WAIOHINE RIVER – GEOMORPHIC TRENDS ASSESSMENT AND ITS APPLICATION TO RIVER MANAGEMENT

Selene Conn Tonkin+Taylor

ABSTRACT

The Waiohine River is located in the Wairarapa Valley and joins the Ruamāhunga River just south of Greytown. The Waiohine River has been actively managed in its current location since 1890 by a number of agencies to prevent it from flooding Greytown, and is now managed by Greater Wellington Regional Council. As part of the development of the Waiohine Floodplain Management Plan, representatives of the Greytown community and Greater Wellington sought to understand the character and behaviour of the Waiohine River to guide current and future management actions.

Our investigation found the Waiohine River has had a change in river behavior following the end of the last glacial maximum, switching from a braided system to a wandering system. As the climate warmed, and there was an increase in precipitation, hillside vegetation cover increased, reducing sediment supply. Increases in precipitation also increased sediment transport. The Waiohine River is still displaying a slight incision trend, which suggests it may still be responding to paleo-climate changes. Infrequent episodic events have also triggered changes in river behavior. Following the 1855 rupture of the Wairarapa fault, the Waiohine River avulsed, and occupied numerous channel locations on the true right floodplain. The earthquake also induced large-scale landsliding in the upper catchment, and head-cut erosion where the fault scarp crossed the bed of the Waiohine River, creating a short-term pulse of sediment into the system.

Today, the Waiohine River is managed using a combination of rock groynes, gravel management and willow planting. It is likely the gravel management is removing the coarse surface armour layer on gravel beaches, enabling more frequent transport of coarse material into downstream reaches, and an increase in fine grained sediment supply. The three reaches identified during the investigation also show different responses to river management and sediment inputs. A tendency towards aggradation in one of the reaches, and the numerous flood channel on the true right floodplain, has created an elevated risk for channel avulsion. This risk will increase under predicted climate change flood scenarios.

Climate change also poses additional challenges for the Waiohine River. Predicted seasonal reductions in precipitation, but increases in temperature may reduce vegetation condition on the hillslopes. This may increase sediment inputs into the river. Sea level rise may change the erosional and depositional areas in the Ruamāhunga River, which could lead to bed aggradation in the lower reaches of the Waiohine River.

High magnitude events may also have different impacts on slope processes, and delivery of sediment. The frequency and timing of these events will largely determine the channel response. Some events may trigger aggradation in upper reaches, and a potential 'sediment starvation' incision response downstream, while other events may be more successful at transporting sediment pulses into downstream reaches.

Our findings highlight the importance of understanding landscape scale behaviours in order to effectively manage New Zealand rivers at a reach scale.

KEYWORDS

River management, fluvial geomorphology, climate change

PRESENTER PROFILE

Selene Conn has over nine years' experience as a fluvial geomorphologist specialising in geomorphic assessments of river systems in both New Zealand and Australia. She has undertaken numerous assessments of river character, behaviour and evolutionary pathways for both urban precinct structure planning, restoration prioritisation and waterway sensitivity to increased discharges associated with industry. Selene's focus over the years has been on combining catchment and/or reach scale geomorphic processes with vegetation dynamics, especially in modified landscapes.

1 INTRODUCTION AND BACKGROUND

The Waiohine River is located in the Wairarapa, next to Greytown (Figure 1) and is managed by Greater Wellington Regional Council. Between 2011 and 2016, the council prepared a floodplain management plan (FMP) for the Waiohine River with recommendations for future management. Through this process, GWRC wanted to understand how the current and future predicted geomorphic processes may inform future management requirements, possible stopbank locations, and their possible contribution to flood impact and flood modelling.

The purpose of the Waiohine geomorphic trends assessment was to assess the evolution of the Waiohine River, with a focus on the geomorphic trends which may increase the risk of flooding to Greytown within the short to medium term, including the risk of major avulsion. Understanding large scale catchment scale processes both historic and current, will help to inform possible landscape and river change now and in the future.

Management of the Waiohine began in the late 1800's to try and address the river instability and frequent avulsions (changes in channel location). By the late 1870's, with significant help from a series of engineering projects, the Waiohine River was coaxed into its current location. The intent of the engineering works, was for the Waiohine River to be managed (by various River/Catchment boards) to maintain this course in perpetuity (Oxenham 1993).

