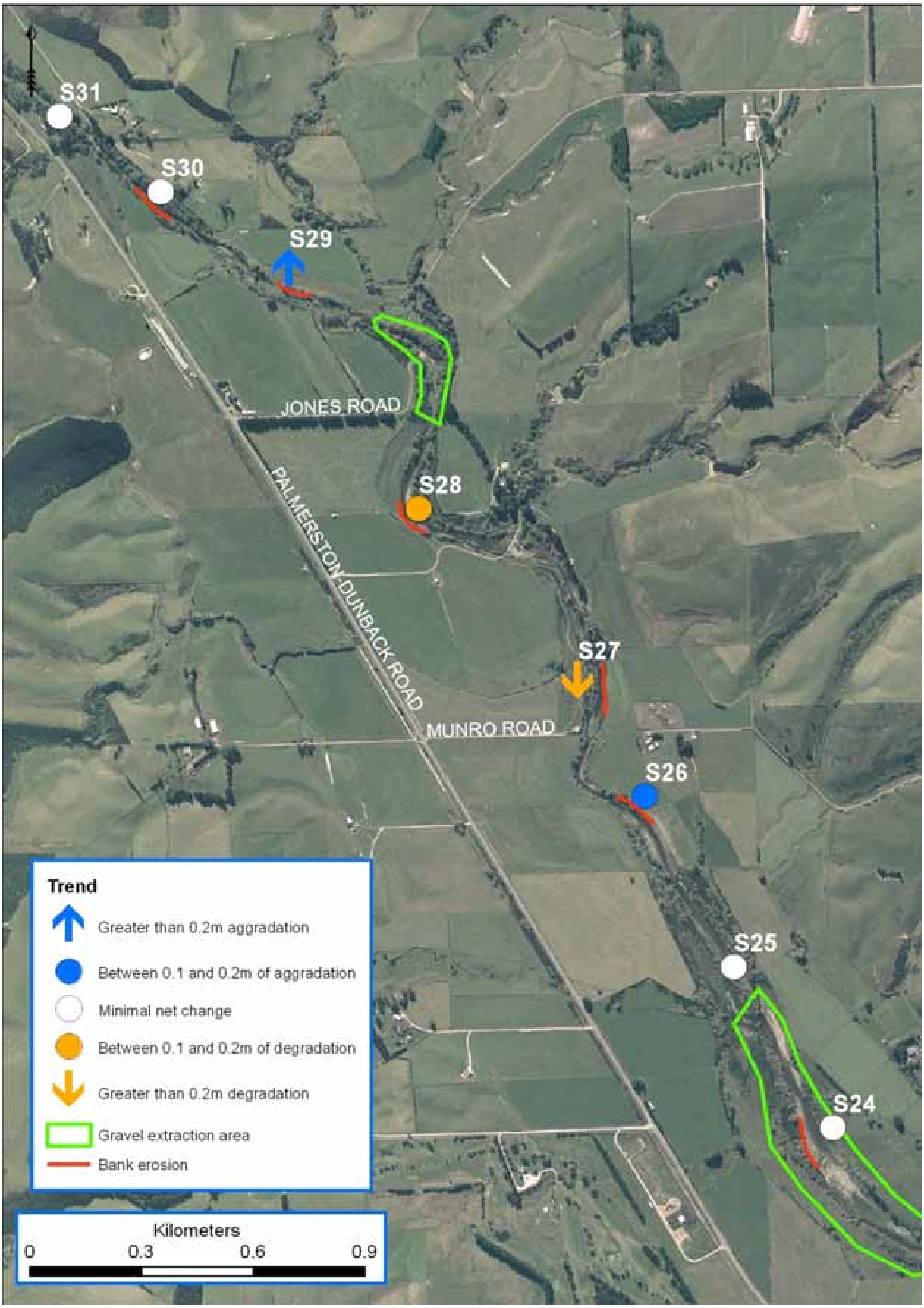

Figure 8. The location of cross-sections S31 to S24 on the Shag/Waihemo River. The white, orange, and blue symbols show the magnitude of MBL change at each cross-section between April 2009 and October 2013. Locations where significant bank erosion (>1m) was observed during this period are shown as red lines. Locations of historic gravel extraction are outlined in green.

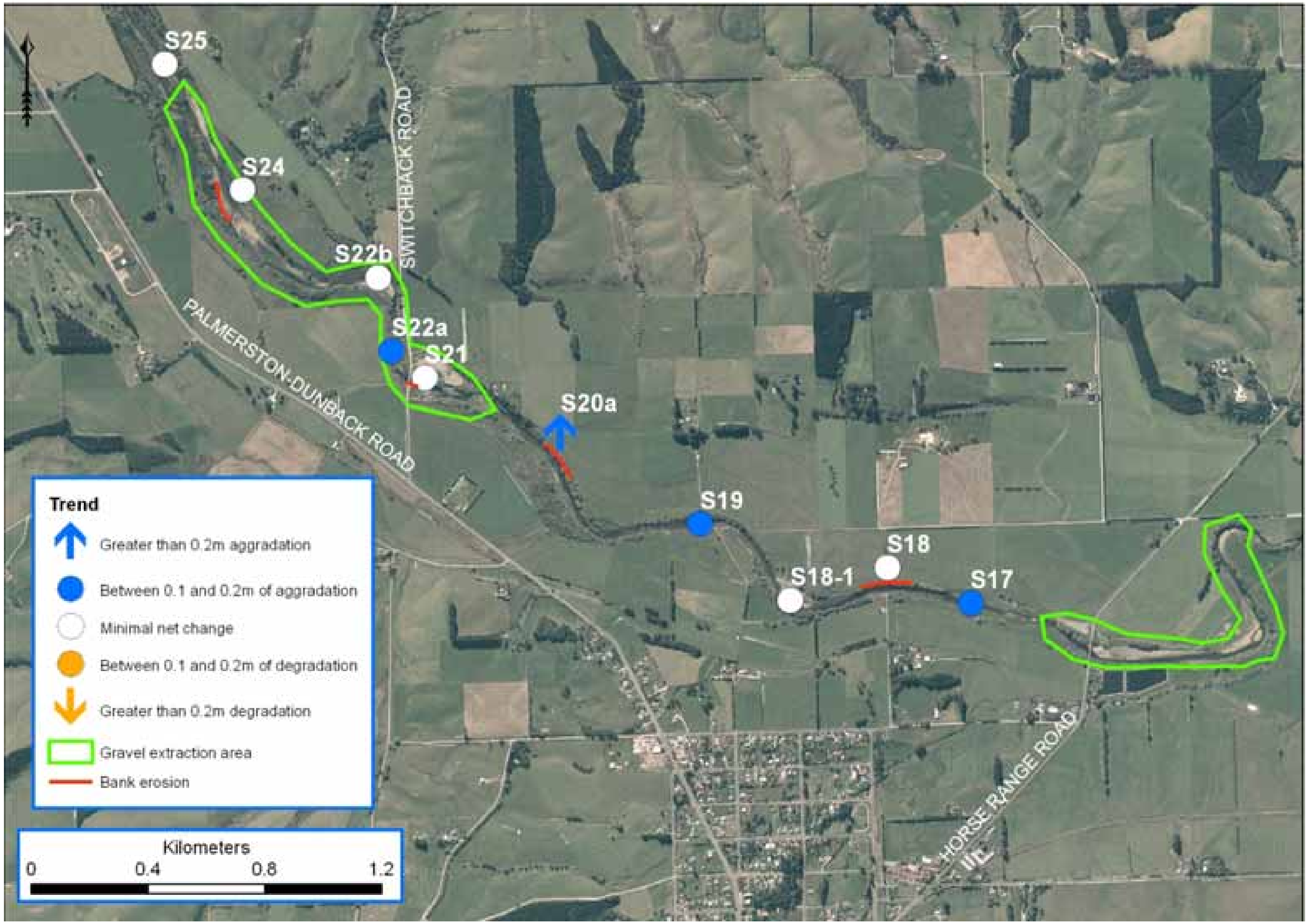

Figure 9. The location of cross-sections S25 to S17 on the Shag River/Waihemo. The white, orange, and blue symbols show the magnitude of MBL change at each cross-section between April 2009 and October 2013. Locations where significant bank erosion (>1m) was observed during this period are shown as red lines. Locations of historic gravel extraction are outlined in green.

2.1.1 Upper reach

(Figure 7)

Cross-sections in the upper part of the surveyed reach (between S37 and S32) generally show an increase in MBL between April 2009 and October 2013 (Figure 7). This increase is expressed either as aggradation of sediment in the channel bed, or as an increase in the level of the wider floodplain. Cross-section S32 was the only site in this reach to display a decrease in MBL during this period (2009 to 2013). During the previous survey period (April 2004 to April 2009) four of the six sites displayed aggradation. ORC (2009) stated that the overall long-term (1977 to 2009) trend observed in this reach was one of degradation. The general increase in MBL between 2004 and 2009 and 2009 and 2013 may indicate that the trend of this reach (in the short term) has changed from degradation to one of aggradation/stability.

2.1.2 Mid reach

(Figure 8)

Two sites located between S31and S24 showed a decrease in MBL between April 2009 and October 2013 (Figure 8). Two sites showed an increase in MBL with cross-section S29 displaying the largest increase in MBL out of all of the surveyed sites (0.43m). This reach has experienced ongoing bed and bank degradation since the mid-20th century (ORC 2009). The most recent results show that the part of the river between S29 and S26 (from above Jones Road to below Munro Road) is still experiencing reasonably significant changes in channel morphology.

2.1.3 Lower reach

(Figure 9)

Cross-sections in the lower section of the survey reach (between S22b and S17) show varying levels of aggradation between April 2009 and October 2013 (Figure 9). This trend was also displayed during the previous survey period (April 2004 to October 2009) with six of the eight sites showing an increase in MBL. ORC (2009) identified the lower reach as an area of localised aggradation which may be due to a lowering of the channel slope causing more sediment to become deposited and therefore aggrading the channel.

Overall 6 of the 22 surveyed sites show a decrease in MBL between April 2009 and October 2013, with only three sites showing a net decrease in MBL of more than 0.1m between April 2004 and October 2013 (Figure 6). While MBL generally increased during the latest survey period, at some cross-sections there was still a net decrease between 2004 and 2009. Between 2004 and 2013, 9 of the 22 sites show net degradation indicating that previous sediment loss is yet to be fully replaced.

12 of the 22 sites experienced noticeable (>1 horizontal meter) bank erosion, either at the edge of the low flow channel, or at the edge of the berm area between the latest two survey periods (April 2009 to October 2013). The most notable bank erosion occurred at cross-section S28 which eroded 12m of the true right bank between 2009 and 2013 (Figure 46)

2.1.4 Observations

Although MBL analysis indicates that, in general, there has been an increase in the river bed and floodplain levels at the monitored cross-sections (between 2009 and 2013), observations by

ORC staff in September 2013 indicate that there are areas of bank erosion occurring outside of those identified by the cross-section analysis. This may be a factor in the increase in MBL at several sites as bank erosion will supply sediment to the river system and cause localised areas of aggradation downstream of the erosion points. Bank erosion and sediment deposition is a natural process of rivers such as the Shag/Waihemo, with these processes allowing the river to meander across the floodplain and form the banks and terraces alongside the river.

ORC (2004)[6] identified that bedrock was exposed in the Shag River/Waihemo channel upstream and downstream of McLew Road, bedrock was also exposed at this location in October 2013 (Figure 10). Bedrock was also exposed at Craig Road bridge in October 2013. Bedrock channels form where the supply of sediment to the channel is insufficient to keep the channel mantled with an alluvial cover and can represent a limited sediment supply (Howard, 2013).[7]

Figure 10. Exposed bedrock upstream of McLew Road bridge, October 2013

2.2 Changes in thalweg level

Figure 13 to Figure 11 show the longitudinal profile of the upper, mid, and lower reaches of the Shag River/Waihemo respectively. The markers represent the thalweg value (minimum bed level) at each cross-section in April 2004, April 2009, and October 2013. The lines represent the longitudinal profile of the river between each cross-section and have been included to give an indication of changes in the profile of the river over time.[8]

[6] ORC. 2004: *Shag River Gravel Management Program.*
[7] Howard, A. D. 2013: *Long Profile Development of Bedrock Channels: Interaction of Weathering, Mass Wasting, Bed Erosion, and Sediment Transport, in Rivers Over Rock: Fluvial Processes in Bedrock Channels* (eds K. J. Tinkler and E. E. Wohl), American Geophysical Union, Washington, D. C.
[8] These are estimates only as the level of the thalweg may vary considerably between cross-sections

During the most recent survey period, noticeable increases in thalweg level occurred at the following locations:

- 0.6km downstream (S20a) to 0.1km upstream (S22a) of Switchback Road bridge
- 4.6km upstream of Switchback Road bridge (S30 to S29)
- at Craig Road bridge (S33)
- at McLew Road bridge (S37).

A noticeable decrease in thalweg level occurred at the following locations:

- 0.42km upstream of Switchback Road bridge (S22b) to 3.3km upstream of Switchback Road bridge (S28)
- 0.57km downstream of Craig Road bridge (S32).

