Ashley River/Rakahuri Geomorphic Study

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Prepared by

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Executive Summary

- This study addresses the geomorphic development of the Ashley River/Rakahuri in its Middle and Lower Reaches downstream of the Ashley Gorge. It provides information for ECan to better respond to stakeholder concerns about the river, and help the community understand the processes occurring along the river channel, the natural or human-induced processes causing environmental change, and the longer timescales associated with the geomorphic evolution of the river. The information will help all parties understand how the river might continue to develop over the next 30 years.
- Specific issues addressed include:
  - Bank erosion between Ashley Gorge and Okuku River which is causing loss of agricultural land in some locations;
  - Increasing vegetation establishment between Ashley Gorge and Okuku River;
  - The move from a wide, bare gravel, braided 'fairway' to a narrower, almost single thread channel between Ashley Gorge and Okuku River; and
  - Gravel degradation/aggradation between Okuku River and the estuary.
- The project area focuses on the main stem of the Ashley River/Rakahuri downstream of the gorge to the coast of Pegasus Bay, with some attention given to its true left tributaries the Garry, Okuku,and Makerikeri Rivers.

Ashley River/Rakahuri fluvial system

- The source areas that are delivering water and sediment from the catchments upstream of the Loburn Basin are in relatively good condition. Forest cover is >30% and the grasslands do not contain large areas of degraded lands. Therefore, bedload sediment delivery to the river system is likely to be within the natural range of variability.
- Analysis of the broad scale geomorphic characteristics of the Ashley River/Rakahuri between the Gorge Bridge and the coast shows it comprises two distinct zones that have different landforms, topography, and processes:
  - The Middle Reach that runs for 25.5 km through the Loburn Basin from the Gorge Bridge to downstream of the Okuku River confluence is a transfer zone where water and sediment have been naturally passing through and there would be changing areas of erosion and deposition, but overall the river landform system would be relatively stable. The reach has not been significantly affected by management interventions. Indeed, it has effectively been deliberately 'non-managed' particularly with respect to vegetation encroachment, and this may have affected the rate of sediment transfer through the reach.
  - The Lower Reach runs for 17.5 km across the plains and for several thousand years has been a sink zone where sediment naturally accumulated in alluvial fan landform complex. This reach has been intensively managed (stopbanks, gravel extraction, willow planting, and braidplain weed control) and no longer behaves as a natural system.
- Seven north bank tributaries join the Ashley River/Rakahuri downstream of the Gorge Bridge, six in the Middle Reach, and one in the Lower Reach. Of these, only the Okuku River that joins near the downstream end of the Middle Reach is considered to deliver an appreciable quantity of flow or bedload sediment. There are no significant south bank tributaries.

Middle Reach of the Ashley River/Rakahuri

- The Middle Reach can be subdivided into three sub-reaches based on changing channel gradient and geomorphic characteristics:

  - Sub reach T#1 extends from the Gorge Bridge to Mairaki Downs (12 km). The valley floor is 0.8 – 1.5 km across and confined between high terraces on both sides. Bed slope is 6.6 m/km.
  - Sub reach T#2 is from Mairaki Downs to Garrymere Rd (4 km). The valley floor narrows to 0.6 km where it is crossed by the Ashley Fault Zone, then widens to 1.2 km, and is flanked by downlands on the south side, and high terraces on the north. Bed slope is 5.8 m/km.
  - Sub reach T#3 extends from Garrymere Rd to Swamp Rd/Hillcrest Rd (9 km). The valley generally widens from 1.5 km to 1.8 km and is flanked on both sides by high terraces. Bed slope remains at 5.8 m/km.

- The margins of the recently mobile riverbed have been eroding at three localities over the last 10 years, and this has resulted in the loss of ~20 ha of farmland. Erosion of the vegetated islands within the braidplain has also occurred. This erosion is considered to have occurred naturally, as part of the normal recycling of sediment that occurs along the river's transfer zone. It appears to have been triggered by two closely spaced small floods in 2008 and continued in further floods over the following three to four years. The two upstream sites have been generally stable since 2015, but the downstream site was actively eroding again in a 2017 flood.
- Vegetated islands and bars were a natural part of the braidplain prior to European settlement although they would have been temporary, being swept away in large floods, and re-established with a few years. It is estimated naturally vegetated areas comprised some 20% of the braidplain. Non-native species such as gorse, broom and willow began to invade the braidplain within a few decades of European settlement. These have now crowded out the native species.
- Mobile riverbed width had declined gradually with increasing vegetation encroachment until 1960. A sharp decline occurred over the next decade with the recently mobile riverbed reducing in width from ~500 m to <200 m in 1970. There was a further decline to ~120 m width between 2000 and 2008. Causes of the 1960s vegetation encroachment are not known. The 2000 – 2008 phase included a period of increased flood frequency thus the association between flood magnitude and vegetation is not straightforward.
- Since early 2008 the mobile riverbed width has recovered somewhat as floods, particularly in mid-2008 have been more frequent and although relatively small, they have been large enough to remove the gorse and broom that had been established between 2000 and 2008.
- Braidplain vegetation encroachment may have reached a dynamic equilibrium such that over the next 30 years, during periods of reduced flood frequency, encroachment by exotic species such as gorse, lupins and blackberry may temporarily increase, to be cleaned out when floods return. One or two particularly large events (>20 yr return period) could cause a significant reduction in braidplain vegetation cover, but within a few flood-free years this would re-grow. However, willow trees are unlikely to respond in this way and are likely to remain and/or increase.
- Flow in the Ashley River/Rakahuri Middle Reach during non-flood conditions is concentrated in one main channel, and this predominantly single-thread characteristic has been a feature of the river since at least the early 1940s. This main channel can have associated small side braids and there tends to be more of these further downstream through the reach.
- Over the last ~70 years there has been a reduction in the number of side braids. This occurred particularly from the 1940s through to the 1960s; and from the early 2000s to the present. In the earlier phase the channel multiplicity declined as vegetation cover increased. However, over the last ten years the pattern has changed as channel multiplicity has decreased while vegetation cover has not increased.
- This continued shift towards a single thread channel despite recent reduced overall vegetation encroachment may suggest the Ashley River/Rakahuri is evolving away from its braided form to a single thread wandering gravel bed river. This would be consistent with reduced bedload supply, be that from upstream or from recycling of the braidplain within the reach itself.
- If this is the case, management interventions to reduce vegetation cover on the braidplain may not have the desired effect of increasing channel multiplicity. Further, reduced bedload sediment

supply to and within the Middle Reach could have implications for gravel extraction management both within the reach and downstream.

Lower Ashley River/Rakahuri bed levels

- The Lower Ashley River has built a large low-angle alluvial fan landform over the last 6,000 years. Over this long period the Ashley River/Rakahuri does not appear to have transported its gravel bedload to the coast. Rather, it deposited this alluvium in the fan landform as the braidplain and flood channels migrated back and forth widely across the fan surface.
- Confining an alluvial fan river between stopbanks is likely to result in aggradation of the bed as the river is no longer able to spread its bedload widely over its alluvial fan.
- Flood protection measures were probably constructed along the braidplain from the 1870s and willows were being planted in order to try to confine the river course. A complete stopbank scheme was constructed in the 1930s, and since then the braidplain has been extensively modified and no longer behaves as a natural system. As a result, floodwaters are no longer able to break out over the alluvial fan and the river's bedload sediment must be accommodated within the now confined braidplain.
- Anecdotal reports attest to riverbed aggradation from at least the 1880s and these continued through to the 1920s when the Ashley River Trust was formed to address river and flood control.
- Topographic surveys of the Lower Ashley River/Rakahuri since 1936 show the bed has been generally degrading rather than aggrading as might have been expected of a managed alluvial fan river.
- The bed degradation has been attributed to gravel extraction from the braidplain. However, other factors could also be involved including natural long-term reduction of bedload sediment supply from upstream, long-term flood regime change that has resulted in fewer sediment transporting floods, or short-term sediment trapping in braidplain vegetation in the Middle Reach upstream.
- There have been a variety of large scale natural long-term fluvial system changes occurring within Ashley River/Rakahuri, with an overlay of human caused changes. The challenge is differentiating natural from human causes of braidplain change and responding appropriately to each.

1.0 Introduction

1.1 Report scope

Environment Canterbury (ECan) seeks to understand the geomorphic development of the Ashley River/Rakahuri in its Middle and Lower Reaches downstream of the Ashley Gorge. This will cover how the river has developed, particularly in terms of its course, braiding, bed aggradation/erosion, vegetation development, bank erosion, bank protection measures, agricultural and urban development on the braidplain; and the drivers contributing to these issues.

The study provides information for ECan to better respond to stakeholder concerns about the river, and help the community understand the processes occurring in the river, the drivers of the observed processes (whether natural or human-made), and their context in the longer timescales associated with the geomorphic evolution of this, and similar, rivers. The information will help all parties understand how the river might continue to develop over the next 30 years.

Several specific concerns are addressed:

- Bank erosion between Ashley Gorge and Okuku River which is causing loss of agricultural land in several locations;
- Increasing vegetation establishment between Ashley Gorge and Okuku River;
- The move from a wide, bare gravel, braided ‘fairway’ to a narrower, almost single thread channel between Ashley Gorge and Okuku River; and
- Gravel degradation/aggradation between Okuku River and the estuary.

The project area focuses on the main stem of the Ashley River/Rakahuri downstream of the gorge to the coast of Pegasus Bay, with some attention given to its true left tributaries the Garry, Okuku, and Makerikeri Rivers.

1.2 Definitions

The Ashely River is widely referred to as a braided river. The Canterbury Land and Water Regional Plan defines a braided river as:

> *any river with multiple successively divergent and rejoining channels separated by gravel islands.*

Rivers are never braided throughout their full length as there will be reaches where there is only ever one channel. Despite this, in general usage in Canterbury if a river has a braided section the whole river is characterised as a braided river. For example, the Waimakariri River is known as a braided river yet for 30% of its course it has only one channel.

In fluvial geomorphology (the scientific context that informs this report) the usage of ‘braided’ tends to be restricted to reaches of rivers rather than the whole river. A braided reach will have the following characteristics: predominantly gravel bedded multiple channels[1] that diverge and rejoin and are separated by mobile bars or small islands that are relatively frequently inundated, destroyed, reformed, or re-shaped in high flow conditions, and that tend not to support permanent vegetation communities.

A braided reach is typically quite wide and may be referred to as a *braidplain,* which in a sense is analogous to the channel and adjacent floodplain of a meandering river. ECan has recently developed a proposed methodology[2] for delineating the extents of the Region’s braided river braidplains. This identifies several ways of defining the braidplain (NIWA, 2017, p 5):

1. *Contemporary braidplain* is the natural area that the river channels could adjust within, based on elevation and topography. This is a geomorphic interpretation that considers controls such as the

[1] Not all multi-channel rivers are braided rivers: anabranching and anastomosing rivers also have multiple channels, but these are separated by stable islands, ridges or even low hills that are rarely if ever inundated and that support permanent vegetation.
[2] NIWA 2017 *Braidplain delineation methodology* NIWA Report 2017419CH prepared by J. Hoyle and J. Bind for ECan.

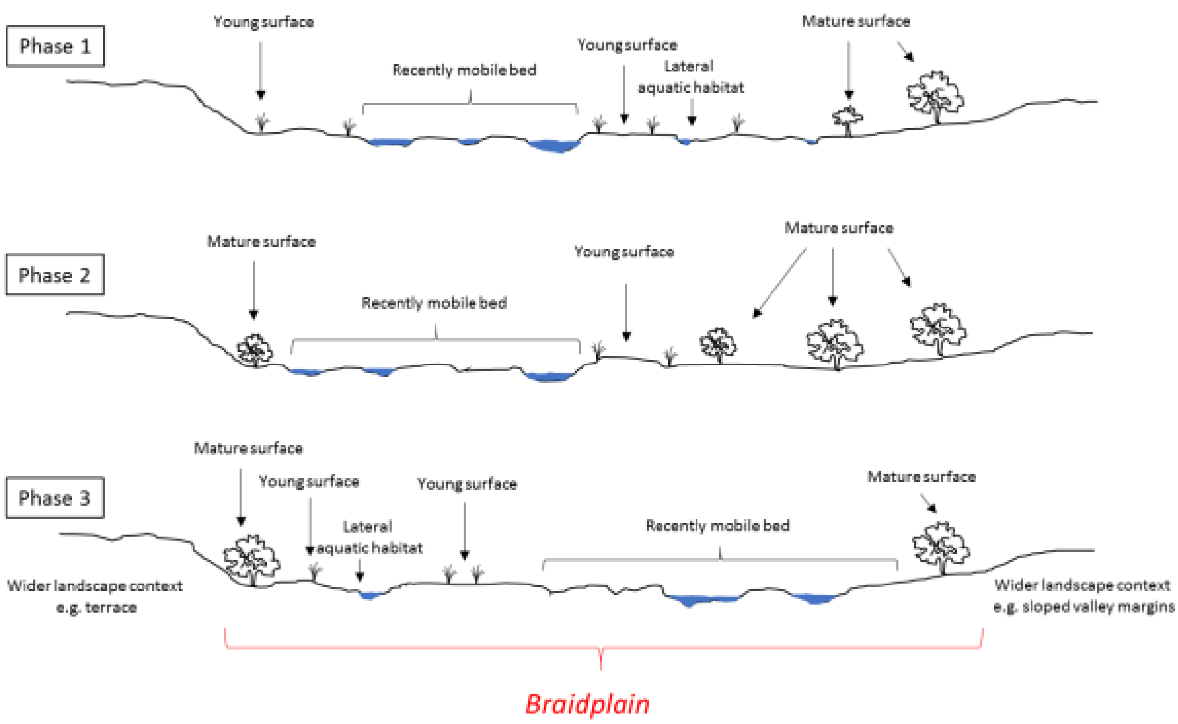
flow regime and sediment supply, and may take into account several hundred years of valley landscape history.

2. *Historical braidplain* is the natural area through which the active channels of the river have been known to migrate since European arrival (effectively since 1850 in Canterbury). This delineation is interpreted from maps and historical imagery.
3. *Managed braidplain* takes account of engineered flood controls such as stopbanks, groynes, or willow plantings that are designed to limit the extent of the river during floods.

Taking these three braidplain concepts together, the contemporary braidplain will generally have a somewhat broader spatial extent than the historical braidplain, while the managed braidplain will be smaller still. There is also a temporal component in this terminology such that a contemporary braidplain could have developed over more than about two centuries, a historical braidplain will have developed since 1850, and a managed braidplain will have been developing since the engineered flood defences have been in place. Along the lower Ashely River/Rakahuri the latter would be since the 1930s.

Although the characteristics of a braidplain can change rapidly with the passage of floods, there will be environments of differing ages within the braidplain as illustrated in Figure 1. This is copied from the NIWA (2017, p7) report.