It wasn't until the 1950's that the Waiohine River Management Scheme actively started managing the Waiohine River in its' current location through a co-ordinated programme to provide protection from flooding and bank erosion. In the 1970's river management included maintaining the Waiohine River in a specific alignment and channel width (80 yards (73 m) D. Peterson pers. comm), with the managed alignment width increasing to 145 m between the gooseneck and SH2 bridge and 70 m downstream of the SH2 bridge in the 1990's (Flanagan 2011).

Gravel extraction has also been used since the 1950's to manage sediment loads between the rail bridge and the SH2 bridge (Reach 2). Several stopbanks have been constructed along the Waiohine River at different times, to protect Greytown and other rural landholders from flooding events. These have generally not been constructed to a specified design criteria or flood depth, with a few exceptions. Rock groynes have been used throughout the Waiohine River since the 1950's to protect properties from bank erosion, namely from Kuratawhiti Street to SH2 bridge. The groynes have been supported through extensive willow planting along the edge of the active channel.

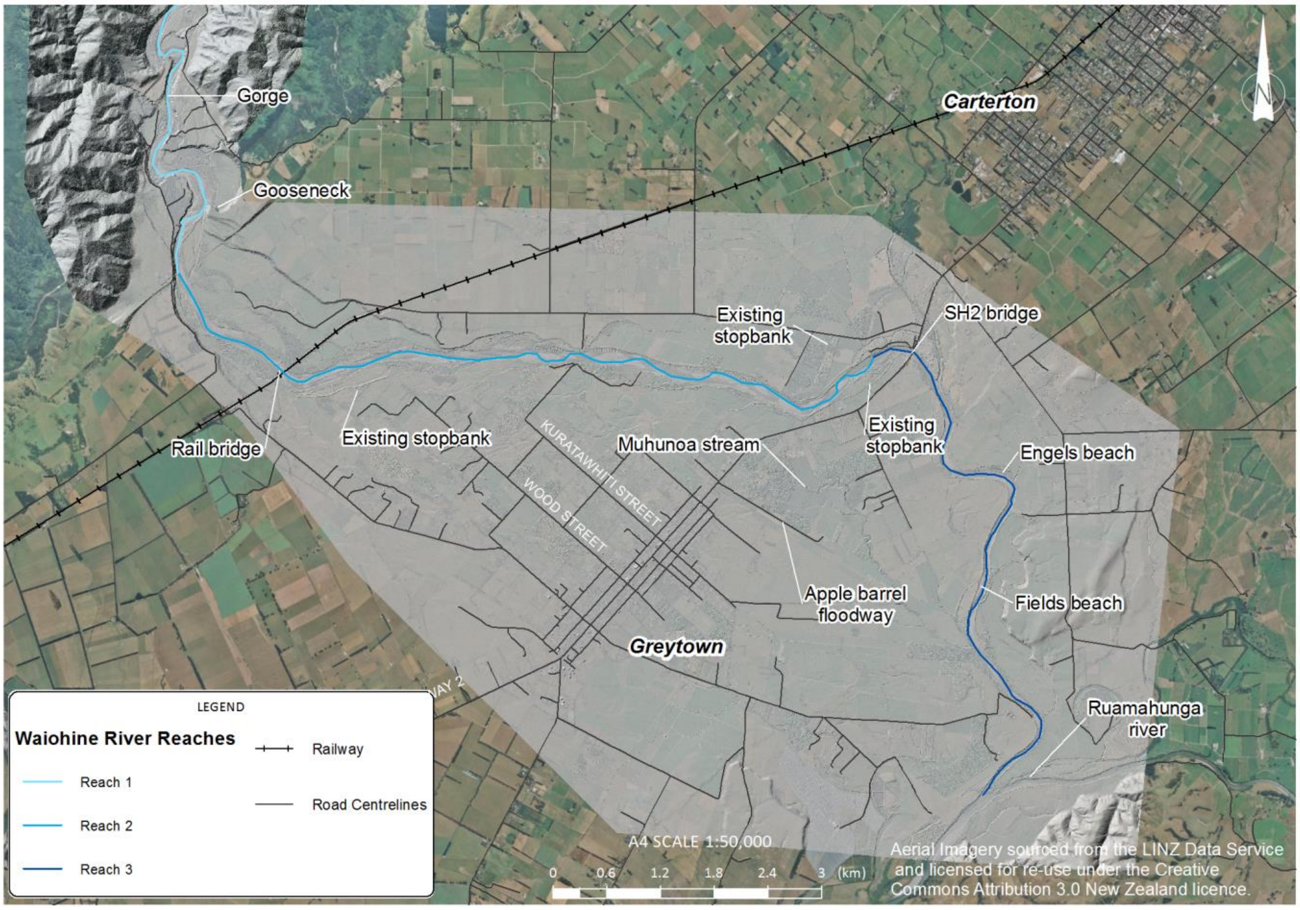

Figure 1: Waiohine River locations, and identified management reaches.

