Taihoro Nukurangi

Investigation into the role of jet boating on bank erosion in the Kaituna River

Prepared for Bay of Plenty Regional Council

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Executive summary

Bay of Plenty Regional Council (BOPRC) commissioned NIWA to assess the effect of jet boating operations on bank erosion along the Kaituna River.

Jet boating began on the Kaituna River in the mid 1980s and has been a point of contention with landowners and the focus of numerous reports ever since. Past assessments of the role of jet boating on bank erosion in the Kaituna River have concluded that jet boat wakes contribute to bank erosion, but are not considered the major cause. The major cause of erosion in the Kaituna River was considered to be degradation of the river bed as a consequence of human modification of the river alignment. Previous investigations have examined changes in cross sections at bank erosion monitoring sites and the size of waves generated by the commercial jet boat, but did not directly measure the effect on the banks. The aim of this investigation was to collect data that might help quantify rates of bank erosion in the Kaituna River and to establish whether or not jet boating is a major contributor.

The investigation was split into two phases. Phase 1 included:

- a review of previous reports relating to jet boating on the Kaituna River,
- consultation with landowners and the commercial jet boat operator,
- a preliminary inspection of the state of bank erosion along the jet boated reach of the Kaituna River, and
- selection of sites to be assessed in detail in Phase 2.

Phase 2 involved:

- measurement of bank erosion at seven sites in the study reach (four in the jet boat reach and three in a control reach immediately downstream) on four different occasions over a 17 month period using a terrestrial laser scanner (TLS),
- installation of surveillance cameras at the seven bank erosion sites, and
- a final inspection of the state of bank erosion along the jet boated reach of the Kaituna River.

The results from Phase 1 were reported by Hoyle (2009) but are also summarised in the introduction of this report.

The results from Phase 2 indicate that bank erosion in the Kaituna River is an ongoing process, with the number of identified bank erosion sites increasing over the period of this project. The TLS approach proved to be a useful means of measuring bank erosion and this approach has provided an indication of rates of erosion within the jet boat and control reach.

The mean bank change and the rate of erosion measured between the first and last TLS scan for each site are as follows:

Site	Time Span	Mean change (erosion) (m)	Rate of erosion (m/yr)
1	Dec09-May11	2.62	1.80
2	Dec09-May11	0.19	0.13
3	Dec09-May11	0.15	0.10
4	Dec09-May11	0.49	0.34
5	Dec09-Dec10	0.26	0.27
6	Dec09-May11	0.58	0.40
7	Dec09-Mar10	0.09	0.31

This study has found that there are a number of factors contributing to bank erosion in this river, albeit to varying degrees. These are:

- floods
- jet boating
- geomorphic adjustment resulting from previous channel realignment
- fluctuations in river level due to the Lake Rotoiti water level control
- stock damage
- naturally weak bank material.

The bank erosion processes occurring in this reach are complex and it is not possible to completely isolate the effect of any single cause. However, the TLS work in combination with the surveillance photographs and observations during the full study reach inspections have provided some clear indications of what the key drivers are. The report concludes that the large floods that occurred in January 2011 were the major cause of bank erosion measured across the full study period. However, jet boating is certainly contributing to bank erosion. The effect of all jet boating between Scans 2 and 3 (30 March 2010 and 6 December 2010 respectively) is believed to have had an effect equivalent to the floods that occurred during that same period, which included two events of approximately 100 m^3/s (a 2 year return period, Surman, 2005).

Management approaches that would allow the effects of jet boating to be mitigated are:

- encouraging riparian planting
- limiting locations of jet boat spins
- other river bank protection options where significant infrastructure is at risk.

1 Introduction

Jet boating began on the Kaituna River in the mid 1980s, and formal complaints from members of the public regarding the operation of jet boats on the Kaituna River began in 1987. The key concerns raised relate to the safety of other river users, the speed of the jet boat, the resource consent for the jet boat to operate, and the potential link between jet boating and bank erosion. As a result of these complaints, numerous reports followed discussing jet boating on the Kaituna River and the related concerns of landowners. Past assessments of the role of jet boating on bank erosion in the Kaituna River have concluded that jet boat wakes contribute to bank erosion but are not considered the major cause. Landowners have expressed their dissatisfaction with the findings of previous reports. In an effort to resolve this issue Bay of Plenty Regional Council (BOPRC) commissioned NIWA to investigate the extent of bank erosion along the jet boated reach of the Kaituna River (Figure 1-1) and to establish whether jet boating is a major cause of bank erosion along this reach.

The investigation was split into two phases. Phase 1 included a review of previous reports relating to jet boating on the Kaituna River, consultation with landowners and the commercial jet boat operator, a preliminary inspection of the state of bank erosion along the jet boated reach of the Kaituna River, and the selection of sites to be assessed in detail in Phase 2. Phase 2 included measurement of bank erosion at seven sites in the study reach (four in the jet boat reach and three in a control reach immediately downstream) on four different occasions over a 17 month period using a terrestrial laser scanner (TLS), installation of surveillance cameras at these seven bank erosion sites, and a final inspection of the state of bank erosion along the jet boated reach of the Kaituna River.

This report starts by summarising the results from the Phase 1 study (reported in detail by Hoyle, 2009) and then outlines the aims of the Phase 2 study. Methods are explained, and the results given from a number of erosion evidence sources. A brief discussion explores what each set of results can tell us about the complex erosion processes in the river, and helps to quantify the role of jet boating in this river. Finally, recommendations for possible approaches to avoid or mitigate the effects of the erosion are identified.

1.1 Results from Phase 1

1.1.1 Summary of past reports and investigations

BOPRC supplied NIWA with copies of reports and letters dating back to June 1992. These reports discuss the speed of the commercial jet boat and the safety of other river users, the consent for the jet boat to operate, and the potential link between jet boating and bank erosion. The report herein provides a summary of past reports relating to bank erosion.

Since jet boating began on the Kaituna River, there have been changes in landowners, changes to the names of local government authorities (e.g. WBOPDC, BOPRC, EBOP), and changes to related legislation. Previously, the commercial jet boating activities occurred as part of ‘Longridge Park’, a property owned by Mr Stuart Steel. The jet boating and other adventure type business was subsequently sold to Mr Graeme McKenzie, and jet boating activities now occur as part of ‘Spring Loaded Fun Park’. Both these property/business names are referred to in previous reports and other documentation.

Figure 1-1: Site map. The approximate location of the jet boated reach on the Kaituna River is circled in pink. The approximate location of the flow recorders referred to later in the report are also highlighted as follows: Kaituna at Taaheke (green), Kaituna at Te Matai (red) and Mangorewa at Saunders Farm (blue).

In June 1992, a report from Western Bay of Plenty District Council (WBOPDC) District Planner Implementation to Development Approvals Committee described site investigations into bank erosion of the Kaituna River, and stated that (WBOPDC) staff believed that it is not possible to directly link bank erosion to the jet boating activity without expert advice. The report also stated that Regional Council staff had previously indicated that bank erosion could be expected on the Kaituna River due to the steepening of the gradients and higher velocities resulting from the realignment work carried out on the river (between the early 1980s and 1993).

The June 1992 WBOPDC report also established that the jet boating activities on the Kaituna River have legal standing. While this isn't the focus of this report, the question as to whether the jet boat operation was legal or not was raised during our consultation with landowners. This WBOPDC report states that Longridge Park was granted planning consent to operate a tourist facility on land adjoining the Kaituna River on 8 September 1986. The application for planning consent involved jet boat tours on the Kaituna River, as well as land-based activities, and is dealt with as a specified departure under the Town and Country Planning Act 1977. At the time of granting consent to Longridge Park, Tauranga County Council (precursor to WBOPDC) had jurisdiction under the Town and Country Planning Act to approve jet boating activity as part of its planning consent. This planning consent carries over under the Resource Management Act 1991 (RMA). The report also established that the environmental effects of jet boating activities are the direct responsibility of (WBOPDC) Council, whilst the safety of jet boat operations on the water is the responsibility of the Ministry of Transport (WBOPDC, 1992).

In December 1992, internal correspondence between BOPRC's Manager Rivers and Drainage (Bruce Crabbe), Manager Technical Services (Ross Titchmarsh) and Director Operations and Rural Services (Greg Pemberton) stated that the areas of bank erosion causing the most concern at the time of the report were in the middle reaches, between the main trunk railway line and the confluence of the Kaituna and Mangorewa Rivers. Erosion existed elsewhere (including in the jet boated reach); however, it was considered generally less severe. This report also stated that the likely causes of erosion in the Kaituna River were one of, or a combination of, the following:

- the normal meandering habit of the river
- fluctuations in river water level due to precipitation, Lake Rotoiti water level control structure, and/or tidal influences (in the lower river only)
- down-cutting of the riverbed caused by channel realignment
- stock damage
- wave action from boating traffic.

The December 1992 BOPRC report concluded that there was little doubt that boat wakes contributed to bank erosion, but that this was not considered the major cause. The major cause of erosion in the Kaituna River was considered to be degradation of the river bed as a consequence of human modification of the river alignment. This was supported by a figure, provided in an Appendix to the report, comparing the thalweg bed level measurements from 1965 and 1989 (covering the reach with the most severe bank erosion, but not including the jet boated reach). This figure demonstrated that there had been up to 3 m of aggradation in the reach 3 km downstream of the jet boated reach, approximately 0.5-2.5 m of bed degradation in the reach 2.5 km either side of the SH2 bridge, and up to 4.5 m of degradation downstream of Junction Raparapahoe (approximately 6 km upstream of the river mouth). The December 1992 report concluded that the extent of bank erosion in the jet boated reach was not considered sufficient at the time of the report for the Regional Council to shut down the commercial jet boat activities (Crabbe and Titchmarsh, 1992).

A letter dated March 1993 from Trevor Thompson, a Civil Engineering Consultant, to Mrs Alison Gibson of the Kaituna River Protection Group described a meeting held with Ross Titchmarsh and Bruce Crabbe of the Regional Council. During this meeting it was clarified that the statement in the December 1992 report, that the major cause of erosion in the Kaituna River was considered to be degradation of the river bed, was only intended to refer to the section of river downstream of Maungarangi Bridge. Furthermore, the letter stated that the Regional Council had formed no definite opinion on the cause, or causes, of the bank erosion in the Upper Kaituna River (upstream of Maungarangi Bridge and in the jet boated reach). This letter stated that there was agreement at this meeting that the factors contributing to erosion could be:

- wave action from jet boats
- fluctuations in river level due to the operation of the Okere control gates
- sudden draw-down effects due to the rate of change in river level under the action of the control gates
- human action at the river banks e.g. cutting down of trees
- stock access to the river etc. (Thompson, 1993).

In June 1993, internal correspondence between BOPRC Manager Rivers and Drainage (Bruce Crabbe), Manager Technical Services (Ross Titchmarsh) and Director Operations and Rural Services (Greg Pemberton) described field investigations carried out on 7 April 1993, during which measurements were made of the waves generated by two different sized jet boats travelling at both 5 knots and 30 knots. Results showed that waves were bigger at slower speeds (with a largest waves generated at 6-9 knots), that wave size was influenced by cross section shape, and that at normal operating speeds both boats generated waves large enough to erode non-vegetated banks. Severe bank erosion was noted just downstream of the jet boated reach and in areas with stock access or with overgrown trees falling into the river. Only a few areas of erosion were noted in the jet boated reach with the worst stated to be on Stan Steele's property, approximately 0.5 km upstream of Maungarangi Bridge. The June 1993 report noted the same potential causes of bank erosion as those listed in previous reports, adding surface water runoff, overgrown trees, and wind to the list. Boat wakes are estimated in this report to be responsible for 20-50% of the erosion (Crabbe and Titchmarsh, 1993) but there is no explanation of how this was quantified.

In May 1994, internal correspondence between Environment Bay of Plenty's[1] (EBOP) Manager Technical Services (Ross Titchmarsh) and Director Operations and Rural Services (Greg Pemberton) detailed the establishment of an erosion monitoring programme. Sixteen existing cross sections (below the jet boated reach) and eight new monitoring sites (within the jet boated reach) were surveyed on 27 January 1994 and resurveyed on 22 April 1994. Only one site showed an increase in erosion over this period and it was proposed that the sites be resurveyed again in six months time (Titchmarsh, 1994a).

In November 1994 internal correspondence between EBOP's Senior Engineering Officer (M. Van Der Vlugt) and Manager Technical Services (Ross Titchmarsh) detailed observations from the six month resurvey of the erosion monitoring sites conducted on 19 October and 2

[1] Environment Bay of Plenty at that time was the trading name of Bay of Plenty Regional Council.

November 1994. It was noted that there was recent erosion (within the previous 6 months) in the section of river upstream of Maungarangi Bridge (the jet boated reach), with a lower incidence of recent erosion downstream of the bridge. Extensive erosion was observed from sites 4R to 5L (in the upper section of the jet boated reach) where typically native vegetation extended to waters edge (Van Der Vlugt, 1994).

Further correspondence in November 1994 between Manager Technical Services (Ross Titchmarsh) and Director Operations and Rural Services (Greg Pemberton) made the point that significant rainfall in July/August had resulted in an increase in flows in the Kaituna of approximately 12 m^3/s above normal (equating to rivers levels elevated by approximately 200 mm). These increased flows were believed to have contributed to the erosion. It was highlighted that very little erosion occurred when jet boat activity was high (between January and April) and that significant erosion occurred when jet boat activity was low (between April and November). The results were described as surprising and inconclusive. It was recommended that the sites be resurveyed mid February 1995 (Titchmarsh, 1994b).

In February 1995, internal correspondence from EBOP's Laboratory Manager (David Bassett) to Director Environmental Monitoring (Paul Dell) detailed results from water quality monitoring conducted at three sites in the jet boated reach on 13 February 1995. It was noted that suspended solids increased after the passage of the jet boat to a fairly consistent degree at all three sites. The report stated that "the sediment is visible at the centre of the river 5 minutes after the boat's first pass and remains for some period of time, affecting the clarity of the river" (Bassett, 1995).

In March 1995, internal correspondence from EBOP's Manager Technical Services (Ross Titchmarsh) to Director Environmental Monitoring (Paul Dell) detailed observations from the second six month resurvey of the erosion monitoring sites conducted on 21 February 1995. It was noted that 2 of the 24 cross sections exhibited changes since the previous survey (November 1994) and that most erosion sites had stabilised with vegetation. The findings from the March 1995 study were again described as inconclusive and the report recommends that the next survey should follow a period when the lake control gates are open at high levels for a significant period of time (Titchmarsh, 1995).

In May 2000, internal correspondence from EBOP's Director Regulation and Monitoring (Paul Dell) to Director Operations and Rural Services (Greg Pemberton) stated that the bank erosion on the Kaituna River was inspected in February 1999, and an assessment was made that jet boats were contributing in the order of 10% to the erosion. The May 2000 letter requested that a report be produced detailing the findings from that inspection (Dell, 2000).

In 2002, Dr Kevin Parnell of The University of Auckland was commissioned by EBOP to assess the erosion effects of jet boat wakes on the Kaituna River. Dr Parnell and three EBOP staff conducted a field inspection on 23 January 2002. This inspection involved visiting sites of concern in the EBOP jet boat, observing wakes generated by the EBOP boat from onboard and from the bank, and taking a trip on the commercial jet boat. Parnell's report stated that wakes generated from the commercial jet boat were generally small, with most estimated at approximately 15 cm high, and were smaller than those generated by the EBOP boat. It was highlighted that, once over critical speed, higher speeds would tend to generate lower wakes for the same hull. The critical speed depends on the depth of water. In 3 m of water, critical speed occurs between approximately 20 and 30 km/hr, and in shallower water, the critical speed is less. The commercial jet boat typically travels between 40 and 70 km/hr. The report concluded that “occasional jet boat passage may ultimately cause very small increases in bank erosion, under some flow conditions”, and that “the amount is insignificant in relation to the amount of erosion likely under high flow conditions” (Parnell, 2002).

1.1.2 Consultation with landowners

A meeting was held in the Paengaroa Community Hall at 7pm on 21 October 2009. The aim of this meeting was to hear the concerns of landowners and other interested parties with regard to bank erosion along the Kaituna River. The meeting also provided an opportunity to explain the planned stages of this bank erosion investigation so that all stakeholders had an opportunity to provide comments and suggestions on our methodology. Graeme McKenzie of the Spring Loaded Fun Park, the commercial jet boat operator, also attended the meeting.

Landowner’s description of bank erosion

Various landowners described areas where fences have been continually undercut. It was reported that water clarity and bank erosion has become much worse in the last 4 – 5 years. It was reported that water clarity can change drastically over a few hours without a change in river flow. One landowner stated that he can tell when the jet boat is operating upstream by the colour of the water. Some areas that were previously accessible by stock have been fenced off, however the erosion at these sites has continued. The landowners were firm in their opinion that the bank erosion and water clarity issues were caused primarily by the jet boating operations.

Suggestions from landowners and jet boat operator on investigation methodology

At the time of the landowner meeting our aim was to select at least two sites in the jet boated reach and at least one site downstream of the jet boated reach (a control) for detailed measurement of bank erosion. The proposed methodology for directly measuring bank erosion using a Terrestrial Laser Scanner (TLS) was explained to the landowners at the evening meeting and to the jet boat owner (Graeme McKenzie) and driver (Mark) prior to the preliminary field inspection.

Graeme McKenzie expressed the opinion that the bank erosion was much worse downstream of the jet boated reach and emphasised the importance of including a survey outside the jet boated reach to allow comparison.

Landowners expressed concern that comparing the bank erosion in the jet boated reach with that outside the jet boated reach may not be fair due to differences in bank material. Landowners also expressed concern that if a flood caused significant erosion during this investigation, that all erosion would be attributed to such flooding.

These comments were each taken into consideration in the final approach chosen for Phase 2.

1.1.3 Observations from the preliminary field investigation

The preliminary field investigation was conducted on 21 October 2009. The investigation was conducted by Bruce Gardner (BOPRC), Greg Meikle (BOPRC), and Jo Hoyle (NIWA). This investigation included observations from a commercial jet boating trip and an inspection of the existing state of bank erosion along the Kaituna River in the 9.2 km jet boat reach and in the 3.4 km reach immediately downstream of the jet boat reach (which was deemed a control reach). This inspection was conducted from the BOPRC jet boat.

Observations during commercial jet boat trip

The trip on the Spring Loaded Fun Park jet boat was a commercial jet boating trip, not a pre-arranged trip for EBOP's benefit. There were seven of us on the boat in total, including the driver and three fee paying passengers. It is acknowledged that the height of waves generated by the jet boat will vary depending on the weight (number of people) carried by the boat and that during the peak jet boating season the boat would likely carry more passengers. However, this commercial trip was considered to be typical and provided an opportunity to observe the way in which these trips are operated. In particular, we observed the waves generated at different speeds and recorded the locations where the boat performed 360^o spins and then re-accelerated. The locations of the spins were recorded by time-synchronising video and handheld GPS coordinates.

Observations from this trip can be summarised as follows:

- The largest waves generated by the jet boat occur during the 360^o spins and when the boat is accelerating to reach planing speed. Once planing, the jet boat generates a lot of spray but relatively small waves.
- When onboard the jet boat and travelling at planing speed it is impossible to get a good view of waves hitting the banks, as the boat has moved too far by the time the waves reach the bank.
- The waves as generated by the 360^o spins and subsequent reacceleration can be observed hitting the bank from onboard the jet boat; however, the energy of these waves and their effect on bank erosion cannot be determined by observation from the boat alone.

The coordinates for the locations where 360^o spins are typically performed, along with other notable locations, were provided by Spring Loaded and are listed in Hoyle (2009). It was noted that the locations of the 360^o spins carried out during this trip on the commercial jet did not all correspond with the locations provided by Spring Loaded.