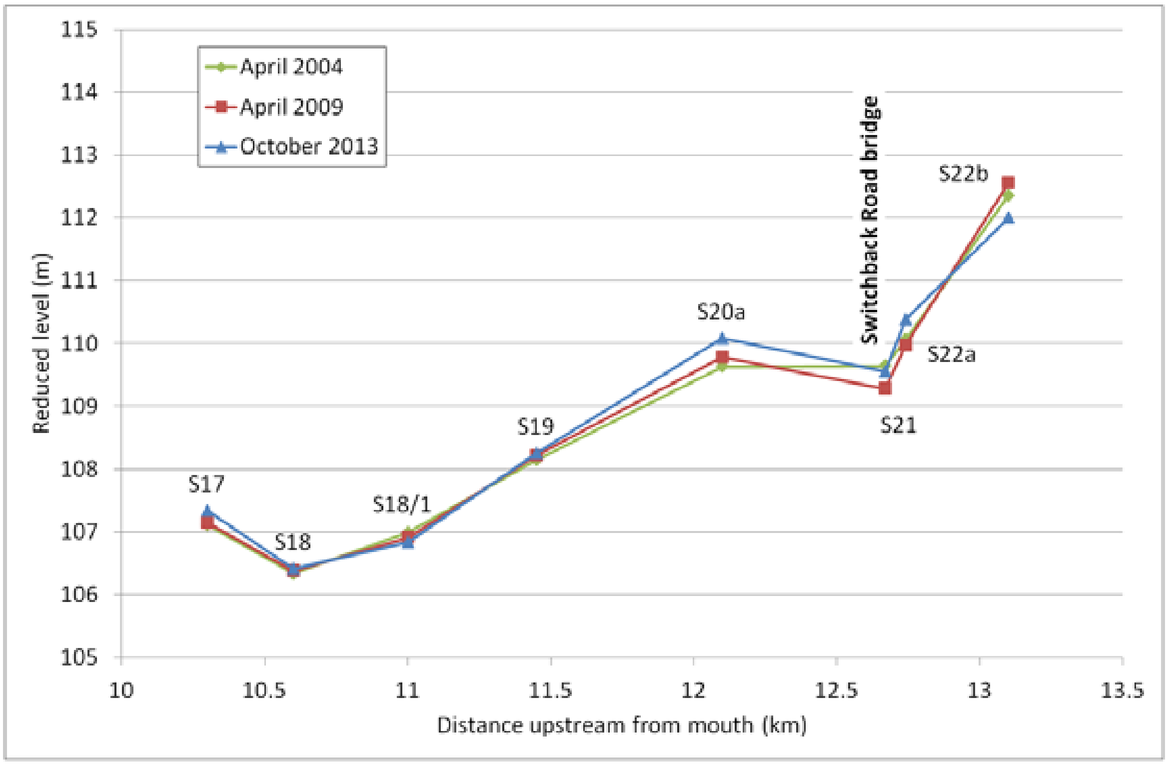

Figure 11. Longitudinal profile showing the thalweg level at cross-sections in the upper reach (as shown in Figure 7) of the Shag River/Waihemo.

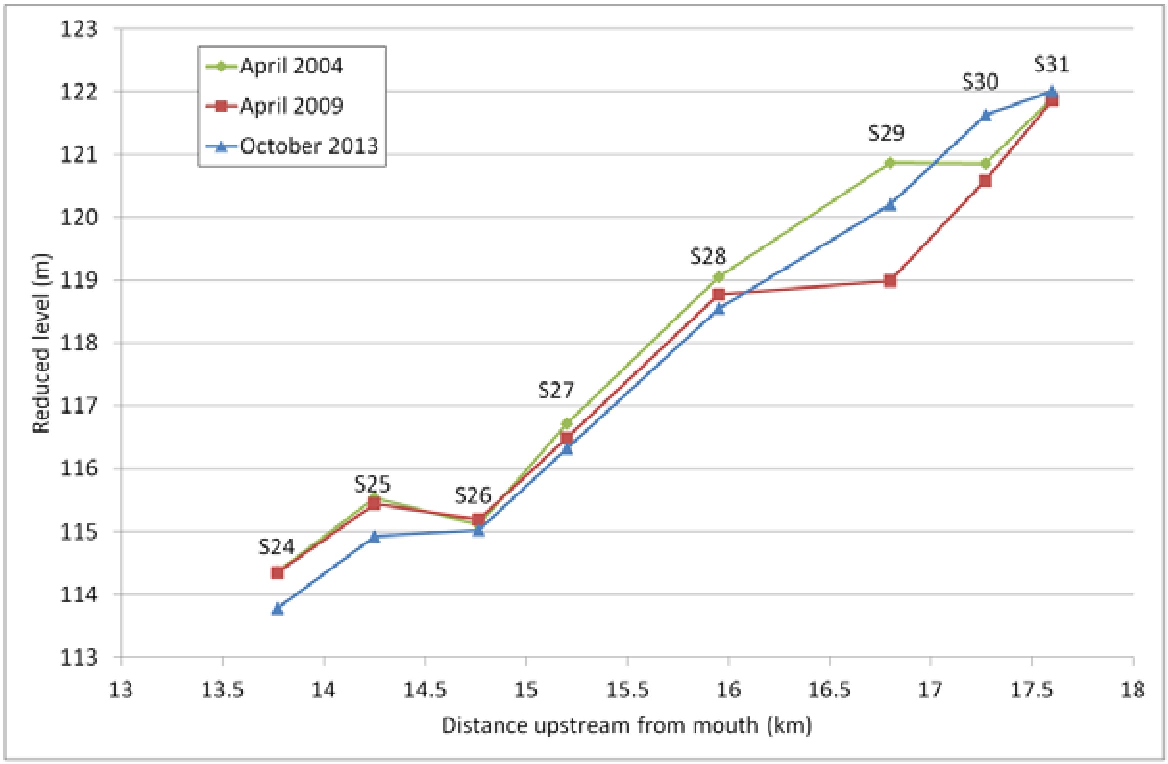

Figure 12. Longitudinal profile showing the thalweg level at cross-section in the mid-reach (as shown in Figure 8) of the Shag River/Waihemo.

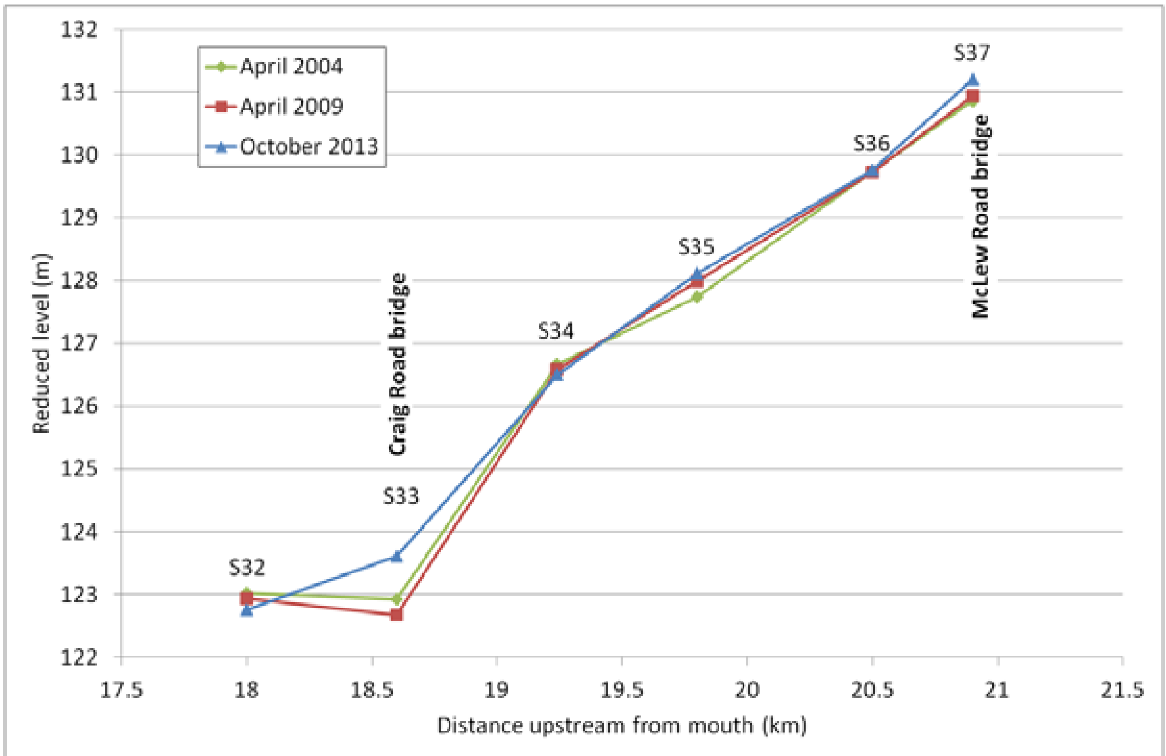

Figure 13. Longitudinal profile showing the thalweg level at cross-sections in the lower reach (as shown in Figure 9) of the Shag River/Waihemo.

2.3 Historic change

The surveyed cross-sections in the Shag River/Waihemo have, in some locations, changed significantly since they were first surveyed in 1977/1984 and in other locations the river has remained stable. The effects of the limited gravel supply and historic gravel extraction activities such as bed degradation and bank erosion (ORC 2009, ORC 2004) are still being experienced in the Shag River/Waihemo, as shown in Figure 14, and Figure 15. However, some locations have shown limited change or bed aggradation since 1977/1984 (Figure 16, Figure 17). The four cross-sections shown below illustrate the range of change/river response over the long term. As shown in Figure 5, these four cross-section locations are spread along the length of the surveyed reach of the Shag River/Waihemo. Change (or lack of) in river morphology can be attributed to factors such as the presence of bedrock limiting the amount of erosion (S37, Figure 16), the effects of large floods, and the location of the cross-section/river reach within the whole river system.

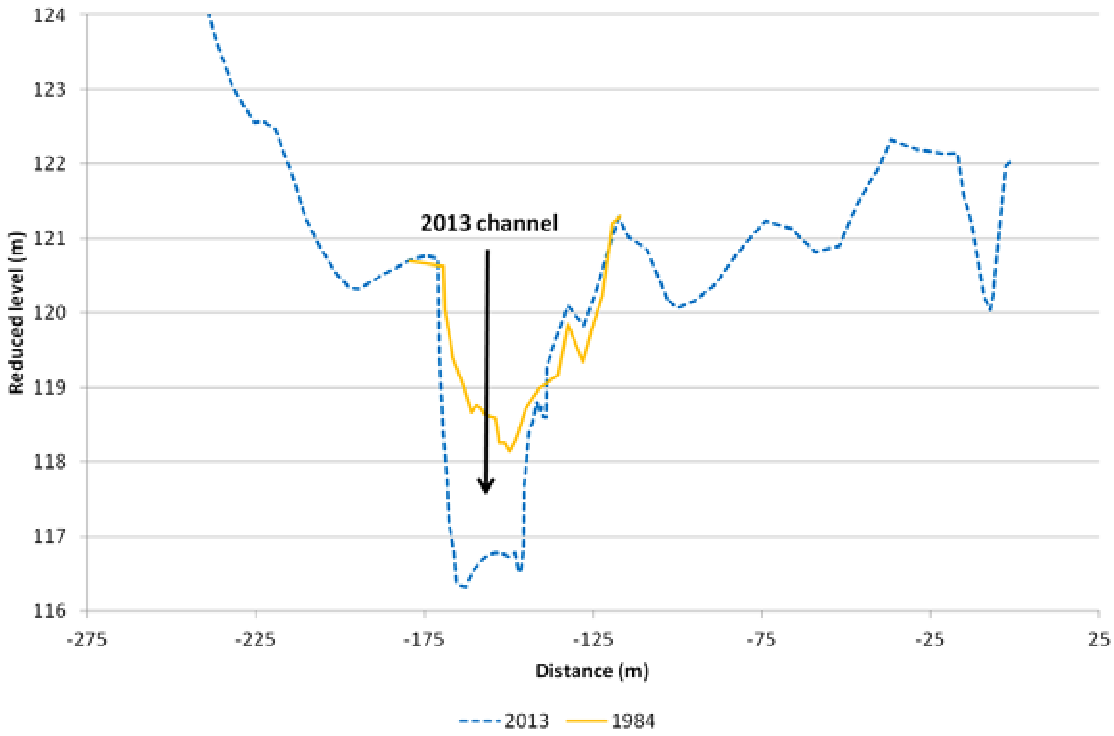

Figure 14. Cross-section S27, looking downstream.

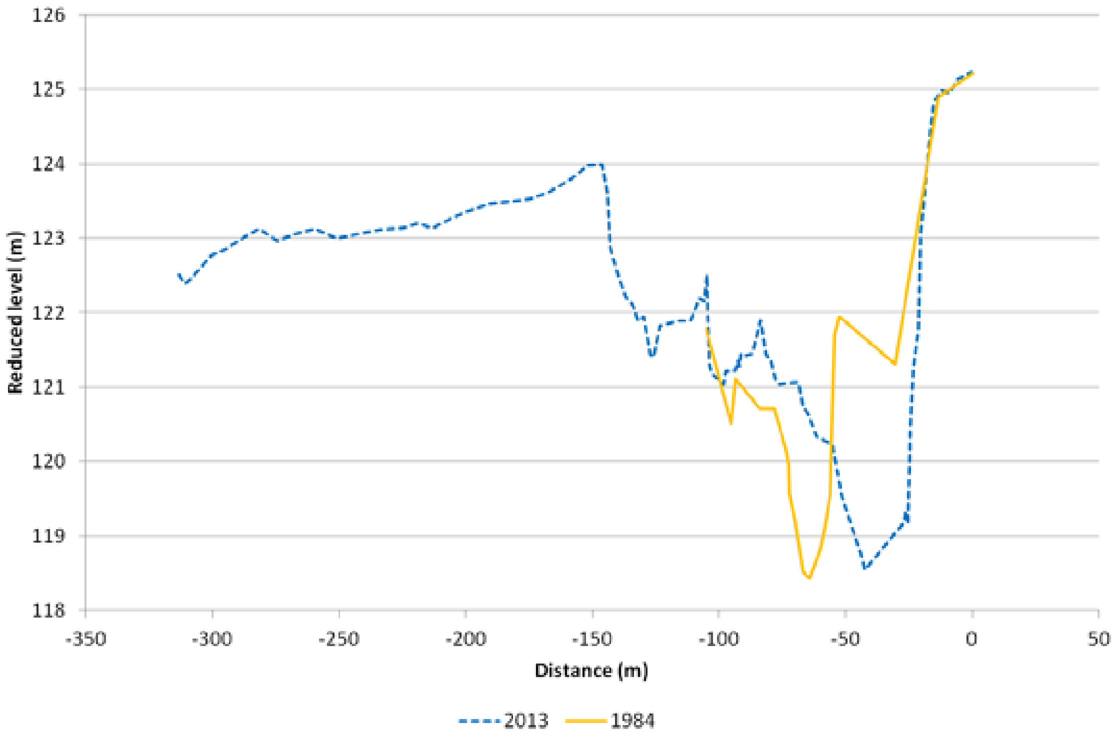

Figure 15. Cross-section S28, looking downstream.