Figure 1 Braidplain environments



- *Recently mobile bed* is wetted channel and bare gravel covered by floodwaters within the last 2 – 5 years. Some of the higher parts of the gravel bars and islands may develop limited herbaceous and grass cover.
- *Young surfaces* are on higher gravel bars and islands on which grass and shrubs have become stablished. In today's braidplains the shrubs will be exotic species such as gorse, broom, lupins and blackberry.
- *Lateral aquatic habitat* will develop in small side braids or groundwater fed pools.

- *Mature surfaces* are on high bars and islands, or at the margins of the braidplain where major flooding has not occurred for perhaps 5 – 10 years and trees are able to develop. In today's braidplains, the tree cover is commonly willows.

Over yearly to decadal timescales these environments will migrate around the braidplain as small floods cause braids to shift and large floods reorganise the bars and islands across braidplain, a sequence of changes identified as Phases 1 – 3 in Figure 1.

The above terminology is used in the present report.

2.0 Geomorphic setting

2.1 The Ashley/Rakahuri Fluvial System

A useful concept in river geomorphology is the *fluvial system*[3]. This provides a unifying framework for understanding a whole river system from its source to the sea. A fluvial system consists of three zones:

The *source zone* delivers the water to the channel system. For the Ashley/Rakahuri this is the high mountains at the back of the catchment in the Puketeraki Range, and the foothills mountains of Mt Oxford, Mt Richardson, the Okuku Range and the Mt Grey block. Most of the water in the river is from precipitation that falls in these mountains. The source zone also delivers most of the sediment carried by the river, and in our case the important bedload mixture of sand, gravel and cobbles. Although this zone covers more than 60% of the catchment (~859 km^2), it is of less direct relevance to this investigation.

The *transfer zone* takes water and sediment from the source zone and transfers it through the catchment. Water passes through this zone directly within a few days (unless there are lakes in a catchment), and actually takes with it the greater proportion of the total sediment load carried by the river – that is the silt, clay and fine sand that is carried in suspension in the flow. The bedload component of the river's sediment load is typically less than 20% of the total sediment load. It travels much more slowly through the transfer zone being moved episodically by floods and may be stored for years in channel bars and islands in the mobile parts of the braidplain, for decades to hundreds of years in the floodplain and less mobile parts of the braidplain, or for thousands of years in terrace landforms. The Lees Valley is part of the Ashley/Rakahuri transfer zone, as is the Ashley Gorge, and the inner plains. A focus of this investigation will be the reach of the Ashley/Rakahuri River downstream of the Gorge where it flows though the Loburn Basin.

The *sink zone* is where water and sediment finally leave the catchment, and for most rivers this will be the ocean. However, this is not entirely the case for the Ashley/Rakahuri. Water, suspended sediment, and some of the sand bedload are indeed discharged to Pegasus Bay. However, the gravel and cobbles and some of the sand bedload do not get delivered to the ocean, rather this material has for the last 6,000 years or so been deposited in a large alluvial fan landform that covers ~110 km^2, and along with the Ashley/Rakahuri channel system that built it, will be another focus of this investigation.

2.2 Ashley/Rakahuri River reaches

This study addresses the downstream parts of the Ashley/Rakahuri River transfer and sink zones that occur in the 44 km reach of the river between the Gorge Bridge and the coast. Based on the above fluvial system concept, it is appropriate to divide this part of the river into two reaches: an upstream transfer zone reach, and a downstream sink zone reach, and within each of these shorter sub-reaches can be identified. These will provide a useful framework within which to understand the issues that will be addressed in this report.

These reaches are defined on topographic and river geomorphology criteria. Downstream flow regime changes are not linked to this environmental classification.

An important differentiator between the sub reaches is changing grade or steepness of the channel. The steeper the channel gradient the more energy there is available for geomorphic work to occur (eg bank erosion and sediment transport). The overall grade of the Ashley/Rakahuri from the gorge to the sea is 5.13 m/km. This is relatively steep in comparison to other Canterbury Plains rivers. For example, the Waimakariri River slopes at 4.14 m/km from its Gorge Bridge to the sea, while the Selwyn River's grade across the plains is 4.26 m/km.

Like all rivers, the Ashley/Rakahuri's grade becomes gentler downstream so that at the Gorge Bridge it ~6.5 m/km, declining to ~3 m/km at the SH1 Bridge. However, this decline is not achieved in a smooth transition, rather there are a series of uniformly sloping segments with subtle, but none-the-less rapid

[3] This concept was particularly developed in the work of the American fluvial geomorphologist S.A. Schumm. His work was informed by visits to Canterbury on several occasions.

transitions between. It is these uniformly sloping segments that differentiate the sub reaches as shown in Table 1.

Table 1 Geomorphic reaches of the Ashley River/Rakahuri

Sub reach #	***Name***	***Distance from coast & Length***	***Slope***	***Notes***
Transfer Zone (Middle) Reach (Gorge Bridge to Hillcrest/Swamp Roads, 25.5 km)				
#T1	Gorge Bridge to Mairaki Downs	43 – 30.9 km 12 km	6.62 m/km	Valley is 0.8 – 1.3 km wide, confined between high terraces on both sides. Below these are degradation terraces that are no longer reached by floodwaters. The historical braidplain was 480 – 750 m across but now is now 420 – 650 m across and much of this is vegetated. Joined by the short and steep Glentui River (14 m/km), and Washpool Creek (20 m/km) that together drain 34 km^2 of Mt Richardson.
#T2	Mairaki Downs to Garrymere Rd	30.9 – 26.9 km 4 km	5.79 m/km	The change in grade into this short sub reach may be related to the Porters Pass fault zone that crosses the river here to link up with the Ashley Fault Zone east of the Okuku River. The valley narrows abruptly to ~575 m but then broadens to 0.8 km and then 1.2 km downstream. It is confined between high terraces on the north and the slopes of Maikraki Downs on the south. The historical braidplain widened downstream from 440 m to 650 m, and while most of this remains it is well vegetated now. The Ashley/Rakahuri is joined by Garry River which is steep (11 m/km) and drains 64 km^2 of Mts Thomas and Richardson.
#T3	Garrymere Rd to Swamp Rd/Hillcrest Rd.	26.9 – 17.4 km 9.5 km	5.79 m/km	There is no change in grade as the river enters this sub reach, but the valley widens abruptly to 1.5 km, and it retains this width downstream apart from a short narrowing to 1.1 km just upstream of the Okuku confluence, then widening again to ~1.8 km at the end of the sub reach where the south bank terrace finally peters out on the inner plains. The valley is confined by high terraces on north bank, and a combination of Mairaki Downs hills and then a lower terrace on the south bank. The historical braidplain varied from 0.7 -1.2 km across and this remains although it is now well vegetated. Bullock Creek/Mt Thomas Stream join from the north, as does the Okuku River (7.1 m/km) which is the largest tributary to join the river downstream of the gorge. It drains 355 km^2 of the same ranges the Ashley/Rakahuri rises in, as well as parts of Mt Grey.

Sub reach #	Name	Distance from coast & Length	Slope	Notes
Sink Zone (Lower) Reach (Swamp Rd/Hillcrest Rd to coast, 18.3 km)				
#S1	Swamp Rd/Hillcrest Rd to Ashley Traffic Bridge	17.4 – 11.4 km 6.0 km	5.33 m/km	This change in grade marks the start of the alluvial fan landform system. From here onwards the river is losing energy. Terrace confinement continues on the north bank marks the edge of the contemporary braidplain there, but there is no terrace on the south bank. The historical braidplain there was ~1 km wide, but to the south the land slopes down away from the river allowing floodwaters to spill off the braidplain and flow away from the main river. Stopbanks now contain floods of up to 100 year magnitude. The historical braidplain was a uniform 1.1 – 1.2 km, and a south bank stopbank now delineates a ~900 m wide managed braidplain. The Makerikeri River joins from the north in this sub reach. It has a steep channel (10 m/km) and drains 42 km^2 of downland hills below Mt Grey.
#S2	Ashley Traffic Bridge to Coldstream	11.4 – 6.5 km 4.9 km	4.18 m/km	The change in grade here is probably artificial as stopbanks along the south bank project well out across the historical braidplain, constricting the managed braidplain to just 290 m width. This creates in effect a large bridge abutment 700 m wide by 2.2 km long. The 600 m long railway bridge is in this sub reach. The north bank terrace confinement ends at the rail bridge, and there is no confinement on the south bank. The Ashley/Rakahuri channel is on the crest of the alluvial fan landform and floodwaters were able to fall away from the channel on both banks. The historical braidplain here was originally 1.0 km across. Due to stopbanks on both sides of the river the managed braidplain is now 640 m to 280 m wide.
#S3	Coldstream to Kings Av	6.5 – 1.8 km 4.8 km	2.81 m/km	This abrupt change in grade is probably natural as it occurs where the river's historical braidplain narrowed initially to 560 m, and then to 330 m at 0.9 km upstream of SH1. Downstream of the bridge the contemporary braidplain widened rapidly to the north to 850 m, then 1.2 km towards Saltwater Creek. Now confined between stopbanks on both sides the managed and historical braidplains are the same width, although formerly floodwaters were able to extend out to both the north and south.
#S4	Estuary	1.8 – 0 km 1.8 km	0.56 m/km	The Ashley/Rakahuri – Saltwater Creek Estuary is tidal and has a very flat gradient. It expands along the north bank of the Ashley River/Rakahuri from 1 km to 2.4 km across. Almost no gravel is transported through this sub reach as the river has run out of energy to move it in all but the largest floods.

The river bed slopes reported here have been measured using the elevation profile tool on the Canterbury Maps website. This uses LiDAR data from 2005 (along the Middle Reach of the Ashley/Rakahuri) and 2014 (along the Lower Reach of the river). This delivers far more elevation information than had previously been available and a more nuanced interpretation of river slope is now possible. While the interpretation herein is broadly similar to previous studies that addressed bed slope (eg Sutherland, 2006), it does differ in some details.

Previous reports have referred to the “Middle Reach” of the Ashley/Rakahuri River, extending from the Gorge to the Okuku River confluence. The logic of this reach differentiation had not been discussed but presumably related to such factors as the size of the Okuku River, the change in the proportion of the braidplain covered by vegetation upstream/downstream of the confluence, and the south bank stopbank system ending adjacent to the confluence. However, on the basis of what can be observed at present, there does not appear to be a significant change in river geomorphic regime at the Ashley/Rakahuri and Okuku confluence. For example:

- The Ashley/Rakahuri remains confined between high terraces downstream of the Okuku River;
- There is no change in the Ashley/Rakahuri river bed slope at the confluence;
- The change in braidplain vegetation proportions only occurred in recent decades; and
- The Okuku River makes no discernible difference to the character of the Ashley River/Rakahuri, in particular the bedload sediment that it delivers does not push the Ashley/Rakahuri away to the other side of its braidplain.

Reference to a “Middle Reach” of the Ashley/Rakahuri remains a useful term to differentiate the upper and lower plains reaches of the river. In this report the Middle Reach terminology will be used, but the boundary between the Middle and Lower Reaches is proposed to be some 3.8 km downstream of the Okuku confluence.

2.3 Contributing catchment characteristics

Table 2 shows various characteristics of the whole Ashley catchment to highlight key parameters of flow, landscape, and sediment yield that influence the fluvial geomorphic environments along the main stem of the Ashley River/Rakahuri downstream of the Gorge Bridge.

The mean annual flood refers to the standard hydrological calculation based on the annual peak flow series which by definition returns the magnitude of the flow event that occurs on average once every 2.33 years. It has been calculated using the method of Griffiths *et al* (2011)[4] and is not from flow gauging data. Flow gauging data is available at Ashley Gorge and the measured mean annual flood there is 291 m^3/s which is close to the estimated value in Table 2 (310 m^3/s). The Okuku River estimate is also consistent with gauged data (from Okuku @ Foxes Creek), and likewise the Ashley River/Rakahuri at the coast is consistent with the nearby Ashley River @ SH1 data. Therefore, these estimates of mean annual flow are considered to be a reasonable guide.

The mean annual flood magnitude is a useful threshold flow to consider as at this flow all of the recently mobile bed and perhaps some of the young surfaces within the braidplain are likely to be wetted, although the flow may not everywhere be very deep at that stage. The braids will be fully flowing, and water will have spread out from these to cover adjacent bar and perhaps some island landforms. Bedload sediment transport will be occurring so that braid channels and bar landforms will be being reorganised. Thus, this mean annual flood may be considered a “channel forming” flow.

The suspended sediment yield data is also an estimate, compiled from NIWA’s NZ River Maps web tool (https://shiny.niwa.co.nz/nzrivermaps/). The suspended sediment modelling used in the River Maps tool is described in Hicks *et al* (2011)[5]. Suspended sediment is not directly relevant to this

[4] Griffiths, G.; A. McKercher; C. Pearson 2001 *Review of flood frequency in the Canterbury Region.* Environment Canterbury Report No. R11/50 prepared by NIWA, 22p.
[5] Hicks, D. M. and 6 others, 2011 *Suspended sediment yields from new Zealand rivers* Journal of Hydrology New Zealand 50(1): 81 – 142.

assessment of river landforms; however, it can be used to provide an estimate of bedload sediment yields. These latter are relevant as it is the movement of bedload material that results in river landform changes. Bedload is transported into a reach from upstream and is also recycled from bed and bank erosion within the braidplain.

It is widely accepted that bedload sediment yield will be equivalent to a relatively small proportion of suspended sediment yield. In this case, bedload is estimated to be 15% of suspended sediment yield (typical ranges for this are 5% – 30%). Conversion from tonnes to m^3 assumes density of 1.8 T/m^3.

Table 2 Characteristics of Ashley River/Rakahuri and tributaries

Catchment Tributary	Area (km^2)	Mean Annual Flood (m^3/s)	Suspended sediment yield (T/yr)	Bedload yield (m^3/yr)	% total bed load	Notes
Ashley R at Gorge Bridge	471	310	47,219	3,935	57%	Mainly steep mountainous catchment (85%), with 34% forest cover
Glentui R	25.5	25	1,508	126	1.8%	Mainly steep mountainous catchment (73%), with 71% forest/scrub cover
Washpool St	8.5	10	247	21	0.3%	Mainly gently sloping cleared downs and terraces (66%)
Garry R	64	55	2,937	245	3.5%	Mainly steep mountainous catchment (70%), with 70% forest/scrub cover
Mt Thomas St/Bullock Ck	50	44	2,145	179	2.6%	Mainly gently sloping cleared downs and terraces (84%), with 22% forest cover
Okuku R	355	242	22,543	1,879	27%	Mainly steep mountainous catchment (77%), with 34% forest cover
Ashley R above Okuku R	669	420	55,892	4,658	67%	Mainly steep mountainous catchment (70%), with 35% forest cover
Ashley R below Okuku R	1,024	607	78,436	6,536	94%	Mainly steep mountainous catchment (77%), with 34% forest cover
Makerikeri R	42	38	2,166	181	2.6%	Mainly gently sloping terraces (80%), with 24% plantation forest cover
Ashley R at coast	1,151	671	83,553	6,963	100 %	Mainly steep mountainous catchment (65%), with 32% forest cover

The bedload sediment transport rates shown in Table 2 are considerably less than other estimates for the Ashley River/Rakahuri. For example, Sutherland (2006) estimated bedload supply to the lower Ashley River/Rakahuri to be in the range 12,000 m^3/yr to 97,500 m^3/yr. The reasons for this have not been explored as it is beyond the scope of this study. However, it is noted that the estimation technique used in Table 2 has been accepted as useful elsewhere in New Zealand.