Observations of existing bank erosion

After the commercial jet boating trip we launched the BOPRC jet boat at the Spring Loaded Fun Park ramp, next to the jetty. We then headed to the upstream end of the jet boated reach, known as the rapids, where we started our survey. We travelled slowly downstream (< 5 knots) photographing and recording details for all sites where erosion could be seen at the banks of the river. The data record for each erosion site is provided in Appendix A. The location of the erosion sites was determined by time-synchronising erosion photos with handheld GPS coordinates. Due to the narrow and vegetated nature of the gorge, there was not always sufficient satellite coverage to record a GPS location. The length and height of each erosion site was estimated by eye. The type of erosion was classified as follows:

- Slips – Also known as slab failures or gravity collapses. They typically occur on steep banks where blocks of bank material slip vertically into the river (e.g. Figure 1-2).
- Slumps – These are mass-failures that occur by rotational collapse; typical of water-logged hillslopes or banks that are high but not particularly steep (e.g. Figure 1-3).
- Gully erosion – These are locations where overland flow scours the surface of a hillslope, terrace, or floodplain, transporting sediment into the river. The sediment may be deposited as a fan, which is subsequently remobilised by the river (e.g. Figure 1-4). Gully material often differs from the surrounding bank material.
- Current scour – These are sites where the river is continually scouring the bank material but there is no sign of gravity failure (e.g. Figure 1-5).
- Undercut – These typically occur where the river erodes sediment from beneath a vegetated bank. Eventually the bank will collapse (e.g. Figure 1-6).

We inspected the full length of the jet boated reach (approximately 9.2 km) as well as the 3.4 km section of river immediately downstream of the jet boated reach. Bank erosion was noted to be active and widespread throughout both of these reaches. In total, 87 erosion sites were recorded (Appendix A), 65 in the jet boated reach and 22 downstream. Erosion occurs at sites with and without stock access and with and without vegetation cover.

Figure 1-2: Typical 'slip' type of erosion. Blocks of bank material have slid into the river.

Figure 1-3: Typical 'slump' type of erosion. The same type of erosion was recorded at this site in 2004.This slump extends at least 15 m up the bank.

Figure 1-4: Typical erosion of 'gully' material. The head of the gully can be seen in the top right of the photo.

Figure 1-5: Typical 'current scour' type erosion.

Figure 1-6: Typical 'undercut' bank. Erosion has occurred to the point that a tree has toppled into the river.

1.1.4 Assessment of bank erosion changes since 2004

In October 2004, NIWA was commissioned by Mighty River Power to conduct an inspection of the banks of the Kaituna River from the upstream end of the jet boated reach down to the river mouth. During this inspection, the location and dimensions of bank erosion features were recorded using the same method employed in this investigation. In the equivalent section of river (the 9.2 km jet boat reach and the 3.4 km reach downstream) the 2004 investigation identified 63 sites with bank erosion. It is difficult to directly compare the number of erosion sites as, in some cases, a large single site in 2004 may be recorded as two separate sites in 2009 and vice versa.

To assess changes in the state of the riverbanks, the location, description and photographs of erosion in 2004 were compared with the erosion recorded in October 2009.

Of the 87 erosion sites recorded in 2009:

- 52 sites may be considered as 'new' erosion, as they were not recorded in 2004
- 34 of the sites can be linked with erosion sites in 2004, i.e. erosion has been occurring at these sites for at least 5 years.

Of the sites with erosion recorded in 2004:

- 29 sites did not get recorded as erosion sites in 2009, i.e. they are now vegetated and no longer eroding, or they were masked by vegetation and were missed during the inspection.

Not all sites were photographed in 2004; however, where available, photographs were compared for the sites recorded with erosion during both inspections. In total, 20 sets of photographs were comparable. Of these, 8 sites appear to have deteriorated in the last 5 years and 12 appear to be no worse. As the sets of photographs have often been taken from slightly different locations and angles, it is difficult to draw firm conclusions from these comparisons.

1.2 Aim and approach for Phase 2

BOPRC wish to monitor the extent of bank erosion in the Kaituna River and to establish whether or not jet boating is a significant cause of the bank erosion. Past reports have listed a number of possible causes of bank erosion on the Kaituna River, however, there has been considerable difficulty determining the significance of each of these potential causes. Two of these reports (Crabbe and Titchmarsh, 1993; Dell, 2000) have estimated that jet boating could be responsible for between 10 and 50% of the bank erosion, but neither explains how these numbers were derived.

Physical measurement of bank erosion in the Kaituna has in the past been limited to repeated surveying of cross sections (8 in the jet boat reach and 16 elsewhere). While this approach may capture local changes in channel geometry, these measurements are spatially very limited i.e. they only tell us the change at each survey point, and each cross section likely comprises less than 50 survey points. Bank erosion can be highly variable in the streamwise direction, and widely spaced profile data (> 1 m spacing) are generally inadequate at representing bank erosion (O'Neal and Pizzuto, 2011). In addition, cross section surveys alone cannot be used to establish the cause of any change.

To improve on previous studies and address the concerns of the landowners and commercial jet boat operator, this investigation uses a three-pronged approach, collecting data at a range of spatial and temporal scales. This approach involves:

1. Broad-scale quantification of the extent of erosion along the jet boat reach and the reach immediately downstream, and a broad assessment of how this has changed over the last 5-10 years.
2. Detailed quantification of bank erosion at 7 selected sites (4 in the jet boat reach and 3 in the downstream reach) using a terrestrial laser scanner (TLS), repeated 4 times over an 18 month period, allowing an estimation of how rates of erosion compare between the jet boat reach and the downstream reach.
3. Installation of surveillance cameras at the same 7 sites and collection of photos at 5 minute intervals, assessing the timing of any erosion in relation to potential disturbances.

A detailed methodology for each part of our investigation is provided in the following section.

2 Phase 2 Methodology

2.1 Full reach inventory of bank erosion sites

Inventories of bank erosion sites along the full length of the 9.2 km jet boated reach and the 3.4 km section of river immediately downstream of the jet boated reach were recorded at the start (21 October 2009) and end (7 April 2011) of this investigation. The type of data and method of collection were kept consistent with the inventory collected by NIWA in October 2004 so that inventories could be compared as much as possible.

Bank erosion was viewed from a jet boat travelling slowly (< 5 knots) along the river. All sites with notable erosion (at least 1 m^2 in area) were recorded and photographed. The approximate height and length of erosion were estimated. In October 2009 the location coordinates of the erosion sites were determined by time-synchronising erosion photos with a tracklog from a handheld GPS. Due to the narrow and vegetated nature of the gorge, there was not always sufficient satellite coverage to record a GPS location, resulting in gaps in the track log. In April 2011 way-points were collected at each site and linked to each photograph. This proved a more reliable method of collecting location coordinates. The type of erosion at each site was classified as either a slip, a slump, gully erosion, current scour or undercutting as in section 1.1.3.

2.2 Terrestrial Laser Scanning

2.2.1 Site selection

Seven sites were selected for detailed bank erosion measurement using a Terrestrial Laser Scanner (TLS). Each site was scanned on 15 December 2009, 30 March 2010, 6 December 2010 and 30 May 2011.

Potential sites for TLS were identified in October 2009 during the field inspection. Of the 87 erosion sites recorded, ten were identified as suitable for TLS (five in the jet boated reach and five in the reach downstream). The final seven sites were selected on the first day of scanning (15 December 2009) in consultation with the TLS field operator (Mike Pinkerton of Aurecon). Photographs of the seven sites, taken prior to the first scan, are presented in Figures 2-1 to 2-7. To be a suitable site for TLS, an erosion site needs to:

- be of sufficient size that there is a good chance of measuring erosion
- have minimal vegetation cover, as vegetation reduces the accuracy of the scan
- have space on the opposite bank to set up the TLS equipment with a clear view of the erosion site. The TLS set up location also needed to be sufficiently stable that it would be unlikely to change over the period of the study.

2.2.2 Scanning

Of all the technologies to emerge in recent years, TLS has been transformative in its potential for mapping channel change, as it provides a means of rapidly collecting topographic data with high point precision (2-4 mm in the xyz) and high-resolution point spacing (less than a centimetre). The resulting data are a 3D point cloud constructed from individual point measurements. The distance of each point from the scanner is determined by either the time of flight or the phase difference of the laser pulse.

Figure 2-1: Bank erosion Site 1. Located at E2806669 N6365226 on the left bank within the jet boat reach.

Figure 2-2: Bank erosion Site 2. Located at E2808097 N6366071 on the left bank of the jet boat reach.

Figure 2-3: Bank erosion Site 3. Located at E2808418 N6366381 on the right bank of the jet boat reach.

Figure 2-4: Bank erosion Site 4. Located at E2808471 N6366858 on the right bank of the jet boat reach.

Figure 2-5: Bank erosion Site 5. Located at E2808574 N6370097 on the right bank of the control reach.

Figure 2-6: Bank erosion Site 6. Located at E2808166 N63670551 on the left bank of the control reach.

Figure 2-7: Bank erosion Site 7. Located at E2807956 N6370912 on the right bank of the control reach.

Two different scanners were used during the study, a Leica Scanstation and a Leica C10. These scanners both collect xyz and intensity of signal return data but the latter also incorporates a photo overlay, collecting RGB (red green blue intensity) data for every point scanned. Both these models have a compensator, which allows for a small amount of movement in the TLS during the scan (e.g. due to wind), and this was used during all scans.

At each erosion site the scanner was set up on the opposite bank with a clear view of the bank erosion in question (Figure 2-8). Prior to each bank erosion scan the scanner calculates its position relative to a site specific coordinate system (with a local 0,0,0 coordinate system and arbitrary orientation) by scanning a series of orientation pegs. It is vital that the position of these orientation pegs remains constant between repeat scans. This allows the repeat scans for each site to be overlaid so that change in the bank can be calculated. Unfortunately some of the orientation pegs at Site 7 moved after the second scan (as a result of bank engineering works) so the final two scans at this site could not be compared with the original scan. Orientation pegs at Site 5 moved after the third scan (as a result of vegetation removal) so the final scan could not be compared.

BOPRC surveyors tried to tie these individual sites into a common coordinate system (e.g. NZMG) by surveying the set up and orientation pegs. However, the limited satellite coverage in the jet boat reach meant that an accurate position could not be established for many of these pegs and this exercise was largely unsuccessful. If this had been successful the movement of the orientation pegs at Sites 5 and 7 would not have been a problem. Unfortunately, the localised control point network used during this investigation has surpassed its design life (primarily due to erosion and peg movement at most sites). This makes the possibility of comparing any future scans with those collected during this study remote.

Figure 2-8: The TLS positioned opposite Site 3 ready for the 30 March 2010 scan.

2.2.3 Analysing the TLS data

The TLS data were processed through six main steps to in order to calculate changes at each site between each survey:

1. The software package Cyclone (developed by Leica) was used to view each data point cloud and, for each site, a vertical reference plane was positioned parallel to the bank in question. A new xyz origin was selected on this reference plane so that all data points measured from this origin would have a positive value (required later during the ‘data filtering’ process) and bank erosion would be represented in a single coordinate direction (i.e. the x dimension in Figure 2-9).

2. All scan data were reoriented relative to the new site specific xyz origin using MATLAB software.

3. Digital Elevation Models (DEMs) are typically viewed from above (i.e. birds eye view) which is inappropriate when looking at changes in a vertical bank. To allow for this, we swapped the x and z coordinates (effectively just changing their labels) in MATLAB so that later processing would allow the data to be viewed from the correct perspective.

4. The TLS runs a series of swaths, collecting data as series of overlapping grids that have a higher point cloud density for points closest to the scanner. The

data also includes laser returns from bank vegetation as well as the bare bank we are interested in. Therefore, the data was filtered to remove redundant and irrelevant data. This process was carried out by overlaying a 10 cm x 10 cm grid on the reference plane (data was of poorer quality at sites 3 and 5 so a 20 cm x 20 cm grid was used) and calculating a series of statistics from the data collected within each grid cell. The point with the greatest distance in the z dimension (z_{max}) in each grid cell was considered to best represent the bare bank at that location. This process of data filtering was carried out using a piece of PYTHON script called TOPCAT, that was developed by Professor James Brasington, currently at University of Canterbury.

5. The filtered data exported from TOPCAT was then imported into ArcGIS as a point shapefile. A polygon was then drawn around the set of points and a TIN (triangular mesh) was generated from the points representing the bank surface. Each TIN was then converted into a raster (grid format) forming a DEM from each data scan.

6. At each site the DEMs from repeat scans were each subtracted from the first DEM generating 'DEMs of difference'. These are essentially a grid representing the change at a site over the scan intervals. Histogram data were generated from these DEMs of difference so that the maximum, minimum, mean and standard deviation of change could be compared. In each case a positive value of difference represents accretion or vegetation growth and a negative value of difference represents erosion.

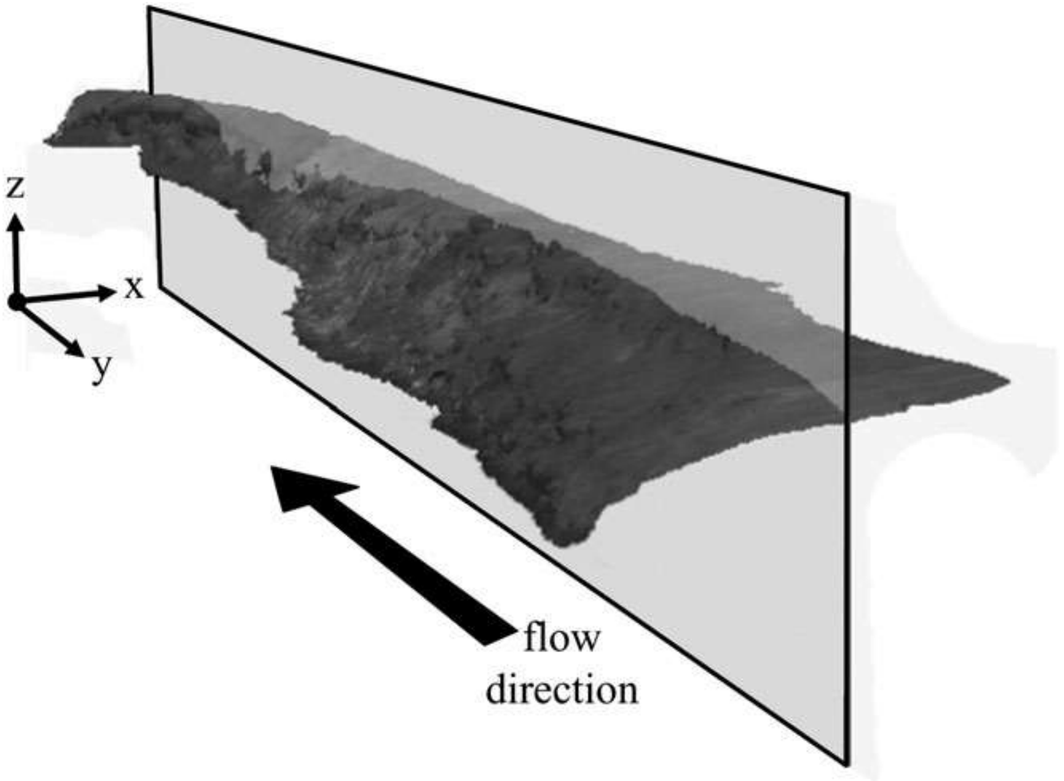


Figure 2-9: Shaded relief image of a river bank with vertical reference plane placed such that change in the x direction is best represented. Figure taken from O'Neal and Pizzuto (2011).

2.3 Surveillance cameras

The cameras installed at each bank erosion site were RedEye surveillance cameras (Figure 2-10). These cameras have a 3.7 mm lens with a focal point of 5 m and take 640x480 pixel colour images. They have a 2GB memory card and very low power consumption for the quality of image collected (1.9 mA standby and 100 mA running). As they also have a solar panel (theoretically removing the need for battery replacement) the intention was that these cameras would only need to be revisited every three months for memory card downloading.

Figure 2-10:The RedEye surveillance camera installed at Site 1.

The cameras were installed at each of the seven bank erosion sites on 31 March 2010 and were set to collect a photograph every five minutes. The periods over which surveillance photos were collected are outlined in Table 2-1. The aim was to attach the cameras to steel warratahs in a position with an oblique view of the bank in question so that any change could be most clearly viewed. This was not always possible with Cameras 2 and 3 having to be set up on the opposite bank and Cameras 5 and 6 needing to be attached to willow trees. The 5 m focal length was also shorter than ideal, particularly for the cameras set up on the opposite bank at a distance of around 30 m, however, the photographs taken were still adequate for their purpose.

The camera at Site 3 stopped working for no apparent reason on 6 June 2010. This camera was restarted at on 9 December 2010. The batteries in Cameras 2, 4, 5 and 6 all died after the 11 August 2010 download. Unfortunately, the cameras installed at Sites 5 and 6 both went underwater on 25 May 2010 during a flood. While the cameras are weather proof, they are not designed to be completely submerged. Luckily, these cameras continued to collect photographs for a couple of months after submergence but the batteries died soon after. It is unclear whether their final demise was the result of submergence, but it seems fairly likely. The camera at Site 1 was never seen again after the 11 August 2010 download. It is believed that the camera fell into the river and was washed away along with the bank it was attached to. The camera at Site 7 had to be removed on 13 April 2010, just 2 weeks after it was installed, as engineering works were carried out on this bank erosion site. This camera was reinstalled on the Hareb's property on 26 April 2010 but stopped working several weeks later. The camera was restarted on 26 June 2010 and then went missing (presumed stolen) sometime after it was last downloaded on 5 July 2010.

Table 2-1: Periods over which surveillance photos were taken for each bank erosion site. Note: Hareb's Site was not one of the main bank erosion study sites but the camera from Site 7 was moved here after Site 7 had to be abandoned due to engineering works.

Camera site	Start of surveillance period	End of surveillance period
Site 1	31/3/2010 12:07	11/8/2010 10:40
Site 2	31/3/2010 13:25	11/8/2010 11:10
Site 3	31/3/2010 14:00	6/6/2010 14:05
Site 3 (restarted)	9/12/2010 10:46	19/1/11 08:37
Site 4	31/3/2010 14:46	11/8/2010 11:43
Site 5	31/3/2010 15:46	11/8/2010 12:10
Site 6	31/3/2010 16:23	27/7/2010 09:25
Site 7	31/3/2010 16:58	13/4/2010 11:05
Hareb's Site	26/4/2010 08:36	6/5/2010 07:00
Hareb's Site (restarted)	23/6/2010 14:27	5/7/2010 16:34

2.4 Collection of Bank Sediments

During the community meeting at the start of this investigation, landowners raised the concern that bank material in the jet boat reach differed from that in the reach immediately downstream (the control reach). To examine whether or not differences in bank material might need to be accounted for when comparing erosion measured at each of the sites, samples of bank material were collected for grain size analysis from each of the bank erosion sites. Each sample was collected by hand and comprised material collected from various parts of the bank in order to represent the bank erosion site as well as possible.

The sediment samples were dried overnight in an oven in the NIWA laboratory at 100^{o}C. These samples were then sieved at ½ phi intervals down to 38 μm and each fraction was weighed to an accuracy of 0.1 g.