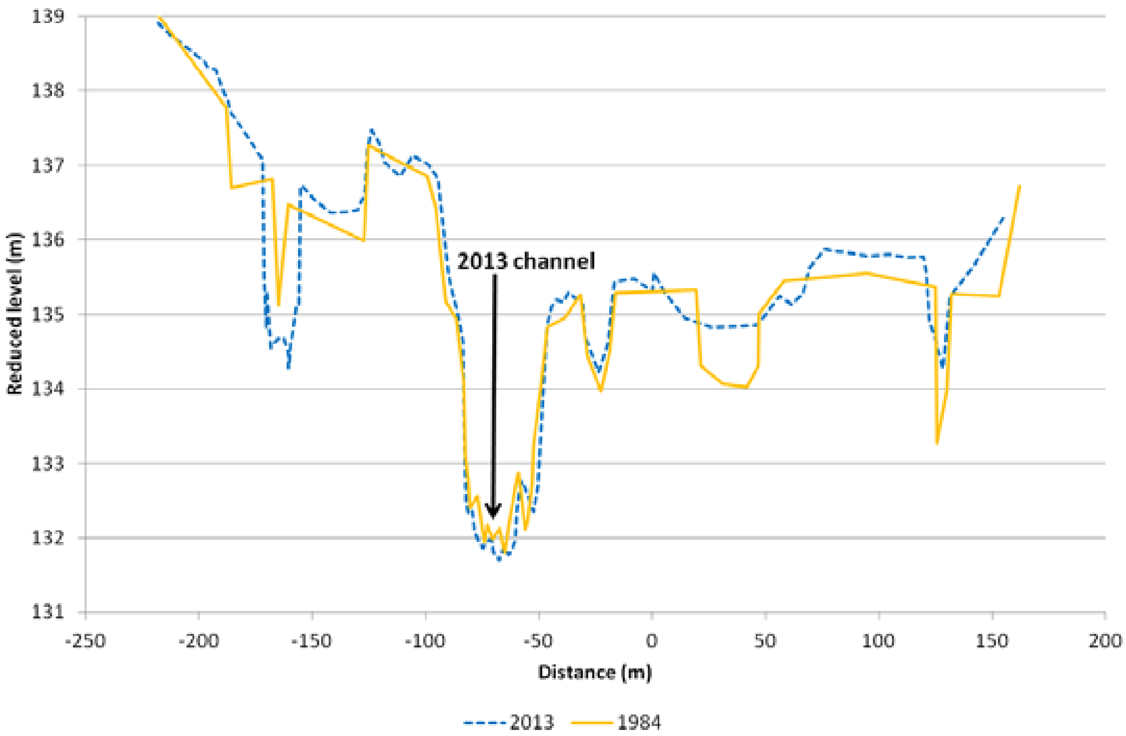

Figure 16. Cross-section S37, looking downstream.

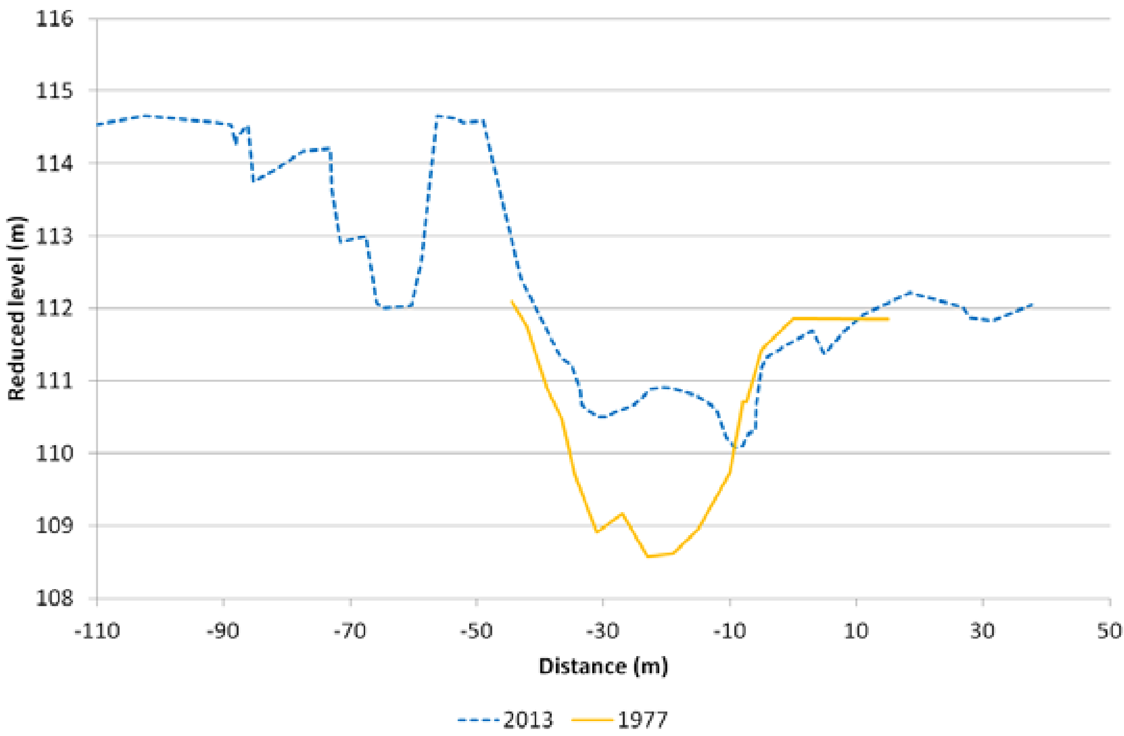

Figure 17. Cross-section S20a, looking downstream.

3 Hydrology and gravel extraction

Changes in the morphology of the Shag River/Waihemo channel are in part driven by the hydrological characteristics of the river including the magnitude and frequency of flood events (Figure 18) and human activities, such as gravel extraction and physical works. Figure 19 shows the flow in the Shag River/Waihemo at Craig Road between April 2009 and October 2013, and for the preceding survey period. Two large flood events occurred during the latter period, in May 2010 and June 2013 (Figure 20), although these were both considerably smaller than the largest flood on record in December 1993. A large flood also occurred in June 1980 (prior to continuous flow records commencing), and anecdotal evidence suggests that this event resulted in a peak flow of 590m^3/sec at Dunback (ORC, 1991).[9]

Approximately 285,000m^3 of gravel was extracted from the Shag River/Waihemo between 1977 and 2003 (ORC, 2004) (Figure 21). A report was prepared by ORC staff in 2004 recommending that "no further consents be issued for gravel extraction in the Shag River/Waihemo catchment until future cross sections indicate a surplus of gravel is available" (ORC, 2004, Appendix 5). The ORC Natural Resources Committee subsequently considered a report in January 2008 that enabled limited extraction to occur between Switchback Road and Horse Range Road for river management or hazard mitigation purposes (ORC, 2010).[10] Since 2004 the consented extraction of gravel from the Shag River/Waihemo has decreased significantly, and records held by ORC indicate that there has been no consented extraction since this time (Figure 21).

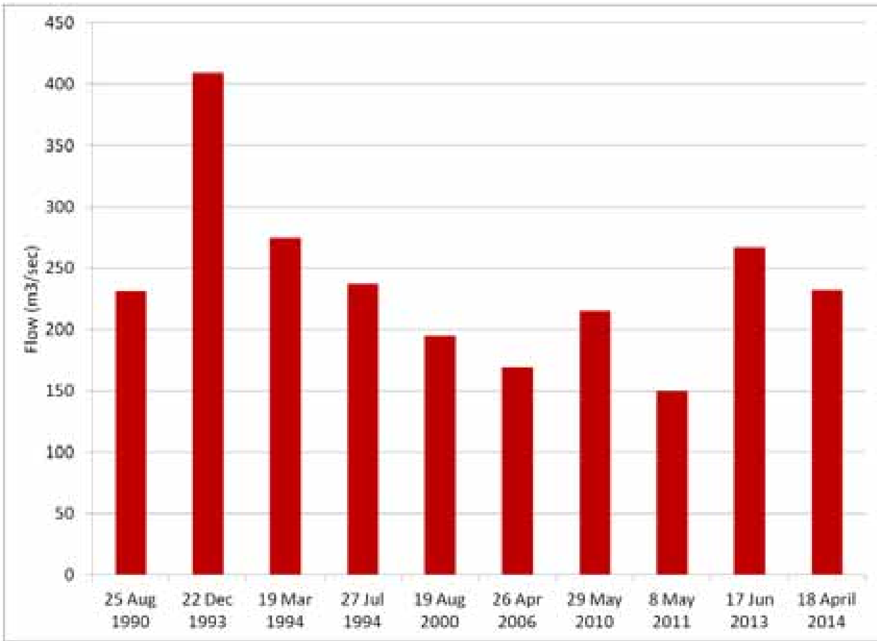

Figure 18. Ten highest flows in the Shag River/Waihemo at the Grange since records began in October 1989.

[9] Otago Regional Council. 1991: *Report on Floodplains within the part of the Waitaki District within the Otago Region.*
[10] Otago Regional Council. 2010: *Shag River Gravel Extraction*, Natural Resources Committee, 2010/2330.

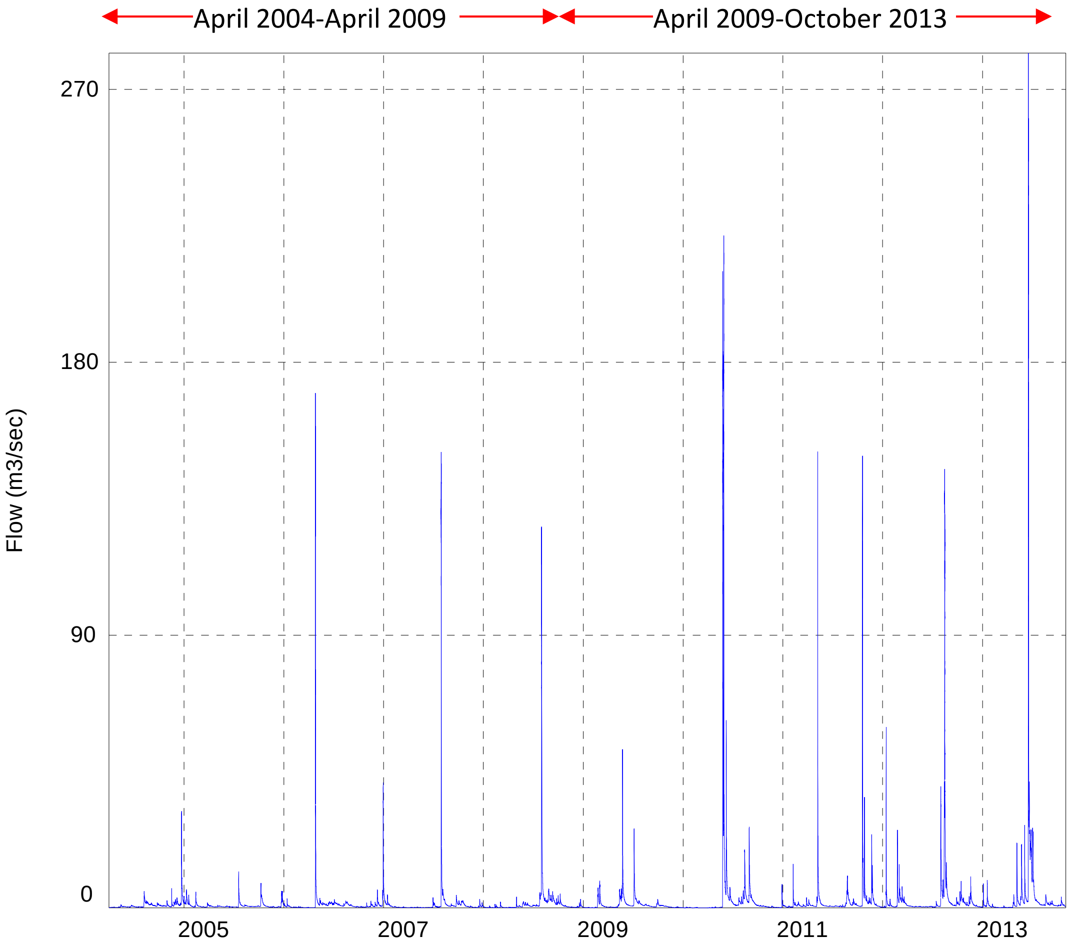

Figure 19. Flow in the Shag River/Waihemo at The Grange for April 2004 to April 2009 and April 2009 to October 2013. These periods correspond approximately with the timing of the cross-section surveys described above.

Figure 20. 7 June 2013, flooding, Shag River/Waihemo, looking downstream to the junction of Craig Road and SH85.

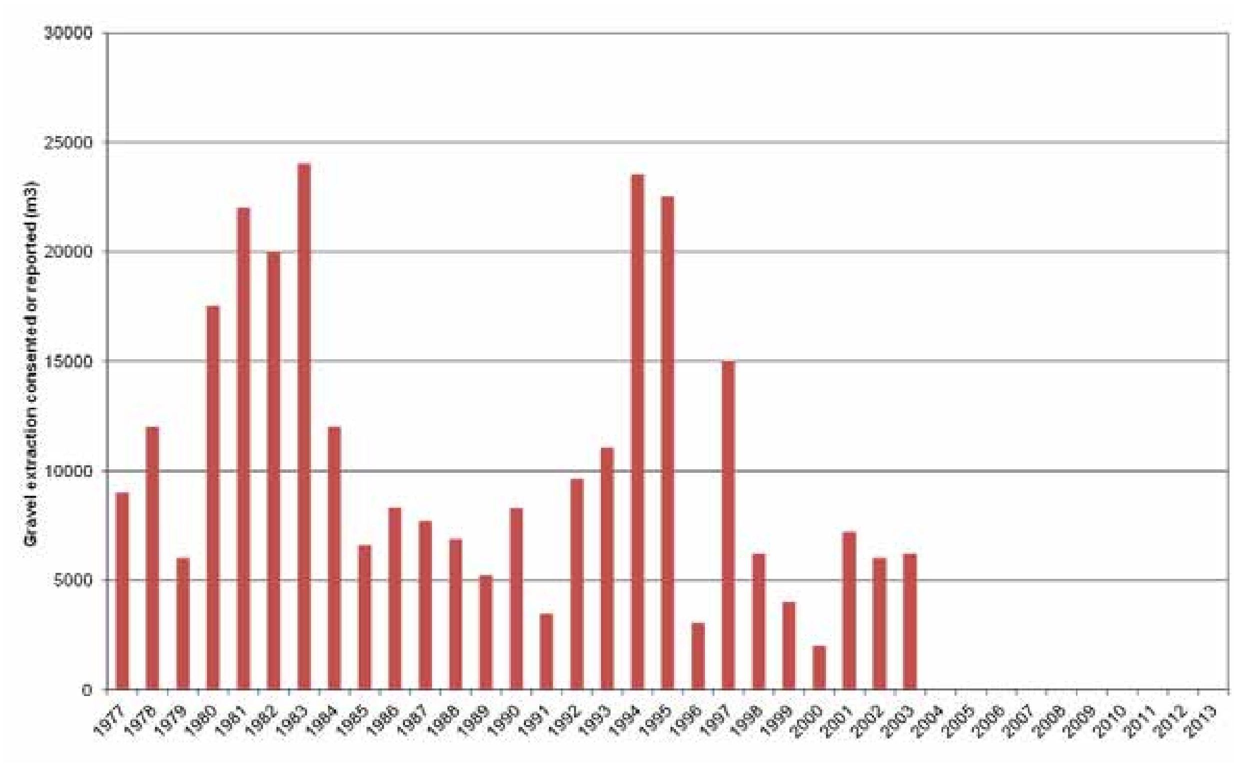

Figure 21. Volume of gravel extracted from the Shag River/Waihemo (1977 to 2003), according to gravel extraction records held by the ORC.