Setting aside the issue of the bedload sediment input rate, the proportional tributary bedload delivery data is considered useful in the context of this report. From this it can be seen that the Ashley above Gorge delivers nearly 60% of the bedload to the river, with the Okuku River also providing a significant ~30%. All the other tributaries deliver trivial amounts of bedload to the main stem of the river.

2.4 Summary

From the above information the following key points provide context for understanding geomorphic issues along Ashley River/Rakahuri from the gorge to the sea.

- The source areas that are delivering water and sediment from the catchments upstream of the Loburn Basin are in relatively good condition. Forest cover is >30% and the grasslands (both managed for grazing, and native tussock) do not contain large areas of degraded lands.
- Bedload sediment delivery to the river system is likely to be well within the natural range of variability.
- Analysis of the geomorphic characteristics of the Ashley River/Rakahuri between the Gorge Bridge and the coast shows it comprises two distinct zones with different landforms, topography, and processes.
  - The Middle reach that runs for 25.5 km through the Loburn Basin from the Gorge Bridge to downstream of the Okuku River confluence is a transfer zone where water and sediment are passing through. The fluvial landform system exhibits changing areas of erosion and deposition but is overall relatively stable. There has been little management intervention in the channel system, indeed it may be considered to have been deliberately 'non-managed'. Three sub-reaches can be identified, based on natural changes in gradient as the river slope declines from 6.6 m/m to 5.8 m/m.
  - The lower reach of the Ashley River/Rakahuri runs for 17.5 km across the plains and is a sink zone where sediment would be naturally accumulating and build up a natural alluvial fan landform complex. This reach is intensively managed (stopbanks, gravel extraction, willow planting, and braidplain weed control) and no longer behaves as a natural system. Four sub-reaches are identified as the channel gradient declines from 5.3 m/m to 0.6 m/m.
- Seven north bank tributaries join the Ashley River/Rakahuri downstream of the Gorge Bridge, six in the Middle Reach, and one in the Lower Reach. Of these, only the Okuku River that joins near the downstream end of the Middle Reach delivers an appreciable quantity of flow or bedload sediment.

3.0 Middle Reach Ashley River/Rakahuri

The Ashley River/Rakahuri Middle Reach runs from the Gorge Bridge downstream to Hillcrest/Swamp Roads on either side of the river about 3.8 km downstream of the Okuku River confluence. This is part of the river's transfer zone, where water and sediment are passing through. There may be some temporary storage of sediment in degradation terraces, or the braidplain islands and bars and this could last for a few years to several thousand years. As outlined above in Table 1 the reach is confined between high terraces and the valley marked by these terraces gradually widens downstream from ~650 m to 1.8 km across. The historical braidplain occupied about half of the space between the high terraces, although much of it is now covered by vegetation, and the recently mobile bed is just 50 m to 250 m across.

Stakeholders and Environment Canterbury have identified a number of issues in this reach as follows.

- Bank[6] erosion between Ashley Gorge and Okuku River that is causing loss of agricultural land in a number of locations.
- Increasing vegetation establishment between Ashley Gorge and Okuku River.
- The move from a wide, bare gravel, braided channel to a narrower, almost single thread channel between Ashley Gorge and Okuku River.

This section documents these issues from analysis of aerial imagery and assesses the factors contributing to these changes.

3.1 Bank erosion

Three sites of recent erosion have been identified along the margins of the recently mobile bed of the Middle Reach of Ashley River/Rakahuri: in sub reach T#1 on the true right margin at 1.2 km downstream of the Gorge Bridge and on the true left margin 5.16 km downstream of the Gorge Bridge; and in sub reach T#3 on the true left margin 20.7 km downstream of the Gorge Bridge. At all three sites the erosion is considered to reflect natural river processes.

Figure 2 Recent bank erosion sites along the Middle Reach of Ashley River/Rakahuri

The locations of the erosion sites within the Middle Reach are shown in Figure 2 (Ashley Gorge in forested area in upper left corner, Okuku River joins from the north at the right of the image. Aerial imagery 15/11/2016).

[6] The term "bank" is often used in relation to rivers, but can be confusing as it also has a particular meaning in the Resource Management Act in relation to the definition of a river bed. The RMA definition of a river bed where it is braided is not straightforward, so for this reason the term "bank" is avoided in this report. Where it is used it will not carry any RMA context. Rather, it will refer to a steep slope at or near the margin of a recently mobile river bed.

3.1.1 Site 1 @ 1.2 km from Gorge Bridge

Erosion at Site 1 has occurred in two locations as shown in Figure 3. The base imagery is dated 15/11/2016 (from LINZ Data Service), and the red line marks the margin of the recently mobile bed in 2004 (mapped from LINZ Data Service imagery flown 22/10/2004). Bank erosion can be seen at the western (upstream) end of this line, and at the eastern (downstream) end. Older aerial photography shows there had been little bank erosion here since at least June 1942.

Figure 3 Site 1 bank erosion @ 1.2 km (width of image ~2.2 km, north upwards, flow from top to right of image)

Between 2004 and 2016 the upstream erosion has removed up to 120 m of mature surface in the braidplain along distance of some 440 m. About 2.7 ha has gone, contributing ~35,000 m^3 of alluvium to the recently mobile riverbed. Google Earth imagery shows fresh erosion here in November 2009, and it had probably resulted from two closely spaced floods in July and August 2008. The erosion continued through into 2012 (there was a flood in May 2010, and another in October 2011), but there has been little further erosion here since November 2012 despite a large flood event in April 2014.

The young surface of the braidplain opposite this erosion site has also been reorganised and the left side of the recently mobile riverbed has moved eastwards, eroding some 4 ha of scrub covered braidplain and re-cycling 40,000 m^3 of material into the mobile bed.

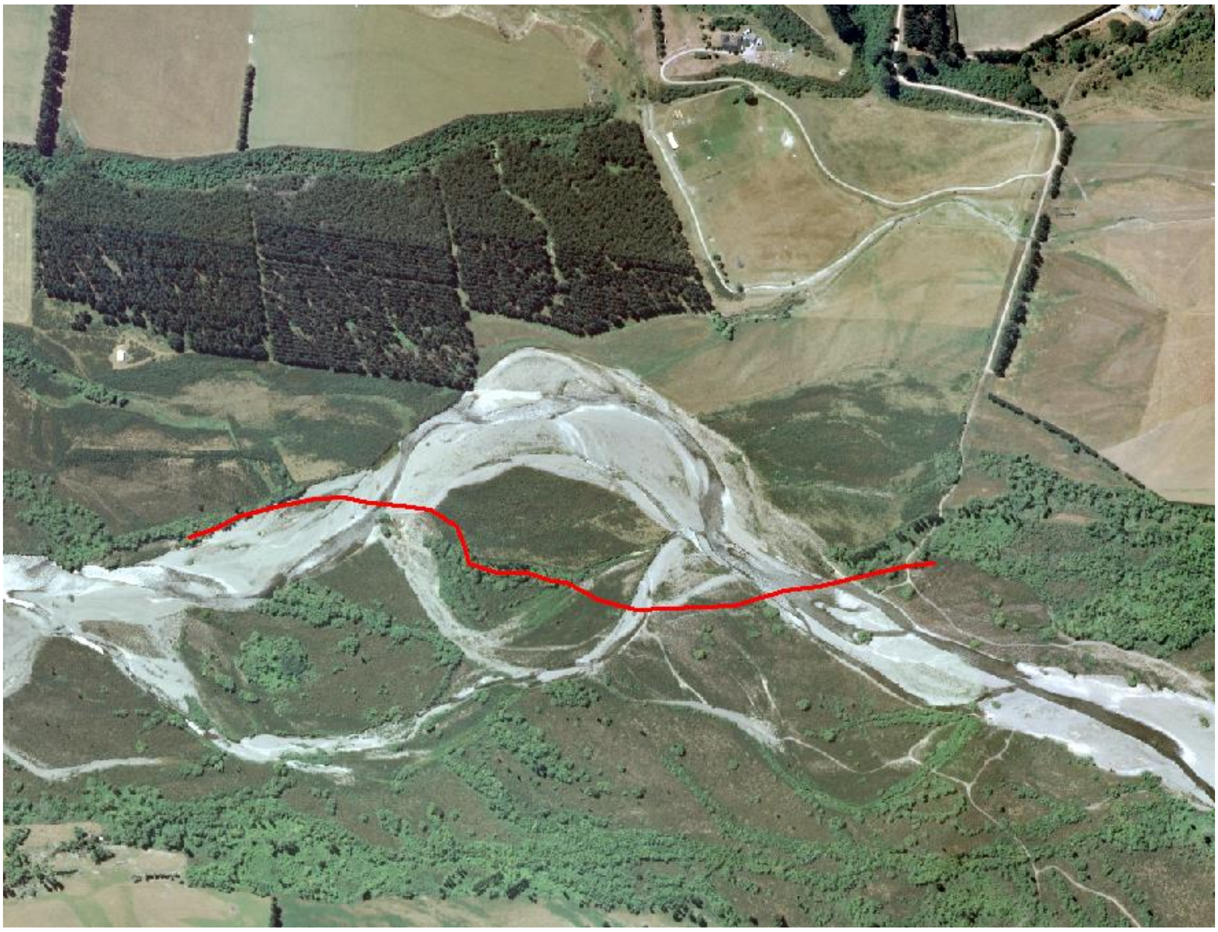
The second erosion location is ~800 m downstream (at the eastern end of the red line in Figure 3). This has affected 590 m along the base of a 16 m high terrace and this has retreated ~8 m since 2004, taking ~0.8 ha of farmland. This released >125,000 m^3 of material into the mobile bed. Downstream of this eroding terrace ~6,500 m^2 of mature surface braidplain has also been eroded away. This had been 1.5 – 2 m above the recently mobile bed would have released ~10,000 m^3 of sediment.

The true left margin along which these two erosion areas are located had been stable for at least 65 year prior to the erosion beginning in 2008. This apparently sudden increase in erosion is not atypical river behaviour, and is to be expected at these sites as they are on the outside of a significant river bend. In total some 216,000 m^3 of material was delivered to the recently mobile bed here.

3.1.2 Site 2 @ 5.2 km

Site 2 is on the true left margin of the Ashley River/Rakahuri, 5.2 km downstream of the Gorge Bridge. It is near the end of O'Halloran's Rd adjacent to a plantation forestry block (see Figure 4). The shift of the recently mobile riverbed towards the planation between 2004 and 2016 is obvious. It has removed part of a mature surface on the historical braidplain.

Figure 4 Site 2 bank erosion @5.2 km (width of image ~1.4 km, north upwards, flow from left to right)



The base imagery is dated 15/11/2016, and the red line marks the edge of the recently mobile bed on 22/10/2004. Up to 260 m of erosion had occurred along a distance of 840 m, with ~10 ha eroded, of which ~8 ha had been farmed. The recently active riverbed is now at a corner of the plantation. The eroded area was <1 m above the river bed, so that ~80,000 m^3 of alluvium had been recycled into the mobile riverbed.

In the earliest available aerial photography (14th February 1960) the whole area is scrub covered young braidplain surface, and it had probably been mobile riverbed in prior decades. In 1970 (5th March) mobile riverbed had redeveloped in part of the area, and areas of trees were present in the scrub. By 1977 (19th February) the scrub area had been converted to grazing, although the trees remained along an old braid channel. A line of willows had been planted along the edge of the mobile riverbed.

In 1994 (26th November) the mobile riverbed of the 1970s had become a scrub and partly tree covered mature braidplain surface again, and willows had advanced out from the 1970s planting. This area showed as intact in 2004 (22nd October), and again in 2009 (Google Earth imagery 25th November).

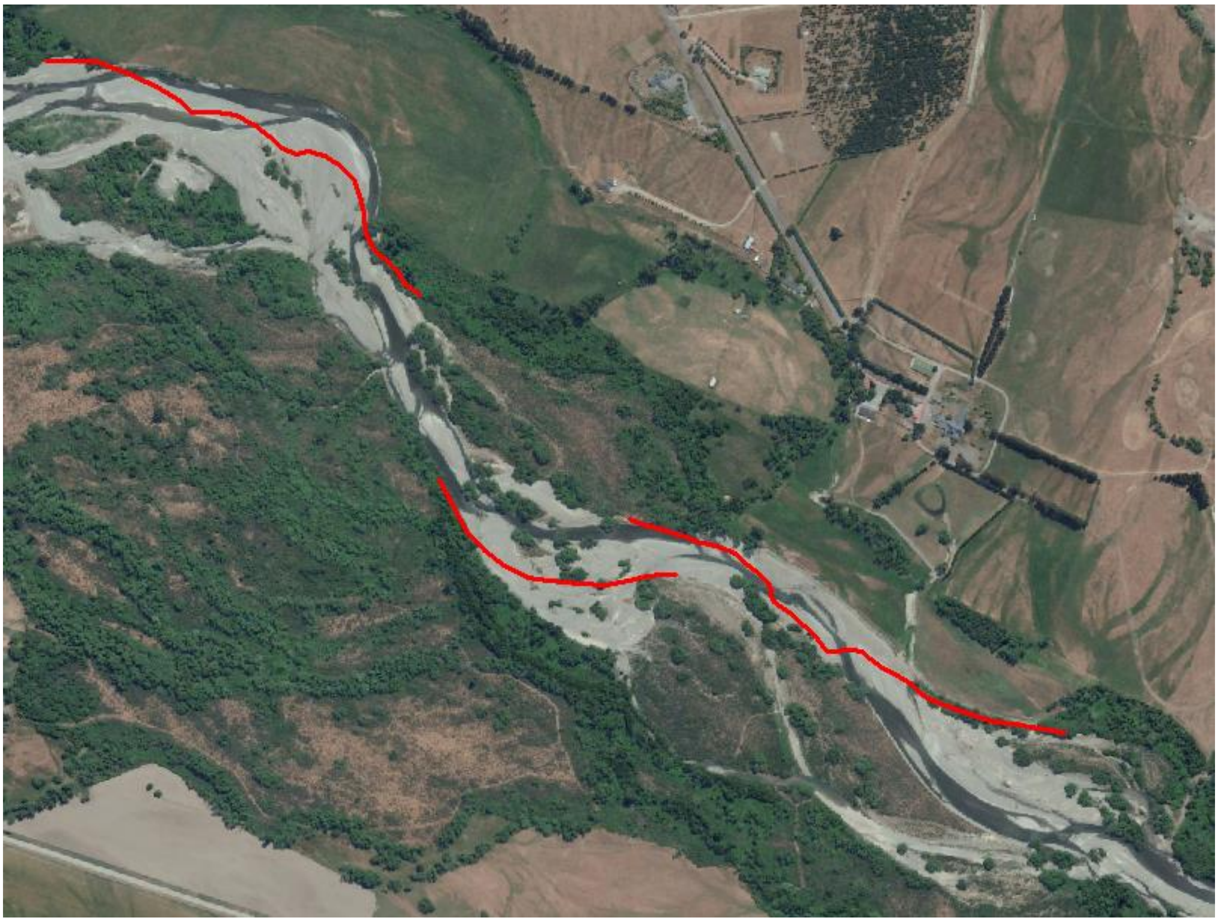
Erosion had occurred by 2012 (7th November) when the main braid of the Ashley River/Rakahuri is shown swinging through the area as the recently mobile riverbed had migrated to this northern side of the braidplain. There was more erosion between March and August 2013, and a further bite by November 2015. No further erosion had occurred up to 21/4/2017 (Google Earth imagery).