3 Results

3.1 River flows during study period

The Mangorewa River joins the Kaituna River just downstream of the jet boat reach and, therefore, flows in the Mangorewa River as well as the Kaituna River are of relevance to this study. The flow record for the reach described in this study are best described by measurements from 3 flow gauges (Figure 1-1). Flow in the Mangorewa River is measured at the Saunders Farm gauge. Flow just downstream of the control reach is measured at the Kaituna at Te Matai gauge. This record is considered representative of the control reach and the difference between the Te Matai record and the Mangorewa record is representative of the jet boat reach. The Kaituna at Taaheke gauge is also of interest, even though it is well upstream of the jet boated reach, as it gives an indication of the flow released into the Kaituna River from the Okere Control Gates at the outlet from Lake Rotoiti. The hydrographs from these three gauges are overlaid and presented in Figure 3-1.

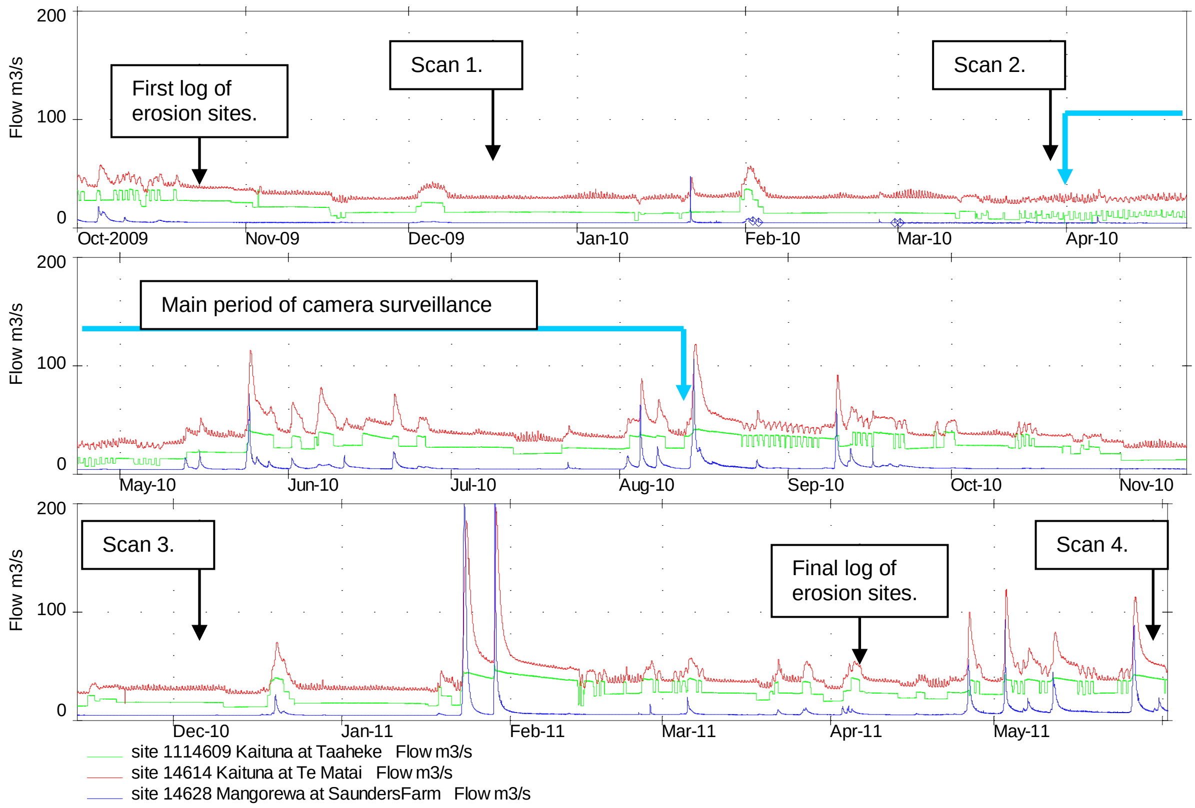


Figure 3-1: Hydrographs for the Kaituna and Mangorewa Rivers during the study period. The timing of the full reach bank erosion assessments, the TLS scans and the camera surveillance period are indicated.

Figure 3-1 highlights that the first three TLS scans were conducted at times of relatively low flow but that water level was relatively high during Scan 4. Two significant floods occurred in close succession in January 2011 between TLS Scans 3 and 4. These floods were both recorded peaking at around 200 m^3/s at the Kaituna at Te Matai gauge, each representing a 5-10 year return period event (Surman, 2005). These floods were particularly large in the Mangorewa River and therefore the effect in the study reach would likely have been greater in the control reach than in the jet boat reach. A number of other moderate events also occurred during the study period. One event in the order of 100 m^3/s occurred during the period in which the surveillance photos were captured. This size flood represents a 2 yr return period event (Surman, 2005). Another flood of this magnitude occurred soon after the August 2010 download of photos and may have been the flood that removed Camera 1 and contributed to demise of several others. A series of moderate sized floods also occurred between the final log of erosion sites along the full reach and Scan 4. The minimum, maximum and mean flow for each of these gauges during the study period are presented in Table 3-1.

Table 3-1: Flow over the full study period.

Gauge site	Minimum flow (m^3/s)	Maximum flow (m^3/s)	Mean flow (m^3/s)
Kaituna @ Taaheke	3.7 on 31 March 2010	51.7 on 29 January 2011	23.6
Kaituna @ Te Matai	15.9 on 22 November 2010	197.0 on 29 January 2011	38.2
Mangorewa @ Saunders Farm	4.3 on 18 March 2010	495.0 on 29 January 2011	6.8

3.2 Terrestrial laser scanning

Results from the TLS work are presented as DEM of difference images and histograms. The DEM of difference images give us an impression of the change measured between the various scans at each site. In particular, they show us where on the bank erosion and deposition (or vegetation growth) has occurred and which scans it occurred between. For each DEM of difference a histogram can be generated and these enable quantification of how much change has occurred, the maximum amount of erosion, the maximum amount of deposition or vegetation growth, and the mean change across the full section of bank scanned. Despite the post-processing of the TLS data to remove erroneous data, the results inevitably include a degree of measurement error. While the TLS instrument is able to measure with a precision of 2-4 mm, for banks with areas of dense vegetation cover local error (or noise) is believed to be in the order of 5-10 cm. For this reason, caution should be taken when considering the absolute values measured for the maximum degree of erosion and deposition at each site.

Note that the distance scale and the degree of change scale for each site varies as the length of bank scanned and the amount of change that has occurred varies between sites. Within each site, the scales are kept the same so that the changes over time can be directly compared. On both the DEM of difference images and the histograms, negative values represent erosion and positive values represent deposition or vegetation growth in the period in question. On each histogram 0 (i.e. ‘no change’) is highlighted with a red line.

3.2.1 Site 1

The DEM of difference images for this site are presented in Figure 3-2 and the histograms are presented in Figure 3-3. Mean change over the full area scanned between the first two scans was 3 cm of erosion. Between Scan 1 and Scan 3 the mean change over the area scanned was 20 cm of erosion. Between the first and last scan mean change over the area scanned was 2.62 m of erosion. Figure 3-2 shows that changes prior to Scan 3 were focused along the toe of the bank, whereas later changes occur over the full area of bank scanned.

The large section of bank at the downstream end of this site eroded into the river during the January 2011 flood. This can clearly be seen in Figure 3-2 c). This was the section of bank that the surveillance camera was attached to.

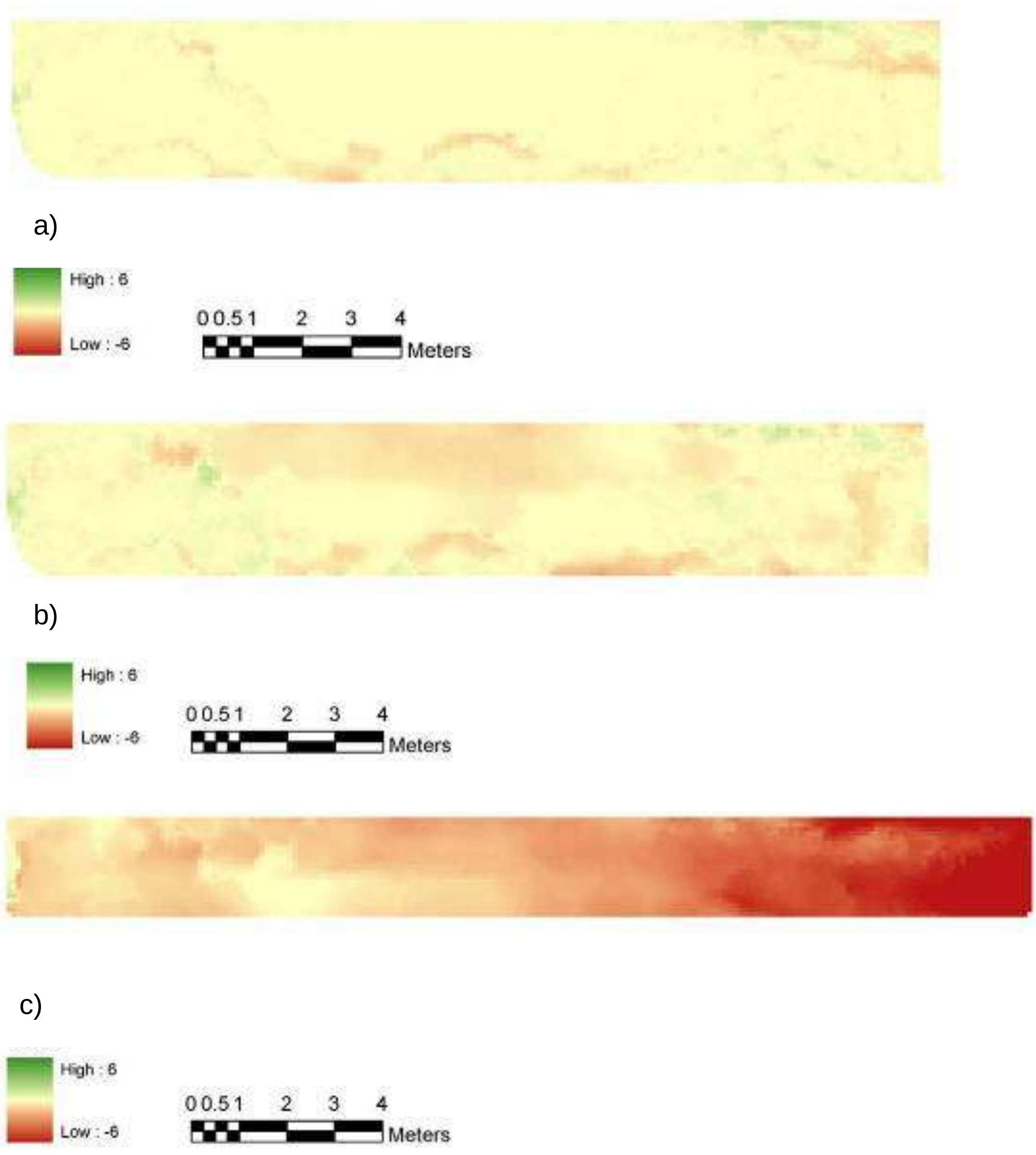


Figure 3-2: DEM of difference images for Site 1. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011). Note flow is from left to right.

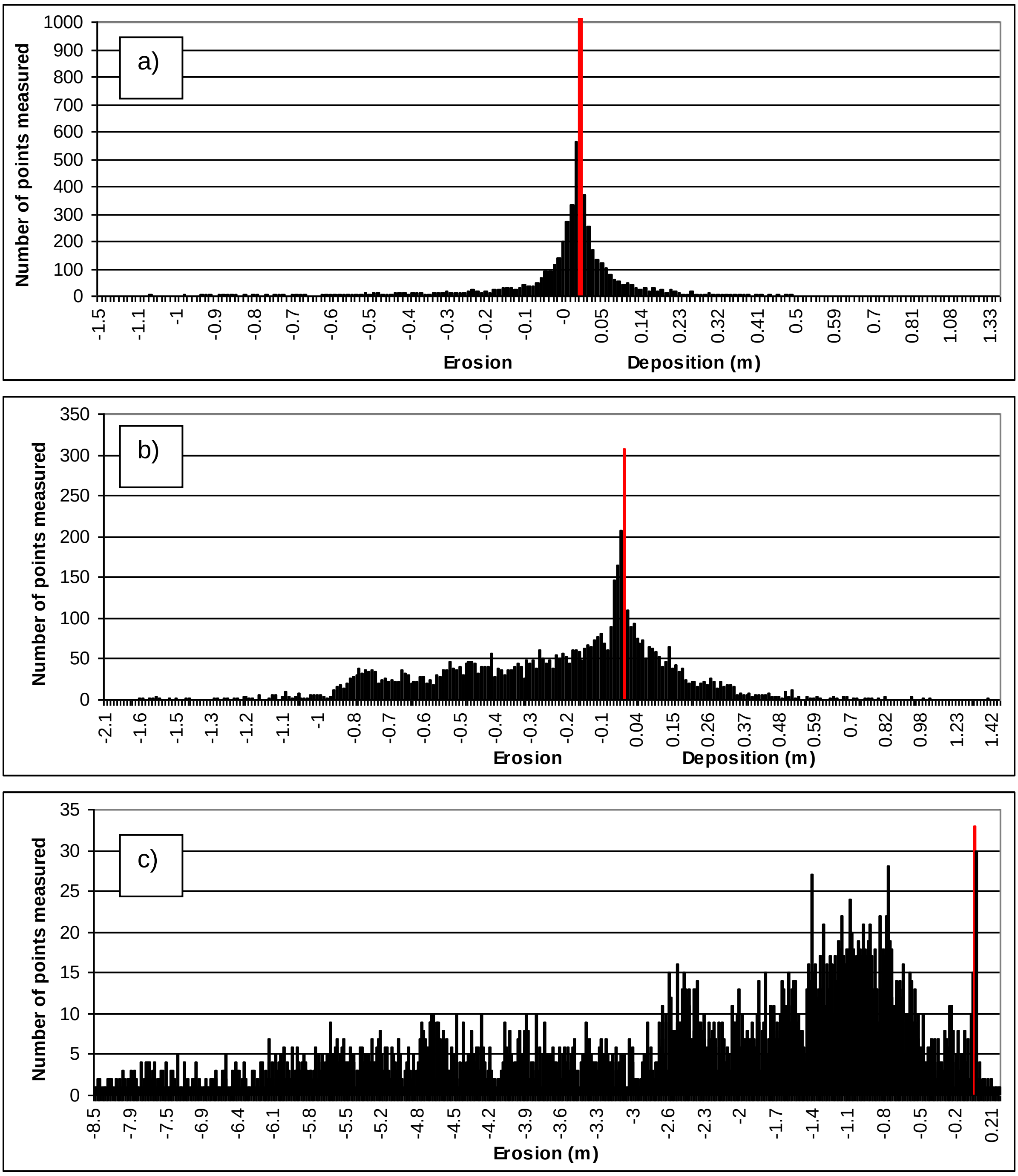


Figure 3-3: Histograms of the DEMs of difference for Site 1. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011).

3.2.2 Site 2

The DEM of difference images for Site 2 are presented in Figure 3-4 and the histograms are presented in Figure 3-5. Mean change over the full area scanned between the first two scans was 14 cm of deposition. This change is more likely vegetation growth than accretion, as a significant increase in vegetation cover was noted at the time of the second scan. Between Scans 1 and 3 the mean change over the area scanned was 8 cm of erosion. Figure 3-4 b) shows that much of this occurred along the toe of the bank. Areas of the previous vegetation growth, particularly at the upstream end of the scan area, clearly remained at the time of the third scan. Between the first and last scan mean change over the area scanned was 19 cm of erosion. The height of bank that was able to be captured during Scan 4 was less than the previous scans, as water level was higher at this time. As a result, the DEM of difference shown in Figure 3-4 c) is a narrower strip of bank. This also means that any further changes along the toe of the bank are obscured.

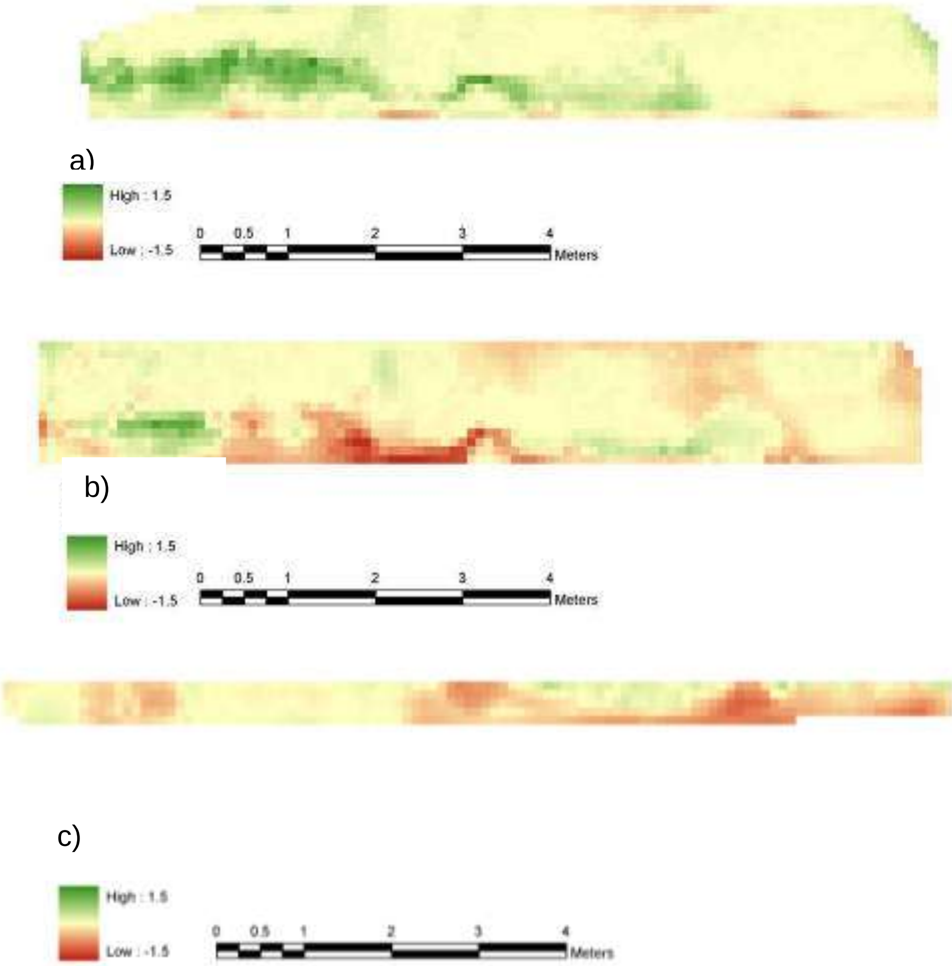


Figure 3-4: DEM of difference images for Site 2. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011). Note flow is from left to right.