1.1 METHODS

Significant work had already been undertaken to develop or inform the Waiohine River FMP. The intent of the Waiohine River geomorphic trends assessment was to collate and review all this existing information, where possible. No new data was collected as part of this project. Existing data sets or information that was reviewed as part of this project included: flood extents for the 50 and 100 year events for three predicted climate change scenarios (RCP2.0, 6.0 and 8.5), potential impacts of climate change in regards to extreme rainfall events in the Waiohine River, ecological assessments, LiDAR derived DEM's, and 50 years of council cross-section and gravel extraction data. A full bibliography of reports prepared in the development of the Waiohine River FMP can be found in GWRC (2016).

To supplement the information collated as part of this project, we also researched the impacts of historic earthquakes, historic accounts of the river (particularly in relation to flooding or early descriptions or the river), terrace formation and dating, as well as reviewing historic aerial imagery dating back to the 1930's.

We also attended a site visit to various locations on the Waiohine River with GWRC flood management staff, river engineers, catchment managers, consultants, and local stakeholders. The site visit was to gain an understanding of the catchment, the historic context of the river from people who have lived beside it their whole lives, and to view and discuss management issues.

All of this information and data gave us an idea of how the Waiohine River has behaved over the last 10,000 years.

2 DISCUSSION

2.1 CURRENT TRENDS

Overall, the Waiohine River appears to be slightly incising. A differential analysis of the two LiDAR sets from 2008 and 2013 show a decrease in elevation in the active channel of between 0.8 and 1 m. Reach 2 also shows an increase of up to 1 m on depositional surfaces outside of the thalweg. Repeat cross-section surveys undertaken by GWRC, and thalweg longitudinal profiles processed from this data by GWRC, also show a similar slight incision trend.

The cross-sectional data also shows how pulses of sediment (sediment slugs) move through the system, and how different reaches respond to sediment inputs. For example, between SH2 bridge and Kuratawhiti Street there is a gain in elevation between 1986-2013, and then a slight loss. While immediately upstream of Kurtawhiti Street and immediately downstream of SH2 bridge, the bed shows limited change over the 27 year monitoring period.

The cross-section surveys show an incision trend from 1990, between the back of Engels property and Fields beach (Reach 3). This incision response can be partly attributable to the sequential loss of a meander bend on the true right bank between 1941 and 1978, and subsequent straightening of the channel between 1970 and 1990. These planform changes shortened the reach length, increasing slope, enabling greater sediment transport at a local scale. Targeted gravel extraction also occurred on Engels and Fields beaches between 2008 and 2010, likely exacerbating the existing incision process.

Localised bank retreat of up to 110 m in Reach 2 was documented by PDP (2014). In a wandering gravel bed river, with limited change in bed level despite gravel extraction, lateral adjustment is expected. As both floodplains are comprised of alluvial material, lateral adjustment of the channel is possible across the whole floodplain and is not limited to the current managed active channel extents. Engagement of the floodplain during out of bank events is likely to limit the extent and severity of lateral erosion, by reducing flood peak velocities.

Site observations during the June site visit showed that bar surfaces had surface armouring in Reach 1, and to a lesser degree in Reach 2, with some gravels showing imbrication (Figure 2). Surface armouring is when the gravels on the surface of a bar are of a larger size (generally gravels or boulders) than the material underneath (sands and silts). This armour layer is generally only moved during larger flood events, where the energy of the floodwaters across the bar surface is sufficient to mobilise the amour layer. Once the armour layer is removed, the smaller material underneath is able to be readily reworked and redistributed.

Imbrication of surface gravels is where the individual gravel or boulders overlap and interlock in the direction of flow, providing greater protection to the bar surface from erosive forces (Plate 1, Figure 2). This kind of armouring suggests that gravel stores in Reach 1 are more resilient, and likely only reworked in less frequent, higher magnitude flows.