Appendix 1. Shag River/Waihemo cross-section summaries

Shag River/Waihemo : S17

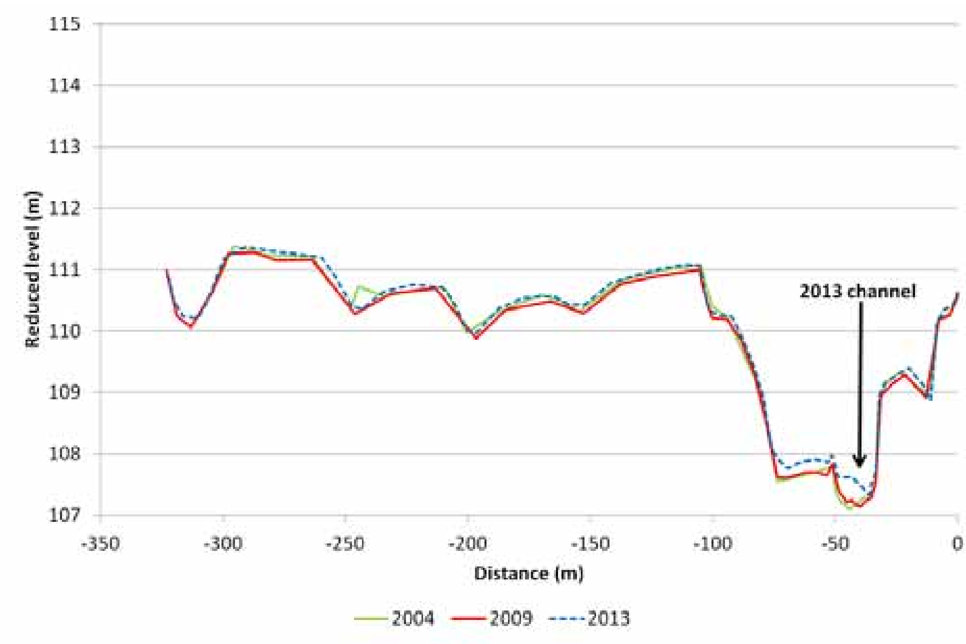

Figure 22. Cross-section S17, looking downstream.

Figure 23. Cross-section S17, looking downstream, October 2013.

Cross-section S17 is located 10.3km upstream of the Shag River/Waihemo mouth and 0.4km downstream of Horse Range Road bridge. The channel bed remained similar between April 2004 and April 2009. Between April 2009 and October 2013 the channel bed aggraded between approximately 0.25 and 0.5m with minimal change in the over bank deposits. The thalweg level increased by 0.2m between 2009 and 2013.

Shag River/Waihemo : S18

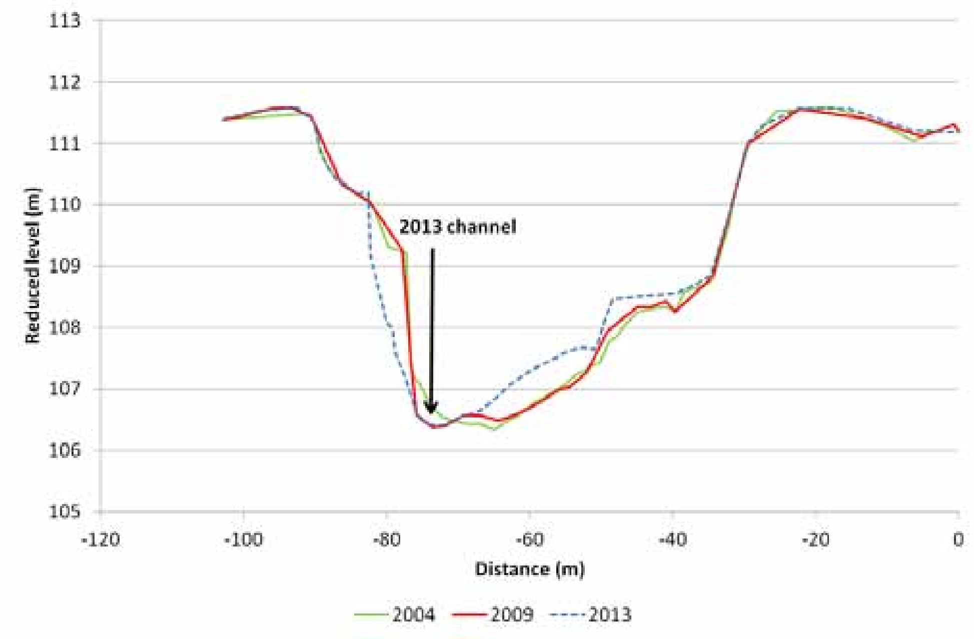

Figure 24. Cross-section S18, looking downstream.

Figure 25. Cross-section S18, looking from true right to true left, October 2013.

Cross-section S18 is located 10.6km upstream of the Shag River/Waihemo mouth and 0.75km upstream of Horse Range Road bridge. The channel bed remained similar between April 2004 and April 2009 with a small amount of degradation occurring on the left of the channel bed and the right bank. Between April 2009 and October 2013 the channel bed and right bank aggraded approximately 0.5m, and the left bank has eroded by approximately 5m. The thalweg remained in the same position between 2009 and 2013.

Shag River/Waihemo : S18/1

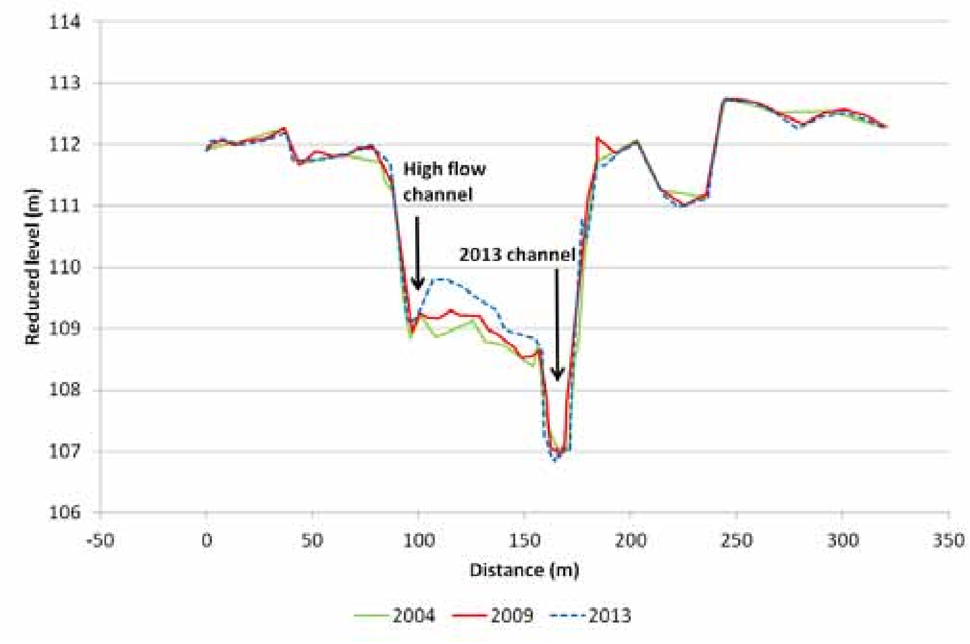

Figure 26. Cross-section S18/1, looking downstream.

Figure 27. Cross-section S18/1, looking upstream, October 2013.

Cross-section S18/1 is located 11km upstream of the Shag River/Waihemo mouth and 1km upstream of Horse Range Road bridge. The main channel bed remained similar between April 2004 and April 2009 with a small amount of aggradation occurring on the left bank of the high flow channel. Between April 2009 and October 2013 the main channel bed degraded approximately 0.1m, and the left bank of the high flow channel aggraded by approximately 0.5m. The thalweg remained in the same position between 2004 and 2013.

Shag River/Waihemo : S19

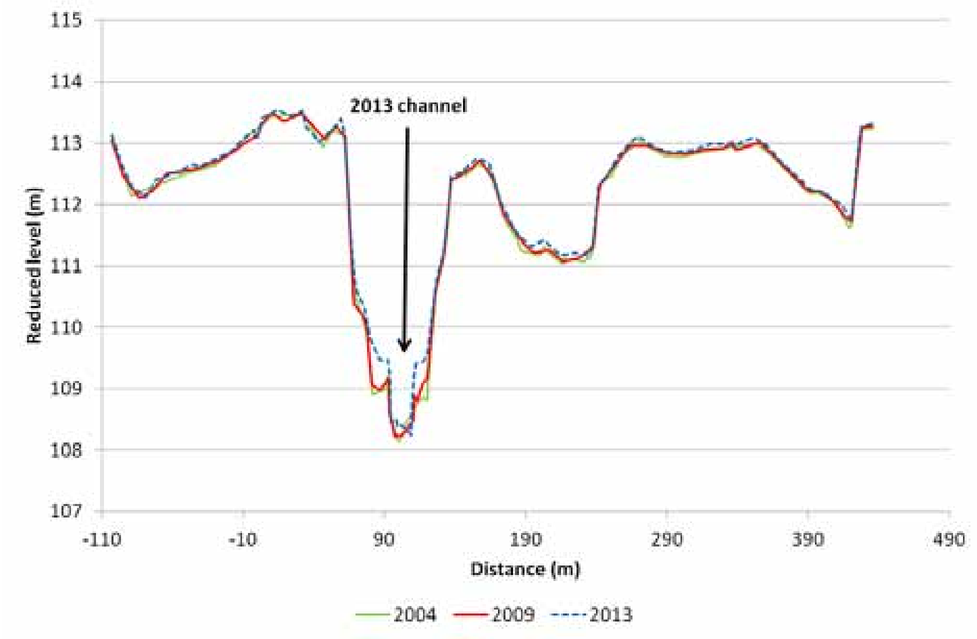

Figure 28. Cross-section S19, looking downstream.

Figure 29. Cross-section S19, looking upstream, October 2013.

Cross-section S19 is located 11.45km upstream of the Shag River/Waihemo mouth and 1.5km upstream of Horse Range Road bridge. The main channel bed remained similar between April 2004 and April 2009 with a small amount of aggradation occurring on the left and right banks of the main channel. Between April 2009 and October 2013 the main channel bed aggraded approximately 0.05m, and the left bank of the high flow channel aggraded by approximately 0.5m.The wider floodplain shows minimal change between 2004 and 2013. The thalweg remained in a similar position between 2004 and 2013.

Shag River/Waihemo : S20a

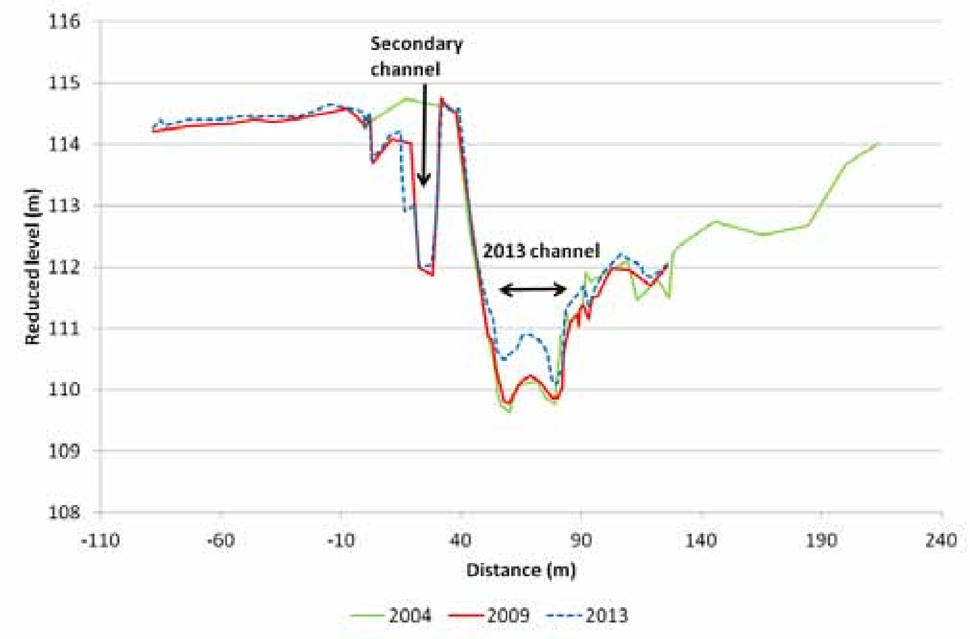

Figure 30. Cross-section S20a, looking downstream.

Figure 31. Cross-section S20a, looking upstream, October 2013.

Cross-section S20a is located 12.1km upstream of the Shag River/Waihemo mouth and 0.6km downstream of Switchback Road bridge. The main channel bed remained similar between April 2004 and April 2009 with the creation of a secondary channel occurring on the left bank and a small amount of degradation on the right bank. Between April 2009 and October 2013 the main channel bed aggraded approximately 0.5m on the right, and approximately 0.5m on the left. The wider floodplain shows minimal change between 2004 and 2013. The thalweg remained in a similar position between 2004 and 2013.