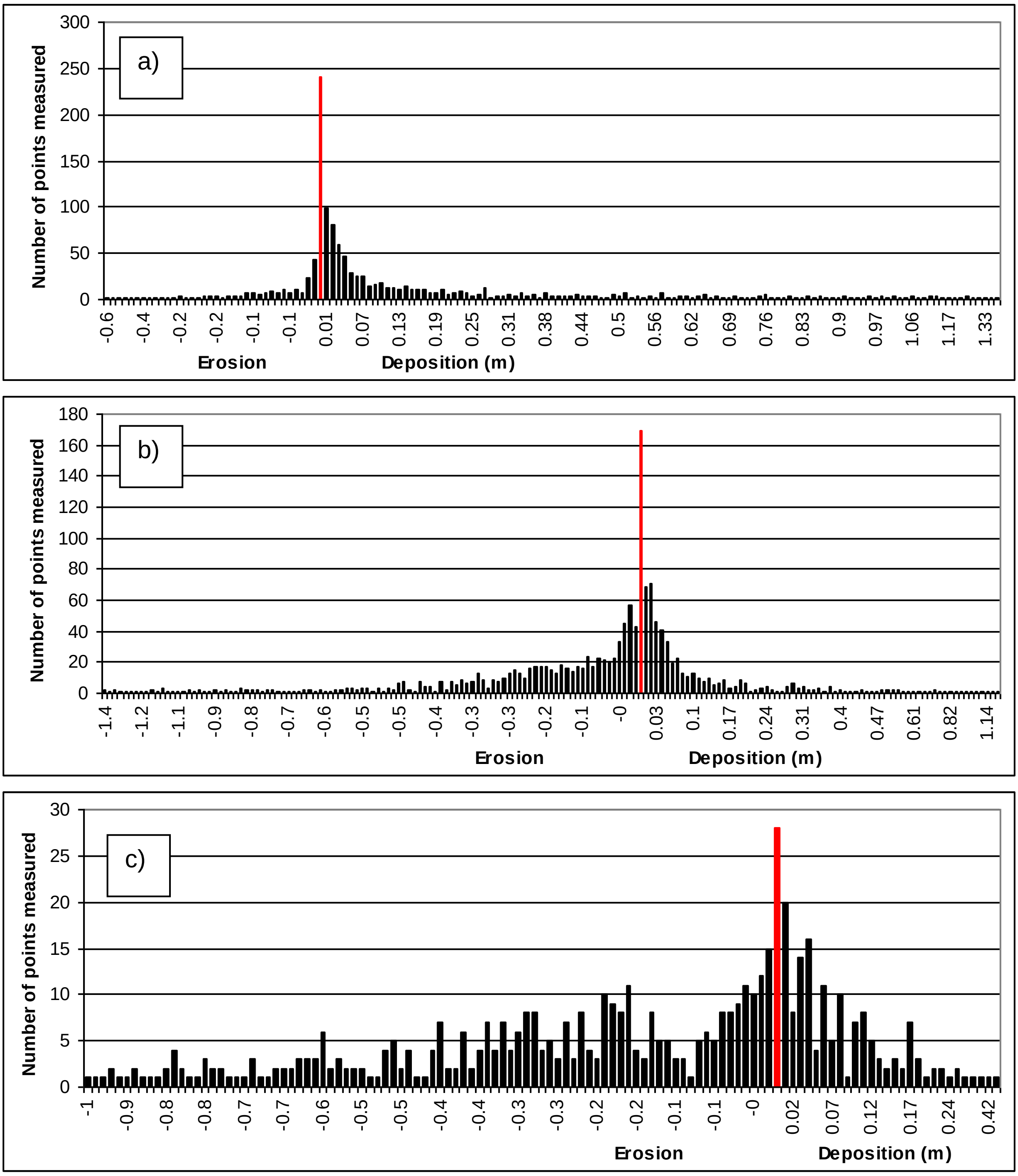


Figure 3-5: Histograms of the DEMs of difference for Site 2. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011).

3.2.3 Site 3

The DEM of difference images for Site 3 are presented in Figure 3-6 and the histograms are presented in Figure 3-7. Mean change over the full bank between the first two scans was 3 cm of deposition (more likely vegetation growth). Between Scans 2 and 3 the mean change over the area scanned was 6 cm of erosion. Between the first and last scan mean change over the area scanned was 15 cm of erosion. The changes over the first three scans can generally be considered negligible as this is a relatively vegetated bank. However, change before Scan 4 is clear in part c) of both figures.

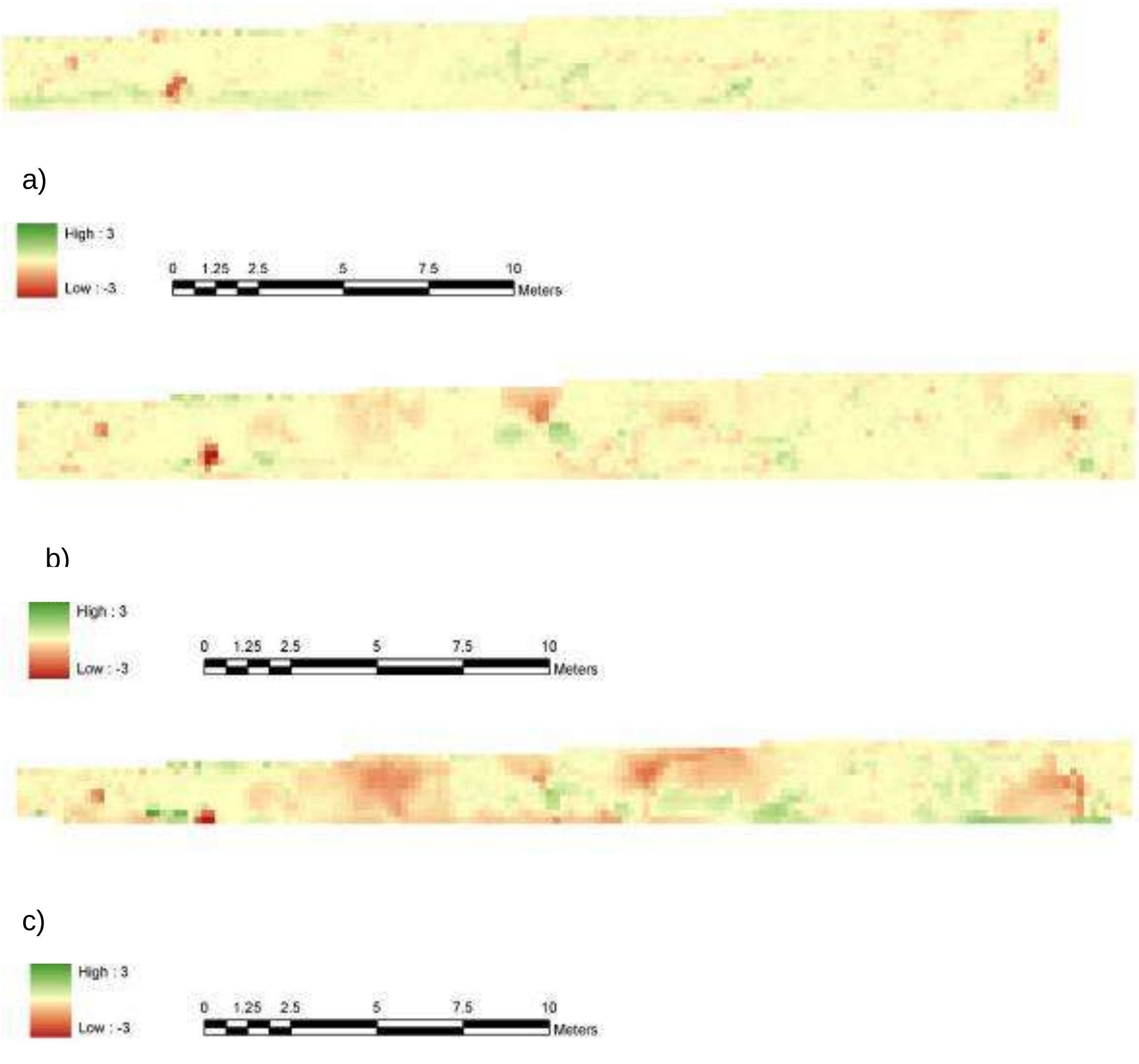


Figure 3-6: DEM of difference images for Site 3. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011). Note flow is from right to left.

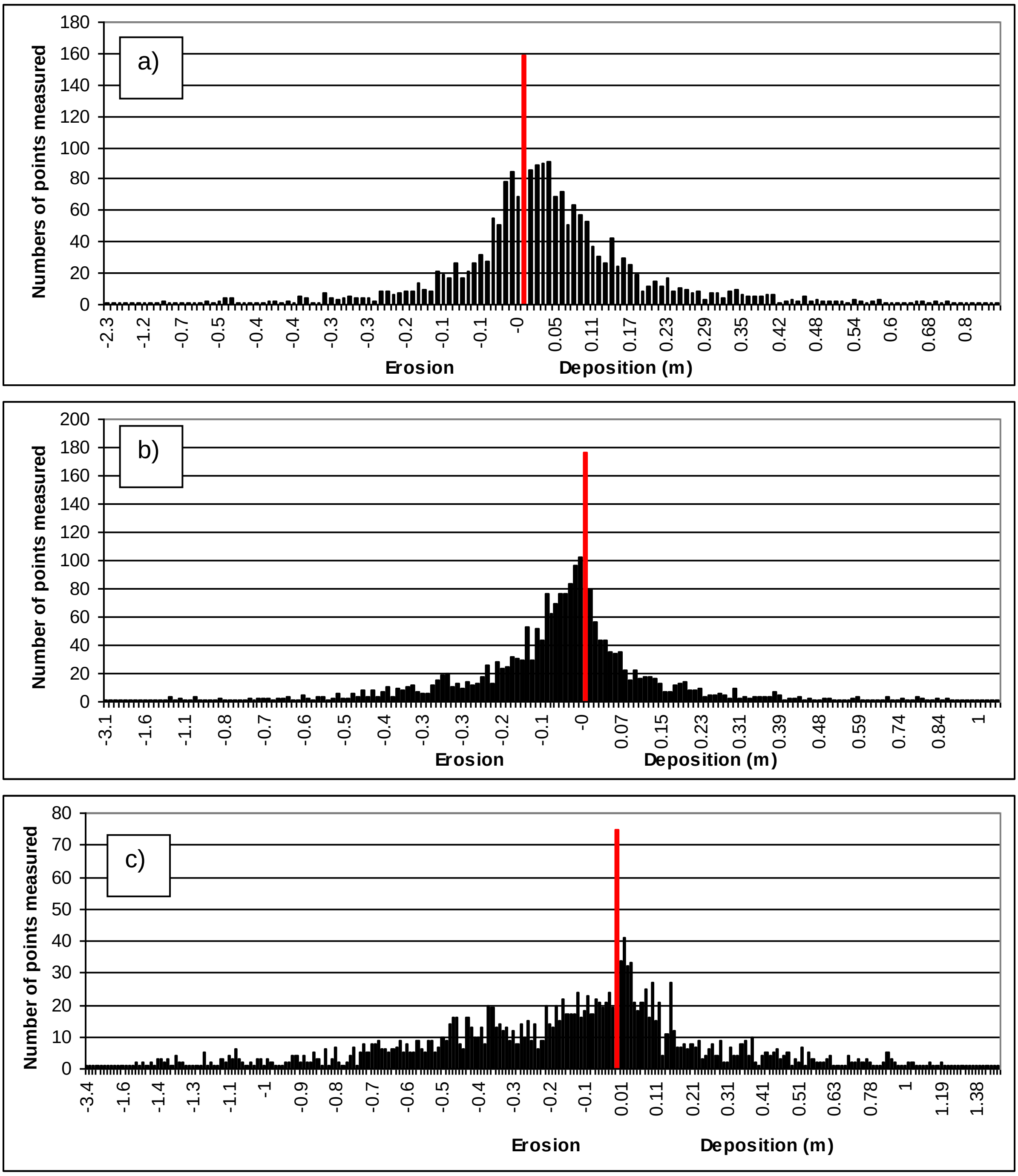


Figure 3-7: Histograms of the DEMs of difference for Site 3. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011).

3.2.4 Site 4

The DEM of difference images for Site 4 are presented in Figure 3-8 and the histograms are presented in Figure 3-9. Overall, change between Scans 1 and 2 at this site is generally negligible with a mean change over the area scanned of 1 cm of erosion. However, Figure 3-8 a) clearly indicates a strip of erosion along the toe of the bank. Mean change between Scans 1 and 3 was 9 cm of erosion. While this mean indicates a net loss of material, Figure 3-8 also indicates that some slumping has occurred, with material removed from the top of the bank but deposited at the bottom of the bank. The same feature is apparent to a greater degree in part c) of Figure 3-8 but much of the slumped material has been eroded from the top of the bank. Mean change over the area scanned between the first and last scan was 49 cm of erosion.

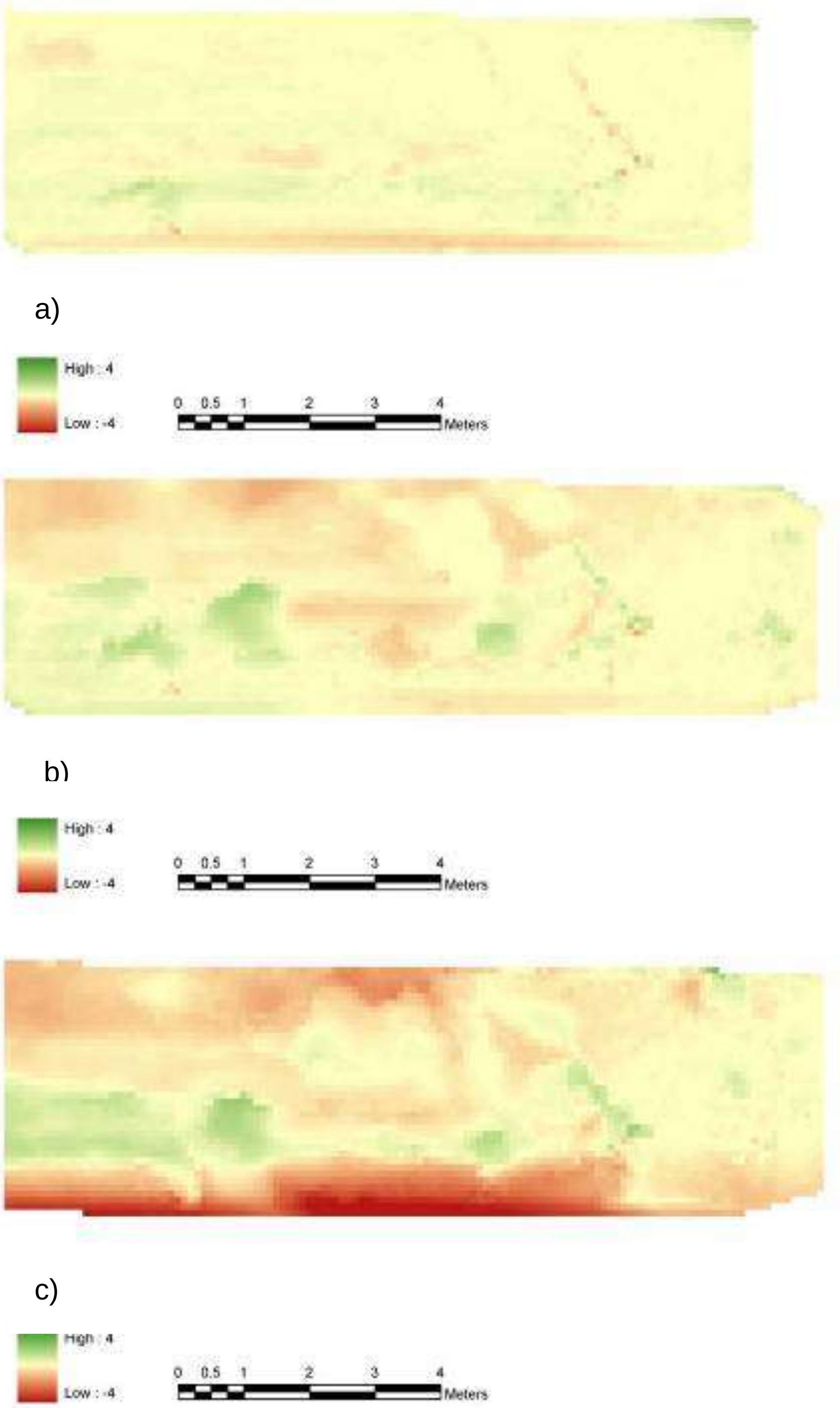


Figure 3-8: DEM of difference images for Site 4. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011). Flow is from right to left.

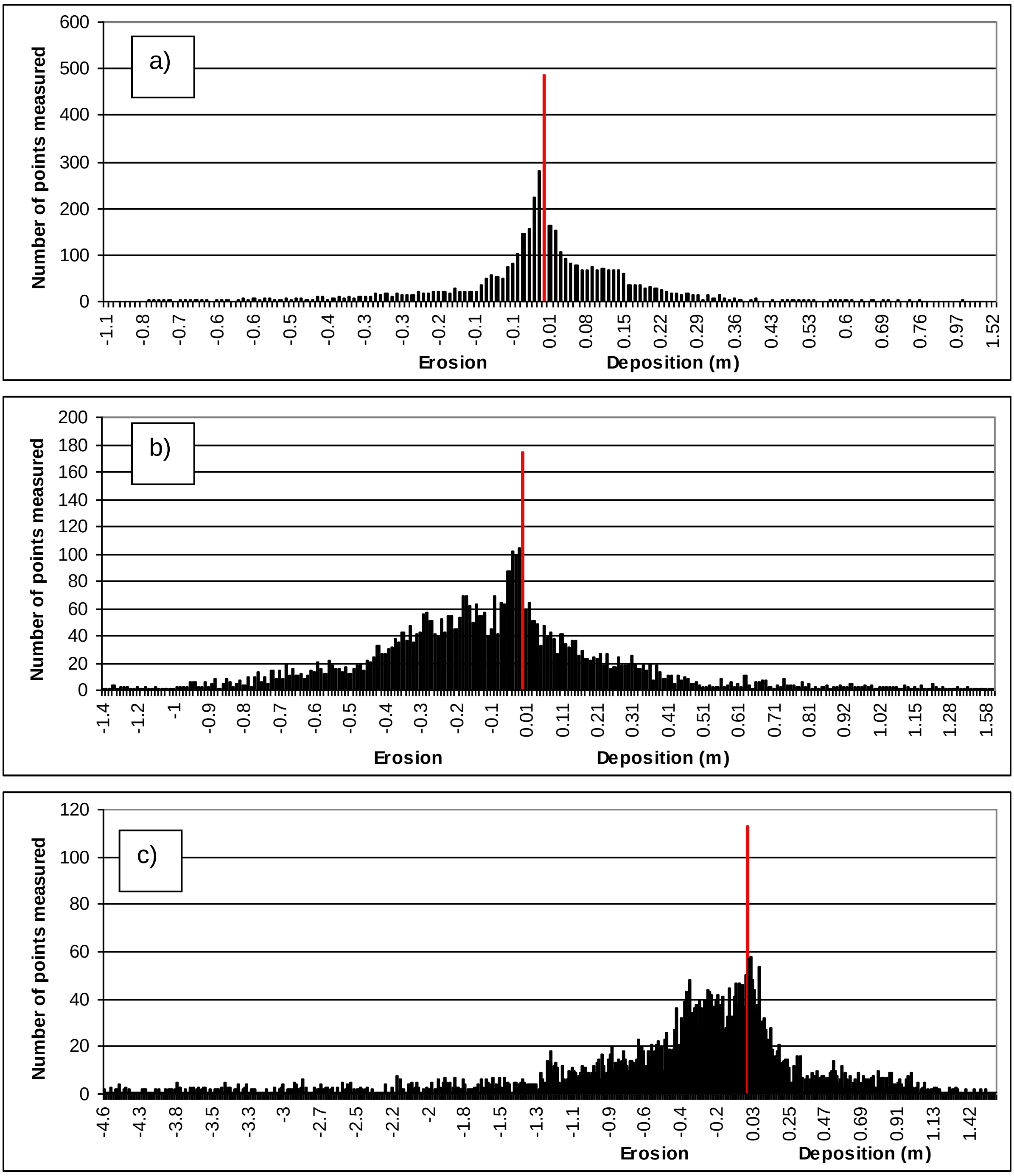


Figure 3-9: Histograms of the DEMs of difference for Site 4. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011).

3.2.5 Site 5

Only three scans could be compared at Site 5, as several of the TLS orientation pegs moved after the third scan. The DEM of difference images for this site are presented in Figure 3-10 and the histograms are presented in Figure 3-11. Between the first and second scans mean change over the full area of scanned bank was 5 cm of erosion, however, most of the change can be seen to have occurred in one particular area (Figure 3-10 a). This differs from the change between Scans 1 and 3 where erosion is clear on Figure 3-10 b) across the full length and particularly the upper part of the bank. Mean change between the Scans 1 and 3 was 26 cm of erosion.