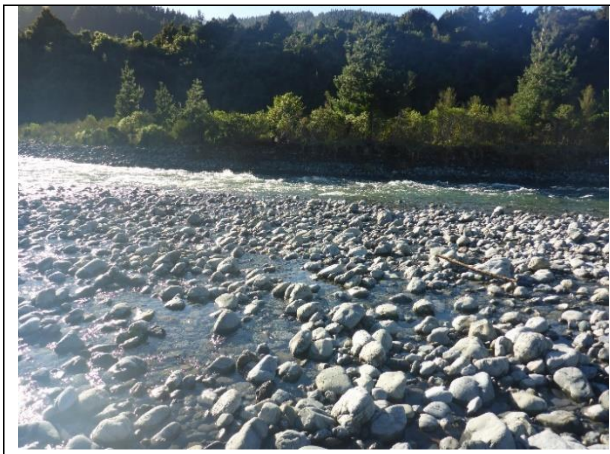	
Plate 1: Imbricated gravels on a point bar at the gooseneck (Reach 1).	*Plate 2: Example of partially imbricated gravels on a lateral bar near the rail bridge (Reach 2).*

Figure 2: Surface armouring of gravel bars in Reach 1.

The Waiohine River displays a slight correlation of large magnitude events with short and medium term climatic cycles (Interdecadal Pacific Oscillation (IPO) and El Niño Southern Oscillation (ENSO)). The three largest floods recorded since 1955 occurring during a positive IPO phase. The largest flood on record (1558 m3/s on 11 December 1982) coincided with both a positive IPO and a very strong El Niño event. A flood event of 1550 m3/s is approximately a 50 yr ARI event. There was a switch to a negative IPO phase in 1999, which could result in a period of lower magnitude events and reduced reworking of gravel surfaces (NIWA 2016, PDP 2014; MfE 2008).

Flood modelling of a 1,500 m3/s flood event with an additional 16% to account for potential climate change (roughly equivalent to a 100 yr ARI event under existing conditions, considered a high magnitude low frequency event) is able to access the true left floodplain upstream of the rail bridge (upper section of Reach 2) and then spills out across the true right floodplain. There are areas of flood ponding upstream of the rail bridge, back-pooling in the Mangatarere Stream and at the confluence with the Ruamahunga River (Figure 3). Peak flow velocities are reduced where flood flows are able to spread across the floodplain. This may reduce the bed load transport capacity within a small localised reach between Wood Street and Kuratawhiti Street during out of bank events, which may reduce channel capacity for following flood events.

Flood depths also appear to increase in three small areas on the true right bank in Reach 2; near the Kuratawhiti access track at the eastern end of Kuratawhiti Street, between Kuratawhiti Street and Fullers Bend, and at Fullers Bend immediately upstream of SH2 bridge (Figure 3). While flood depth does not necessarily predict erosion, it can indicate that higher velocity flows may occur in these three locations during out of bank events increasing erosion susceptibility.