This erosion represents typical behaviour of a river like the Ashley/Rakahuri. The land has always been part of the braidplain, and although the mobile riverbed had for many years been 300 m to the south on the other side of the braidplain, the meander wavelength of the mobile bed had shifted 300 m downstream, causing the bend to relocate to this north bank.

3.1.3 Site 3 @ 20.7 km

Site 3 is on the true left margin of the Ashley River/Rakahuri, 20.7 km downstream of the Gorge Bridge, and 1.3 km upstream of the Okuku River confluence. It is near the end of Foothills Road at Serenada Farm and there are three erosion areas as shown in Figure 5.

Figure 5 Site 3 bank erosion @20.7 km (width of image ~1.8 km, north upwards, flow from top left to bottom right)



The base imagery is dated 30/11/2017 and is from Google Earth. The red lines mark the edge of the recently mobile riverbed on 22/10/2004. The two erosion areas on the true left margin have resulted in loss of farmland, while middle area shows an example of erosion of a mature braidplain surface evidenced by migration of the mobile riverbed.

At the upstream site some 80 m of erosion has occurred along 500 m of bank, and 2.2 ha of farmed land has gone. This erosion has eaten into the margin of the historical braidplain with the contemporary braidplain margin a further 180 m to the north. The land had been in pasture since at least the early 1940s.

From at least the late 1950s there had been a row of willow trees along this bank, which remained stable until the late 1990s when about ~60 m of these were lost. By 2004 a further 40 m had gone and willow trees were replanted along this gap. These grew well through to early 2008, but by November 2009 there had been a fresh erosion event that this time removed some 0.6 ha of farmland. Further minor erosion losses occurred between May 2012 and January 2013, then between January and July 2014, and again in early 2017. Then between May and November 2017 the largest single erosion event occurred, taking 1.0 ha and bringing the total lost since 2004 to 2.2 ha.

The eroding margin is 2 m high above the riverbed, so that some 44,000 m^3 of bedload were contributed to the mobile bed between 2004 and 2017. There has a main channel flowing along this bank since at least the late 1950s, and the eroded part is on the outside of a major bend where erosion is to be expected.

The middle erosion site in Figure 5 does not affect any farmland and shows how the braidplain can be naturally recycled after some years of stability. From the 1940s to the 1960s the area was mobile riverbed. By the mid-1990s a mature braidplain surface occupied the area. Erosion began from mid-2011 as a braid meander formed in the recently mobile riverbed and worked its way into the area, continuing through to late 2017. Some 1.6 ha has been eroded, taking with it ~8 willow trees.

At the downstream site some 60 m of retreat has occurred along 380 m and 1.5 ha of farmed land has gone, probably in a flood in July 2017. The area had only been recently converted to managed pasture between 2015 and 2017. Prior to that it had been a mature braidplain surface for about 40 years, and from the 1940s to the 1960s it was mobile riverbed.

The eroding margin is 1.5 m high above the riverbed, so that some 24,000 m^3 of bedload were contributed to the mobile bed between 2004 and 2017. The erosion has occurred due to a channel bend in the mobile bed migrating downstream along this bank.

Taking all three of these erosion sites together, about 355,000 m^3 of gravel was added to the reach bedload sediment budget from 2004 to 2017 equivalent to a mean annual contribution rate of ~27,000 m^3/yr.

3.1.4 Vegetation as a factor influencing bank erosion

It has been suggested that a factor influencing channel migration (and therefore bank erosion) in the Middle Reach of the Ashley River/Rakahuri is vegetation on the braidplain. Several mechanisms could be occurring including a general build-up of gravel amongst vegetation, individual trees trapping sediment and steering flow towards nearby banks[7], and rows of trees deflecting flow and influencing braid alignment for a considerable distance downstream. These effects are more likely to occur with willows while gorse and broom, being smaller plants are unlikely to cause such effects.

The build-up of gravel is discussed below in Section 3.2. The effects of individual trees and groups of trees steering flow towards banks can be tested at the three erosion sites described above. In each case aerial imagery from 2004 is available, showing the sites before erosion had started.

At Site #1 there are very few willows in the mobile bed and none near the eroding margins. However, upstream ~0.5 km from the first erosion bay on the true left side of the braidplain a nearly straight section of the channel ran between willow lined banks in 2004. These trees may have played a role in steering downstream flow towards the upstream erosion bay. However, large gravel bars in the channel there had also changed shape and they have clearly directed flow towards the downstream eroding bank. At Site #2 a willow tree in the mobile bed close to the bank might have contributed to directing flow towards a small part of the eroding margin. However, the main active braid here has shifted more than 200 m to flow directly at the bank and this is likely to have been the primary causative factor there. At Site #3 the braidplain has many willows that had been well established for at least a decade prior to the 2004 imagery. A block of willows at the upstream end may have steered flow towards an eroding bank there, but they had they had been in place for some 30 years prior to the erosion starting.

Thus, for the three sites of recent bank erosion in the Middle Reach it is considered unlikely that willow growth in the braidplain played a major direct role in the post-2004 bank erosion. Rather, the erosion appears to have been due to in-channel processes such as gravel bar deposition causing shifts in flow direction that resulted in the meander path of the main braid changing orientation slightly within 0.5 – 1

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[7] For example in the Ashley River/Rakahuri, Boyle and Surman (2013, p9, full citation in footnote 9 below) refer to "keeping the channel within the proposed control lines rather than it being diverted laterally by the vegetation and sedimentation build up around that vegetation which, ever increasingly, occurs at present."

km upstream. This caused the apexes of bends to shift phase a few hundred metres, bringing them into contact with the banks where the erosion then occurred.

3.2 Bed level change

Bed level change along the Middle Reach of the Ashley River/Rakahuri River has not been identified as a significant issue. However, Environment Canterbury monitors bed level change at ten cross sections across the braidplain and these data provide useful information on the geomorphic behaviour of the river. Three sets of bed level data have been obtained: August 1979 – December 1980; June/July 2001; and June/July 2012. These data have previously been analysed by Sutherland[8] (2006) who considered only the first two surveys, and Boyle & Surman[9] (2013) who had access to all three surveys.

Sutherland (2006) considered that the changes between 1979/1980 and 2001 had been small, although with some evidence for overall aggradation. Boyle and Surman's (2013) analysis showed the changes over the 2001 – 2012 period had again been modest, with overall aggradation again being evident.

Sutherland (2006) also calculated volume change between these cross sections and determined that there had been 57,000 m^3 of deposition over the 22 years of the survey data then available, an average rate of change of 2,600 m^3/yr. Boyle and Surman (2013, Table A 1.7) show different values for this reach, with calculated rates of change of -8,450 m^3/yr between 1979 and 2001, and +41,000 m^3/yr between 2001 and 2012. The differences between these volume calculations have not been resolved.

The ten cross section surveys have been reanalysed for this report. The survey lines are long (629 m – 1039 m) and include considerable distances of well-vegetated mature surfaces within the braidplain. From aerial photographs it appears these areas have not been affected by the recently mobile bed since 1979. The weighted mean bed levels reported here have been calculated from the section of each cross section that can be interpreted as having been affected by the mobile bed at least once since 1979. Some parts of the cross sections have been mobile bed throughout the last 37 years. Some 24 – 44% of the total cross section lengths have been included in the analysis[10].

Table 3 shows the cross section and aggradation/degradation trend calculated by linear regression[11]. There has been a mix of aggrading and degrading cross sections, with downstream and upstream sections showing erosion and the middle parts of the reach showing deposition.

Table 4 shows the weighted mean bed levels for 1979/1980, 2001, and 2012. The >1 m change in mean bed level at XS#41.3 is more apparent than real. The bed has not dropped by this amount; rather the erosion arises from both the true left and true right banks having retreated by 47 m and 24 m respectively between 1979 and 2012. No other Middle Reach XSs have shown this pattern, which arises from the bank erosion at Site #1 described above in Section 4.1.1.

The analysis does not take into account consented gravel extraction through the Middle Reach of Ashely River/Rakahuri. Sutherland (2006) reported 24,600 m^3 of extraction between 2000 and 2005, which was 3.6% of the total volume taken from the Ashley River/Rakahuri. Post-2005 gravel extraction data has not been compiled for this report, although extraction has continued. For example, two sites in the 2 km reach above the Okuku River confluence were active in 2013 – 2014, and 2014 – 2016.

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[8] Sutherland, 2006: *Ashley River Report Status of Gravel Resources and Management Implications* Environment Canterbury Report No R06/13 prepared by MWH Ltd.
[9] Boyle & Surman, 2013: *Middle Ashley (Rakahuri) (Gorge – the Okuku confluence) bed level investigation* Environment Canterbury Report No R13/64.
[10] The 1979 mobile riverbed was interpreted from 1977 aerial photographs. The outer edges of the analysed cross sections included 5 – 10 m of the young or mature surfaces adjacent to the mobile bed, and these start/end chainages were fixed for all three surveys. Volume calculations followed the end area method with prismoidal correction as used by ECan for riverbed gravel extraction consents.
[11] These trends are provided for indicative purposes only. There are as yet too few data points to work with, it is unlikely the distributions will be normal so regression analysis would be inappropriate, and the trends are not statistically significant.

Table 3 Bed level change 1979 – 2001 in Middle Reach of Ashley River/Rakahuri

XS# (distance from coast, km)	Approximate location	Sub-reach	Rate of change 1979/80 – 2012 (mm/yr)
41.3	Near Gorge Bridge	T#1	-37.8
38.9	~3 km downstream of Gorge Bridge	T#1	6.8
37.3	Near Ashley Grange	T#1	-1.4
34.9	Near Glentui River confluence	T#1	10.1
33.3	~1 km downstream of Washpool Stream confluence	T#1	2.3
31.7	Near Okuku Country Lodge	T#1	2.2
29.3	~0.75 km upstream of Garry River confluence	T#2	4.3
26.9	~1.5 km downstream of Garry River confluence	T#2	-3.3
24.5	Near Bullock Creek confluence	T#3	-6.8
22.1	Near Okuku confluence	T#3	-1.5

Table 4 Weighted mean bed levels* along Middle Reach of the Ashley/Rakahuri River

XS# (km)	1978/1980 (m)	2001 (m)	2012 (m)	'79/'80 – '01 (m)	'01 – '12 (m)	'79/'80 – '12 (m)
41.3	213.559	213.235	212.210	-0.324	-1.025	-1.349
38.6	196.396	196.479	196.634	0.083	0.154	0.238
37.3	185.860	185.860	185.805	0.000	-0.055	-0.055
34.9	169.555	169.694	169.902	0.139	0.209	0.347
33.3	159.689	159.690	159.777	0.001	0.087	0.088
31.7	148.936	148.759	149.062	-0.176	0.303	0.126
29.3	134.401	134.274	134.593	-0.127	0.318	0.192
26.9	120.407	120.348	120.296	-0.059	-0.052	-0.111
24.5	106.254	106.277	105.991	0.023	-0.286	-0.263
22.1	91.788	91.729	91.747	-0.059	0.018	-0.041

* XSs surveyed between August 1979 and December 1980; June – July 2001; and June – July 2012.

The end area method was used to calculate the change in sediment volume in the Middle Reach of the Ashley/Rakahuri River between XS#41.3 and XS#22.1 between the survey years. This showed:

- 1979/1980 – 2001 sediment volume lost -53,300 m^3 at rate of -2,470 m^3/yr; and
- 2001 – 2012 sediment volume gained +16,840 m^3 at a rate of 1,960 m^3/yr.

These changes are in the same direction, but much smaller than calculated by Boyle and Surman (2013). The annual rates of change in sediment storage in the reach are smaller than but consistent with the ~4,000 m^3/yr annual bedload sediment supply to the Middle Reach estimated rate above in Table 2. This cross section analysis shows no evidence for the post-2004 contribution of 360,000 m^3/yr of sediment from bank erosion documented above in Section 3.1.

Factors influencing these changes could include changes in braidplain vegetation and/or changes in sediment transporting flow regime and these are discussed below in Section 3.3 and Section 3.5.

3.3 Vegetation cover changes

Vegetation encroachment across the braidplain and the resulting contraction of the mobile riverbed along the Ashley River/Rakahuri has been recognised by stakeholders, but no data on the extent of the loss of mobile riverbed has been found. Braidplain delineation by NIWA (2017) shows a maximum extent that is probably where the margins were in 1850, but does not show how much, if any, vegetation cover there may have been within the braidplain. The braidplain as mapped is wide, increasing from ~400 m near the Gorge Bridge to ~1,500 m in the downstream sub reach T#3 near the Okuku River confluence.

There is no information on vegetation cover along the Middle Reach until aerial photography becomes available in the 1940s. The first aerial photographs date from June 1942 but there is no coverage in the upstream 10 km of the reach. Thereafter there are one or two sets of aerial photographs per decade until the 2000s when much more frequent satellite imagery becomes available.

Quantitative data on vegetation changes in parts of the Middle Reach have been developed for the 1942 – 2017 period. For this assessment the extent of mobile bed was measured at the ten cross section survey sites discussed above in Section 4.2. As the areas of bare gravels and flowing channels decline, they are replaced by vegetation. This is a simple sampling exercise at the ten cross section sites and no attempt has been made to map different vegetation communities or to measure the encroachment of farmed land onto the braidplain. The vegetation encroachment consisted of trees (presumably willows), scrub (presumably gorse, broom, lupins, blackberry etc), and grasses although the latter are more difficult to unambiguously identify on the images. Imagery has been accessed through the RetroLens website, the Canterbury Maps website, the LINZ Data Service, and Google Earth imagery.

Most of the cross sections are in the upstream T#1 sub-reach (XS#41.3 – XS#31.7), two are in sub-reach T#2 (XS#29.3 and XS#26.9), and two are in the downstream T#3 sub-reach (XS#24.5 and XS#22.1).