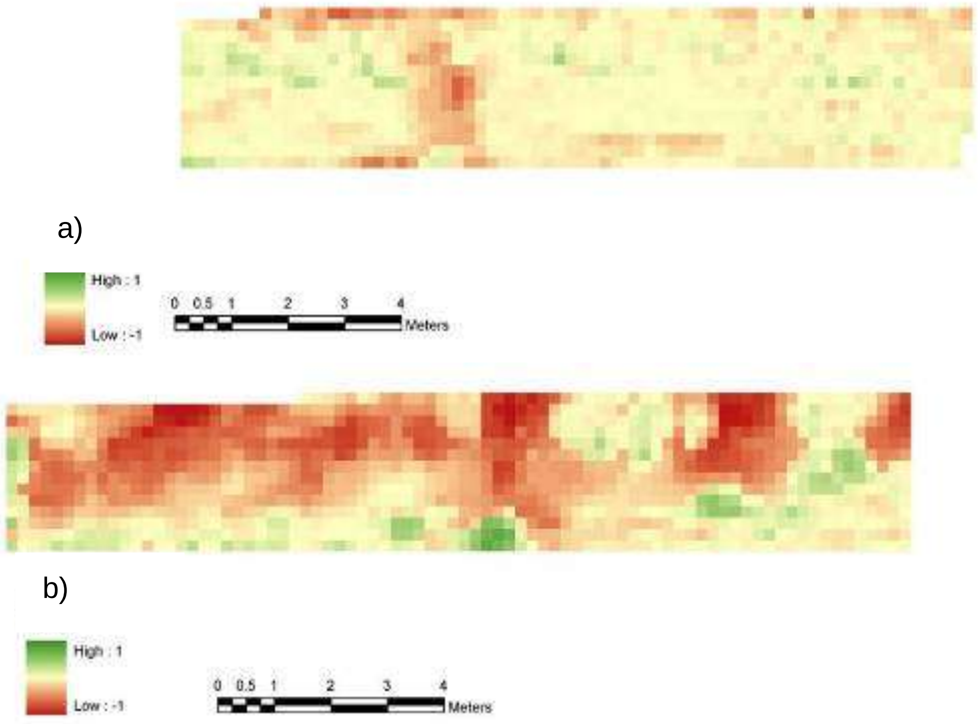


Figure 3-10:DEM of difference images for Site 5. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010). Note flow is from right to left.

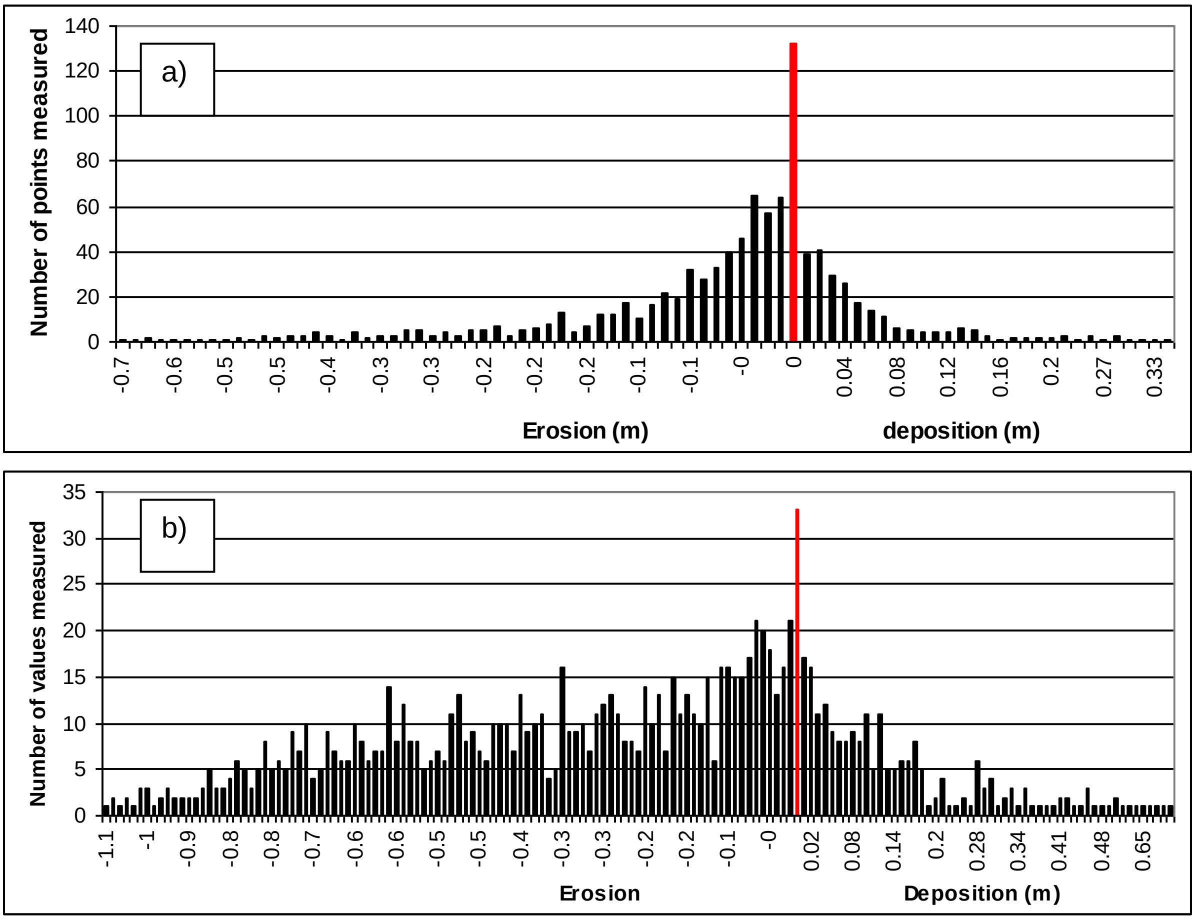


Figure 3-11:Histograms of the DEMs of difference for Site 5. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010).

3.2.6 Site 6

The DEM of difference images for Site 6 are presented in Figure 3-12 and the histograms are presented in Figure 3-13. Change between the first and second scans is negligible with a mean over the area scanned of 1 cm of erosion. Change between the first and third scans is clearer with a patch of vegetation growth at the upstream end, a slip about a third of the way along the bank and erosion at the toe along the downstream half of the bank (Figure 3-12 b). Mean change over the area scanned for this period was 8 cm of erosion. Erosion between the first and last scans increases considerably. It is generally focussed in the same areas of the bank but there is a new area of erosion at the downstream end. Mean change over the area scanned for this period was 58 cm of erosion.

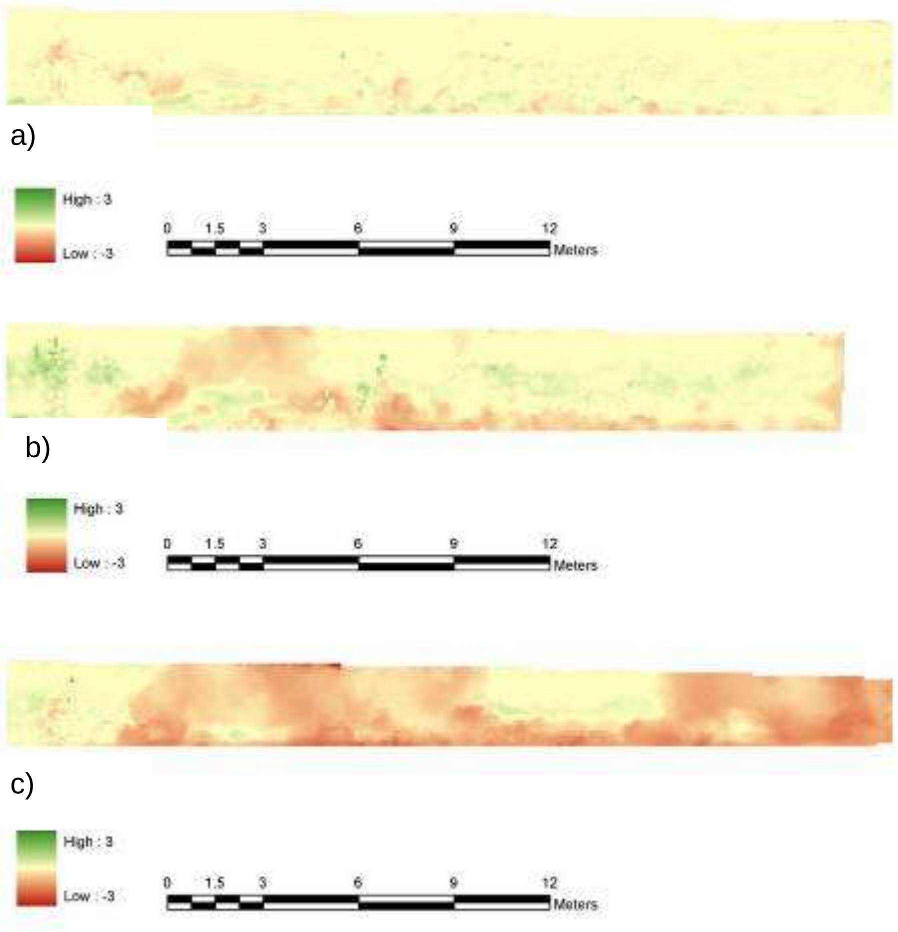


Figure 3-12:DEM of difference images for Site 6. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011). Note flow is from left to right.

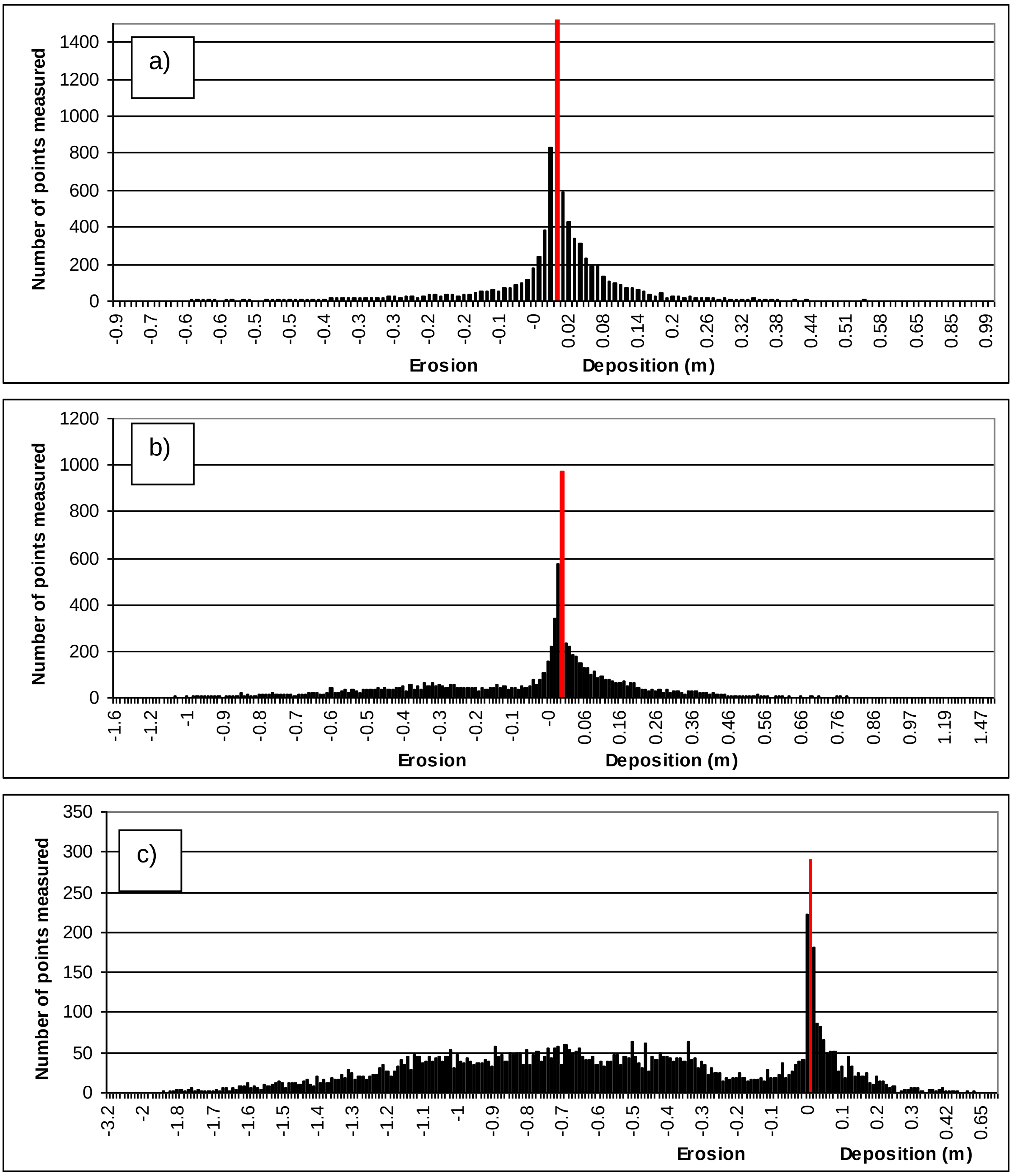
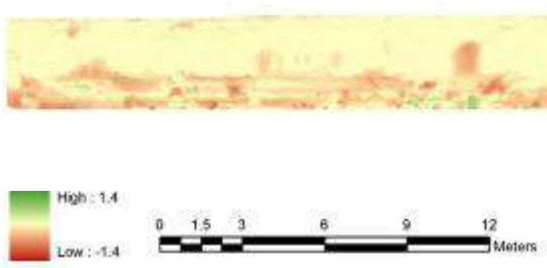


Figure 3-13:Histograms of the DEMs of difference for Site 6. a) between scan 1 (December 2009) and scan 2 (March 2010); b) between scan 1 and scan 3 (December 2010); c) between scan 1 and scan 4 (May 2011).

3.2.7 Site 7

Only two scans could be compared at Site 7, as several of the TLS orientation pegs were removed when the bank engineering works were carried out in April 2010. The DEM of difference image is presented with the histogram in Figure 3-14. As the third and fourth scans could not be used, changes after the second scan cannot be quantified. However, photographs taken during Scan 3 and during the final inventory of bank erosion along the full reach clearly show that significant erosion occurred after Scan 2. These photographs are presented in the following section where they can be compared with surveillance photos.

Mean change over the area scanned between the first and second scan was 9 cm of erosion. This was a period of relatively low flow and the erosion occurred along the toe of the bank. The DEM of difference image in Figure 3-14 shows an area around the middle of the bank where a block of material higher up the bank has collapsed and registers as deposition (green) at the toe of the bank.



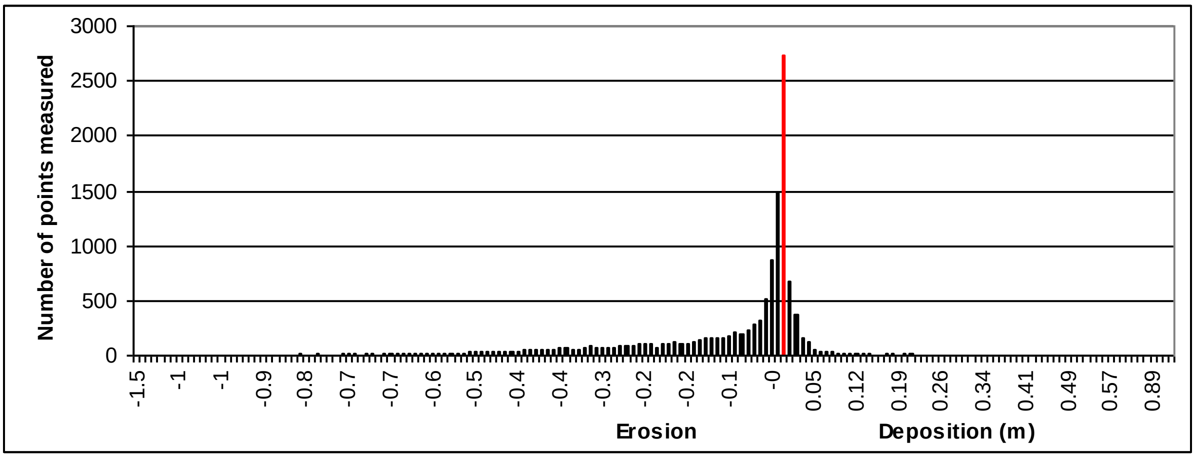


Figure 3-14: DEM of difference and the associated histogram for Site 7. For the period between scan 1 (December 2009) and scan 2 (March 2010). Note flow is from right to left.

3.3 Surveillance cameras

Problems with the surveillance cameras meant that the period over which photographs were collected was much shorter than was anticipated. Nonetheless, Cameras 1-6 each captured between 16,000 and 19,000 photographs, and Camera 7 collected 2000 photographs before it had to be removed following the river bank engineering work. Examining the record of photographs was time consuming but also very revealing. A series of photographs for each site are presented in this section highlighting:

- small areas of bank erosion
- the height and effect of the 25 May 2010 flood (100 m^3/s)
- the presence of stock at every site
- the effect of the jet boat.

Note that each surveillance photo is stamped with the site, date and time that the photo was taken.

Gradual changes in the banks are best viewed by playing the set of photographs for each site as a time-lapse movie. This is the method that was used for analysing all surveillance photos. The movies created play at a rate of 15 photos per second. While photographs of small areas of bank erosion are presented within these results, the differences between each photo may not always be easy to discern. For this reason, the time-lapse movies will also be made available to BOPRC. The photographs presented here can be used to highlight sections of the movies that will be of particular interest.

The period of surveillance occurred between TLS Scans 2 and 3 and, therefore, changes viewed on the surveillance photos contribute to the changes presented in part b) of each figure in the previous section.

Flows in the Kaituna and Mangorewa Rivers during the surveillance period are presented in Figure 3-15. These hydrographs show a number of interesting features. The daily fluctuations in river flow throughout April at the Taaheke gauge site is likely the result of control of the Okere Gates at the outlet of Lake Rotoiti. A corresponding 5-10 cm water level increase could be observed on the surveillance photos each evening during this period. All flood events apparent on the Kaituna at Te Matai hydrograph, including the 25 May 2010 flood, have a corresponding peak on the Kaituna at Taaheke hydrograph, indicating that flow would have increased in both the jet boat and control reaches in each case.

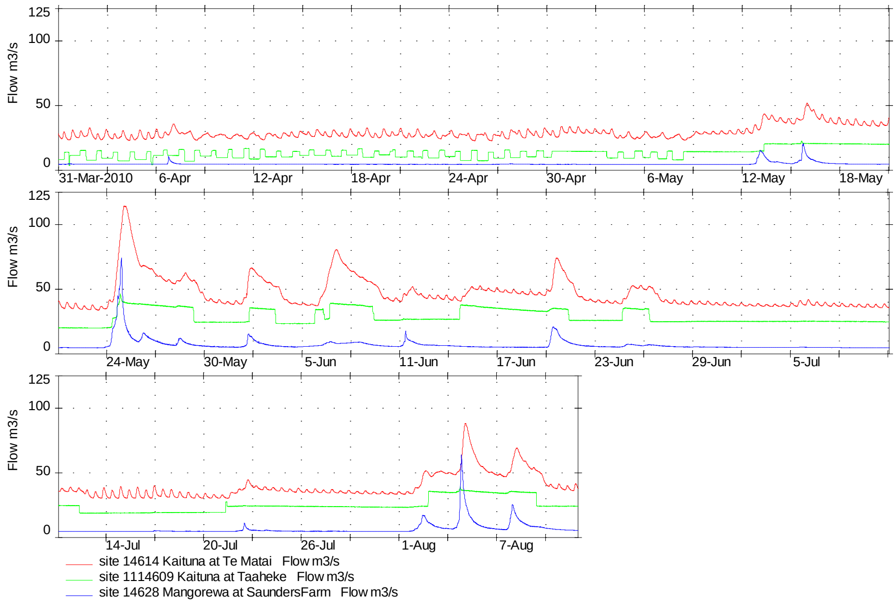


Figure 3-15:Hydrograph for the Kaituna and Mangorewa Rivers for the period during which surveillance cameras were installed.