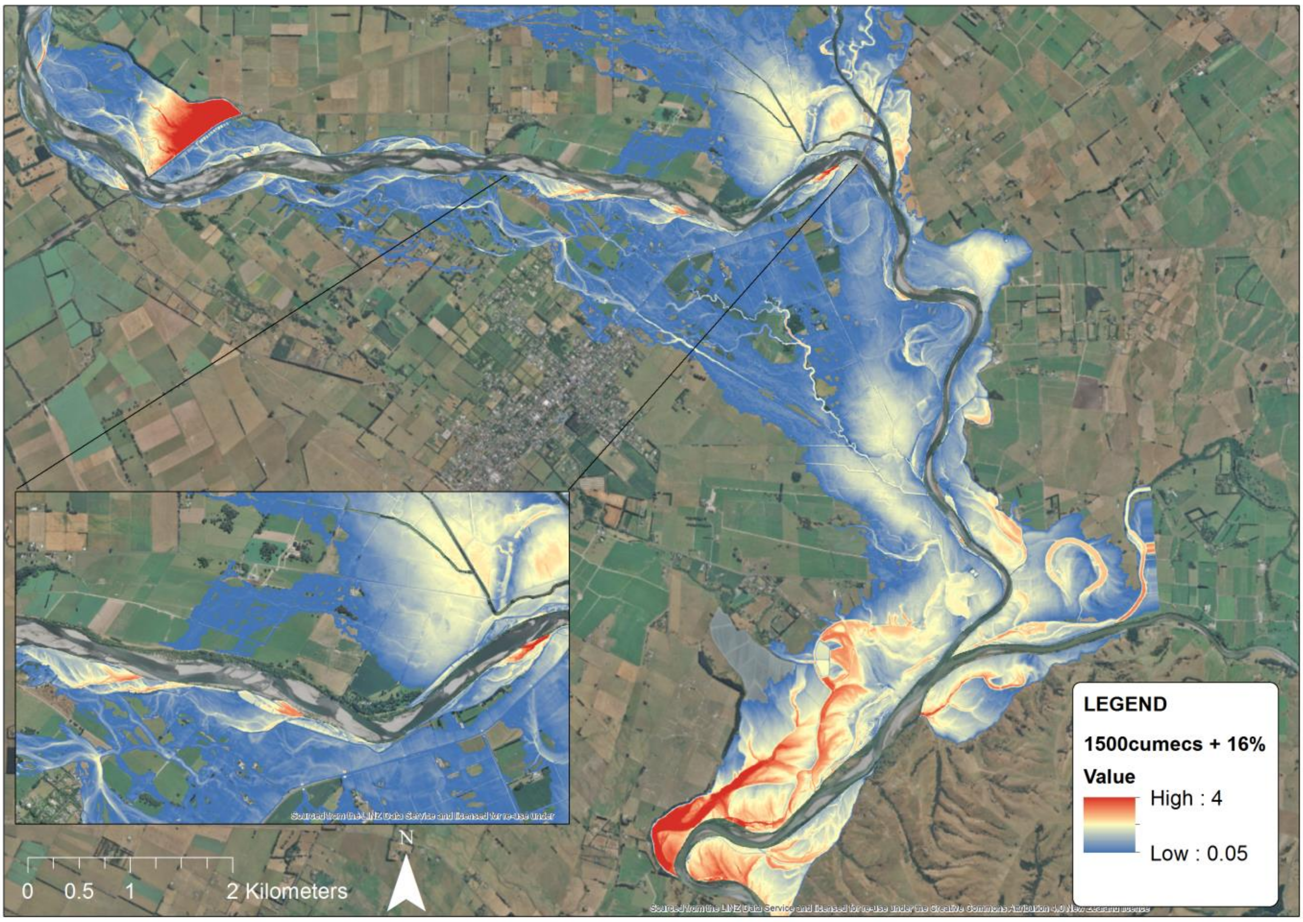

Figure 3: Flood depths for a 1,500 m3/s flow event with the inclusion of flows from a 16% increase in rainfall intensity. Zoomed in data frame shows three areas of deeper flood waters in Reach 2.Data supplied by GWRC.

2.2 CLIMATE INDUCED CHANGE

It is likely that at the end of cooler periods (glacial maximums), the Waiohine River would have exhibited a braided river channel form set on an active alluvial fan, most notably from downstream of the gorge. This predicted response is evident in the paleochannels still evident on the terraces and floodplains throughout the catchment, and can be attributed to long global climate cycles (Formento-Trigilio et al, 2002; Carne et al. 2011). As climates warmed, however, hillslope vegetation condition would have improved and precipitation increased leading to a transition from a braided system to a wandering gravel bed river through incision of the thalweg.

MfE (2016) predict an increase in annual temperatures and a decrease in annual precipitation (for RCP6.0 and 8.5) by 2090 for the Wairarapa. Further to this, NIWA (2018) predict that the rainfall variation associated with ENSO (El Niño and La Niña) is likely to intensify under increased temperature scenarios, which would result in a marked increase in rainfall under La Niña, and dryer summers under El Niño for the Waiohine River catchment. These cycles can stress vegetation, with the possibility of drought induced canopy-die-off or complete vegetation community shift away from woody vegetation.

Should a reduction in vegetation condition occur, it is possible there will be an increase in secondary sediment stores within the channel in the upper catchment. It is unlikely these stores will able to be significantly redistributed to Reaches 1, 2 and 3 during bankfull events. Based on historic catchment processes and other catchment studies (Phillips, 1989), it is likely the volume and size of sediment will exceed the Waiohine River's ability to transport it. This process will result in aggradation of the channel bed in the upper catchment, and would suggest that there may be a net loss in sediment supply to Reaches 1, 2 and 3 under normal flow conditions. As in Phillips (1989), these secondary sediment stores are most likely to be reworked during low frequency high magnitude events, delivering large pulses of sediment specifically to Reaches 1 and 2.