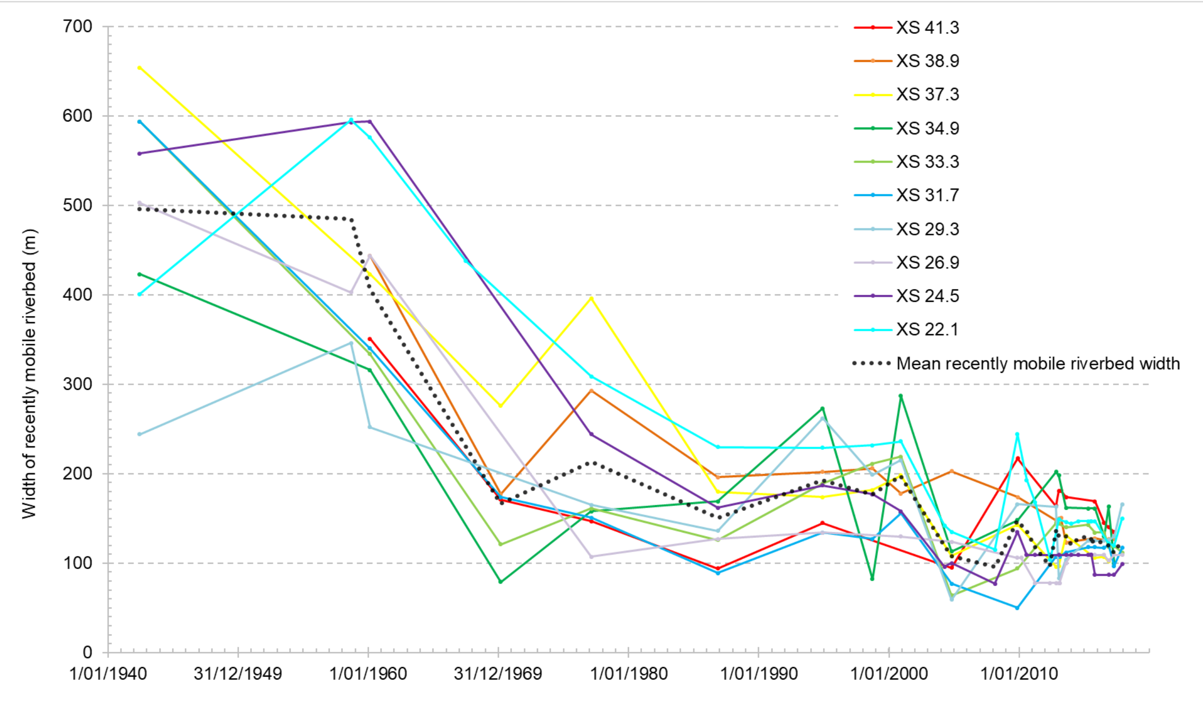
A coherent pattern of vegetation cover change through the Middle Reach of the Ashley River/Rakahuri can be identified as shown in Table 5 and Figure 6.

Table 5 Changing width of Middle Reach Ashley River/Rakahuri recently mobile riverbed 1942 - 2017

	Recently mobile riverbed width (m)										
Date	**XS 22.1**	**XS 24.5**	**XS 26.9**	**XS 29.3**	**XS 31.7**	**XS 33.3**	**XS 34.9**	**XS 37.3**	**XS 38.9**	**XS 41.3**	***Mean***
6/6/1942	401	558	503	244	594	594	423	654	-	-	*532*
11/09/1958	596	593	403	346	-	-	-	-	-	-	*531*
22/02/1960	576	594	444	252	340	334	316	423	444	351	*425*
5/03/1970	-	-	-	-	174	121	79	276	177	171	*166*
19/02/1977	309	244	107	165	151	161	158	396	293	147	*218*
14/11/1986	230	162	127	136	89	126	169	180	196	94	*153*
26/11/1994	229	187	134	262	134	189	273	174	202	145	*185*
29/09/1998	232	177	-	199	127	211	82	182	206	-	*174*
5/12/2000	236	158	130	215	156	219	287	198	178	-	*195*
14/04/2004	142	96	-	-	-	-	-	-	-	-	*119*
22/10/2004	135	100	124	59	77	64	113	108	203	95	*113*
27/02/2008	115	77	-	-	-	-	-	-	-	-	*96*
11/11/2009	244	135	106	166	50	94	148	143	174	217	*146*
3/08/2010	193	109	106	-	-	-	-	-	-	-	*136*
28/03/2011	168	109	78	-	-	-	-	-	-	-	*118*
21/05/2012	104	109	78	-	-	-	-	-	-	-	*97*

	Recently mobile riverbed width (m)										
Date	**XS 22.1**	**XS 24.5**	**XS 26.9**	**XS 29.3**	**XS 31.7**	**XS 33.3**	**XS 34.9**	**XS 37.3**	**XS 38.9**	**XS 41.3**	***Mean***
7/11/2012	-	-	78	163	107	145	202	96	148	164	*134*
26/01/2013	149	109	78	83	107	144	198	97	150	181	*135*
17/02/2013	-	-	78		107	-	-	-	151	181	*129*
12/08/2013	146	109	100	104	112	140	162	131	123	174	*133*
2/01/2014	144	109	109	-	-	-	-	-	-	-	*121*
27/07/2014	147	109	109	-	-	-	-	106	128	169	*128*
18/04/2015	147	109	109	125	118	143	161	-	-	-	*131*
7/07/2015	147	109	-	-	-	-	-	-	-	-	*128*
12/07/2015	147	109	109	-	-	-	-	-	-	-	*122*
22/07/2015	147	109	109	125	-	-	-	-	-	-	*122*
1/11/2015	147	87	109	125	118	134	161	-	-	-	*126*
15/07/2016	-	-	109	125	117	118	130	107	126	145	*122*
15/11/2016	122	87	103	126	121	119	163	102	127	140	*120*
22/04/2017	120	87	109	130	97	119	100	110	127	135	*112*
30/11/2017	150	99	109	166	117	112	-	-	-	-	*126*

Figure 6 Middle Reach Ashley River/Rakahuri recently mobile riverbed width 1942 - 2017



There have been five periods of vegetation change as follows:

i. 1942 – 1960 the mobile riverbed was 250 – 650 m across and varied around a mean of ~465 m.
ii. 1960 – 1970 there was a rapid increase in braidplain vegetation, and the mean width of the recently mobile riverbed contracted by 240 m.
iii. 1970 – 2000 the mean width of the recently mobile riverbed remained relatively stable varying from 215 m to 150 m around the mean value of 185 m.
iv. 2000 – 2004 there was another increase in braidplain vegetation as the mobile riverbed contracted by ~80 m.

v. 2004 – 2017 the mean width of recently mobile riverbed varied around a lower mean of 123 m, ranging from 96 m to 146 m.

The causes of the two steep declines in the 1960s and the early 2000s are not clear. While there is likely to be a relationship between flood frequency and braidplain vegetation encroachment (more/larger floods = less vegetation encroachment) the association cannot be tested for the 1960 – 1970 period of braidplain vegetation increase as there is no Ashely River flow data prior to 1972. Rainfall may have played a role, with more abundant growing season rainfall likely to promote vegetation growth. However, the 1960s were drier than normal with September to May rainfall totals at Glentui (Site # 4809/H32221) falling below the long term mean for eight years out of ten, and the decade overall was 13% below the long-term rainfall mean.

The second period of braidplain vegetation cover increase between 2000 and 2004 is not obviously related to flow as this period included the 2nd and 4th largest floods on record. However, the 2009 increase in recently mobile riverbed width was likely flow-related as two closely spaced smaller floods had occurred in the winter of 2008.

The increase in braidplain vegetation cover and accompanying decrease in recently mobile riverbed is not a recent phenomenon with most of it having occurred nearly 50 years ago.

The above quantitative assessment of braidplain vegetation is based on sampling at the 10 cross section survey sites. A qualitative assessment of broader braidplain vegetation patterns along the Middle Reach can be obtained from historical aerial photographs and this is provided below.

3.3.1 Sub reach T#1

This sub reach is not well covered by aerial photography until 1960. However, a narrow strip along most of the south bank is visible in the July 1942 images and recently mobile riverbed is present in same places out to the historical braidplain margin mapped by NIWA. There are also scrub-covered islands in the braidplain, some up to 9 ha in area. The downstream 2 km of the sub reach is fully covered, and along both sides of the braidplain vegetation has encroached in 40 – 190 m from the 1850 margins. This appears to consist of scrub, with a few scattered trees. The recently mobile riverbed is 275 m to 410 m wide.

The 1960 images show the whole sub reach, and the recently mobile riverbed is 250 m – 650 m across with the margins of the 1850 braidplain showing similar vegetation encroachment to the 1942 images and scrub covered islands within the braidplain.

The 1970 aerials show the braidplain dramatically grown over with scrub cover leaving a recently mobile riverbed of just 75 m to 200 m width. Trees (presumably willows) are only present along ~2 km of the north bank at the downstream end of the sub reach.

The 1977 aerials show a recently mobile riverbed 180 m to 360 m across that had been partially cleared out, possibly by a 667 m^3/s flood in May 1972. The vegetation encroachment extended more than 200 m from the margins in places and had thickened up. For the first time, scattered trees (willows?) are visible along the whole sub reach.

Until 2000 the overall braidplain vegetation cover fluctuated although showed a generally increasing trend. Tree cover became noticeably denser in the vegetated margins and scattered trees became established across the recently mobile riverbed.

The October 2004 imagery shows the braidplain at its most densely vegetated, with the recently mobile riverbed typically <100 m across and some parts just 50 m wide. The mobile riverbed that had been active in 2000 can still be seen clearly but supports extensive grass and scrub cover. Since then the braidplain vegetation cover has reduced a little as the recently mobile riverbed has increased in area with the passage of floods, although the vegetated parts of the braidplain are becoming more established.

3.3.2 Sub reach T#2

This short sub reach 12 – 16 km downstream of the Gorge Bridge has a good coverage of imagery from 1942 onwards. At that time there were two large areas (45 ha and 12 ha) of scrub cover near the margins of the braidplain, with the recently mobile riverbed almost clear of vegetated islands. The mobile bed was 185 m to 630 m wide. In the 1958 and 1960 imagery vegetated islands increased in the braidplain although the margins were not encroaching. By 1977 the north margin of the braidplain had vegetated over considerably and the widest parts of the recently mobile riverbed were only ~250 m across. Trees were well established at the edges of the braidplain, but not further out.

The 1986 imagery showed further small vegetation encroachment, but in 1994 and 2000 the recently mobile riverbed had recovered somewhat, although tree cover had expanded with dense stands along old channels, and there were scattered willows in the recently mobile riverbed.

The 2004 image shows the recently mobile river bed much reduced to 50 m to 130 m across, with the young surfaces of the braidplain supporting grass and scrub. These surfaces had been partially cleared out by November 2009 and the recently mobile bed was up to 190 m across, although most of it was less than 100 m wide. In 2016 the recently mobile bed was reasonably clear within the 120 m to 210 m range, although it is only 70 m wide at its narrowest.

3.3.3 Sub reach T#3

The downstream 9.5 km of the Middle Reach of Ashley River/Rakahuri shows a similar pattern of vegetation change as the upstream sub reaches.

In 1942 the recently mobile bed was 400 m to 950 m across through this sub-reach, although there were large scrubby islands up to 25 ha in area, and a similar pattern was evident in the 1958 images. There is no further imagery until the late 1980s, by which time the recently mobile riverbed is much reduced to between 100 m and 340 m across. There is a general downstream decrease in recently mobile riverbed width through the sub reach.

By 1977 some 140 ha of mature surface braidplain on the south side upstream of the Okuku River confluence had grown over with scrub and scattered trees, and the recently mobile riverbed was little more than 250 m across. This pattern persisted through to 2000, albeit with some fluctuations and new vegetated islands developing within the recently mobile riverbed. Tree cover increased and there were dense stands along the courses of abandoned braids.

The 2004 imagery of sub reach T#3 shows a remarkable extent of vegetation encroachment with a recently mobile riverbed less than 100 m wide. This was about 65% grass and scrub, and 35% trees along old braid channel. Less than 25% of the recently mobile riverbed area in 1942 remained. However, by 2009 the recently mobile bed had increased in area and was generally ~120 m across where it has remained since then.

3.3.4 Summary of vegetation cover changes

There is no information on vegetation cover within the braidplain prior to the middle of the 20th Century. The purpose of the NIWA mapping of the historical braidplain (from the 1850s onwards) had not been to show much, if any vegetation cover there may have been. The braidplain was certainly quite wide, increasing from ~400 m near the Gorge Bridge to ~1,500 m in the downstream sub reach #T3 near the Okuku River confluence.

More detailed information on vegetation encroachment onto the braidplain is available from the 1940s in aerial photographs. The first of these are from 1942 may show the braidplain in a more cleaned out condition than normal for that time (see Section 4.4 below), but none-the-less, the recently mobile riverbed had probably narrowed since 1850. Where the maximum width had been ~1.5 km it was 0.95 km in 1942 (in sub-reach T#3 downstream of the Okuku River junction).

Vegetation encroached rapidly across the braidplain between 1960 and 1970, as the 400 – 500 m wide recently mobile riverbed contracted to 110 – 210 m wide. There followed some thirty years of fluctuation up and down but with no trend of vegetation increase. Between 2000 and 2004 there was another rapid increase in braidplain vegetation cover, and this continued until 2008. In 2009 the recently mobile bed gained some width as floods had been large enough to remove the gorse and broom plants that had been starting to become established in 2004 – 2008. In 2016 the recently mobile riverbed along the Middle Reach was mostly 100 m to 210 m wide, with the narrowest parts just 70 m wide, and the widest parts >350 m.

3.3.5 Discussion

The NIWA mapping of the historical braidplain provides the outer edge of the braidplain, but there is no information on the characteristics of the braidplain within these margins. What did the braidplain look like? Was it a wide expanse of bare gravel with multiple actively flowing braids? Or were there vegetated islands and bars within the braidplain?

Some indications of the original characteristics of braidplain can be gleaned from reports from the early days of the Canterbury Settlement. For example, Charles Torlesse explored the Canterbury Plains probably in late 1850 and early 1851 and the Lyttelton Times published his report in four instalments between 14/6 – 5/7/1851. Torlesse would not have been familiar with braided gravel bed rivers as these do not occur in England, so it is interesting he does not draw much attention to this unusual characteristic. He was not impressed with the rivers as he found they were not particularly useful for transport inland or ports at their mouths. In a particularly trenchant remark he stated *these rivers* (the Rakaia and the Waimakariri) *are huge nuisances, as they form barriers in the country without possessing any counterbalancing advantages.*

One useful comment is in relation to the Waimakariri River which he reports *flows in several streams through a wide bed of shingle, and between flooded islands which bear a luxuriant vegetation*. This suggests the braidplains were not wide bare gravel expanses, but there was some vegetation on islands. Unfortunately, he does not give any details on the “luxuriant vegetation”. He also refers to the Ashley River as being similar to the larger rivers as it winds its way down a wide shingle bed. From this it can be interpreted that when Torlesse saw the Ashley River/Rakahuri in 1850/51 it was similar to other Canterbury Plains rivers having a wide braidplain that likely included some vegetated islands. Therefore, it is considered unlikely that the natural braidplain was originally completely bare gravel.