Shag River/Waihemo : S21

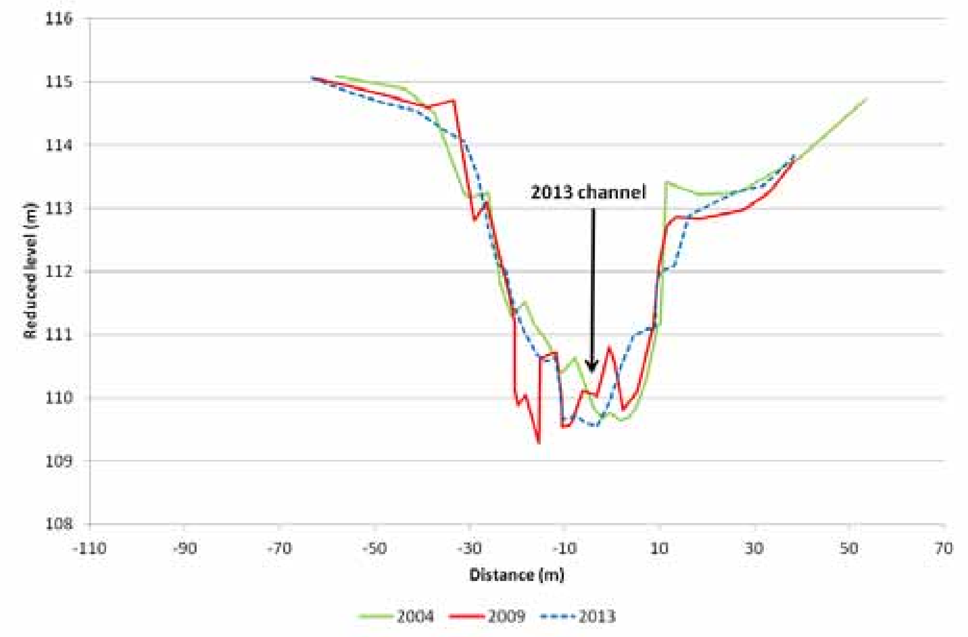

Figure 32. Cross-section S21, looking downstream.

Figure 33. Cross-section S21, looking from true right to true left, October 2013.

Cross-section S21 is located 12.67km upstream of the Shag River/Waihemo mouth at Switchback Road bridge. The main channel bed and the top of the right bank degraded between April 2004 and April 2009 with the creation of three low flow channels. Between April 2009 and October 2013 the bed aggraded approximately 1m on the left and right side of the main channel. Aggradation and degradation occurred on the left and right banks between 2009 and 2013. The thalweg aggraded 0.38m between 2009 and 2013 and is located in a similar position (vertically) to 2004.

Shag River/Waihemo : S22a

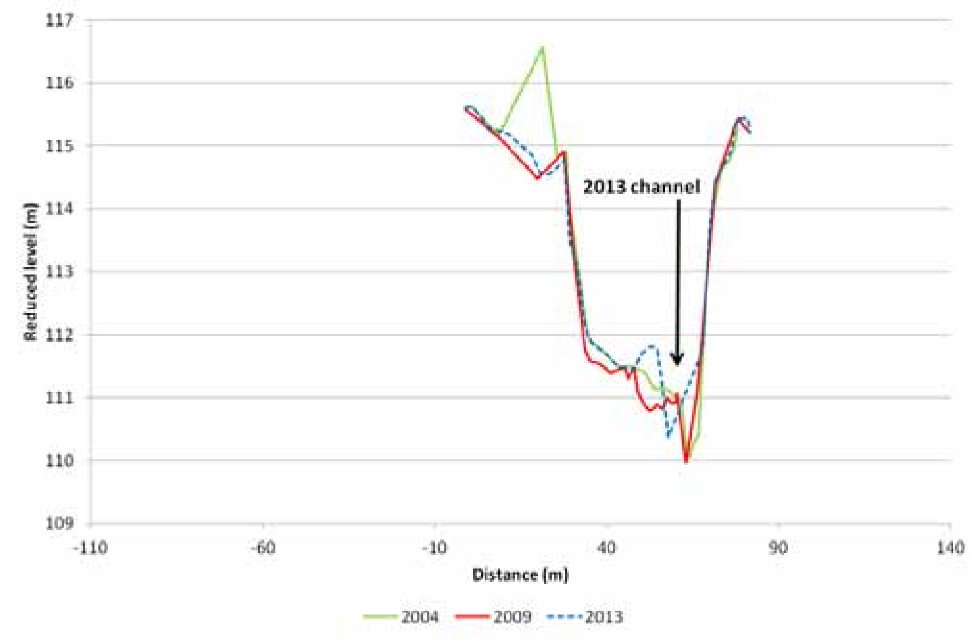

Figure 34. Cross-section S22a, looking downstream.

Figure 35. Cross-section S22a, looking upstream, October 2013.

Cross-section S22a is located 12.74km upstream of the Shag River/Waihemo mouth and 0.1km upstream of Switchback Road bridge. The main channel bed degraded on the left bank between April 2004 and April 2009 as well as the top of the left bank losing approximately 1m of material. Between April 2009 and October 2013 the main channel bed aggraded approximately 1m and moved towards the left bank. The wider floodplain shows minimal change between 2009 and 2013.The thalweg aggraded 0.41m between 2009 and 2013.

Shag River/Waihemo : S22b

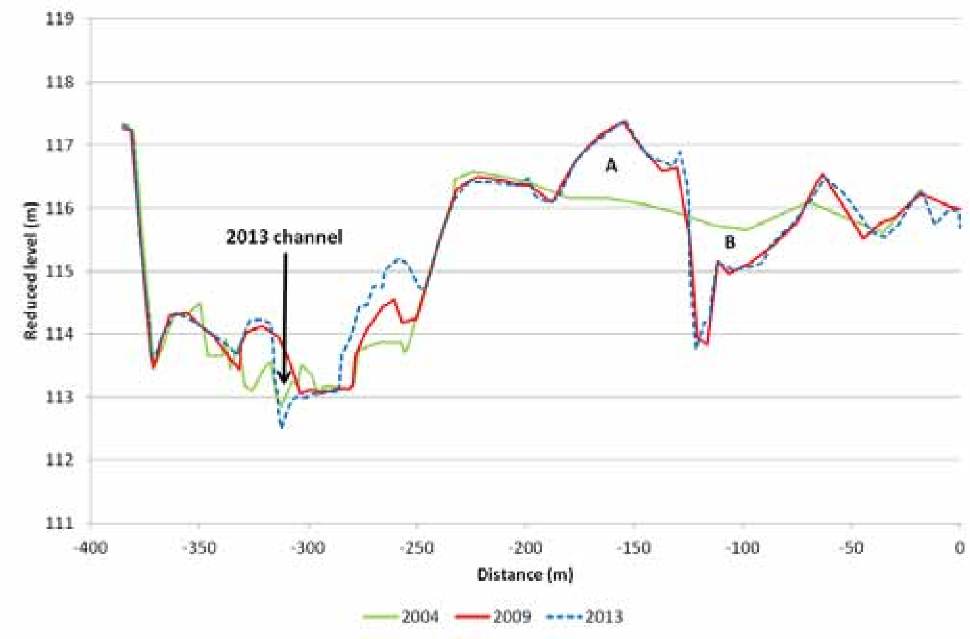

Figure 36. Cross-section S22b, looking downstream.

Figure 37. Cross-section S22b, looking downstream, October 2013.

Cross-section S22b is located 13.1km upstream of the Shag River/Waihemo mouth and 0.42km upstream of Switchback Road bridge. The main channel bed aggraded between April 2004 and April 2009, creating a smoother channel form. The right bank floodplain experienced aggradation of approximately 1m (at the point labelled A) and degradation of approximately 1.5m (at the point labelled B). Between April 2009 and October 2013 the main channel degraded approximately 1m with the right bank continuing to aggrade and erosion of the left bank. The wider floodplain shows minimal change between 2009 and 2013.The thalweg degraded 0.53m between 2009 and 2013.

Shag River/Waihemo : S24

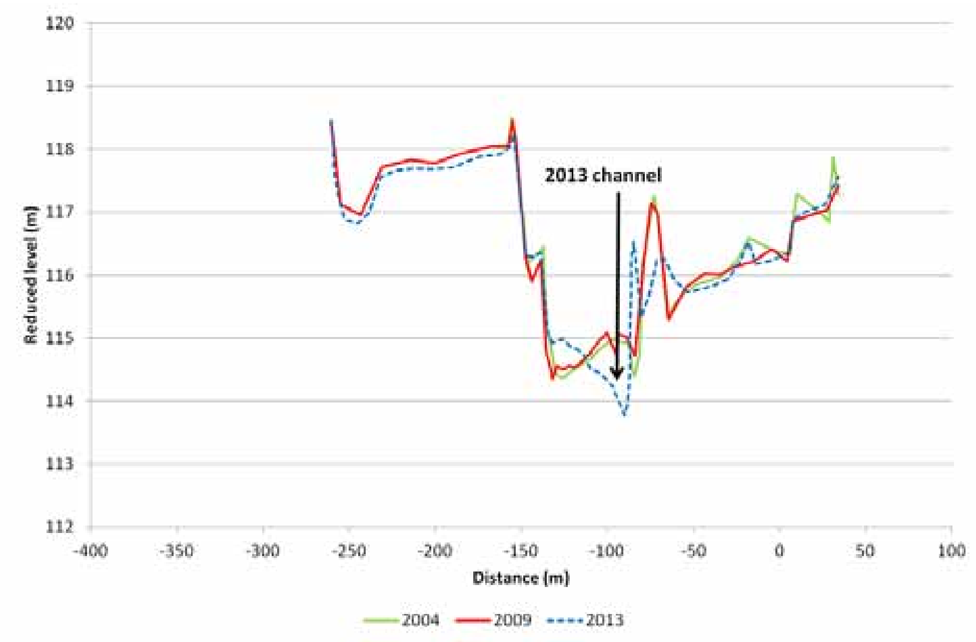

Figure 38. Cross-section S24, looking downstream.

Figure 39. Cross-section S24, looking upstream, October 2013.

Cross-section S24 is located 13.77km upstream of the Shag River/Waihemo mouth and 1.1km upstream of Switchback Road bridge. The main channel bed remained in a similar position between April 2004 and April 2009 with a small amount of bed aggradation occurring. The right bank floodplain experienced degradation of approximately 0.4m. Between April 2009 and October 2013 the main channel degraded approximately 1m with aggradation of the left of the main channel. The wider floodplain showed a general lowering of the left bank and both degradation and aggradation of the right bank between 2009 and 2013.The thalweg degraded 0.57m between 2009 and 2013.

Shag River/Waihemo : S25

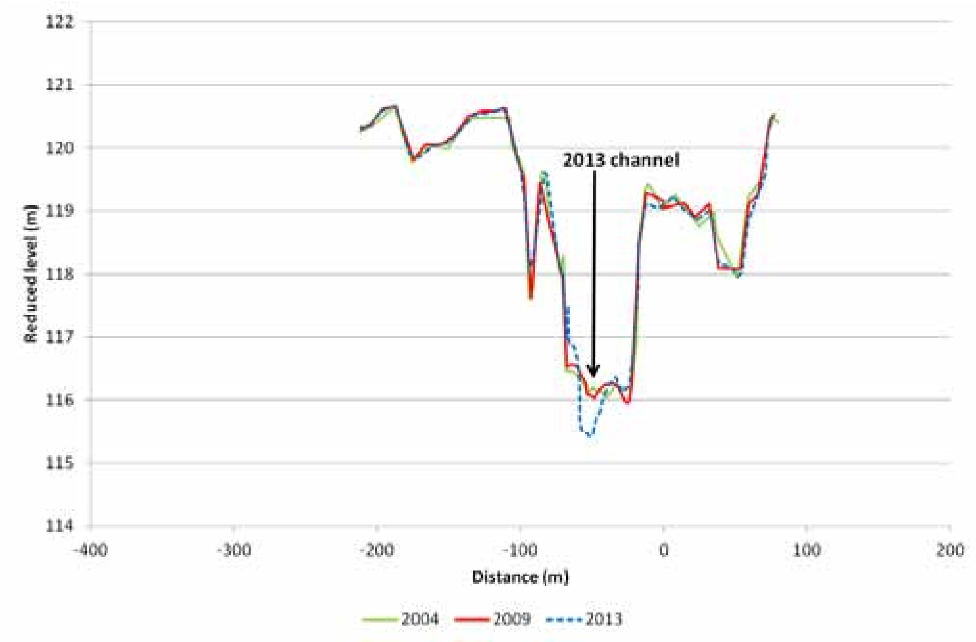

Figure 40. Cross-section S25, looking downstream.

Figure 41. Cross-section S25, looking upstream, October 2013.

Cross-section S25 is located 14.25km upstream of the Shag River/Waihemo mouth and 1.6km upstream of Switchback Road bridge. The main channel bed remained in a similar position between April 2004 and April 2009 with a small amount of bed aggradation and degradation occurring. The left bank experienced minor degradation and the right bank secondary flow channel widened. Between April 2009 and October 2013 the main channel degraded approximately 0.5m with aggradation on the left of the main channel. The wider floodplain remained in a similar position between 2009 and 2013 with minor aggradation of the left bank occurring. The thalweg degraded 0.53m between 2009 and 2013.

Shag River/Waihemo : S26

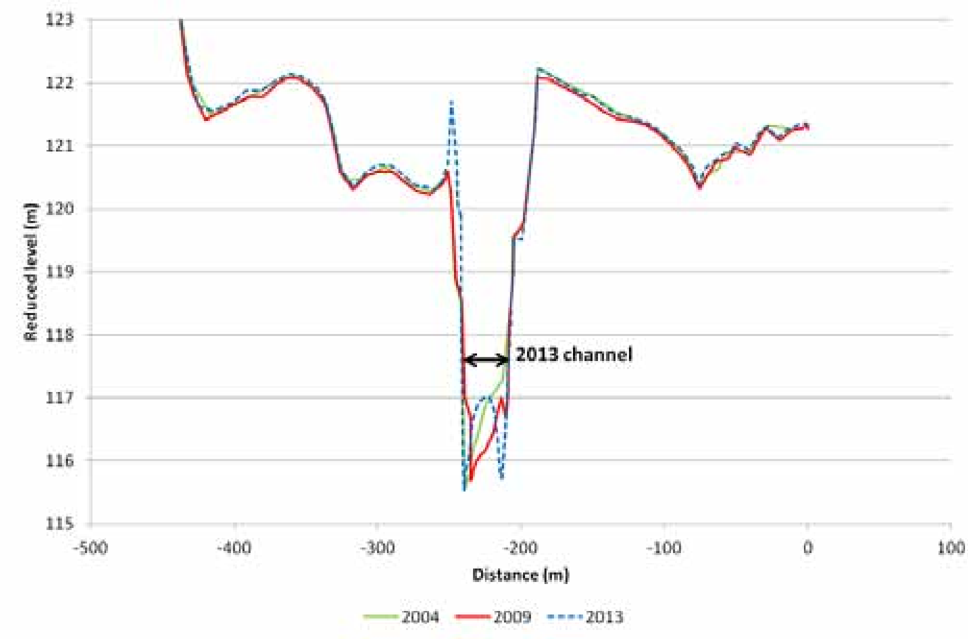

Figure 42. Cross-section S26, looking downstream.