Changes in sea-level may also indirectly impact the geomorphic processes in the Waiohine River. As sea-level rises, the sediment transport and depositional zones within the Ruamahunga River may shift upstream, prompting a change in bed level within the Ruamahunga River. For example, if sea-level rise causes the Wairarapa Valley to flood to approximately the top of Wairarapa Moana, then it is likely that the bed of the Ruamahunga River will aggrade at least up to the confluence of the Waiohine River, initiating aggradation in the lower reaches of the Waiohine River in response. There may be increased flood risk in the Waiohine River as a result.

Increases in flood depth, potential localised aggradation and the potential increase in frequency of high magnitude events under different climate scenarios increases the risk of flooding and avulsion in the Waiohine River. Of concern is the potential for a partial or full avulsion of the Waiohine River into the Muhunoa Stream and / or the Apple Barrel floodway during an overbank event.

The highest risk area for the start of the avulsion is the end of Wood Street (Figure 4) where a stopbank is preventing engagement of the numerous flood channels present on the floodplain. At present the stopbank does not cover the entire length between the terrace margin and the active channel, and there is a risk the flood channels will be engaged downstream of the stopbank. Should this occur, there is a high likelihood that the flood channels may become incised and compromise the integrity of the stopbank from the downstream side. The avulsion risk will increase if lateral bank erosion occurs immediately upstream of the end of Wood Street (Figure 4). This has a high possibility of occurring, particularly in the RCP8.5 scenario.

There is a further risk that the Waiohine River may avulse into Beef Creek on the true left floodplain. A stopbank is present on the top of the true left bank, from River Road to upstream of SH2. The stopbank is overtopped in an existing 100 yr flood event in two places, and may outflank the upstream end of the stopbank in the RCP8.5 100 yr flood scenario. As described above, there are several flood channels on the true left floodplain, and engagement of these may increase the risk of them incising and compromising the integrity of the stopbank from the floodplain side.