The general extent of natural vegetation cover within the braidplain can be estimated from an 1875 map of grazing lease areas in the Ashley River. This chart (BM175) maps braid islands along an 11.5 km reach of the Lower Ashley River/Rakahuri upstream and downstream of Rangiora. The braidplain is ~1 km across – the same width as the NIWA braidplain mapping for 1850, and the total area in this reach is 1,207 ha. The chart shows 32 areas that were to be made available as grazing leases. Some are large islands of >35 ha within the braidplain, while other areas are along and attached to the banks. In all, some 245 ha of potential grazing land is mapped, representing 20.3% of the braidplain area. The inferences that can be drawn from this map are:

- There were areas of braidplain that were stable enough to have developed grass cover (whether native tussock or English grasses is not stated); and
- These areas were considered suitable for grazing with an acceptably low risk of stock being lost in a flood.
- The chart was prepared 7 years after what is still today regarded as the largest known flood in the Lower Ashley River/Rakahuri (February 1868). It is highly likely the braidplain would have been swept clear and this vegetation had only re-established since that flood.

The planting of willows for flood protection was underway by at least 1874 (*Globe*, 14/10/1874), and it cannot have been long after settlement of the area that the gorse and broom planted across the plains for fences got into the river bed. By the 1890s newspaper reports were suggesting *gorse and broom were causing a diversion of the channels, and should be cleared”* (*The Press*, 27/2/1897). A few years later a Borough Council Committee reported on the Ashley River between Rangiora and Loburn, commenting that *the bed of the Ashley was much overgrown with growths.* Although the area of vegetation in the braidplain is not quantified in these reports, it is clear that encroachment of non-native species has been a long-standing problem.

From this discussion it may be concluded:

- In its natural state, the Ashley River/Rakahuri braidplain probably included some vegetated islands and bars, possibly covering at least 20% of the plain area;
- Large floods would have occasionally reworked the braidplain and swept it clear of vegetation;
- The vegetation would have rapidly re-established, probably within five years of the passage of the flood; and
- Non-native woody species have been present in the braidplain for over 140 years.

3.4 Channel multiplicity

The Middle Reach of the Ashley River/Rakahuri has characteristics consistent with a braided channel as defined above in Section 1.2. It has channels that flow in multiple interlaced branches that divide and rejoin. The channels or braids are separated by bars which if they remain stable for long enough may become vegetated islands. In floods the number of braids initially increases as dry channels start to carry flow, then as the flood continues to rise bars are eroded away or submerged and the number of braids reduces. In very large floods there may be just one wide flowing channel as the braidplain becomes fully engaged with flow. High gravel bedload rivers are often braided, and braiding can be seen as the river's response to accommodating the high bedload it is being asked to carry.

In river classification schemes, braided channels (multi-thread) are often contrasted with meandering channels (single thread). However, there is also a transitional type called the wandering river that consists of stable single channel reaches that may be eroding and alternating with unstable multichannel reaches where aggradation may be occurring.

Environment Canterbury has noted that the Middle Reach the Ashley River/Rakahuri braidplain has been showing a transition from a wide bare gravel 'fairway' to a narrower, almost single thread channel. This change in channel character is related to the issue of vegetation encroachment onto the braidplain that is reviewed above in Section 3.2.

A qualitative assessment of channel multiplicity changes in the Middle Reach is provided below. This has been interpreted from historical aerial photography and satellite imagery. Each image shows a snapshot of the channel system that will reflect the characteristics of the flow on that day. Channel multiplicity is strongly affected by flow: at very low flow there will be one or no channels; at a moderate flow or small fresh there could be many actively flowing braids; and in a bank-to-bank flood there will be just one channel visible. Each of these flow conditions is important in its own way, whether ecologically, hydraulically, or in terms of sediment transport so channel multiplicity may have varying values depending upon flow condition.

All of the imagery examined shows the Ashley/Rakahuri in what appears to be non-fresh or non-flood conditions. Therefore, it is considered this assessment should not be significantly affected by flow conditions at the time of the aerial photography.

3.4.1 Sub-reach T#1

Where this sub-reach is shown in the 1942 aerial photographs there are 4 – 6 actively flowing braids. By 1960 the braidplain had one main channel and 2 – 4 smaller side braids. Since then the number of side braids has declined, and since 2000 there has generally been only one main braid. However, the upstream part of the reach still retains 3 – 4 actively flowing braids.

3.4.2 Sub-reach T#2

Sub reach #T2 showed one main channel with 1 – 3 minor braids in 1942, but by 1960 the minor braids had reduced to 1 – 2, and this pattern has remained until the recent 2016 aerial imagery that shows the river in one main channel with only occasional sections with 1 – 2 smaller side braids.

3.4.3 Sub-reach T#3

Sub reach #T3 had a busier channel pattern in 1942 with one main braid and up to 5 smaller side braids. This multiplicity declined to 4 minor braids in 1958 then 3 in 1960. This latter pattern remained until the early 2000s and since then the main braid has only had 1 – 2 small side channels.

3.4.4 Discussion

In summary, most of the Ashley River/Rakahuri flow in the Middle Reach has tended to be concentrated in one main channel during normal (ie low) flow conditions. Thus, the predominantly single-thread character of the Ashley River/Rakahuri has been a long term persistent feature of the river. However, this main channel has often had a number of small side braids associated with it, the number of these increasing downstream. Over the last ~70 years there has been a reduction in the number of these side braids. An initial decline occurred from the early 1940s to early 1960s, followed by a further decline starting about 15 years ago in the early 2000s.

Broadly, these changes in channel multiplicity are inversely associated with vegetation cover changes such that as braidplain vegetation cover increases, channel multiplicity declines. However, this pattern has changed since the early 2000s: vegetation cover has decreased (the recently mobile bed width has recovered after 2004), but channel multiplicity has continued to decline. Therefore, there may be other factors involved. Perhaps the Ashley/Rakahuri is naturally evolving towards a wandering gravel bed river due to a decline in bedload supply, and the increased vegetation cover may have been hastening this transition.

The causes of the decline in channel multiplicity (and increase in vegetation cover) have not been investigated in detail. Several factors may be in play:

- The 1942 aerial imagery provides the baseline for subsequent assessments. However, how representative is this of the historic vegetation cover on the braidplain? Newspaper reports record a number of quite significant Ashley/Rakahuri floods in the years prior to the images being flown (6th June 1942). The Press reported damaging floods in February 1936, March 1936, December 1936, July 1938, May 1940, and March 1941. Thus, the braidplain is likely to have been kept well cleared out by these events prior to 1942 and that imagery probably showed the braidplain rather more cleared out than normal for the time.
- Vegetation growth (often of willow, gorse and broom) in the braidplain had been the subject of many newspaper reports since the 1860s. It is not necessarily a recent phenomenon.
- An 1875 survey map shows parts of the Ashley River/Rakahuri available for grazing leases (although this only covers the Lower Ashley/Rakahuri). This implies there were grassed braidplain islands considered stable and flood-free enough to be used for grazing.
- There may have been a decline in the frequency of bed disturbing floods.
- There may have been a decline in the supply of bed load to the river so that available sediment has been moved through the system leaving an armour layer of larger cobbles on the bed that then require much larger floods to disturb, thus giving vegetation more time to establish and encroach.

3.5 Flow events in the Middle Reach

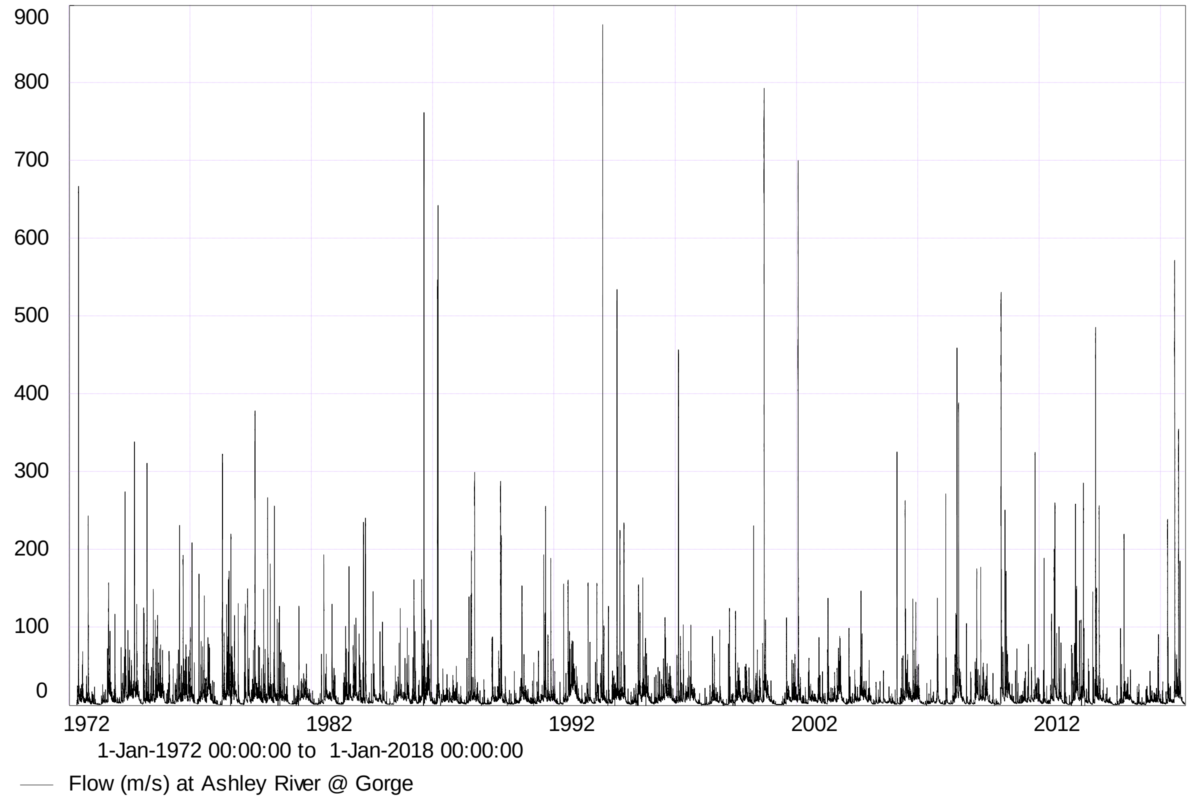
Figure 7 shows the recorded hydrograph of the Ashley @ Gorge site form 1972to 2017. The gauge is just above the upstream end of the Middle Reach and as few major tributaries enter downstream of there (see Table 2) it gives a good indication of the flow variations that have influenced the patterns of change along the reach identified in this section.

Table 6 shows event magnitude and frequency statistics calculated from the Ashley @ Gorge flow record (using HillTop hydrological data analysis software, for flow data 19/4/1972 – 21/12/2017, using the GEV distribution that provides the best fit for the data). This provides categories against which to compare floods of different magnitudes.

Table 6 Magnitude and frequency of Ashley River/Rakahuri floods at Gorge (1972 – 2017)

Return period (years)	Magnitude (m^3/s)
100	1,172
50	972
20	740
10	585
5	443
2.33 (Mean Annual Flood)	291

Figure 7 Ashley River @ Gorge hydrograph (1972 – 2017)



Floods above the 5-year return period threshold have the potential to cause damage to property and infrastructure. Table 7 lists notable floods since 1972 that have peaked at or above this threshold at the Ashley @ Gorge recording site. The 1970s and 1980s decades only experienced one or two such events, while subsequent decades have been busier. These events certainly attract attention, but they are quite infrequent. In the 46 years of flow record at Ashley Gorge, the 5-year flood was equalled or exceeded for a total of just 5.4 days or 0.033% of the time.

Table 7 Ashley River/Rakahuri floods >5 yr return period at Gorge (1972 - 2017)

Date	Flood peak (m^3/s)
16/05/1972	668
11/08/1986	762
12/03/1987	643
23/12/1993	875
26/07/1994	535
6/02/1997	457
19/08/2000	794
13/01/2002	701
31/07/2008	460
26/05/2010	531
18/04/2014	486
21/07/2017	572

Of more significance in terms of fluvial geomorphic 'work' along the Ashley River/Rakahuri braidplain are smaller floods below the 1 in 5-year return period thresholds. These are summarised in Table 8 that shows counts[12] of floods greater than various flow thresholds for various blocks of years since the start of the flow record in 1972. The upper rows show mainly decadal event counts, while the lower rows show periods relevant to the cross section topographic surveys and braidplain vegetation monitoring.

Table 8 Decadal characteristics of Ashley River @ Gorge floods

Period	% time ≥MAF	Mean flow ≥MAF (m^3/s)	≥MAF	Frequency	≤5 yr	≤10 yr	≤20 yr	≤50 yr
1972 – 2017	*0.075%*	*443*	*21*	*0.46 / yr*	*8*	*7*	*3*	*3*
1972 – 1981	0.064%	347	5	0.5 / yr	4	-	1	-
1982 – 1991	0.064%	488	3	0.3 / yr	-	1	1	1
1992 – 2001	0.060%	535	4	0.4 / yr	-	2	-	2
2002 – 2011	0.097%	423	6	0.6 / yr	3	2	1	-
2012 – 2017	0.078%	404	3	0.5 / yr	1	2	-	-
1979 – 2001	0.073%	489	8	0.36 / yr	1	3	1	3
2001 – 2012	0.088%	423	6	0.55 / yr	3	2	1	-
2000 – 2004	0.088%	493	2	0.52 / yr	-	-	1	1
2004 - 2008	0.003%	318	1	0.3 / yr	1	-	-	-

The data in column two show that significant fluvial geomorphic 'work' along the Middle Reach of Ashley River/Rakahuri occurs more frequently than the large floods but still does not occur very often – on average just 0.075% of the time or a total of 6.6 hours per year. In addition, there is variability around this mean value, from nearly 0.01 % to as little as 0.003 % of the time. Column three gives an indication of how strong the geomorphic work might have been. The long term average flow for those floods equal to or greater than the mean annual flood threshold was 443 m^3/s. The period with the higher magnitude floods was 1992 – 2001 with mean flood flow of 535 m^3/s, and this included two 1 in 20 yr events.

The sections below assess the association between these flood frequencies and magnitudes, and the geomorphic work accomplished along the reach; ie the amount of bank erosion, the extent of bed level and sediment volume change, and the extent of the recently mobile riverbed (or conversely the amount of vegetation encroachment across the braidplain).

3.5.1 Bank erosion and flow events

Erosion at the margin of the recently mobile bed has been identified at three sites along the Middle Reach (Section 3.1). Each of these sites had been relatively stable prior to the mid-late 2000s, largely unaffected by six floods of greater than 1 in 10-year magnitude between 1972 and 2008, including the largest flood on record of 875 m^3/s in December 1994.