Figure 43. Cross-section S26, looking downstream, October 2013.

Cross-section S26 is located 14.76km upstream of the Shag River/Waihemo mouth and 2.1km upstream of Switchback Road bridge. The right bank of the main channel eroded between April 2004 and April 2009 with the rest of the floodplain remaining similar. Between April 2009 and October 2013 the main channel divided into two low flow channels separated by a gravel bar. A build-up of material on the left bank created a 1m high bank. The wider floodplain remained in a similar position between 2009 and 2013.The thalweg degraded 0.2m between 2009 and 2013.

Shag River/Waihemo : S27

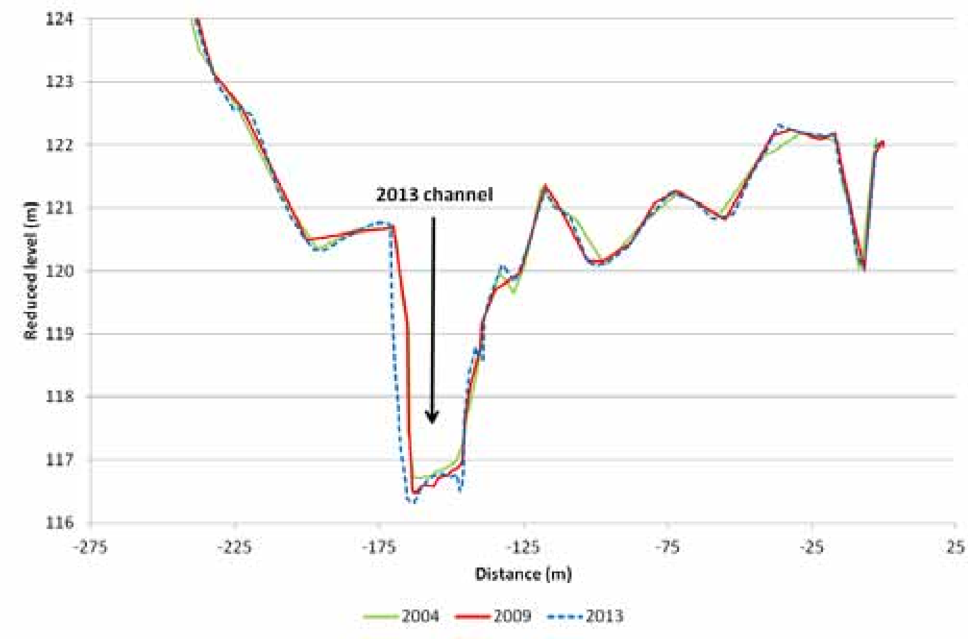

Figure 44. Cross-section S27, looking downstream.

Figure 45. Cross-section S27, looking downstream, October 2013.

Cross-section S27 is located 15.2km upstream of the Shag River/Waihemo mouth and 2.55km upstream of Switchback Road bridge. The main channel bed degraded between April 2004 and April 2009 with a small amount of degradation and aggradation occurring in the wider floodplain. The main channel bed continued to degrade between April 2009 and October 2013 with erosion of the left bank by approximately 5m.The wider floodplain remained in a similar position between 2009 and 2013. The thalweg degraded 0.05m between 2009 and 2013.

Shag River/Waihemo : S28

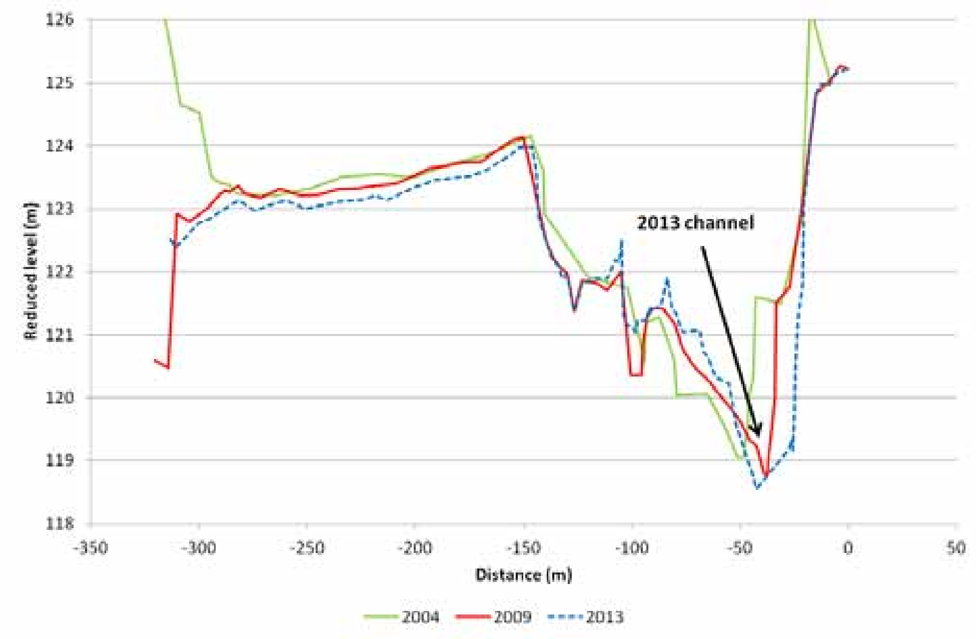

Figure 46. Cross-section S28, looking downstream.

Figure 47. Cross-section S28, looking from true left to true right, October 2013.

Cross-section S28 is located 15.95km upstream of the Shag River/Waihemo mouth and 3.3km upstream of Switchback Road bridge. The main channel bed degraded and moved towards the right bank between April 2004 and April 2009 with predominantly degradation occurring across the wider floodplain. The main channel bed continued to degrade and move towards the right bank between April 2009 and October 2013 with erosion of the right bank occurring by approximately 10m.The wider floodplain showed predominantly degradation between 2009 and 2013. The thalweg degraded 0.63m between 2009 and 2013.

Shag River/Waihemo : S29

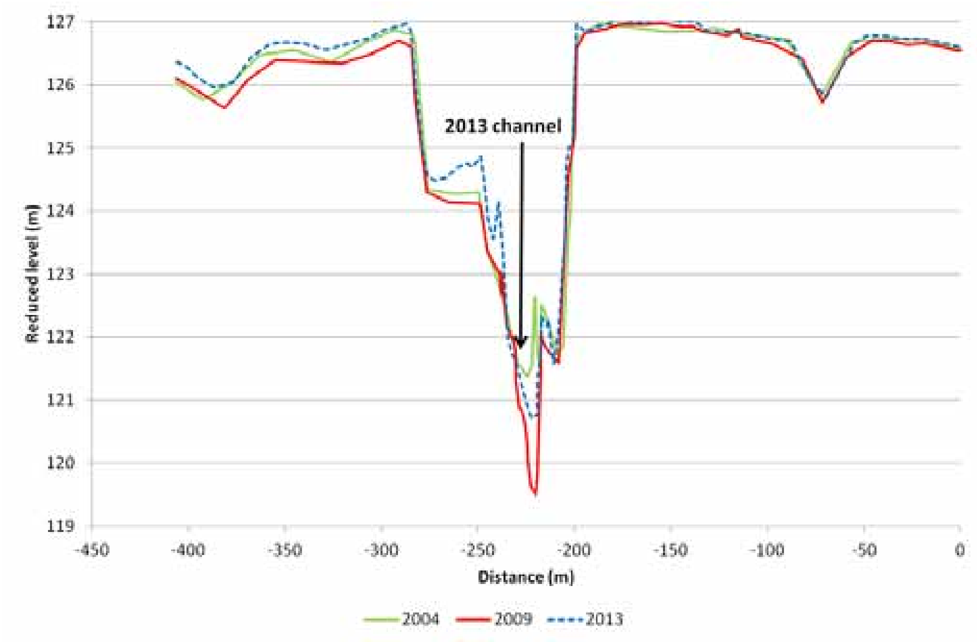

Figure 48. Cross-section S29, looking downstream.

Figure 49. Cross-section S29, looking from true right to true left, October 2013.

Cross-section S29 is located 16.8km upstream of the Shag River/Waihemo mouth and 4.2km upstream of Switchback Road bridge. The main channel bed degraded by approximately 1.75m between April 2004 and April 2009 with a small amount of degradation occurring on the left terrace and wider left floodplain. The main channel bed aggraded between April 2009 and October 2013, but it is still lower than the 2004 channel bed level. Aggradation occurred on the left bank terrace and wider left floodplain between 2009 and 2013 with levels predominantly being higher than those in 2004.The thalweg aggraded 1.2m between 2009 and 2013.

Shag River/Waihemo : S30

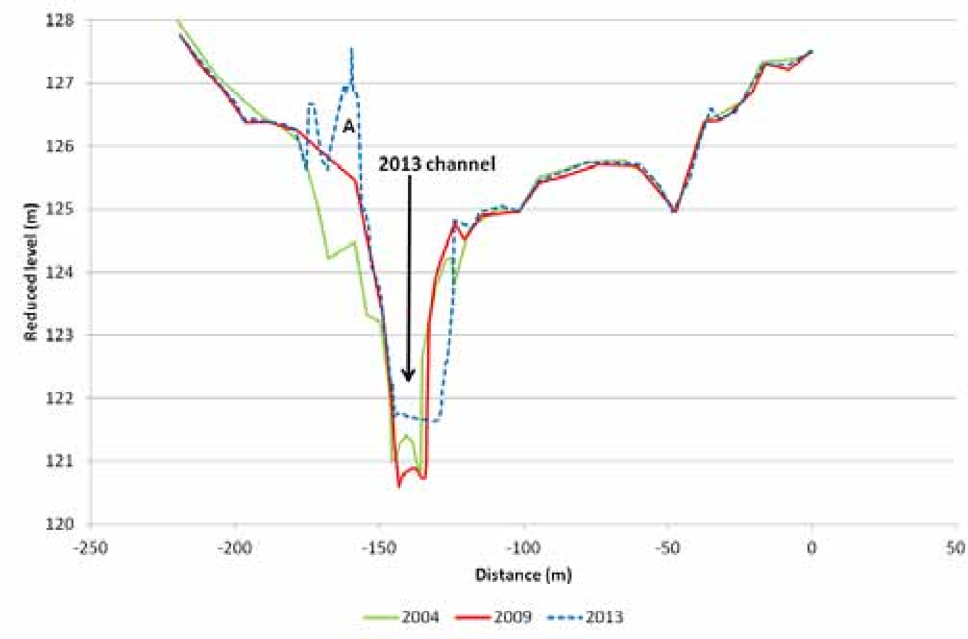

Figure 50. Cross-section S30, looking downstream.

Figure 51. Cross-section S30, looking downstream, October 2013.

Cross-section S30 is located 17.27km upstream of the Shag River/Waihemo mouth and 4.6km upstream of Switchback Road bridge. The main channel bed degraded between April 2004 and April 2009 with erosion of the left bank by approximately 13m occurring. The main channel bed aggraded and widened between April 2009 and October 2013, eroding the right bank by approximately 10m. The top of the left bank shows aggradation and the creation of two natural levees (at the point labelled A), and the wider floodplain remained similar between 2009 and 2013. The thalweg aggraded 1m between 2009 and 2013.

Shag River/Waihemo : S31

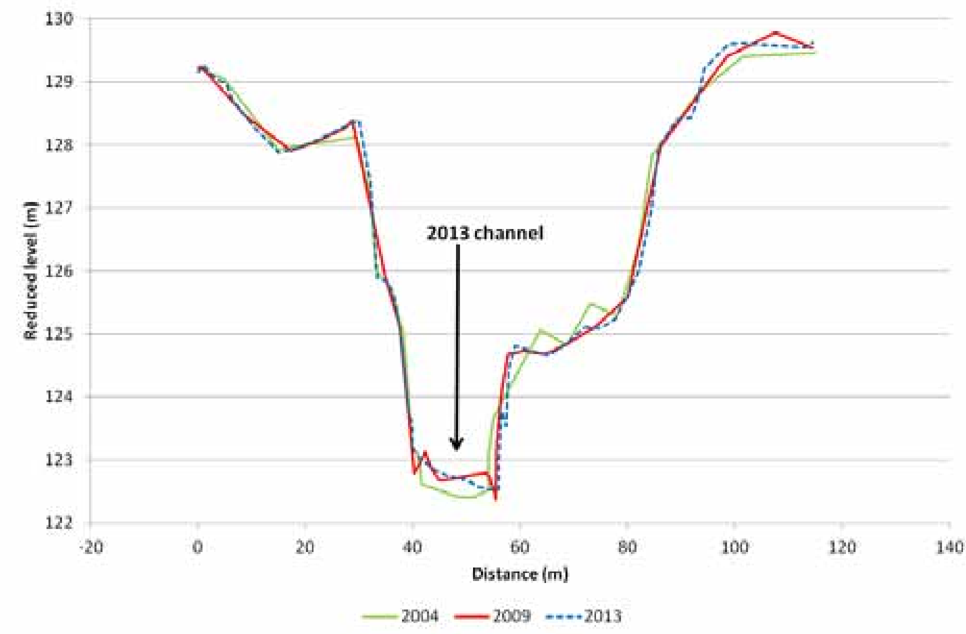

Figure 52. Cross-section S31, looking downstream.

Figure 53. Cross-section S31, looking upstream, October 2013.

Cross-section S31 is located 17.6km upstream of the Shag River/Waihemo mouth and 1km downstream of Craig Road bridge. The main channel bed aggraded between April 2004 and April 2009 with erosion of the right bank and both aggradation and degradation of the wider floodplain. The main channel bed aggraded, degraded and widened between April 2009 and October 2013. The wider floodplain remained similar between 2009 and 2013. The thalweg aggraded 0.15m between 2009 and 2013.