3.3.1 Site 1

A series of surveillance photographs from Site 1 are presented in Figures 3-16 to 3-27. The camera was set up at the downstream end of the bank so flow is towards the viewer. The first photograph is at the start of the surveillance period just after the second TLS scan. Water levels were particularly low on the 31st of March 2010, as reported in Table 3-1. Figure 3-17 shows Site 1 during the May 2010 flood, with water level approximately a metre higher than it was in the previous photograph. Figure 3-18 is taken 11 days later, and shows that bank material and vegetation has been removed from the downstream end of the bank (in the foreground). The area circled can be compared with the following photo taken just 10 mins later (Figure 3-19), where a small amount of material has been eroded just above the water's edge. The clarity of the water has also reduced slightly in this photo. The water level does not change between these two photographs and, therefore, the erosion is believed to be the result of a jet boat passing. Figure 3-20 clearly shows that stock have access to this site and graze right up to the edge of the bank.

Figures 3-21 and 3-22 are taken 2 hours apart and show a section of bank in the middle of the site slumping into the river. The water at the toe of the bank is also discoloured on Figure 3-22, showing that sediment is being mobilised. This slump may have been caused by jet boating and/or by bank saturation, as this period was preceded by rain. Figure 3-23 shows a wave hitting the toe of the bank and spilling over the vegetation in the foreground. This wave is clearly viewed on the time-lapse movie and is believed to be from a jet boat wake. The following figure (Figure 3-24) is taken 5 minutes later and shows no apparent change. However, Figure 3-25 is taken 25 minutes later and clearly shows that the water is discoloured. During the remaining part of this day, the water cleared and became murky again. This is believed to be the result of a jet boat passing up and down the river. Figures 3-26 and 3-27 show further slumping in the middle part of the bank on 8 August 2010. This corresponds with a flow peak apparent on the hydrograph in Figure 3-15.

Figure 3-16: Initial photo of Site 1 on 31/3/10 To compare with future photos.

Figure 3-17:Site 1 on 25/5/10, during the largest flood that occurred while surveillance cameras were installed.

Figure 3-18:Active erosion at waters edge at Site 1 on 5/6/10. See following figure for site 10 mins later.

Figure 3-19:Active erosion at waters edge at Site 1 on 5/6/10. 10 mins after previous photo.

Figure 3-20:Stock access at Site 1 on 27/6/10.

Figure 3-21:Area of erosion at waters edge at Site 1 on 28/6/10. See following figure for same site 2 hrs later.

Figure 3-22:Area of erosion at waters edge at Site 1 on 28/6/10. 2 hours after previous photo. Note water discolouration.

Figure 3-23:Site 1 on 4/7/10 at 12:25, just as a small wave is hitting the bank. It is assumed that this wave has been generated by a jet boat.

Figure 3-24:Site 1 on 4/7/10 at 12:30. 5 minutes after the previous photo.

Figure 3-25:Site 1 on 4/7/10 at 12:50, 25 minutes after the small wave hit the bank. Note the murky water. The water goes murky at this site on the same day at 13:56, 14:26 and 16:03

Figure 3-26:Active erosion at waters edge at Site 1 on 8/8/10 at 12:20. See the following figure for the same site 5 mins later.

Figure 3-27:Active erosion at waters edge at Site 1 on 8/8/10 12:25. 5 mins after the previous photo. Note the peg in the circled area has disappeared.

3.3.2 Site 2

A series of surveillance photographs from Site 2 are presented in Figures 3-28 to 3-35. This camera was set up directly opposite the bank erosion site so small scale changes are difficult to detect. Flow is from left to right. The first photograph is at the start of the surveillance period just after the second TLS scan. The degree of vegetation growth measured by this TLS scan is clear on this photograph in comparison with Figure 2-2 taken prior to the first scan. Figures 3-29 and 3-30 show an area of bank erosion that occurs over night between 19th and 20th April for no apparent reason. This area of erosion at the top of the bank can be seen in the centre of the DEM of difference in Figure 3-4 b). Jet boating is highly unlikely after dark and the hydrograph indicates no water level change between these 2 photographs that would account for erosion in the upper part of this bank. Figure 3-31, taken later on the same day, shows that stock have been grazing this site, and this is believed to be the cause of the erosion the previous night. Figures 3-32 shows this site during the flood of 25th May. The following photo, showing the site 5 days later, indicates little change with the bank still well vegetated. Figure 3-34 shows the wake of a jet boat that has just passed and, again, the final photograph shows little change at this site. The surveillance photographs indicate that much of the change measured at this site between the first and third TLS scan is likely to be vegetation growth and removal (potentially through grazing).

Figure 3-28:Initial photo of Site 2 on 31/3/10. To compare with future photos.

Figure 3-29:The last photo taken of Site 2 before nightfall on 19/4/2010. The area circled is the site of erosion that occurs overnight.

Figure 3-30:The first clear photo of Site 2 on the morning of 20/4/10 showing an area of new erosion (circled).

Figure 3-31:Cows grazing at Site 2 later on 20/4/10 (17:30).

Figure 3-32:Site 2 during the flood of 25/5/10. Note water level was higher earlier in the day but this was the first clear photograph.

Figure 3-33:The first clear photograph of Site 2 after water level had dropped (30/5/10). Note no apparent new erosion.

Figure 3-34:Site 2 showing the wake of a boat (presumably the commercial jet boat) just prior to it hitting the bank on 21/7/10.

Figure 3-35:Final photo of Site 2 on 11/8/10.

3.3.3 Site 3

A series of surveillance photographs from Site 3 are presented in Figures 3-36 to 3-46. This camera was set up opposite and upstream of the bank erosion site so, again, small scale changes in the bank erosion site itself are difficult to detect. Flow is from right to left. The first photograph is at the start of the surveillance period just after the second TLS scan. Figures 3-37 and 3-38 show that stock have access to both sides of the bank, however, the bank erosion site on the right bank is fenced so that stock cannot graze right to the edge of the bank. Figure 3-39 shows a jet boat passing and the following photograph, taken later on the same day, shows the wake of a jet boat that has just passed hitting the bank in several locations. Unfortunately, the camera is too far away from the far bank to see if any bank material is mobilised.

Figure 3-41 shows this site during the 25 May 2010 flood. The following four figures (3-42 to 3-44) are perhaps the most revealing of all the surveillance photos taken, with regard to the effect of jet boating. These four photos are all taken on 27 May 2010. This follows a period of elevated flow, however, the first photo (Figure 3-42) shows that the river is relatively clear and calm. However, the following photo (Figure 3-43) taken just 5 minutes later shows a strip of turbid water along the edge of the near bank indicating active bank erosion. This is attributed to jet boat activity, supported by Figures 3-44 and 3-45, which show a jet boat passing and then 5 minutes later, a turbid fringe along the near bank (although not as obvious as in Figure 3-43). The final photo shows this site at the end of the surveillance period, but change in comparison with the initial photograph is difficult to detect at this distance from the site.

Figure 3-36:Initial photo of Site 3 on 31/3/10. To compare with future photos.

Figure 3-37:Stock access at Site 3 on 8/4/10.

Figure 3-38:Stock access opposite Site 3 on 19/4/10 at camera set up location.

Figure 3-39:Jet boat passing Site 3 on 1/5/10.

Figure 3-40:Jet boat wake hitting Site 3 on 1/5/10 at 16:50. Waves hitting the bank are circled.

Figure 3-41:Site 3 during the flood of 25/5/10.

Figure 3-42:Site 3 on 27/5/10 at 12:10. For comparison with following photo 5 mins later

Figure 3-43:Photograph taken on 27/5/10 at 12:15 clearing showing a high degree of suspended sediment along the edge of the near bank opposite Site 3.

Figure 3-44:Photograph of Site 3 later on 27/5/10 (16:20) showing that the commercial jet boat was opperating on this day.

Figure 3-45:Site 3 on 27/5/10 at 16:25. Taken 5 mins after jet boat passes. Although not as extreme as the photo taken at 12:15, this photograph also shows suspended sediment along the bank opposite Site 3.

Figure 3-46:Final photo of Site 3 on 18/1/11.

3.3.4 Site 4

A series of surveillance photographs from Site 4 are presented in Figures 3-47 to 3-54. This camera was set up at the downstream end of Site 4 so flow is from left to right and towards the viewer. The first photograph is at the start of the surveillance period just after the second TLS scan. Figures 3-48 and 3-49 both show the wake of a jet boat that has just passed and Figure 3-50 shows the commercial jet as it passes. Figures 3-51 to 3-53 show areas of bank erosion and vegetation (both circled) that occur as a result of the 25 May 2010 flood. Figure 3-54 again shows the jet boat passing and an area of vegetation regrowth is highlighted.

Figure 3-47:Initial photo of Site 4 on 31/3/10. To compare with future photos.

Figure 3-48:Jet boat wake at Site 4 on 14/4/10.

Figure 3-49:Jet boat wake at Site 4 on 1/5/10.

Figure 3-50:Jet boat passing Site 4 on 5/5/10.

Figure 3-51:Site 4 on 24/5/10 immediately prior to flood of 25/5/10. Circled area is the site of soil loss (white) and vegetation removal (green) apparent after flood waters recede.

Figure 3-52:Site 4 during flood of 25/5/10. Water was higher earlier in the day but this was the first clear photograph.

Figure 3-53:Site 4 after flood waters had receded on 26/5/10. Circed areas show site of soil loss (white) and vegetation removal (green) in comparison with photo taken on 24/5/10.

Figure 3-54:Jet boat passing Site 4 on 26/6/10. Note this is 1 month after the previous photo and grass is regrowing on the bank.

3.3.5 Site 5

A series of surveillance photographs from Site 5 are presented in Figures 3-55 to 3-63. This camera was set up at the downstream end of Site 5 so flow is towards the viewer. The first photograph is at the start of the surveillance period just after the second TLS scan. Figures 3-56 to 3-57 show an area of vegetation (circled) that is removed as a result of the 25 May 2010 flood. The time-lapse movie clearly shows this camera going underwater for several hours during this flood. Figures 3-59 to 3-62 show two pairs of photographs which capture areas of bank erosion occurring on the 31st July and the 7th August. This is of interest because, although the 7th of August followed a period of high flow, the period preceding the 31st of July was one of relatively stable low flow. Site 5 is in the control reach, so this erosion cannot be attributed to the jet boat.

Figure 3-55:Initial photo of Site 5 on 31/3/10. To compare with future photos.

Figure 3-56:Site 5 on 22/5/10 just prior to the flood of 25/5/10. Some of the vegetation circled is removed during the following flood – see photo taken 30/5/10

Figure 3-57:Site 5 during the flood of 25/5/10. Note the camera went underwater during the previous night. This was the first clear photo after the camera lens dried out.

Figure 3-58:Site 5 on the 30/5/10. This is the first clear photo of the bank after floodwaters receded. Note some vegetation removal is circled.

Figure 3-59:Erosion at waters edge of Site 5 on 31/7/10. Compare with following photo.

Figure 3-60:Erosion at waters edge of Site 5 on 31/7/10. Compare with previous photo.

Figure 3-61:Erosion at waters edge of Site 5 on 7/8/10. Compare with following photo.

Figure 3-62:Erosion at waters edge of Site 5 on 7/8/10. Compare with previous photo, taken 5 mins earlier.

Figure 3-63:Final photograph of Site 5 on 11/8/10.

3.3.6 Site 6

A series of surveillance photographs from Site 6 are presented in Figures 3-64 to 3-69. This camera was set up at the downstream end of Site 6 so flow is from left to right towards the viewer. The first photograph is at the start of the surveillance period just after the second TLS scan. Figures 3-65 to 3-67 show the bank before, during and after the 25 May 2010 flood. The time-lapse movie clearly shows this camera going underwater for several hours during this flood. Small areas of erosion and vegetation removal are detectable in various locations along this bank, with one particular spot circled. Figure 3-68 shows that stock can graze right to the edge of this bank. Figure 3-69 shows one of the final photographs from this site. This camera stopped collecting photographs several weeks before the other cameras. The area of greatest bank erosion over the surveillance period is circled.

Figure 3-64:Initial photo of Site 6 on 31/3/10. To compare with future photos.

Figure 3-65:Site 6 on 23/5/10 prior to flood of 25/5/10. Circled feature to be compared with photo following flood.

Figure 3-66:Site 6 during flood of 25/5/10. The camera went underwater during the previous night. This is the first clear photo after the camera lens dried..

Figure 3-67:Site 6 after floodwaters had receded on 31/5/10. Circled feature to be compared with photo prior to flood.

Figure 3-68:Cows at Site 6 on 23/6/10.

Figure 3-69:Final photograph at Site 6 taken on 26/7/10. The area circled highlights an area of bank erosion since the start of surveillance.

3.3.7 Site 7

A series of surveillance photographs from Site 7 are presented in Figures 3-70 to 3-73. An additional photograph taken after the surveillance camera was removed is presented in Figure 3-74. This surveillance camera was set up at the downstream end of Site 7 so flow is towards the viewer. The first photograph is at the start of the surveillance period just after the second TLS scan. Figures 3-71 and 3-72 show stock access on the opposite bank and the latter figure also shows the engineering works underway at Site 7. Figure 3-73 shows the engineering works completed and is the final photo taken at this site from the surveillance camera before it was removed from the site. As these engineering works removed some of the TLS orientation pegs, further comparison of TLS scans was also no longer possible. However, the site was photographed at the time of the third TLS scan (6 December 2010) and considerable erosion at this site was evident (Figure 3-74). Note that this photograph was taken before the large floods of January 2011. This photograph also provides an interesting comparison with Figure 2-7, taken in October 2009.

Figure 3-70:Initial photo of Site 7 on 31/3/10. To compare with future photos.

Figure 3-71:Site 7 on 6/4/10. Note cows on opposite bank.

Figure 3-72:Site 7 part way through battering of the bank on 12/4/10. Note cows on opposite bank.

Figure 3-73:Final photograph of Site 7 after engineering works were completed on 13/4/10.

Figure 3-74:Photograph taken at Site 7 on 6/12/10 showing erosion following engineering works.

3.3.8 Hareb's site

As the Site 7 surveillance camera had to be removed, it was relocated to a site on the Hareb's property. TLS was not carried out at the Hareb's site as instrument set up was not possible on the opposite bank. A series of surveillance photographs taken from this site are presented in Figures 3-75 to 3-81. This camera was positioned facing upstream so flow is towards the viewer. The first photograph is at the start of the surveillance period in April 2010. Figure 3-76 shows a jet boat passing this site on 1 May 2010. This site is well vegetated at water level and no change in bank erosion was detectable over the following 5 days. On the 6th of May this camera stopped working for no apparent reason. It was restarted on 23 June but two days later the camera moved so that it was pointing at the sky. The camera failed to capture anything of interest to this study in the following days, other than a horses head (Figure 3-78) indicating that stock have access to this site. The camera was repositioned on the 30 June 2010 and no change in the bank is apparent from the time the camera was pointed away. Figure 3-80 shows another jet boat wake at this site and Figure 3-81 is the final photo downloaded before this camera went missing.

Figure 3-75:Initial photo of Hareb's Site on 26/4/10. To compare with future photos.

Figure 3-76:Jet boat passing Hareb's site on 1/5/10. The camera unexpectedly stopped working at this site on the 6/5/10 but was restarted on the 23/6/10

Figure 3-77:Photograph of Hareb's site after the camera was restarted on the 23/6/10. Two days later the camera suddenly moved to be pointing at the sky.

Figure 3-78:A horse head captured on camera on 27/6/10. The apparent cause of camera movement at the Hareb's site

Figure 3-79:The camera was repositioned on the 30/6/10 and this photo shows the bank at Hareb's site the following day.

Figure 3-80:A jet boat wake at Hareb's site on 4/7/10.

Figure 3-81:Final photograph downloaded from Hareb's site, taken on 5/7/10. When this site was next visited for photo downloading the camera was missing, apparently stolen.

3.4 Bank sedimentology

Figure 3-82 presents the results of the grain size analysis of bank material samples collected at the seven bank erosion sites. Sites 1-4 are in the jet boat reach and Sites 5-7 are in the control reach. Results show that the bank material in each case is dominantly composed of fine sand, making it naturally prone to erosion. However, material at site 3 may contain up to 30% silt and clay sized material (<64 μm), as the samples were only sieved down to 38μm. Material with a higher proportion of clay may be expected to be more cohesive and less prone to bank erosion. Sites 5 and 1 comprise the coarsest material. Overall the results indicate that there is as much variability between individual sites as between the two reaches and, therefore, the reaches may be considered comparable in terms of bank material.

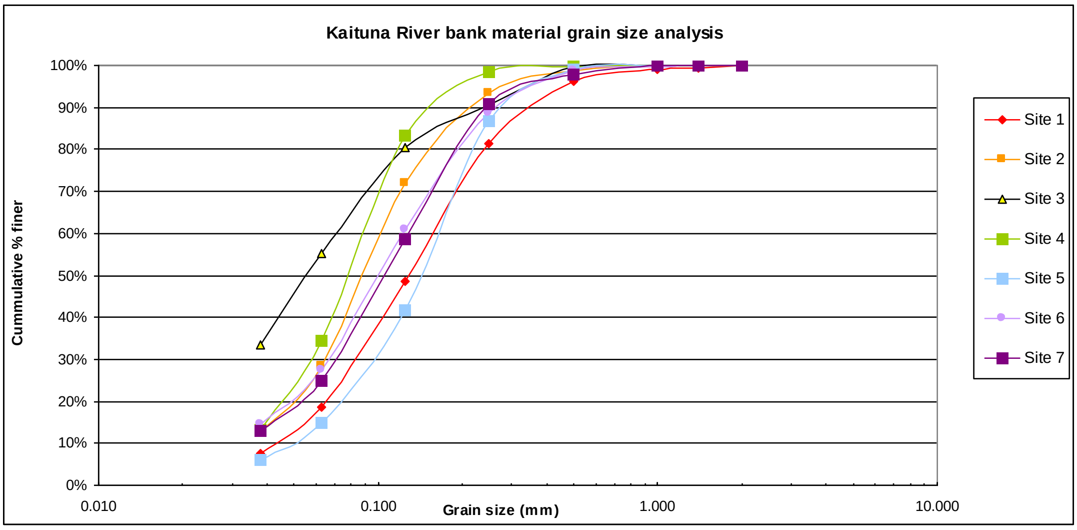


Figure 3-82:Grain size analysis of bank material samples taken from the 7 bank erosion sites.

3.5 Jet boating log

Spring Loaded supplied NIWA with summary statistics outlining the total number of trips taken by their jet boats each month and the number of hours a jet boat was on the river each month. These data are presented as a histogram in Figure 3-83 and supplied in Table 3-2.