Erosion at these sites appears to have been initiated by two smaller but closely spaced floods in July and August 2008. Further erosion occurred in association with subsequent modest flood events between 2009 and 2015, and in late 2017.

These observations show the recent erosion issues in the Middle Reach have been occurring during a period of more active floods, but the erosion is not necessarily triggered by large floods, with closely spaced smaller floods starting the erosion, and subsequent smaller events able to carry this on.

[12] These data have been compiled from mean hourly flow data so flood peaks lasting just a few minutes are not included. "≤10 yr" counts events that peaked between 5 yr and 10 yr return period thresholds. "≤20 yr" counts events that peaked between 10 yr and 20 yr return period thresholds, and so on.

3.5.2 Bed level change and flow events

Bed level change and sediment volume change along the Middle Reach is documented above in Section 3.2. Between 1979/1980 and 2001 most cross sections showed some bed level decline, and there was an overall loss of gravel volume from the reach. Although the percentage of time above the mean annual flood flow was a little below the long-term average, there were some large flood events, including three 1 in 20-year events that would very likely have been large enough to transport gravel out of the Middle Reach. A 761 m^3/s flood had occurred in August 2000, just a year prior to the 2001 survey and this event is likely to have contributed significantly to the erosion trend[13].

The 2001 to 2012 period saw a rise in a majority of the cross sections and gravel volume stored in the braidplain increased along the reach. Although this period had more frequent floods and a longer proportion of time above the mean annual flood threshold, they were small flood events with only one exceeding the 1 in 10-year threshold and that was in 2002, ten years before the survey.

Inspection of the cross-section survey data showed the 2001 – 2012 aggradation had occurred mostly within the recently mobile riverbed and was not related to vegetation trapping in the young or mature braidplain surfaces.

It is noted that the 16,840 m^3 of aggradation[14] that is estimated to have occurred between 2001 and 2012 is just 4.8 % of the 360,000 m^3 of sediment delivered to the Middle Reach from the erosion sites documented above in Section 3.1. The bulk of this sediment is probably still in the Middle Reach channel system as most of it was delivered at the upstream end near the gorge. It is interesting that the cross section analysis above shows no evidence for this bank erosion material.

In summary, these observations of bed level and change and sediment transport show:

- The calculated changes in sediment storage in the Middle Reach, whether over periods of increase or decrease, have not been large. At present, there is no evidence for a trend of erosion or deposition through the reach.
- Larger floods of >10-year magnitude are likely to be responsible for much of the sediment transport along the reach and will erode and transport more sediment than they deposit.
- Smaller floods <10-year magnitude will deposit more sediment than is moved, causing aggradation.
- Sediment transport capacity is approximately in equilibrium with sediment supply over multi-decadal time scales. While there are periods of channel erosion and reduction in channel sediment storage which will deliver increased bedload to the Lower Reach, there are also periods of aggradation when floods are not large enough to transport sediment through the reach, and there will be decreased bedload delivery downstream.
- Vegetation encroachment does not appear to be a major factor causing sediment trapping and bed aggradation since the late 1970s.

3.5.3 Vegetation change and flow events

Vegetation changes along the Middle Reach are described above in Section 4.3. As noted, flow data are not available prior to 1972 so it has not been possible to explore possible linkages between flow and the rapid increase in braidplain vegetation through the 1960s. Vegetation encroachment did not decrease between 1970 and 2000 despite there being two 1 in 20-year floods and two 1 in 10-year floods. However, the first part of this period had only one large flood at the start and there were some 14 years of small floods during which time vegetation encroachment may have been able to become well established.

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[13] Sutherland (2006) reported that 22,000 m^3 of gravel had been extracted from the Middle Reach of the Ashely River/Rakahuri in 2000. This extraction occurred at xs 21.3 where a large hole can be seen in both the surveyed profile and the December 2000 aerial photograph. Less than 20 % of the extraction was upstream of the xs line so would have contributed less than 10% to the calculated erosion.

[14] If it is assumed that the volume of gravel extraction would have otherwise contributed to aggradation, this figure could be as high as 70,000 m^3, which would represent 20% of the bedload added to the reach from bank erosion.

The 2000 – 2004 increase in vegetation cover occurred during a time of more significant flood activity, including two 1 in 10-year events. The second of these was in January 2002, and there were no floods for 4 years after that, presumably giving the grass and low scrub cover seen in the 2004 and 2008 imagery an opportunity to become established. However, this was relatively easily removed in the winter 2008 floods.

These observations suggest that braidplain vegetation encroachment is partially affected by flood magnitude and frequency, but the association is not strong. Other factors such as growing season rainfall, groundwater levels, or vegetation clearance may be involved.

3.6 Summary

This section has documented several issues that stakeholders have identified as occurring within the fluvial geomorphic environments along the Middle Reach of the Ashley River/Rakahuri. The following summarises the key points of what has been happening, and why this has been occurring.

- The Middle Reach of the Ashley River/Rakahuri is a transfer zone through which water and sediment are being transported, with some temporary storage of sediment occurring in bars and islands within the braidplain (for years or decades), and terraces adjacent to the braidplain (for hundreds of thousands of years).
- The main contributor of water and bedload sediment is the Ashley River/Rakahuri from above gorge (~60%), with the Okuku contributing ~30%. Small tributaries such as the Glentui and Garry Rivers make up the balance.
- The catchments that are delivering water and sediment to the Middle Reach are mountainous and in relatively good condition. Forest cover is >30% and the grasslands do not contain large areas of degraded lands. Therefore, bedload sediment delivery to the river system is likely to be well within the natural range of variability.
- The Middle Reach runs for 25.5 km through the Loburn Basin from the Gorge Bridge to downstream of the Okuku River confluence. Three sub-reaches are identified, based on natural changes in gradient.
    - From the Gorge Bridge to Mairaki Downs (sub-reach T1, 12 km) the valley floor is 0.8 – 1.5 km across and confined between high terraces on both banks. The braidplain was 0.5 – 0.75 km across, but the active width is now 0.42 – 0.65 km. Bed slope is 6.62 m/km.
    - From Mairaki Downs to Garrymere Rd (sub-reach T2, 4 km) the valley floor narrows to 0.58 km where it is crossed by the Ashley Fault Zone. The valley then widens downstream to 1.2 km, and is flanked by downlands on the south bank, and high terraces on the north. Bed slope is 5.8 m/km.
    - From Garrymere Rd to Swamp Rd/Hillcrest Rd (sub-reach T3, 9.5 km) the valley generally widens from 1.5 km to 1.8 km and is flanked on both banks by higher terraces. Bed slope remains at 5.8 m/km.
- The Middle Reach channel system has not been significantly affected by deliberate management interventions such as groynes or stopbanks. However, limited areas of bank protection willows have been planted, and the braidplain has been encroached on by self-seeded gorse, broom, lupins, blackberry and willows.
- Erosion has been occurring at three localities along the Middle Reach within the last 10 years. This has resulted in the loss of ~20 ha of productive farmland. Erosion of the vegetated islands within the braidplain also occurred. Both the bank and braidplain erosion are considered to have been natural processes, occurring as part of the normal recycling of sediment that occurs along the channel system in a river's transfer zone. The erosion appears to have been triggered by two closely spaced small floods in 2008. At the upstream sites the erosion has slowed since 2015, although it continues at the downstream site.
- Vegetated islands and bars are a natural part of braided river systems although these were likely to have been temporary, being swept away in large floods, and re-establishing with a few years. It is likely that naturally vegetated areas comprised some 20% of braidplains.

- Non-native species such as gorse, broom and willow began to invade the braidplain within a few decades of European settlement of the area. These have crowded out the native species and become dominant in the braidplain.
- The earliest aerial photography of the Middle Reach dates from June 1942 and shows a wide braidplain with limited vegetation cover. However, the decade prior to this had included a number of floods of sufficient size to be noted in newspaper reports, and it may be the 1940s images show the braidplain with less vegetation due to the effects of these floods.
- Vegetation encroachment caused sharp decline in braidplain width between 1960 and 1970, and again between 2000 and 2008. The most significant period of vegetation encroachment was in the 1960s.
- There are no flow records covering the 1960s period of vegetation encroachment. However, the 2000 – 2008 vegetation encroachment included a period of increased flood frequency, and vegetation encroachment occurred in spite of this, thus the association been floods and vegetation may not be straight forward.
- Since early 2008 the recently mobile riverbed width has recovered somewhat as floods, particularly in mid-2008 have been more frequent and although relatively small, they have been large enough to remove the gorse and broom that had been established between 2000 and 2008.
- This pattern of vegetation cover change suggests the system may have reached some sort of dynamic equilibrium such that over the next 30 years, during periods of reduced flood frequency, the vegetation encroachment may temporarily increase, to be cleaned out when floods return. One or two particularly large events (>20-year return period) could cause a significant reduction in braidplain vegetation cover, but within a few flood-free years this would re-grow. However, established willow tress may not be affected by this cycle.
- Most of the Ashley River/Rakahuri flow in the Middle Reach has tended to be concentrated in one main channel during normal flow conditions. This predominantly single-thread character of the river has been a persistent feature since the earliest available aerial photography of the 1940s. However, the main channel often has a number of small side braids associated with it, and the number of these increases downstream through the reach.
- Over the last ~70 years there has been a reduction in the number of these side braids. This occurred in two phases: between the 1940s and 1960s; and from the early 2000s to the present. Broadly, these changes in channel multiplicity are inversely associated with vegetation cover changes such that as vegetation cover on the braidplain increases, channel multiplicity declines. However, this association is less obvious since the late 2000s: as vegetation cover has decreased, channel multiplicity has also decreased.
- This continued trend towards a single thread channel despite reduced braidplain vegetation encroachment may suggest the Ashley River/Rakahuri is evolving towards a single thread wandering gravel bed river as bedload supply declines, and the increased vegetation cover may have been hastening this transition. If this is the case, management interventions to clear vegetation from mature surfaces on the braidplain may not have the desired effect of increasing channel multiplicity. Further, the reduced sediment supply would have implications for gravel extraction management both within the Middle Reach and downstream.

4.0 Lower Reaches of Ashley River/Rakahuri

This section addresses the geomorphology of the lower reaches of the Ashley River/Rakahuri as it relates to understanding of gravel aggradation/degradation between the Okuku River confluence and the estuary. It therefore covers the downstream part of the sub reach T#3 which is in the Ashley River/Rakahuri's transfer zone, and the sink zone sub reaches S#1 – S#4 (see Table 1).

The Lower Ashley River/Rakahuri flows across a large low-angle alluvial fan landform. Alluvial fans have some distinctive characteristics:

- They form where a river emerges from a relatively confined valley and the overall gradient abruptly becomes gentler so that it loses energy and is forced to deposit its sediment load.
- The fan has a narrow apex at its top end then spreads out widely downstream. As sediment builds up the channel bed rises and in floods the water is able to spill out and form a new channel ("avulsion") that can head off down the fan surface many kilometres away from its previous channel. At times the main channel may have several minor avulsion channels that operate during flood conditions and then dry up.
- The active channel may operate across a sector of the alluvial fan for a few decades, then avulse in a flood and switch to new sector of the fan kilometres away. A few metres of lateral shift of the channel in the fan apex can result in many kilometres of shift in the channel lower down the fan landform.

In this way, the fan aggrades or builds up, with the apex area rising more rapidly than the down-fan parts of the landform, and the channel switching to and fro. Alluvial fans are by their very nature, inherently hazardous landforms for human occupation.

The Lower Ashley River has built up its alluvial fan landform over the last 6,000 years[15].

4.1 Lower Ashley River/Rakahuri alluvial fan

A detailed geomorphic map of the alluvial fan was prepared in 1992 by R.I. McPherson and published in May 1995. It was revised in 2002 and has formed part of several ECan reports[16]. This forms the basis of understanding of the geomorphology of Lower Ashley alluvial fan.

4.1.1 Alluvial fan outline

The apex of the fan is 18 km up-river from the coast at the point the river transitions from its Middle Reach into the Lower Reach. This is 75 m above sea level. As it is followed to the east, the north side of the fan is hemmed in by old high terrace landforms until the rail bridge. From there it is able to expand to the north for ~4 km far as The Boyle Creek near Sefton. To the east the fan butts up against the inner side of a 1.8 km wide belt of coastal sand dunes within which is nestled the Waikuku Beach community. To the south it has been much freer to expand with the southern edge running along the former courses of the Cust River and to the Cam River. Fernside, Southbrook and Tuahiwi are all near this margin of the fan which extends 8.7 km south to the end of the Northern Motorway. Rangiora, Woodend, Pegasus Town and Waikuku all sit on the alluvial fan which covers ~112 km^2.

The McPherson geomorphic map is not reproduced here as it will not be examined in detail and is widely available in other reports. However, it is noted that the landforms McPherson has mapped impose a southeast oriented 'grain' to the Ashley plains which will direct surface water flow. The maps of hydraulic modelling of Ashley River/Rakahuri flood hazards by Oliver (2008), and Oliver and Wild

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[15] Approximately 6,000 years ago marks a reference point in time with respect to global sea level. Prior to this time sea level was much lower than an present due to water being locked up in ice sheets. These began to melt around 15,000 years ago and sea level rose rapidly as this water was decanted back into the oceans. This melting stopped about 6,000 years ago and since then global sea level has been relatively stable at around its present elevation (±1 m). All coastal landforms have developed since 6,000 years ago.

[16] *Ashley River Floodplain Management Regional Plan Technical Investigation* ECan Report 95(6) May 1995.
AJ Boyle and MR Surman, 2009 *Ashley River bed level investigation* ECan Report No. R09/71.
Oliver, T. 2008 *Waimakariri District Flood Hazard Management Strategy Ashley River Floodplain Investigation* ECan Report No. R08/23.
Oliver and Wild 2016 *Ashley River Floodplain investigation – 2016 update* Report No. R16/36.
NIWA 2017 *Braidplain delineation methodology*

(2016) shows patterns that closely follow the geomorphic mapping. This demonstrates the way landforms provide boundary conditions for other processes that act on the land surface.

4.1.2 Gravel deposition

The Ashley River/Rakahuri is, throughout its length a distinctively gravel bedded river, except in the last 1.5 – 2 km before it reaches the sea where the gravel becomes much less common. Why is this? Where has the gravel gone?

The high-level answer lies in the fact that the Lower Ashley River/Rakahuri is a sink zone where bedload sediment has been deposited, rather than passing through to end up in the sea (as outlined above in Section 2.1. The river is not 'powerful' enough to deliver its gravel bedload[17] all the way to Pegasus Bay – although it does transport sand to the coast.