Shag River/Waihemo : S32

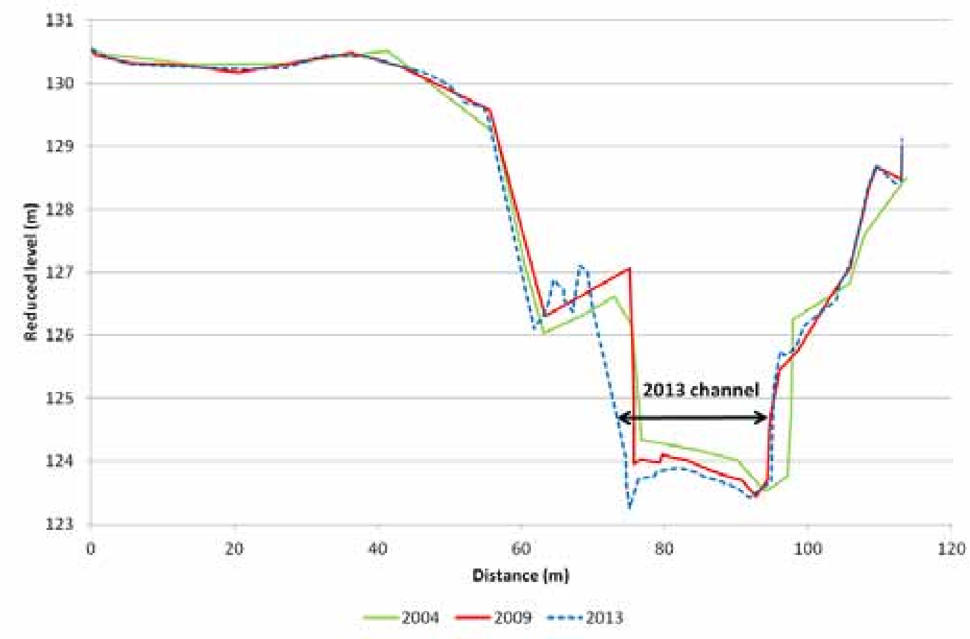

Figure 54. Cross-section S32, looking downstream.

Figure 55. Cross-section S32, looking upstream, October 2013.

Cross-section S32 is located 18km upstream of the Shag River/Waihemo mouth and 0.57km downstream of Craig Road bridge. The main channel bed degraded and narrowed between April 2004 and April 2009 with aggradation of the left and right banks. The main channel bed degraded between April 2009 and October 2013 with erosion of the left bank by approximately 6m occurring. The wider floodplain remained similar between 2009 and 2013. The thalweg degraded 0.3m between 2009 and 2013 and is now located on the left of the main channel.

Shag River/Waihemo : S33

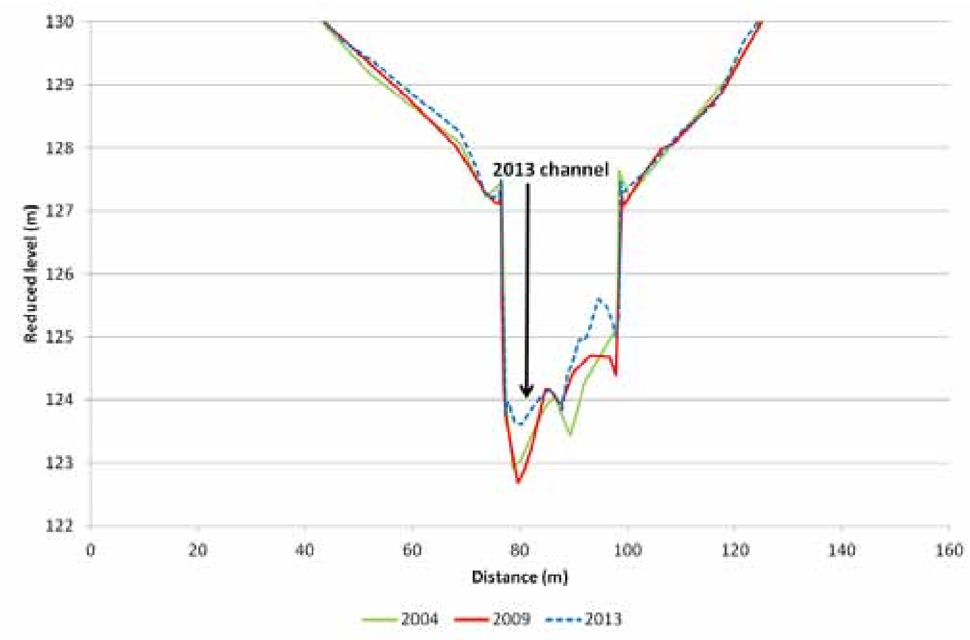

Figure 56. Cross-section S33, looking downstream.

Figure 57. Cross-section S33, looking downstream, October 2013.

Cross-section S33 is located 18.6km upstream of the Shag River/Waihemo mouth at Craig Road bridge. The main channel bed aggraded on the right and degraded on the left, causing the thalweg level to decrease between April 2004 and April 2009. The main channel bed aggraded by 1m between April 2009 and October 2013, causing the low flow channel to narrow. The wider floodplain remained similar between 2009 and 2013. The thalweg aggraded 0.93m between 2009 and 2013.

Shag River/Waihemo : S34

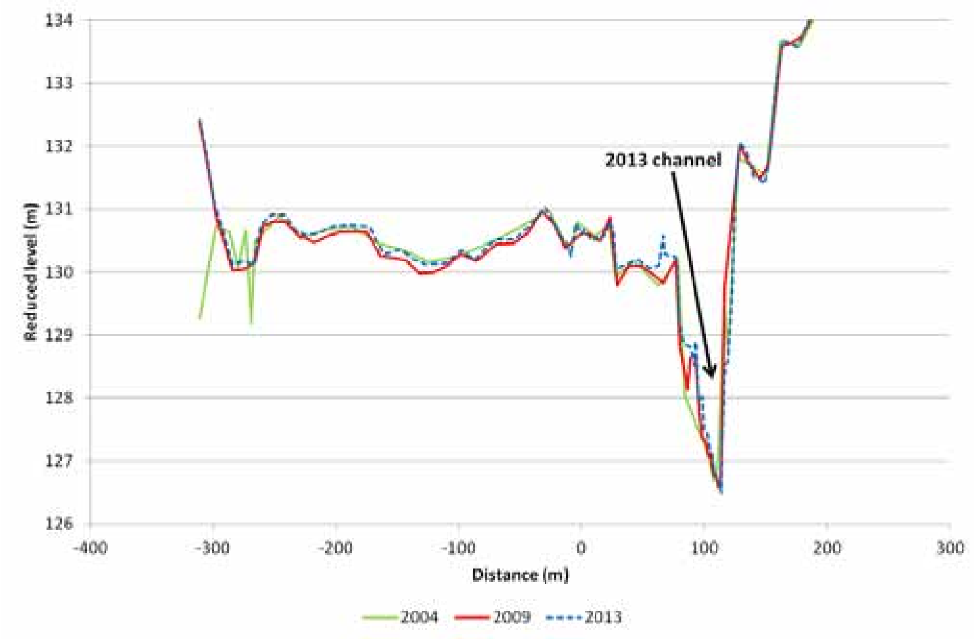

Figure 58. Cross-section S34, looking downstream.

Figure 59. Cross-section S34, looking downstream, October 2013.

Cross-section S34 is located 19.24km upstream of the Shag River/Waihemo mouth and 0.65km upstream of Craig Road bridge. The main channel bed aggraded on the left bank, narrowing the channel, while the left side floodplain showed degradation or limited change between April 2004 and April 2009. The main channel bed in October 2013 remained similar to the 2009 bed with a small amount of aggradation on the left bank. The left side floodplain aggraded between 2009 and 2013. The thalweg stayed in the same position between 2009 and 2013.

Shag River/Waihemo : S35

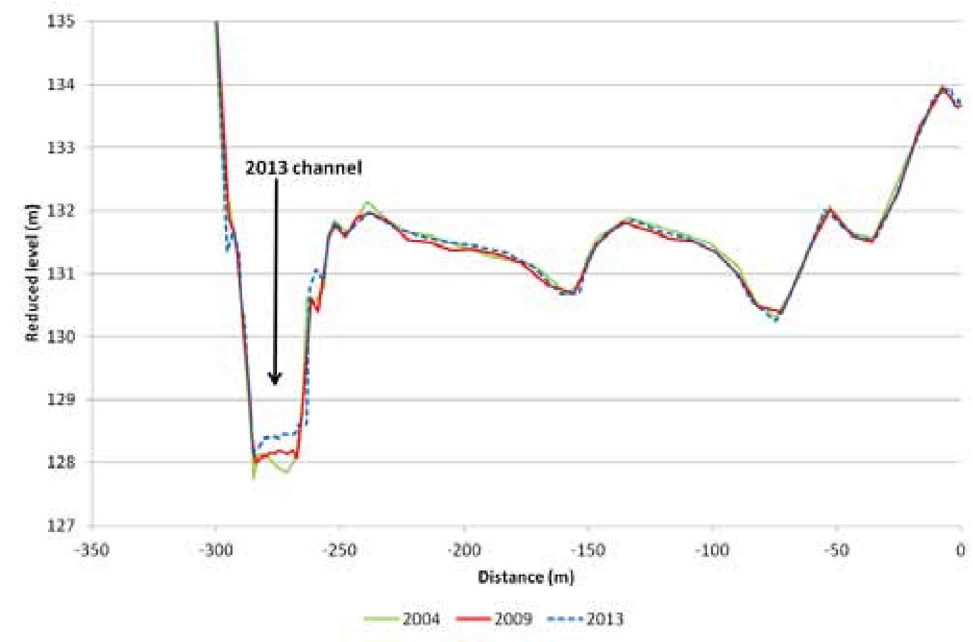

Figure 60. Cross-section S35, looking downstream.

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Figure 61. Cross-section 35, looking upstream, October 2013.

Cross-section S35 is located 19.8km upstream of the Shag River/Waihemo mouth and 1.2km upstream of Craig Road bridge. The main channel bed aggraded on the right between April 2004 and April 2009 and continued to aggrade, eroding the right bank between April 2009 and October 2013. The wider floodplain remained similar between 2004 and 2009. The thalweg aggraded 0.19m between 2009 and 2013.

Shag River/Waihemo : S36

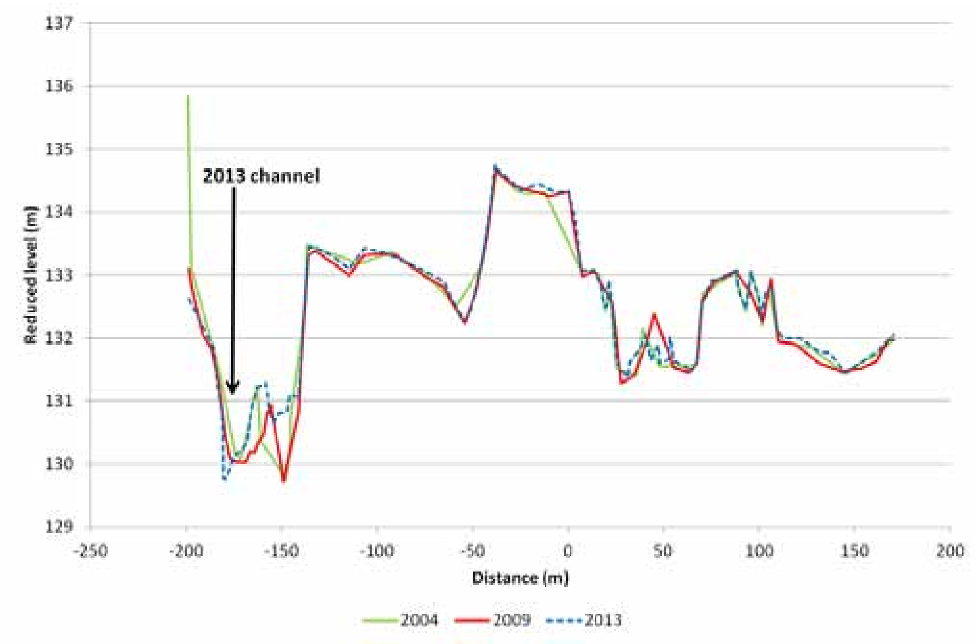

Figure 62. Cross-section S36, looking downstream.

Figure 63. Cross-section S36, looking downstream, October 2013.

Cross-section S36 is located 20.5km upstream of the Shag River/Waihemo mouth and 0.39km downstream of McLew Road bridge. The main channel bed is divided into two low flow channels. Between April 2004 and April 2009 the left channel widened with the right channel narrowing, and the right side floodplain both aggraded and degraded. Between April 2009 and October 2013 the left channel became narrower and deeper with the right channel aggrading approximately 1m. The right side floodplain remained similar between 2009 and 2013 with some minor aggradation and degradation occurring. The thalweg remained in a similar position (vertically) between 2004 and 2013.

Shag River/Waihemo : S37

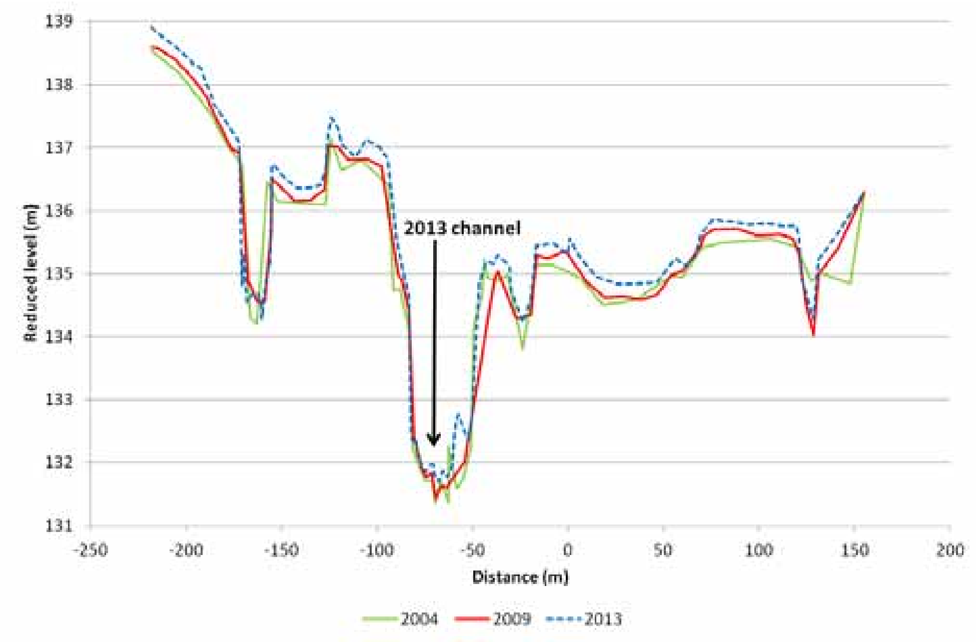

Figure 64. Cross-section S37, looking downstream.