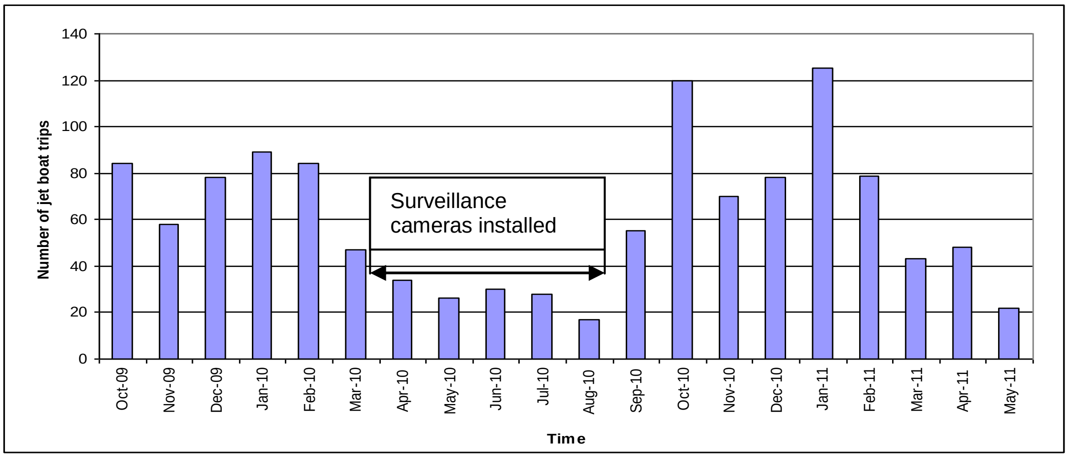


Figure 3-83:Histogram of jet boat activity over the study period. Period in which the surveillance cameras were installed is indicated.

The average number of trips per month is 57, but the number of trips clearly peaks over the summer period. In summary, there is typically at one trip (two passages) per day in autumn/winter (36 trips per month on average) and two to three trips per day (four to six passages) in spring/summer (83 trips per month on average).

Table 3-2: Commercial jet boating activity over the study period. Supplied by Graeme MacKenzie of Spring Loaded. The period in yellow is the period between the first and second TLS scans and the period in grey is the period in which surveillance cameras were installed.

Month	Total time of jet boat on the river (hours)	Number of jet boat trips
Jan-09	86.8	125
Feb-09	69.0	95
Mar-09	43.1	70
Apr-09	41.2	66
May-09	19.7	30
Jun-09	17.5	25
Jul-09	19.0	36
Aug-09	16.6	26
Sep-09	14.5	21
Oct-09	55.3	84
Nov-09	34.9	58
Dec-09	50.7	78
Jan-10	60.0	89
Feb-10	59.3	84
Mar-10	30.0	47
Apr-10	21.0	34
May-10	13.2	26
Jun-10	15.9	30
Jul-10	22.5	28
Aug-10	12.2	17
Sep-10	32.0	55
Oct-10	67.9	120
Nov-10	40.0	70
Dec-10	54.1	78
Jan-11	84.2	125
Feb-11	56.6	79
Mar-11	25.8	43
Apr-11	29.5	48
May-11	20.9	22
Jun-11	29.1	33
Jul-11	15.3	24

3.6 Full reach inventory of bank erosion sites

The inventory of bank erosion sites undertaken in April 2011 is provided in Appendix B. A full inventory of bank erosion along the reach of interest (the 9.2 km jet boat reach and the 3.4 km reach downstream) has now been conducted on 3 separate occasions:

- the October 2004 investigation (commissioned by Mighty River Power) identified 63 sites with bank erosion
- the October 2009 inspection identified 87 bank erosion sites
- the April 2011 inspection identified 155 sites with bank erosion.

It is difficult to directly compare the number of erosion sites as, in some cases, a large single site recorded on one inspection may be recorded as two separate sites on following inspections, and vice versa.

To assess changes in the state of the riverbanks, the location, description and photographs of erosion in 2004 and 2009 were compared with the 2011 record of erosion.

Of the 155 erosion sites recorded in 2011, 69 sites may be considered as ‘new’ erosion, as they were not recorded in the 2009 inventory.

Of the 87 sites identified in 2009:

- 41 sites could be linked with erosion sites in 2011, i.e. erosion has continued.
- 46 sites could not be linked to 2011 site. i.e. they have either revegetated and are no longer considered active erosion sites, or they were not recognised as the same site, or they were missed in the inspection.

4 Discussion

The results presented in this report indicate that bank erosion in the Kaituna River is an ongoing process, with the number of erosion sites increasing over the period of this project. Bank erosion is a natural fluvial process and all rivers erode on the outsides of their bends to a certain degree. The Kaituna River exhibits bank erosion on the insides and outsides of bends, and on straight reaches as well as sinuous ones. This behaviour indicates that other than natural influences are also at play. There are clearly a number of interconnected factors contributing to bank erosion in this river, albeit to varying degrees:

- **Floods** – bank material may be removed during a flood or may slump in the period immediately following a flood when water level drops but the pore pressure in the banks remains high. Floods were the major cause of bank erosion during the full study period.

- **Geomorphic adjustment resulting from previous channel realignment** (including a meander cut off opposite the Mangorewa confluence, just downstream of the jet boat reach) – meander cut offs increase the bed gradient and a river will adjust to this change by incising into the riverbed. This downcutting of the bed will gradually work its way upstream and, as banks become heightened and steepened, will be associated with some bank instability. This adjustment was considered to be the most significant driver of bank erosion in the 1990’s (BOPRC, 1992, Thompson, 1993). However, the current contribution of this process to bank erosion is not clear. This issue could be explored further by conducting a morphological modelling exercise. This would help assess how much further adjustment might be expected and how long this might take.

- **Fluctuations in river level due to the Lake Rotoiti water level control structure** – During the first month of the surveillance photo period a regular daily fluctuation in water level (in the order of 5-10 cm) was observed in the study reach. This water level fluctuation is believed to be due to operation of the Okere Gates, providing optimal conditions for river rafters. This fluctuation can be seen on the Kaituna at Taaheke hydrograph (well upstream of the study reach) in Figure 3-1 (green line). Water level fluctuation can inhibit vegetation growth at the waters edge and continual wetting and drying can weaken banks, as wet banks have less cohesion than dry banks. Both these factors may leave the edge susceptible to erosion from other causes (such as jet boating and flooding). However, this regular fluctuation was not directly observed to cause bank erosion on the surveillance photos.

- **Stock damage** - trampling by stock up and down banks directly erodes the banks, and grazing decreases erosional resistance by reducing vegetation and exposing more vulnerable substrate (e.g. Trimble and Mendel, 1995). Damage caused by the hooves of stock was apparent at a number of locations along the reach during the full reach inspections, particularly the low banks where stock can access the water. Stock are able to graze right to the edge of the bank at Sites 1, 2, 6 and 7 and this may weaken the top of the bank. At sites 1 and 2, depending on water level, it could be possible for stock to get right down to the water. At site 3 the top of the bank above the TLS scan area is fenced preventing stock access, however, stock are able to get right down to the water on the opposite bank. This was captured by the surveillance cameras (Figure 3-38).

- **Wave action from boating traffic** – Bank material around water level may be directly removed from the bank when waves impact on the bank. Once travelling at planing speed, the wakes generated from the commercial jet boat are generally small, with most estimated at approximately 15 cm high, but the energy of these waves is clearly sufficient to mobilise bank sediments and cause turbid water at the edge of the channel (Figure 3-43). The energy of the jet boating waves hitting the bank, and the continual wetting and drying of the banks, will inhibit the growth of vegetation at the waters edge and will weaken the banks. This may leave the edge more susceptible to erosion from flooding.

  The commercial jet boat also conducts numerous 360^o spins during its trips up and down the river (8 spins were conducted during the trip we attended on 21 October 2009). The waves generated during the 360^o spins and when the jet boat is accelerating to reach planing speed are estimated to be approximately double those generated once planing. Information regarding the number of jet boating trips and 360^o spins, which could be obtained from a daily log, is currently not provided to BOPRC.

- **Naturally weak bank material –** the banks along the study reach are dominantly composed of fine sands, and have very little cohesion. This material is particularly susceptible to erosion.

The main question to be answered in this report is what role jet boating is playing on the bank erosion in this reach, and whether or not it is significant. The surveillance photos (particularly Figures 3-42 to 3-45) clearly show that jet boat activity is contributing to bank erosion, and also to reduced water clarity, but quantifying its effect is less simple.

The TLS work enables us to quantify rates of erosion at particular locations and how these rates have changed over the period of this study. These data are presented in Figure 4-1. The rates of erosion measured over the longest period possible for each site are highlighted in Table 4-1 in bold. While the total erosion measured over the study period at each site is generally the result of multiple causes, the majority of the erosion was caused by the large floods of January 2011 (Period C, indicated in pink on Figure 4-2). However, as the dominance of flooding varies in each of the periods between the TLS scans (Figure 4-2), the relative contribution of jet boating may be examined by investigating the timing of changes in Periods A and B.

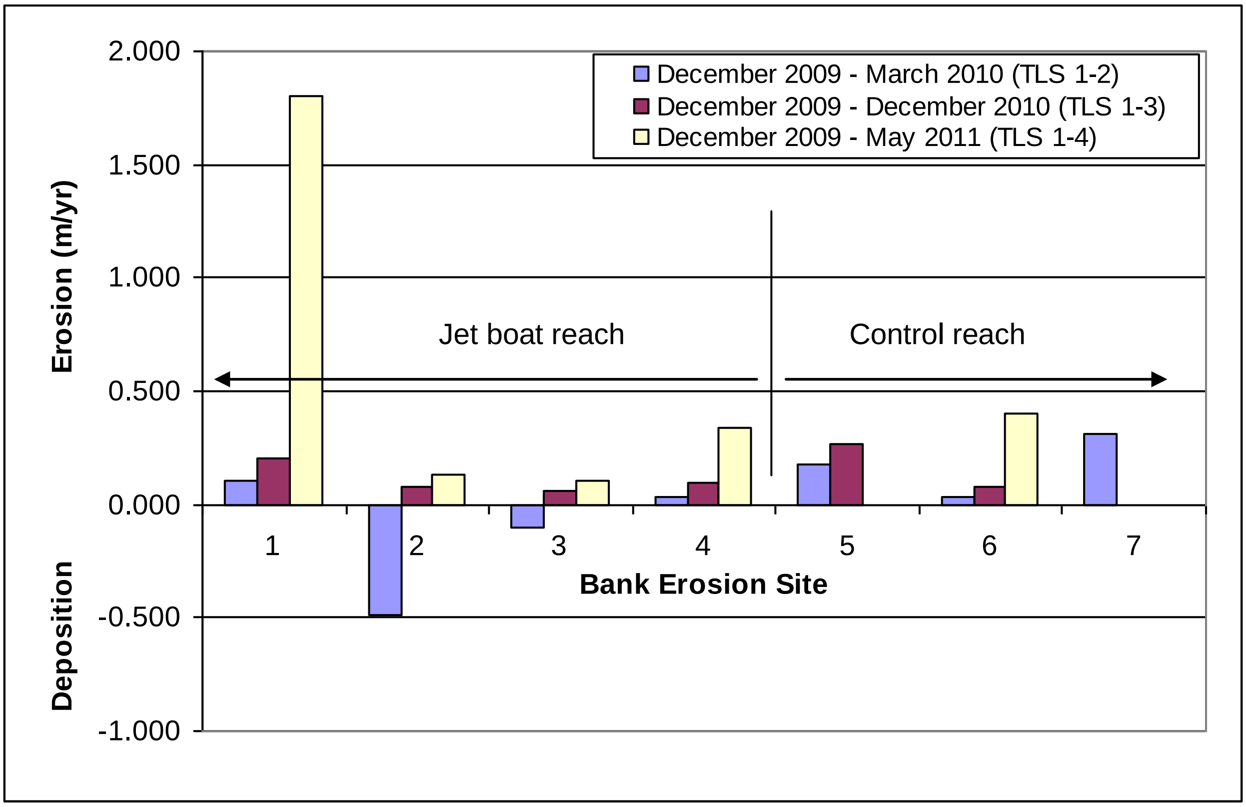


Figure 4-1: Rates of bank erosion measured by TLS.

Period A (between the first and second TLS scans) was one of relatively low river flow, with only one small flood in early February, and there was little fluctuation in water level caused by the Okere Gates (Figure 4-2). This is also a period of increased jet boat activity (summer) with around 260 trips during this period (Table 3-2, half of the December trips are assumed to have occurred after the 15^{th} of December). Therefore, rates of erosion at Sites 1-4 during Period A may largely be attributed to jet boating. While erosion did occur at Sites 2 and 3, the net change during Period A at these two sites was vegetation growth (observed on surveillance photos).

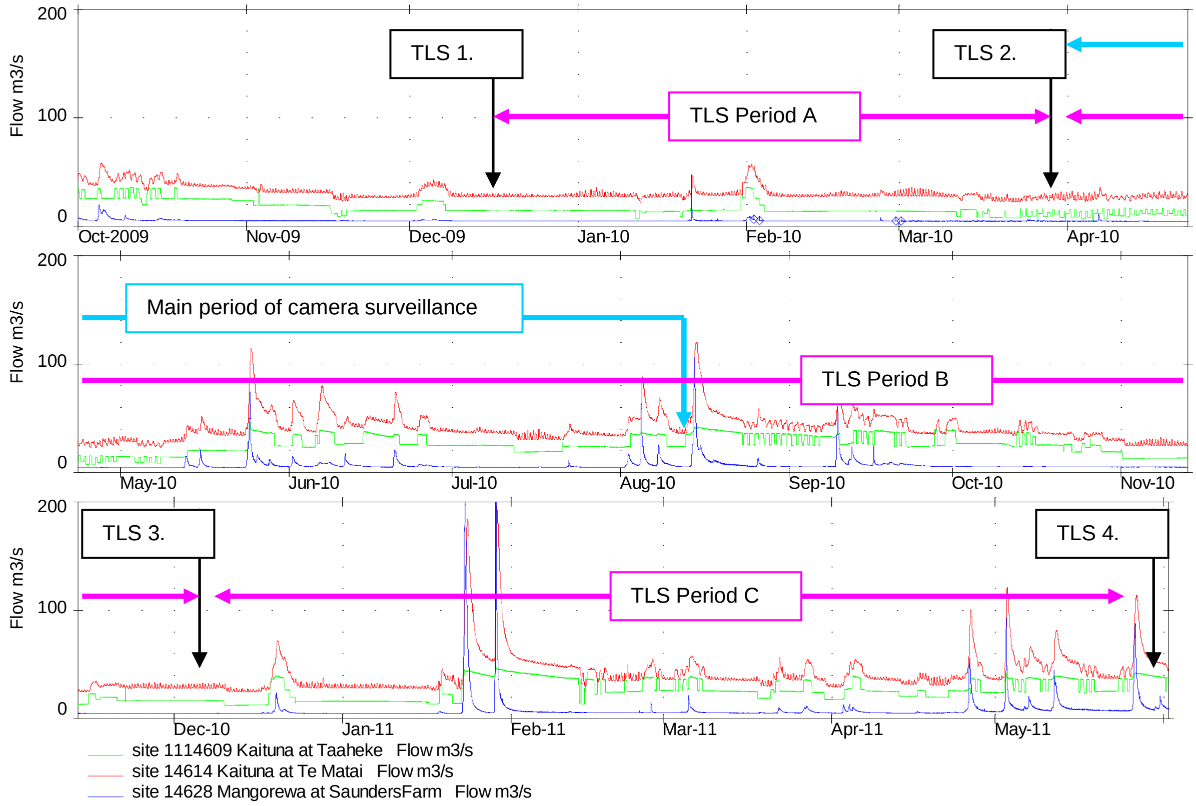


Figure 4-2: Timing of floods relative to TLS scan periods (pink) and surveillance period (blue).

Period B (between the second and third scans) included several moderate sized floods as well as 380 jet boat trips (Figure 4-2 and Table 3-2). The only way of separating out the effects of jet boating from flooding during Period B is through observation of changes on the surveillance photos, which were only taken over part of Period B (indicated in blue on Figure 4-2). Erosion directly resulting from the moderate flood of 25 May 2010 was observed on the surveillance photos at Sites 1, 4, 5 and 6. Erosion directly resulting from jet boat boating during the surveillance period was observed at Sites 1 and 3 (on opposite bank). The erosion from jet boating at Site 1 during the surveillance period was of the same order of magnitude as that from the 25 May 2010 flood (a 2 year return period event, Surman, 2005). Only 135 of total 380 trips in Period B occurred during the surveillance period, so it's likely that jet boating contributed to more erosion in Period B than just that observed on the surveillance photos.

It is estimated that the effect of all jet boating on bank erosion during Period B is approximately equivalent to the total amount of flooding that occurred during the same period. Rates of erosion in the control reach were greater than those in the jet boat reach during Period B, however, the flood magnitudes were also greater in the control reach than the jet boat reach, because a significant proportion of the flow was sourced from the Mangorewa confluence (Figure 4-2).

Table 4-1: Changes measured at each site between TLS scans. Note minimum refers to the biggest negative change (i.e. erosion) and maximum refers to the biggest positive change (deposition or vegetation growth). The rates of erosion are based on the mean erosion over the period between scans. Negative rates of erosion are likely vegetation growth. Bold figures are the data collected between the first and last scan at each site (i.e. maximum change measured).

Site	Time Span	Minimum (m)	Maximum (m)	Mean (m)	SD (m)	Period between scans (days)	Rate of erosion (m/yr)
1	Dec09-Mar10	-1.53	1.47	-0.03	0.22	105	0.10
1	Dec09-Dec10	-2.13	1.68	-0.2	0.39	355	0.21
1	**Dec09-May11**	**-8.46**	**1.38**	**-2.62**	**2.01**	**530**	**1.80**
2	Dec09-Mar10	-0.63	1.56	0.14	0.29	105	-0.49
2	Dec09-Dec10	-1.39	1.27	-0.08	0.28	355	0.08
2	**Dec09-May11**	**-1.02**	**0.43**	**-0.19**	**0.28**	**530**	**0.13**
3	Dec09-Mar10	-2.34	1.22	0.03	0.21	105	-0.10
3	Dec09-Dec10	-3.13	1.28	-0.06	0.27	355	0.06
3	**Dec09-May11**	**-3.38**	**2.62**	**-0.15**	**0.49**	**530**	**0.10**
4	Dec09-Mar10	-1.15	1.52	-0.01	0.2	105	0.03
4	Dec09-Dec10	-1.36	1.67	-0.09	0.37	355	0.09
4	**Dec09-May11**	**-4.62**	**2.35**	**-0.49**	**0.99**	**530**	**0.34**
5	Dec09-Mar10	-0.72	0.4	-0.05	0.13	105	0.17
5	**Dec09-Dec10**	**-1.12**	**0.77**	**-0.26**	**0.33**	**355**	**0.27**
6	Dec09-Mar10	-0.92	1.11	-0.01	0.14	105	0.03
6	Dec09-Dec10	-1.61	1.62	-0.08	0.32	355	0.08
6	**Dec09-May11**	**-3.17**	**1.91**	**-0.58**	**0.51**	**530**	**0.40**
7	**Dec09-Mar10**	**-1.46**	**1.34**	**-0.09**	**0.17**	**105**	**0.31**

The aim of this investigation was to monitor the extent of bank erosion in the study reach of the Kaituna River and to establish whether or not jet boating is a significant cause of the bank erosion. The TLS approach proved to be a useful means of measuring bank erosion and this approach has provided an indication of rates of erosion within the jet boat and control reach. The bank erosion processes occurring in this reach are complex and it is not possible to completely isolate the effect of any single cause. However, the TLS work in combination with the surveillance photographs and observations during the full study reach inspections have provided some clear indications of what the drivers are. This report concludes that, while floods were the major cause of bank erosion during the full study period, the jet boating is certainly contributing to bank erosion. The total jet boating that occurred between 30 March 2010 and 6 December 2010 (an estimated 395 trips or 790 passages) is believed to have had an effect equivalent to the floods that occurred during that same period, which included two events of approximately 100 m^3/s (a 2 year return period, Surman, 2005).