The fact that the gravel bedload peters out before it reaches the coast could perhaps be a recent phenomenon, resulting from the intensive gravel extraction from the riverbed upstream. However, two observations indicate this gavel loss has been a long-term factor throughout the 6,000 years of development of the alluvial fan.

i. There are no gravel beach ridges adjacent to the Ashley River/Rakahuri mouth; instead there are extensive sand dune ridges. If gravel was being delivered to the coast, it should be present in the coastal landforms. To the south, the Waimakariri River also does not deliver its gravel bedload to the coast and has a similar – but much larger alluvial fan landform with associated sand dune systems along the southern Pegasus Bay shoreline. However, to the north of the Ashley/Rakahuri the Kowai and Waipara Rivers have not built alluvial fans at the coast, they deliver their gravel bedload to Pegasus Bay and there are wide gravel beach ridge plains at their mouths with limited sand dune development.

ii. The natural Lower Ashley River/Rakahuri channel (prior to river control works) became steadily narrower in its last 7 km down to the coast (as does the Waimakariri River channel). This is unusual for a river channel, which would normally get wider towards its mouth. The Ashley/Rakahuri channel got smaller downstream because it had less work to do. Water and bedload sediment readily escaped from the channel upstream in floods to spread out over the alluvial fan surface away from the main channel.

This shrinking river channel towards the coast and the absence of gravel in the coastal landforms at the mouth of the Ashley River/Rakahuri strongly suggest the river has never been a significant contributor of gravel to Pegasus Bay. Rather, its gravel bedload was deposited across its alluvial fan landform before reaching the coast.

The alluvial fan landform is some 6,000 years old and has built up many tens of metres depth of gravels over this time. The surface of the landform that is visible today represents the last few hundred years of its development and shows evidence of the main channel and its flood channels switching back and forth across the fan surface.

4.1.3 Phases of alluvial fan development

The McPherson geomorphic map shows there have been several 'recent' (ie last few hundred years) phases of alluvial fan growth, with quieter phases in between. These phases of increased aggradation will be related to factors such as changes in the rate of bedload sediment supply, and/or changes in flood regime due to natural climate changes.

4.1.3.1 Climate change and flood regimes

Changes in the magnitude and frequency of floods will affect the river's capacity to transport its bedload. In the last few hundred years (from about 1300 to 1850 AD) many mountainous temperate latitude environments around the world experienced the "Little Ice Age". Temperatures cooled, and mountain glaciers advanced. Weather conditions were probably stormier. While the Ashley/Rakahuri would not have had any glaciers, the cooler temperatures would have supressed alpine vegetation growth potentially allowing for increased erosion and sediment delivery to the river. The stormier

[17] It is not strictly correct to state that no gravel reaches the coast. Small accumulations of gravel can be found in parts of the estuary and in the dunes at the coast suggesting that occasionally some floods are large enough to carry some gravel all the way to the coast. However, the amount of gravel involved is small.

weather regime would have resulted in more floods to transport this sediment downstream to eventually be deposited in the alluvial fan landform.

4.1.3.2 Earthquakes

Earthquakes are known to deliver large volumes of sediment into river systems. Alpine Fault earthquakes occur about every 300 years or so, and they result in severe and prolonged ground shaking throughout North Canterbury. The resulting mountain slope failures will deliver vast amounts of shingle to rivers like the Ashley/Rakahuri and Okuku. Over succeeding decades this sediment is carried down river as a pulse of sediment that will result in a phase of alluvial fan growth at the Ashley/Rakahuri, and development of a new beach ridge at the mouths of the Kowai and Waipara Rivers.

4.1.3.3 Ashley River/Rakahuri in 1850

When Europeans arrived in the Ashley district in the 1850s it would have been about 130 years since the previous Alpine Fault Earthquake (in ~1717 AD) and that pulse of earthquake generated bedload was probably still making its way down the river. In addition, this was towards the end of the Little Ice Age period and sediment production in the mountains may have been more active and there may have been a slightly higher magnitude flood regime due to the different climate regime.

4.1.3.4 Ashley River/Rakahuri since 1850

The natural drivers of environmental change in the Ashley River/Rakahuri have been changing over the last 170 years:

- The climate has warmed as the Little Ice Age has waned;
- The rivers' flood regimes may have become less vigorous;
- Bedload sediment supply may have dwindled as the Alpine Fault induced pulse of sediment has moved through, and as the climate ameliorated after the Little Ice Age; and
- Human influences in the landscape have brought changes to the river system[18]:
    - Stopbanks, groynes, bank erosion protection, bridges and their abutments, and other engineered structures;
    - Willows, gorse, broom, lupins and other invasive non-native species
    - Gravel extraction from the braidplain;
    - Woody weed control by aerial spraying; and
    - Encroachment of farmland into the braidplain.

Thus, there have been a variety of large scale fluvial system changes occurring naturally within the Ashley River/Rakahuri, with an overlay of human caused changes. The challenge is differentiating the natural from the human causes and responding appropriately to each.

4.2 Channel migration management

As noted above, alluvial fans are hazardous landforms given the mobile nature of the channel, and its propensity to flood out widely over the landscape. In the past, the response to this had been to restrict channel migration and flood breakouts by confining the river been stopbanks, with the expectation that the confined river would flow more swiftly and erode and transport its bed sediment and entrench itself in a deeper, more stable channel. This understanding has not been borne out by experience in Canterbury rivers.

[18] It is likely that Maori activities in the landscape over the ~1,000 years prior to the arrival of Europeans had also resulted in landscape and river system changes.

Unfortunately, rivers on alluvial fans aggrade their beds if confined between stopbanks as they are unable to spread their sediment load out over the fan and as the bed aggrades the effectiveness of the stopbanks is lost[19].

Given the alluvial fan landform setting of the Lower Ashley River/Rakahuri, channelization of the river between stopbanks would likely lead to aggradation of the bed particularly after the 1930s when the major stopbank schemes were put in. However, various flood control measures had been constructed along the river almost as soon as settlement began, and especially after the very large 1868 flood.

4.3 Historic reports of river bed levels

Anecdotal evidence of Ashley River/Rakahuri bed aggradation was appearing by the late 1880s. *The Press* (24/9/1888) reported:

> *Perhaps it is not generally understood that during the last twenty-five years the bed of the Ashley has risen to an alarming height. About twenty-five years ago […] the bed of the river was 3 feet higher than the low-lying land a short distance from the river bank. Now […] the bed of the river is 19ft higher…"*

This ~5 m rise in bed level is dramatic and possibly an exaggeration, but none-the-less it can be taken to show that aggradation was occurring.

In the late 1890s *The Press* (27/2/1897) reported that *rivers like the Ashley were bedding up with shingle assisted by the growth of gorse*.

The issue continued to attract attention into the early decades of the 20th Century. For example, in 1919 the Government's Rivers Commission held public hearings in Rangiora and the Chairman of the County Council told the commission that *the silting up of the Ashley River had engaged the attention of the Council for a considerable time* (*The Press,* 23/6/1919). The Council surveyor gave evidence to the commission on the filling up of the riverbed. He had known the river from 1878 and reported the bed was gradually silting up. As an example, he had seen a traction-engine and plant go under the bridge, but now it was almost impossible for a horse and trap to pass underneath (*The Press,* 24/7/1919). Five years later the issue was still of concern and at a meeting to discuss formation of the Ashley River Trust, the chairman stated *the silting-up of the Ashley River was becoming a very serious matter* (*The Press* 19/12/1924).

Clearly, there was a perception that the bed of the Ashley River/Rakahuri had been rising for 40 – 50 years and it is reasonable to accept that this was indeed occurring. Was this due to a natural pulse of bedload moving down the river, or was it due to the early channelization efforts?

4.4 Bed level topographic surveys

It was some years before systematic surveys were established to document bed level changes. The first topographic surveys of the Lower Ashley riverbed were in 1936 around the time the flood protection scheme stopbanks were constructed. Eight section lines were surveyed between the Makerikeri and Okuku Rivers, and one at the State Highway 1 Bridge. These were repeated in the early 1960s and a further 17 sections were surveyed between the Makerikeri River and the estuary. These 25 lines have since been resurveyed[20] a number of times (1976, 1986/1988, 1997, 2001 and 2005 (both partial only), 2008/2009 and 2014. LiDAR data obtained in 2005 and 2014 was also used to create cross sections for those years. ECan expects to continue surveying the cross sections at five yearly intervals.

Between 1936 and 1960 bed level lowering ('degradation') was reported for seven of the eight surveyed cross sections (88%). This is the reverse of the prior anecdotal evidence for bed

[19] A spectacular example of this is the alluvial fan of the Waiho River at Franz Josef Glacier. Wright's Cut on the lower Waimakariri River alluvial fan has similar issues.

[20] The cross section data is archived by ECan. It has been analysed and used in several reports including:
Ashley River Floodplain Management Regional Plan Technical Investigation Report 95(6) 1995
Sutherland, N. 2006 *Ashley River Report Status of Gravel Resources and management implications* ECan Report No. R06/3
Boyle, A.J. & M.R. Surman 2009 *Ashley River bed level investigation* ECan Report No. R09/71
Gardner, M. 2016 *Ashley River geomorphic change detection mouth to Okuku confluence 2005 to 2014.* Land River Sea Consulting Ltd.

aggradation. Subsequent surveys have shown a mix of mainly degrading[21] and some aggrading cross sections: between 1960/1962 and 1976, 48% of the sections were degrading; from 1976 to 1986, 57% were degrading; from 1986 to 1997, 72% were degrading; from 1997 to 2008/2009, 84% were degrading; and from 2008/2009 to 2014, 58% were degrading. The reported mean bed level changes were in the range of +0.257 m to –0.372 m. Degradation appears to be generally increasing, and this is to be expected given the amounts of gravel extracted from the riverbed.

4.5 Interpreting bed level changes

The geomorphic characteristics of the surveyed cross sections could not be interpreted from the reported mean bed level data. Only Gardner (2016) addressed the bed levels directly in developing a method to accurately quantify the volume of alluvium lost/gained between LiDAR survey dates. The other reports were concerned with bed levels in relation to stopbanks and flood hazards, and there was little commentary on the bed levels themselves as it was considered the bed levels were generally being managed satisfactorily.

It is noted that since the mid-1930s the overall pattern of bed level change along the lower Ashley River/Rakahuri has been degradation and given the extent of gravel extraction from the braidplain in recent decades, this decline in bed levels is not unexpected. However, it is not possible to provide a definitive assessment of the geomorphic significance of bed level changes along the lower Ashley River/Rakahuri.

Attempts have been made to develop a sediment budget for the river by quantifying the amount of gravel entering the reach (from the Middle Reach of the Ashley River/Rakahuri, Okuku River, and Makerikeri River), how much is removed by gravel extraction, and how much passes through to the coast. This budgeting approach has not been particularly informative as there have been uncertainties and information gaps. Unresolved issues include:

- Why did the river bed degrade between 1936 and the early 1960s? Was there a significant gravel extraction industry over those years sufficient to counteract the anecdotally reported prior aggradation trend?
- Is gravel extraction solely responsible for the declining bed levels or has there been a decline in bedload supply from upstream?
- How much bedload does the Middle Reach deliver to the Lower Reach? Is Middle Reach vegetation encroachment onto the braidplain having a significant impact to reduce sediment supply and thus promote bed degradation in the Lower Reach downstream?
- What are the flow thresholds that mobilise and move sediment through the reach? Has the frequency of these events been increasing/decreasing?
- What is the fate of gravel in the downstream sub reaches near the estuary?

It was established above (Section 4.2) that the lower Ashley River/Rakahuri flows across an alluvial fan landform, and that controlling the channel between stopbanks so that it remains in a fixed position would likely lead to aggradation of the river bed. Anecdotal reports indicated aggradation was occurring prior to the stopbank schemes being established in the 1930s, but topographic survey data shows the bed has been degrading since the mid-1930s. The expected aggradation has not been occurring, and while the gravel extraction from the braidplain in recent decades is presumably driving the recent degradation patterns, how can the historic and recent patterns of bed level change along the Lower Ashley River be best understood, and in the light of this, how should that system be best managed in the future?

4.6 Summary

- The Lower Ashley River has built a large low-angle alluvial fan landform over the last 6,000 years. Starting in the late 1800s and more particularly since the stopbank scheme was constructed in the late 1930s, the river channel has been extensively modified and no longer behaves as a natural system channel. Importantly in the context of sediment transport processes and bed level changes, floodwaters are no longer able to break out of the channel to

[21] ‘Degrading/degradation’ is used in this report as the opposite of aggrading/aggradation. Vertical lowering as opposed to growth of the bed. None of these terms are meant to imply any particular process that may have caused the elevation change.

spread water and sediment over the alluvial fan surface and the channel that naturally would have migrated widely across the landform is now fixed in place.

- The topography of the alluvial fan landform acts as a boundary condition for the dispersal of floodwaters across the lower Ashley plains (should the stopbanks fail). Thus, floodplain hazard mapping closely follows the mapped minor landforms across the alluvial fan.
- Historically the Ashley River/Rakahuri did not transport its gravel bedload to the coast. Therefore, confining the channel between stopbanks would be expected to promote aggradation of the bed. Numerous anecdotal reports attest to channel aggradation at least between the 1880s and 1920s.
- Topographic surveys of the Lower Ashley River/Rakahuri since 1936 show the bed has been generally degrading, and this is attributed to gravel extraction from the braidplain. However, other factors could also be in play including a natural long-term reduction of bedload sediment supply from upstream, or short-term sediment trapping in braidplain vegetation in the Middle Reach upstream, or a long-term flood regime change that has resulted in fewer sediment transporting floods.
- There have been a variety of large scale natural long-term fluvial system changes occurring within Ashley River/Rakahuri, with an overlay of human caused changes. The challenge is differentiating the natural from the human causes, and responding appropriately to each.

5.0 Recommendations

This assessment of the Ashley River/Rakahuri geomorphic system has documented a number of natural and human caused changes occurring in this environment. The geomorphic approach has provided both background understanding of and explanations for aspects of the fluvial system behaviour. Further investigations would provide useful insights as follows:

- What are the threshold flows for initiation of bedload sediment movement, particularly the thresholds for sand movement, surface flushing, and the depth flushing that mobilises the whole channel bed? How often do these flows occur? Has the frequency of these flows changed? Will future climate change affect the frequency of these flows?
- Has there been a decline in bedload sediment supply?
- What is the sediment budget for the Lower Ashley River/Rakahuri and what are the ramifications of this for gravel extraction and braidplain management? Are minimum bed levels for gravel extraction appropriately set?
- Is the channel system in the Middle Reach evolving towards a non-braided state? If this is occurring, is it due to natural factors or human factors? What are the ramifications of such changes for management of the Middle Reach?
- What are the fluvial geomorphic characteristics of the Middle Reach such as braiding intensity, channel sinuosity; and how has braidplain vegetation encroachment affected these characteristics?
- What has been driving braidplain vegetation encroachment in the Middle Reach? What might be the effects of braidplain vegetation management on channel behaviour and bedload sediment transport?
- Can useful information be gleaned from the pre-1972 flow records at the Ashley@Gorge flow recording site?