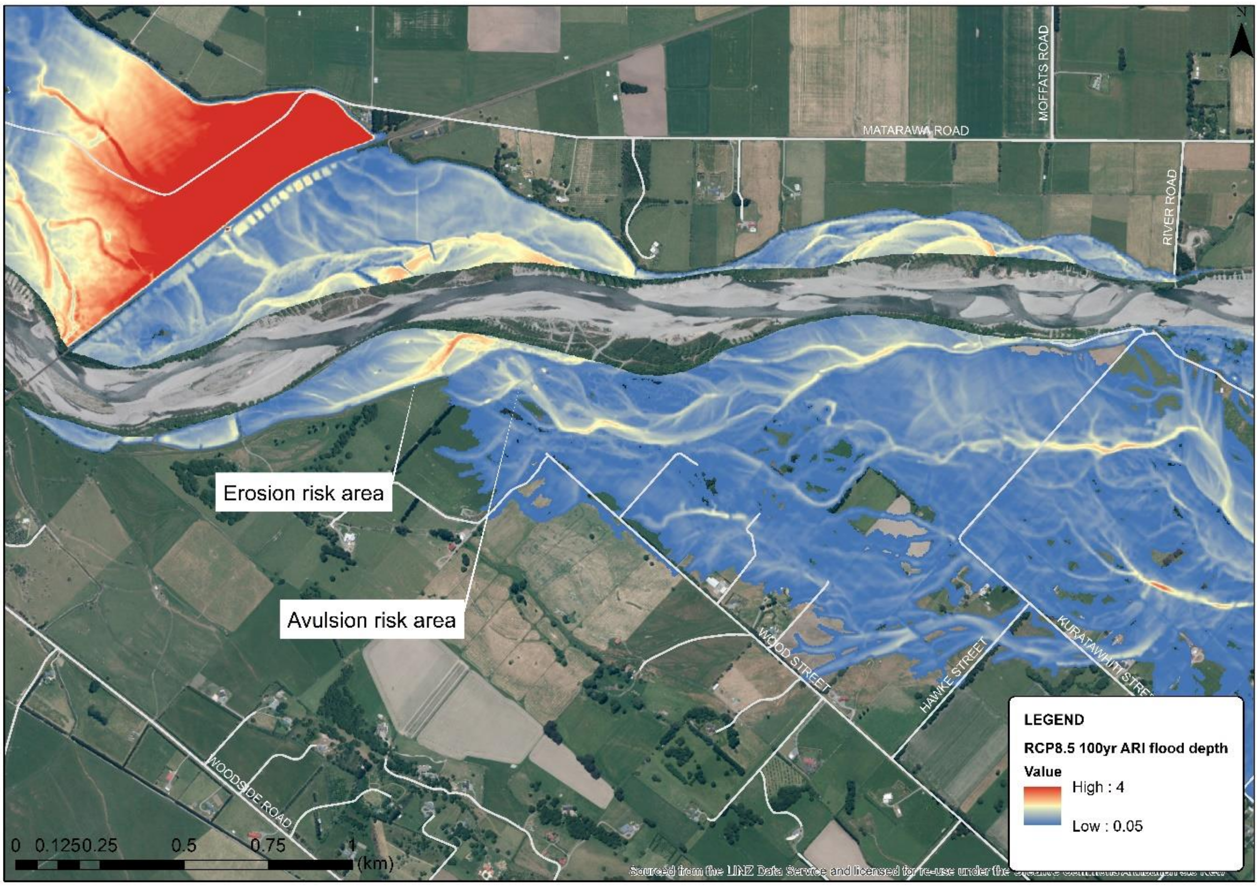

Figure 4: Potential lateral bank erosion and avulsion risk area at the end of Woods Street under RCP8.5 100 yr ARI flood scenario. Data supplied by GWRC.

2.2.1 EPISODIC EVENTS

Several historic episodic events are likely to have triggered a relatively short-term change in river character and behaviour. Berryman et al (2002) suggest that the most recent rupture of the Wellington fault (1640-1440 AD) matches a dateable aggradation event in the Waiohine River (1650-1450AD), which resulted in aggradation of 1.5-3 m in coarse alluvial deposits. It is likely the earthquake triggered numerous landslides, resulting in an episodic pulse of colluvium to the Waiohine River catchment. This material would have been transported downstream in subsequent flood events, and stored within the channel on aggradation terraces and consolidated bars. As the supply of sediment reduced, the bed would have incised. The timeframes for sediment to flush through the system is largely dependent on the amount and size of sediment and magnitude and frequency of subsequent flood events.

Based on evidence from the Poerua River, South Island, an episodic pulse of colluvium from a landslide dam was moved through the impacted reach within 4 years of the dam break. Significant incision of the bed through the aggraded bed (attributed to the dam break) had occurred at the end of this period. However, 6 years after the dam break, aggradation had still not been recorded approximately 10 km downstream (Hancox et al 2010). This event also shows the behaviour of the river following this pulse of sediment, with aggradation of the bed initiating channel avulsion and subsequent erosion of a new channel through the floodplain.

Anecdotally, this is a similar response to the Waiohine River following the 1855 earthquake, with reports of aggradation of the channel bed (Heslop 1993) and 20 years after the earthquake, it was noted that the 'channel bed was the same level as its banks' (Oxenham 1993). Lateral migration and frequent avulsions across the true right floodplain were described for at least 25 years post-earthquake (Flanagan 2011; Oxenham 1993). Uplift on the upstream side of the Wairarapa Fault would have caused a differential elevation change in the river bed resembling a head-cut. This head cut would have worked its way upstream during subsequent flow events, mobilising large pulses of sediment to downstream reaches.

The Waiohine River also experienced a landslide dam break in the gorge during a storm event in 1982 (Oxenham 1993), although no mention of associated sedimentation or river response is made. Effects of a landslide dambreak on sediment dynamics in the Waiohine River catchment would be dependent on the amount of material that was brought down in the landslide. A significant landslide in the Waiohine River (similar to that in volume as the Poerua River landslide) would likely promote a similar response to that recorded for the Poerua River.

2.2.2 HIGH MAGNITUDE RAIN EVENTS

High magnitude rain events may have different impacts on the hillslope and fluvial processes operating in the Waiohine River catchment. Phillips (1989) documents the differences in geomorphic processes in a catchment from the Gisborne/East Coast region from three rain events of similar magnitude (similar 24 hour totals) which occurred in the 1980's. The first event in 1980 (580 mm over 8 days) triggered largescale landsliding, contributing significant sediment volumes to the valley floor. Further landsliding occurred in the 1982 event (220 mm over 3 days), with the sediment delivered to valley floors stored on the floodplain, riparian margins and in the channel in the upper reaches. The last storm in 1988 (600 mm over 3.5 days) did not have the same landsliding as evident in the previous storms (slope exhaustion) but remobilised the sediment stores from the two previous storms and redistributed this material downstream, increasing floodplain widths between 2-10 m and aggrading the stream bed and enabling erosion of the riparian surfaces (Phillips 1989).