5 Recommendations

BOPRC are responsible for the management of natural and physical resources in the Bay of Plenty region, and this includes river management issues. The erosion discussed by this report has a number of contributing factors, including floods, jet boating, geomorphic adjustment resulting from previous channel realignment, fluctuations in river level due to the Lake Rotoiti water level control, stock damage and naturally weak bank material. Erosion is a natural process, and some erosion is unavoidable. Findings from this report may be used to help BOPRC with the management of this river. Of the factors that contribute to bank erosion in the Kaituna River, some are able to be managed to either avoid or mitigate effects, whereas others are not. Impartial suggestions are made here for BOPRC to consider. The final decisions regarding the management of the Kaituna are BOPRC's responsibility.

The factors contributing to bank erosion that cannot be managed are:

- flooding
- geomorphic adjustment to previous channel alignment
- the naturally weak bank material.

Management approaches that allow effects to be avoided are:

- removal of stock access (further fencing of the river bank)
- non-renewal of the licence and/or the consent for jet boating.

Management approaches that allow effects to be mitigated are:

- encouraging riparian planting
- limiting locations of jet boat spins and other controls such as number of trips
- other river bank protection options where significant infrastructure is at risk.

Further studies and information that might help BOPRC with river management issues are:

- surveying a long profile of the Kaituna River to examine how much adjustment to previous channel alignment has occurred since the 1992 survey
- morphological modelling of the Kaituna River to examine how much further adjustment to previous channel alignment might be expected and how long this might take
- requiring the commercial jet boating operation to supply BOPRC with a daily log of jet boat activity, to better understand this pressure on the river.

Consents for the jet boating activities are due for review soon. The findings from this report suggest that consent conditions for the future could include:

- offsetting the effects of jet boating through river vegetation plantings.

6 Acknowledgements

I would firstly like to thank the landowners who attended the community meeting and explained their concerns, despite the fact that they have explained them many times before. Thank you to Graeme McKenzie for allowing us to join a commercial jet boat trip so that we could see first hand how these trips are conducted, and for supplying a summary of the jet boating activity. I acknowledge the work of Aurecon in the TLS fieldwork and give thanks to the numerous BOPRC staff who helped along the way, particularly Bruce Gardner for providing past reports and for his assistance during the first field inspection and landowner meeting, Steve Pickles for his help with installation and downloading of the surveillance cameras, and Greg Meikle for skippering the BOPRC boat and for his help during the numerous field visits. The help of Richard Williams, Aberystwyth University, with the TLS data post processing and the PYTHON script supplied by James Brasington were also invaluable. I would like to acknowledge Mighty River Power for allowing us to use data from the 2004 bank inspection.

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Appendix A Bank erosion sites October 2009

Locations and descriptions of bank erosion observed on 21 October 2009.

	Easting (NZMG)	Northing (NZMG)	Bank	Type	Length (m)	Ht (m)	Photo (.jpg)
1	No satellites		L	Slip	1	1	PA220147
2	No satellites		R	Slip	3	2	PA220148
3	No satellites		R	Slip	5	1	PA220149
4	No satellites		R	Slip	5	0.5	PA220150
5	2806013	6364668	L	Slump	5	?	PA220151, PA220152
6	No satellites		R	Scour	5	1.5	PA220153
7	No satellites		R	Undercut	5	0.3	PA220154
8	No satellites		R	Scour	1	1	PA220155
9	2806244	6365007	L	Slip	2	10	PA220156
10	2806321	6364950	R	Scour	2	1.5	PA220157
11	2806350	6364913	R	Scour	10	2	PA220158, PA220159
12	2806393	6364907	L	Scour	3	1.5	PA220160
13	2806417	6364908	R	Scour	3	1.5	PA220161
14	No satellites		L	Scour	15	1.5	PA220162
15	No satellites		R	Scour	5	1	PA220163
16	No satellites		L	Gully	10	1	PA220164
17	No satellites		L	Slip	3	4	PA220165
18	2806703	6365217	L	Gully	15	1.5	PA220166, PA220167
19	2806669	6365226	L	Scour	15	1.5	PA220168
20	2806740	6365392	R	Scour	3	1	PA220170
21	2806789	6365410	R	Slump	1	1	PA220171
22	2806995	6365307	R	Slump	1	1	PA220172
23	2807060	6365304	L	Scour	20	1.5	PA220173
24	2807153	6365243	L	Scour	20	1-2	PA220174 - PA220176
25	2807240	6365315	R	Slip	1	2	PA220177
26	2807196	6365472	L	Gully	20	0.5	PA220178
27	2807191	6365477	L	Scour	10	1	PA220179, PA220180
28	2807288	6365835	L	Slump	10	0.5	PA220181
29	2807469	6366007	L	Undercut	3	2	PA220183
30	2807561	6366086	L	Scour	30	2	PA220185, PA220186
31	2807560	6365928	R	Slip	15	2-3	PA220187 - PA220189
32	2807769	6365779	L	Scour	30	0.5	PA220190
33	2807898	6366015	R	Scour	1	1.5	PA220191
34	2807906	6366011	L	Scour	1	1	PA220192
35	2807943	6366005	R	Scour	2	1.5	PA220193, PA220194
36	No satellites		R	Scour	4	1	PA220195

	Easting (NZMG)	Northing (NZMG)	Bank	Type	Length (m)	Ht (m)	Photo (.jpg)
37	No satellites		L	Scour	2	1	PA220196
38	2808029	6366140	R	Scour	Local	1	PA220197
39	2808097	6366071	L	Scour	3	0.5	PA220198
40	2808130	6366033	R	Scour	2	1.5	PA220199, PA220200
41	2808292	6366024	R	Scour	5	1	PA220201
42	No satellites		L	Scour	1	1.5	PA220202
43	2808291	6366205	L	Scour	20	1	PA220203, PA220204
44	2808418	6366381	R	Scour	20	1	PA220206, PA220207
45	No satellites		R	Scour	2	1	PA220209
46	No satellites		L	Scour	1	1	PA220210
47	2808471	6366858	R	Scour	5	2	PA220211
48	2808443	6366855	L	Scour	10	0.3	PA220212, PA220213
49	2808451	6366902	R	Scour	3	1	PA220214
50	No satellites		R	Scour	3	1.5	PA220215
51	2808234	6367510	R	Scour	15	2	PA220216, PA220217
52	2808156	6367554	L	Scour	4	0.5	PA220218
53	2808314	6367768	R	Scour	1	1	PA220219, PA220220
54	2808310	6367787	R	Scour	2	2	PA220221, PA220222
55	2808564	6367861	R	Slip	1	2	PA220223
56	2808548	6368215	R	Scour	2	0.3	PA220225
57	2808551	6368283	L	Slip	2	2.5	PA220226
58	2808573	6368338	R	Scour	4	1	PA220227, PA220228
59	2808638	6368359	R	Slump	10	4	PA220229
60	2808710	6368362	L	Scour	2	1	PA220230
61	2808851	6368477	R	Scour	2	1	PA220231
62	2808917	6368584	R	Scour	1	1	PA220232
63	2808948	6368629	R	Scour	10	1	PA220233
64	2808965	6368645	R	Scour	20	1.5	PA220234, PA220235
65	2809016	6368814	R	Scour	15	1.5	PA220236
End of jet boated reach							
66	2808879	6369050	R	Scour	10	1	PA220238
67	2808586	6369240	R	Scour	10	1	PA220239
68	2808519	6369272	L	Scour	5	2	PA220240
69	2808453	6369345	L	Scour	3	2	PA220241
70	2808449	6369373	R	Scour	4	0.5	PA220242
71	2808440	6369427	R	Scour	2	0.5	PA220243
72	2808421	6369511	R	Scour	2	0.5	PA220244
73	2808403	6369549	R	Scour	1	1	PA220245
74	2808215	6369580	L	Scour	5	1.5	PA220246
75	2808271	6369690	R	Scour	5	1	PA220248

	Easting (NZMG)	Northing (NZMG)	Bank	Type	Length (m)	Ht (m)	Photo (.jpg)
76	2808480	6370004	L	Scour	1	1	PA220250
77	2808515	6370032	L	Scour	1	1	PA220251
78	2808574	6370097	R	Scour	3	1	PA220252
79	2808772	6370284	L	Scour	15	0.5	PA220253
80	2808805	6370325	L	Scour	40	1.5	PA220254, PA220255
81	2808731	6370445	R	Scour	30	1.5	PA220257, PA220258
82	2808356	6370407	R	Scour	5	1	PA220259
83	2808314	6370445	R	Scour	4	1	PA220260, PA220261
84	2808166	6370551	L	Scour	15	1.5	PA220262
85	2808110	6370601	R	Scour	5	2	PA220264
86	2807980	6370665	R	Scour	~ 50	2	PA220265, PA220266
87	2807956	6370912	R	Scour	~ 80	1.5	PA220267 - PA220270

Appendix B Bank erosion sites April 2011

	Easting (NZMG)	Northing (NZMG)	Bank	Type	Length (m)	Ht (m)	Photo (.jpg)
1	2805816	6364148	L	slip	20-30	10	DSC03648, 651
2	2805860	6364152	R	slump	5	1	DSC03647
3	2805888	6364166	R	Scour	3	0.7	DSC03646
4	2805968	6364277	R	Scour	10	1	DSC03645
5	2805968	6364277	L	Scour	10	0.5	DSC03644
6	2806067	6364924	R	Scour	5	1	DSC03643
7	No satellites		L	Scour	5	0.5	DSC03642
8	2806067	6364924	R	Scour	5	0.5	DSC03641
9	2806067	6364924	L	Scour	3	1	DSC03640
10	2806067	6364924	R	block erosion	20	1.5	DSC03638, 639
11	No satellites			Scour			DSC03637
12	2806067	6364924	L	slump/slip	5	1	DSC03636
13	No satellites		R	Scour			DSC03633, 634
14	2806067	6364924	L	slump	7	1.5	DSC03632,635
15	No satellites		R	Scour	5	1	DSC03631
16	2806067	6364924	L	Scour	6	1	DSC03630
17	2806067	6364924	R	Scour /slump	7	0.5	DSC03628
18	2806067	6364924	R	Scour	7	1.5-2	DSC03627
19	2806067	6364924	L	gully fan	3	0.3	DSC03626
20	2806067	6364924	R	Scour	10	0.3	DSC03625
21	No satellites		L	Scour			DSC03624
22	2806056	6364991	L	Scour	10	0.3	DSC03623
23	2806056	6364991	R	Scour	15	0.5	DSC03622
24	2806082	6365137	L	Scour	2	1	DSC03621
25	2806059	6365126	L	slump	2	1	DSC03620
26	2806086	6365120	L	rock slip	3	10	DSC03619
27	No satellites		R	Scour	5	1	DSC03618
28	2806199	6365165	R	Scour	10	0.5	DSC03617
29	2806208	6365183	L	Scour	2	0.7	DSC03616
30	2806252	6365210	L	slip/waterfall	7	20	DSC03613, 614, 615
31	No satellites		L	slip/waterfall	3	7	DSC03612
32	2806321	6365199	L	Scour	1	1.5	DSC03611
33	2806321	6365199	R	Scour /deposition?	15	1	DSC03610
34	2806321	6365199	L	slip	5	3	DSC03609
35	2806392	6365131	R	Scour	20	0.4	DSC03608
36	2806389	6365129	L	Scour	7	0.7	DSC03607
37	2806476	6365052	R	Scour	15	0.3	DSC03606

	Easting (NZMG)	Northing (NZMG)	Bank	Type	Length (m)	Ht (m)	Photo (.jpg)
38	2806476	6365052	L	Scour	15	1.5	DSC03605
39	2806538	6365040	L	Scour	10	0.5	DSC03604
40	2806584	6365056	R	Scour	2	1	DSC03603
41	2806584	6365056	L	Scour	3	0.5	DSC03602
42	2806628	6365059	R	Scour/slump	5	0.5	DSC03600
43	2806628	6365059	L	Scour	2.5	0.3	DSC03599
44	2806779	6365318	R	slip	2	10	DSC03596
45	2806779	6365318	L	slip	5	5	DSC03595
46	2806779	6365318	L	gully fan	12	1	DSC03594
47	2806668	6365472	L	gully fan	20	1-1.5	DSC03590, 591, 592
48	2806684	6365508	R	Scour	15	0.5	DSC03589
49	2806684	6365508	L	Scour	20	1.5	DSC03586, 587, 588
50	2806704	6365538	L	gully fan	5	0.3	DSC03585
51	2806761	6365580	L	Scour	10	1	DSC03584
52	2806788	6365612	R	Scour	7	2	DSC03583
53	2806890	6365593	L	Scour	10	1	DSC03580, 581, 582
54	2806996	6365560	L	Scour	1.5	1	DSC03579
55	2807083	6365500	R	Scour	10	0.3	DSC03578
56	2807083	6365500	L	Scour	5	0.3	DSC03577
57	2807168	6365455	L	Scour	10	0.7	DSC03575, 576
58	2807195	6365494	L	Scour	10	0.5	DSC03574
59	2807195	6365494	L	older slump	7	1	DSC03573
60	2807279	6365835	L	gully fan	20	2	DSC03572
61	2807284	6365871	L	Scour	15	1	DSC03571
62	2807295	6365964	L	deposition			DSC03570
63	2807295	6365964	L	slump	6	0.5	DSC03569
64	2807523	6366230	L	Scour	1.5	1	DSC03565
65	No satellites		L	Scour	3	0.5	DSC03564
66	2807586	6366265	R	Scour	2	1	DSC03563
67	2807586	6366265	L	slump	3	5	DSC03562
68	2807646	6366251	L	Scour	10	4	DSC03560
69	2807665	6366178	L	Scour	7	3	DSC03558, 559
70	2807619	6366128	R	Scour	40	0.3	DSC03557
71	2807582	6366044	L	Scour	40	0.3	DSC03555, 556
72	2807637	6366006	L	Scour	25	1	DSC03553, 554
73	2807803	6365988	L	Scour	20	0.5	DSC03551, 552
74	2807824	6366061	L	slump	20	0.5	DSC03550
75	2807830	6366227	L	Scour	15	0.5	DSC03548, 549
76	2807981	6366159	L	Scour	15	0.5	P1010184
77	2807981	6366159	R	Scour	30	0.5	P1010182

	Easting (NZMG)	Northing (NZMG)	Bank	Type	Length (m)	Ht (m)	Photo (.jpg)
78	2807981	6366159	L	slump	1	1	P1010181,183
79	2807959	6366293	R	Scour	1.5	1	P1010180
80	2807959	6366293	L	Scour	1.5	1	P1010179
81	2808072	6366340	L	Scour	10	0.3	P1010178
82	2808072	6366340	R	Scour	10	0.3	P1010177
83	2808197	6366197	L	Scour	10	1	P1010176
84	2808197	6366197	R	Scour/slump	20	2	P1010173, 174, 175
85	2808197	6366197	L	Scour			P1010172
86	2808374	6366255	L	Scour	20	2	P1010171
87	2808337	6366246	R	gully fan	7	1	P1010169, 170
88	2808337	6366246	L	undercut	10	1	P1010166, 168
89	2808337	6366417	L	Scour	3	1	P1010165
90	2808335	6366415	R	Scour	4	1.5	P1010160, 161, 162
91	2808389	6366482	R	slump	10	0.5	P1010159
92	2808451	6366517	R	gully fan	10	0.5	P1010158
93	2808392	6366651	L	Scour	1.5	1	P1010157
94	2808337	6366798	R	Scour	6	2	P1010156
95	2808364	6366910	R	Scour	1	1	P1010155
96	2808364	6366910	L	Scour	1	1	P1010153, 154
97	2808425	6367120	L	Scour	1	1	P1010151
98	2808415	6367154	R	Scour	3	0.5	P1010150
99	2808396	6367594	R	slump	12	2	P1010149
100	No satellites		R	Scour			P1010148
101	2808329	6367671	R	Scour	2	0.3	P1010147
102	2808258	6367698	R	Scour /slip	5	2.5	P1010146
103	2808273	6367903	R	Scour	15	2	P1010144, 145
104	2808389	6368002	R	Undercut/Scour	10	1	P1010143
105	2808396	6367959	L	slip	3	3	P1010142
106	2808452	6367968	R	Scour	5	1	P1010141
107	2808495	6367973	L	Scour	3	0.3	P1010140
108	2808559	6368355	L	Scour	3	1	P1010139
109	2808693	6368526	R	Scour	7	1	P1010138
110	2808734	6368537	R	Scour			P1010137
111	2808802	6368563	L	Scour	5	0.5	P1010136
112	2808894	6368724	L	Scour	1	0.5	P1010135
113	2808924	6368794	L	slump	20	1	P1010134
114	2808924	6368794	L	Scour	5	2.5	P1010133
115	2808971	6368819	L	Scour	5	2	P1010132
116	2809025	6368891	R	Scour	3	1	P1010131
117	2809047	6369081	R	Scour	1	1	P1010130

	Easting (NZMG)	Northing (NZMG)	Bank	Type	Length (m)	Ht (m)	Photo (.jpg)
118	2809047	6369081	R	slump	5	2	P1010129
End of jet boated reach							
119	2808879	6369241	R	Scour	5	1	P1010127
120	2808690	6369341	L	Scour	5	1	P1010126
121	2808633	6369390	L	Scour	15	3	P1010125
122	2808555	6369443	R	Scour	10	2	P1010124
123	2808536	6369594	L	Scour	15	2	P1010122, 123
124	2808536	6369594	L	Scour	5	1.7	P1010121
125	2808298	6369689	R	Scour	20	1.5	P1010120
126	2808267	6369700	R	Scour	7	1.5	P1010119
127	2808267	6369700	L	slump	10	1.5	P1010118
128	2808281	6369842	L	Scour	10	2	P1010117
129	2808330	6369954	L	Scour	5	1.2	P1010116
130	2808330	6369954	R	Scour	50	1.5	P1010115
131	2808322	6370076	R	Scour	20	1	P1010114
132	2808367	6370138	L	Scour	15	3	P1010113
133	2808405	6370102	L	Scour	10	2	P1010112
134	2808464	6370171	R	Scour	10	1	P1010111
135	2808541	6370253	L	Scour	15	1.2	P1010110
136	2808570	6370295	L	Scour	25	1	P1010109
137	2808598	6370349	R	Scour	10	1.5	P1010108
138	2808650	6370435	R	Scour	10	1	P1010107
139	2808650	6370435	L	Scour	15	2	P1010106
140	2808791	6370441	L	Scour	5	1.5	P1010105
141	2808810	6370495	R	Scour	10	2.5	P1010104
142	2808769	6370596	L	Scour	60	1.5	P1010103
143	2808769	6370596	R	Scour	?	?	P1010102
144	2808662	6370588	R	Scour	30	2	P1010100, 101
145	2808524	6370509	L	Scour	5	2	P1010099
146	2808484	6370533	L	Scour	5	2	P1010098
147	2808285	6370649	R	Scour	35	2	P1010096, 97
148	2808188	6370709	L	Scour	30	1.7	P1010095
149	2808164	6370747	L	Scour	30	0.5	P1010093, 94
150	2808117	6370766	R	Scour	15	2	P1010092
151	2808096	6370762	L	Scour	10	0.5	P1010091
152	2808010	6370855	L	Scour /slump	15	2.5	P1010090
153	2808017	6370902	R	slump	30	2	P1010089
154	2808028	6370967	R	Scour	10	2	P1010088
155	2807923	6371134	R	Scour	200	2	P1010086, 87