Figure 65. Cross-section S37, looking upstream, October 2013.

Cross-section S37 is located 20.9km upstream of the Shag River/Waihemo mouth at McLew Road bridge. The main channel bed both aggraded and degraded but became smoother between April 2004 and April 2009. The right bank eroded approximately 6m with both aggradation and degradation occurring across the wider floodplain between April 2004 and April 2009. The main channel bed and right bank aggraded between April 2009 and October 2013 with predominantly aggradation occurring across the wider floodplain. The thalweg aggraded 0.4m between 2009 and 2013.

Appendix 2. Methods

Background

ORC has collected cross-section survey information on the Shag River/Waihemo, from Palmerston to McLew Road. The monitoring programme dates back to 1977, although cross-sections have been added since. Comprehensive surveys of all the existing cross-sections in the Shag River/Waihemo were undertaken in September 1984, March/April 2001, April 2004, April 2009, and more recently in October 2013.

This analysis is intended to show the changes in morphology that have occurred since the last comprehensive survey was undertaken in 2009. Although changes before this time are described more fully in ORC (2009), this report does place the more recent changes within the context of longer-term trends.

Parameters

The minimum (thalweg) bed level of each cross-section and for each survey period were determined. Analysis of thalweg levels between survey periods can indicate whether the gradient of the river has changed over time as a result of sediment movement (aggradation and/or degradation). Thalweg values are shown in graphical form, and the changes that have occurred up till 2013 are discussed in section 2.1.

The MBL of the channel at each cross-section was calculated using the MBL algorithm in the XSECT program. XSECT compiles a list of widths and their associated elevations for each cross-section and survey period. XSECT calculates all output information (minimum, maximum and MBL) from the respective widths and elevations.

MBL represents a 'horizontal straight line across the channel, positioned so there is as much bed above the line as below it' (Griffiths, 1979).[11] To estimate MBL, the lateral margins of the channel were identified as being either:

- the point where flood water would begin to overtop the channel, and spill out onto the wider floodplain,[12] or
- the widest extent of the survey data, where such a point was not obvious.

The cross-section data collected in 2013 were used to define these lateral margins.[13] MBL was calculated for the 2013 survey, and also for the two previous surveys (using the same lateral margins). An example of how MBL was calculated is shown in Figure 66.

[11] Griffiths, G. A. 1979: Recent Sedimentation History of the Waimakariri River, New Zealand, *New Zealand Journal of Hydrology*, 18, p. 6-28.
[12] In many cases the cross-section extends beyond this point, onto the adjacent floodplain
[13] The true-left and true-right margins of the channel, identified from the 2013 survey data, and used to calculate MBL, are listed in Appendix 3

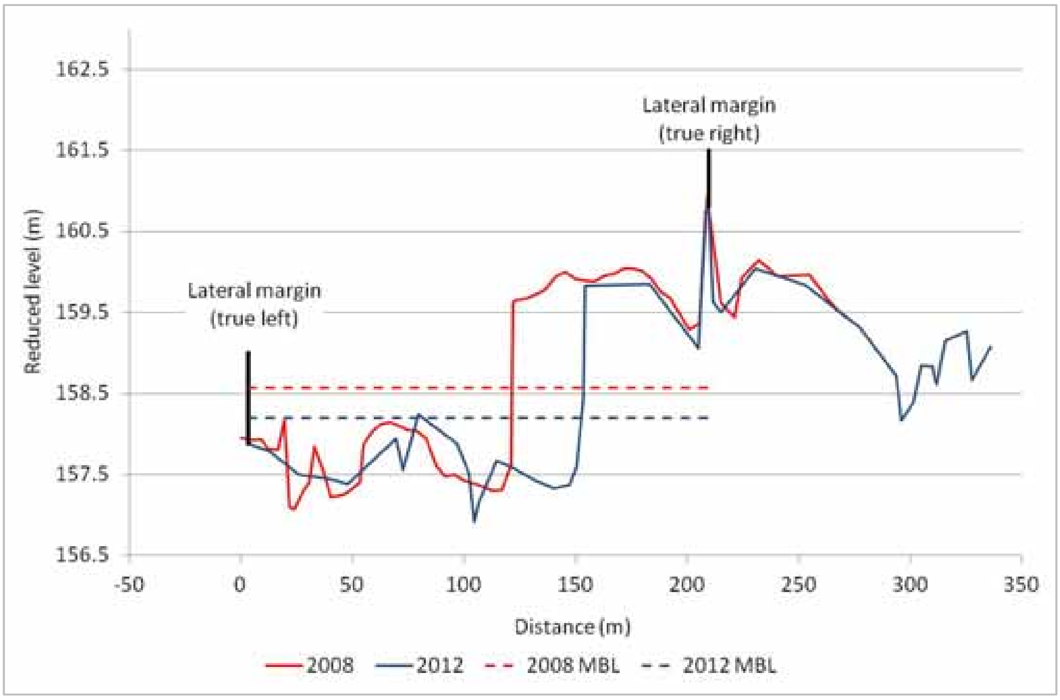

Figure 66. Change in MBL at a cross-section. MBL was calculated for that part of the channel within the true-left and true-right lateral margins (Appendix 3).

A reduction in MBL between survey periods does not necessarily mean that the level of the low-flow channel or thalweg has reduced. Rather, it shows that the average level of the whole channel has reduced. This may be a result of significant bank erosion rather than a decline in the level of the thalweg (e.g. Figure 66). MBL values are shown in graphical form, and changes between survey periods are discussed in section 2.1.

Limitations

A limitation of the cross-section data is that it shows the river as it was at the time the survey was undertaken; therefore, it provides a snapshot view of the river morphology for that particular time and place. Furthermore, survey methods involve taking an elevation and distance measurement at every major break in slope. This method has limitations in terms of transect resolution. The interpretations should, therefore, be viewed within the context that the data was collected.

All cross-section graphs are looking downstream, with the true left of the river being on the left side of the graph. All reduced level measurements are in expressed in Otago datum, which lies 100m above the Dunedin vertical datum 1958. The horizontal (distance) scale varies between each cross-section. A consistent scale has been used for the vertical axis.

Appendix 3. The lateral margins of channel cross-sections used to calculate mean bed level (as described in Appendix 2)

Table 1. Mean bed level calculation extents for cross-sections on the Shag River/Waihemo

Shag River/Waihemo cross-sections	Left bank	Right bank
S17	-105.27	0
S18	-92.57	-15.33
S18/1	77.58	244.8
S19	13.8	270.23
S20a	-56.232	18.358
S21	-63.25	38.42
S22a	-80.477	-3.357
S22b	-382.02	-154.3
S24	-154.57	-17.82
S25	-111.66	-11.96
S26	-248.42	-188.21
S27	-174.4	-117.4
S28	-146.24	0
S29	-287.2	-199.02
S30	-219	-77.97
S31	29.97	102.18
S32	32.95	113.14
S33	16.01	139.31
S34	-29.55	128.9
S35	-303.96	-238.58
S36	-198.73	-38.3
S37	-123.97	0.83

Appendix 4. Timing of cross-section surveys in the Shag River/Waihemo

A blank space indicates a cross-section was not surveyed that year.

Table 2. Surveyed cross-sections on the Shag River/Waihemo

Cross-section	Oct.1977	Sep.1984	Oct.1987	Jan.1988	Mar.2001	Apr.2004	Apr.2009	Oct.2013
S17		X	X		X	X	X	X
S18		X	X		X	X	X	X
S18/1		X	X		X	X	X	X
S19		X	X		X	X	X	X
S20a	X	X		X	X	X	X	X
S21	X	X		X	X	X	X	X
S22a	X	X		X	X	X	X	X
S22b		X		X	X	X	X	X
S24		X			X	X	X	X
S25		X		X	X	X	X	X
S26		X		X	X	X	X	X
S27		X		X	X	X	X	X
S28		X		X	X	X	X	X
S29		X			X	X	X	X
S30		X		X	X	X	X	X
S31		X		X	X	X	X	X
S32		X		X	X	X	X	X
S33		X		X	X	X	X	X
S34		X		X	X	X	X	X
S35		X		X	X	X	X	X
S36		X		X	X	X	X	X
S37		X		X	X	X	X	X

Appendix 5. Recommendation to cease gravel extraction

Note this report was not presented to the Policy Committee

REPORT

File: I261

Report No.: 2004/230
Prepared for: Policy Committee
Prepared by: Stephen Swabey, Projects Manager/Frances Lojkine, Manager Resource Planning
Date: 14 April 2004

Subject: Gravel extraction in Shag and Waianakarua Rivers

1. Précis

Gravel management studies in the Shag and Waianakarua Rivers suggest there has been degradation of the river banks and beds since first surveys in 1977. Rates of extraction were reduced in the 1990s and rates of degradation have also slowed. However, it is recommended that gravel extraction should now cease altogether in these rivers until evidence for a gravel surplus again is noted.

2. Background

As part of the gravel management project for 2003-2004, individual gravel management plans are being prepared for the Lower Clutha, Shag, Waianakarua and Pomahaka rivers. Recently, several gravel extraction consents have been applied for in the Shag and Waianakarua rivers. As part of the consent process, the Projects Manager has been consulted on the availability of gravel for extraction from those rivers.

3. Data collection

Cross sections across the lower Shag River have been surveyed in 1977 (three), 1984 (twenty-two), 1987-1988 (twenty) and 2001 (twenty-two). Further K-section surveys are being completed at present. Additional surveys of river morphology and fluvial processes were investigated at fifteen sections in April 2004. The latter fifteen sections are concentrated around existing gravel extraction sites.

Cross sections are not available for the Waianakarua River. The first cross sections are being surveyed at the moment. The river was examined for channel morphology and fluvial processes at various sites above and below the State Highway 1 bridge in April 2004. Most sites visited are around (ie, both upstream and downstream of) existing gravel extraction sites.

4. Analysis

The channel of the Shag River from McLew Road bridge downstream to Switchback Road bridge alternates between bedrock bed and a thin alluvial veneer on the bedrock. The channel banks are composed predominantly of coarse to medium size gravels. The floodplain deposits are relatively thin – varying from approximately 2-6 m in height above the river. The floodplain varies in width from 200-800 m in the study area. Palaeochannels are visible on the floodplain, but the present river generally occupies a single-thread channel, not a braided channel.

Gravel stores in the channel are small in volume and the relatively thin floodplain indicates floodplain gravel stores are also small. The bedrock-bedded channel form indicates the river is supply-limited for gravel. Rates of gravel extraction in the Shag River were highest in the 1980s, but were reduced in the 1990s in response to high rates of degradation of the channel.

More recent cross sections show reduced rates of degradation. The cross sections available show general degradation of the bed and banks since 1977 in reaches where the channel still has an alluvial veneer. However, where the channel has a bedrock bed, degradation is only possible when the bedrock has been eroded. Many sites exhibit signs of active bank and bed erosion, including bridge abutment abandonment and bank collapse. Channel degradation is continuing at a lower rate, with most of the gravel supply probably derived from the riverbanks.

The Waianakarua River is incised in an elevated gravel floodplain through the reaches that experience most gravel extraction. The gravel cliffs are up to 15 m high. This is significant, because every m^2 of retreat of a 1 m high cliff supplies 1 m^3 of gravel to the channel. When the cliff is 15 m high, 15 m^3 of gravel is supplied. The channel alternates between bedrock-bedded reaches and alluvial reaches, formed in medium-size gravels. The bedform of the river also varies between single thread channel and multi-channel reaches. In places, the river has been realigned in its bed for management purposes.

No cross sections are available for the Waianakarua River to permit objective analysis of the rate of channel degradation. However, there are strong indicators that degradation is taking place. Bank erosion and channel incision is very active in the reaches of the river around the SH1 bridge. At Sharps Bend, the river has been re-aligned in its bed, but also appears to be re-working floodplain deposits, rather than receiving gravel supply from upstream.

The form of the river, its bedrock-bedded nature and the indicators of degradation suggest the Waianakarua River is gravel supply-limited. The sources of gravel supply appear to be mainly from the banks, probably in individual ‘slugs’ of significant volume following cliff collapse and floodplain re-working during floods.

5. Regional Plan: Water

Gravel extraction in the region is controlled by rules in the Regional Plan: Water for Otago. Extraction of more than 20 cubic metres in any month requires a consent and is a restricted discretionary activity. The Council can therefore decline applications and should do so until an appropriate surplus of gravel is available in both the Waianakarua and the Shag rivers.

There are eight current permits for gravel extraction in the Shag River. The last of these permits will expire on 1 May 2005. These consents should not be replaced when they expire.

There are ten current permits for gravel extraction in the Waianakarua River. The last of these permits will expire on 1 December 2005. These consents should not be replaced when they expire.

It should be noted that once the consent holders have extracted the volume of gravel allowed by the permit no further extraction is authorised and extraction from the river may therefore cease earlier than the expiry dates noted above. There are no applications in the system for gravel extraction from the Waianakarua.

6. Conclusions

The Shag River is extremely supply-limited with respect to gravel. Continued gravel extraction is likely to lead to further bank and (where the bed is composed of alluvium) bed degradation. Gravel extraction should cease in the Shag River when the current consents expire. Gravel extraction may be permitted to resume when future cross sections indicate a surplus of gravel is available again. One consent holder has indicated that they may voluntarily cease extracting gravel in the Shag River.

The Waianakarua River is also supply-limited with respect to gravel. Continued gravel extraction is also likely to lead to further bank erosion and degradation of the bed. Gravel extraction should cease when the current consents expire. Gravel extraction may be permitted to resume when morphological or cross section analyses shows evidence for aggradation.

7. Recommendations

That this report be noted.

That no further consents be issued for gravel extraction in the Shag River catchment until future cross sections indicate a surplus of gravel is available.

That no further consents be issued for gravel extraction in the Waianakarua River catchment until morphological or cross section analysis shows evidence of aggradation.

Graeme Martin

Chief Executive