Nanson and Croke (1992) suggest that high magnitude events in gravel bed rivers are also the drivers of floodplain change, with only the largest, less frequent events able to strip the floodplain of sediment. While this process sounds extreme, allowing the channel to access the floodplain, there are less erosive forces confined to the channel (Brierley and Fryir 2005; Nanson and Croke 1992; Burchsted et al 2013). The smaller, more frequent floods accessing the floodplain are responsible for 'rebuilding' the floodplain surface (Nanson and Croke 1992).

3 IMPLICATIONS FOR RIVER MANAGEMENT

We identified a number of potential issues for the future management of the river, including increasing erosion remediation costs with changes in river processes, and the potential for willow loss through biological agents (such as the willow aphid).

Current gravel extraction, beach ripping and bed recontouring methods are likely to be reducing the surface armouring of the bar surfaces within Reach 1 and Reach 2. This means the bar surfaces are able to be reworked more frequently under smaller flood events than if the surface armouring was intact. These actions are also likely to increase the amount of fine grained sediment mobilised. Annual gravel extraction within Reach 1, 2 and 3 of the Waiohine River of between 35,000 and 60,000 m3, does not appear to be having a detrimental impact on bed levels.

Data provided to Tonkin+Taylor (T+T) shows a minor degradation response in Reach 2 of the Waiohine River since 1986. An assessment of the wider landscape supports this, showing a slow long-term incision trend as secondary sediment stores in the upper catchment associated with the end of the last glacial maximum are slowly exhausted.

Possible reductions in willow condition through biological agents (giant willow aphid and willow sawfly) and natural stand aging could limit their effectiveness in maintaining design lines and reducing bank erosion. Complimenting these plantings with suitable indigenous species will have a long term benefit for both management of Waiohine design widths, maintenance of bank stability if mass wasting initiates, and riparian and aquatic ecological values.

Lateral adjustment of the channel is characteristic of wandering gravel-bed rivers, and protection from lateral erosion is likely to be on-going, and potentially increasing in severity under several of the climate change scenarios. Allowing the Waiohine River to wander freely within an 800 m corridor (e.g 400 m either side of the channel), supported with willow and indigenous plantings on the floodplain would reduce maintenance costs in the long term, and potentially alleviate some of the concerns around flooding of neighbouring properties. The majority of the flood channels should be captured within the corridor, slowing peak flood velocities, increasing flood storage (both surface and sub-surface storage)(Burchsted et al 2013) and therefore reducing flood risk. Increasing the accessible floodplain will also increase floodplain deposition (especially in the flood channels (Nanson and Croke 1992)), therefore reducing avulsion risk.

Encouraging a wider corridor will increase the resilience of the Waiohine to episodic events, where a greater degree of geomorphic change (such as aggradation, degradation or lateral bank erosion) would be acceptable before a lesser degree of management intervention is required reducing management costs (Piégay et al. 1997; Piégay et al. 2005).

Locating stopbanks away from the active floodplain is also advisable. This will allow engagement of the floodplain to reduce flood velocities and will reduce shear stress on the stopbanks themselves.

Bank failure during dry conditions or parallel cracking at the top of the bank may indicate a change in erosion mechanisms, and should be investigated. This will most likely be linked to bed degradation. Similarly, increases in the occurrence of fluvial bank erosion may indicate bed aggradation.

Changes in river character are also likely after episodic. Therefore, an adaptive management approach should be taken following extreme flood events (such as events greater than a 50 yr ARI or 1,600 m3/s peak flow), as well as rain events which trigger largescale landsliding in the headwaters. Earthquakes have the potential to generate large pulses of sediment, and additional management actions may be required following an earthquake to alleviate any flood risk to Greytown.

To aid future management, we suggested breaking the river into management reaches to ensure the right actions are applied in the right places, based on a sound understanding of geomorphic processes. We also suggested a transition to two year LiDAR and thalweg surveys which will be better at picking up geomorphic trends and river response to events.

ACKNOWLEDGEMENTS

T+T would like to thank Greater Wellington Regional Council, especially Mark Hooker and James Flanagan, as well as the Waiohine Action Group.

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