Mangahauini Geomorphology and Tokomaru Bay legacy landfill

Envirolink Report
Gisborne District Council

2216-GSDC169

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August 2022

Executive Summary

The Mangahauini catchment is steep, with a range of sediment sources and high-energy tributaries. This catchment context sets up the Mangahauini River to be dynamic and characterised by frequent lateral shifting within a relatively (naturally) confined river corridor. Small to moderate floods occupy the active river corridor, which comprises active channel (wetted channel, bars and vegetated bar surfaces) and floodplain. Higher river terraces are not inundated in these floods, but may be subject to lateral erosion as the channel adjusts its position and alignment within the river corridor. Channel adjustments also contribute to (re)activation of adjacent slope processes, notably earthflow.

Location of the Tokomaru Bay landfill site within the active river corridor (1945 active channel) renders it extremely vulnerable to erosion by lateral channel adjustment as well as overwashing by flood flows. Large floods in the river are likely to cause significant damage via bank erosion and flood scour at the landfill site. Floods in the Mangahauini are likely to increase in frequency and magnitude in response to predicted climate change.

Erosion of the Tokomaru Bay landfill releases physical waste to the environment. This waste is readily transported to the coastal zone where it contaminates the beach and bay. It is unknown to what extent toxic leachate and other harmful substances are released into the river and coastal environment from erosion of this landfill.

In light of the risks posed to the environment by the site of a landfill in an active river corridor, and given the size of the site, removal of the landfill is recommended as soon as is practicable. Removal of the material from the site should be undertaken in a controlled approach to minimise further release of waste into the environment. Removal of the landfill should not have any detrimental effects on the river or coastal environment, since this course of action will return the site to its original condition as an active part of the Mangahauini River channel.

Removal of the landfill from the river corridor returns the land to the riverbed, which it last was in 1945. From a te ao Māori perspective, this respects the rights of the awa and restores its mana and improves the health of the river. As such, removal of the landfill is in keeping with the principles of Te Mana o te Wai.

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1. Introduction

1.1 Aims

This document provides a desk-based review of available information on the Tokomaru Bay landfill and the adjacent Mangahauini River in light of the June 2021 floods, which impacted the area by addressing

1. Mangahauini catchment characteristics and river behaviour,
2. Risks associated with the landfill site (erosion and environmental impacts, river and coast),
3. Options for dealing with landfill sites of this nature,
4. Recommendations for remediation

1.2 Approach

The substance of this report is based on a geomorphological assessment of the river, since the landfill is sited in the river corridor. The drivers of behaviour in this river are considered, but it should be noted that hydrological information is not available, since there has been no gauging of discharge in the catchment, neither is rainfall routinely measured.

A brief high-level literature review of primary research into management of landfill sites in environmentally vulnerable situations provides some broader context and perspective to inform an understanding of both risks and remediation possibilities.

Although primarily desk-based, the catchment and landfill site were visited at the end of November 2021. It had been anticipated to meet with local iwi, but due to the risks posed by covid that hui was cancelled. The site visit was used to get a better understanding of the issues and the nature of the environment, which informs the content of this report.

1.3 June 2021 storm summary

A significant storm occurred in the Mangahauini catchment on 20th June 2021, which regionally was within the norms of storms experienced every one or two years. However, within this storm a high intensity storm cell impacted a narrow coastal band from Waipiro to the south of Tokomaru Bay. In Tokomaru Bay around 75 mm fell within a 1 to 1.5 hour period, representing a 35 year to 100 year ARI event (although accurate determination is not possible because there is no official rain gauge record in the catchment). GDC relied on the rainfall total recorded from a private rain gauge that gave overall event duration along with interviews with community members, which is summarised in Cave (2021).

Discharge generated in this storm event inundated the landfill and the transfer station that sits above it (hereafter referred to as the landfill) and resulted in downstream environmental impacts including remobilising of landfill waste, which impacted the coast and the scour of the upper margin of the landfill despite remedial armouring undertaken over the previous 2 years (Cave, 2021).

2. Mangahauini catchment and river behaviour

2.1 Catchment overview and sediment sources

The Mangahauini is the principal catchment draining into Tokomaru Bay and drains an area of 25.2 km^2 (Figure 1a). The upper catchment is underlain by East Coast Allochthon, while harder Late Miocene Sandstone outcrops in the middle catchment (Figure 1b). This geological contrast gives rise to distinct topographic differences within the catchment. Upper catchment slopes are gentler, with subdued topography, while the steepest and highest relief is associated with the Late Miocene Sandstone.

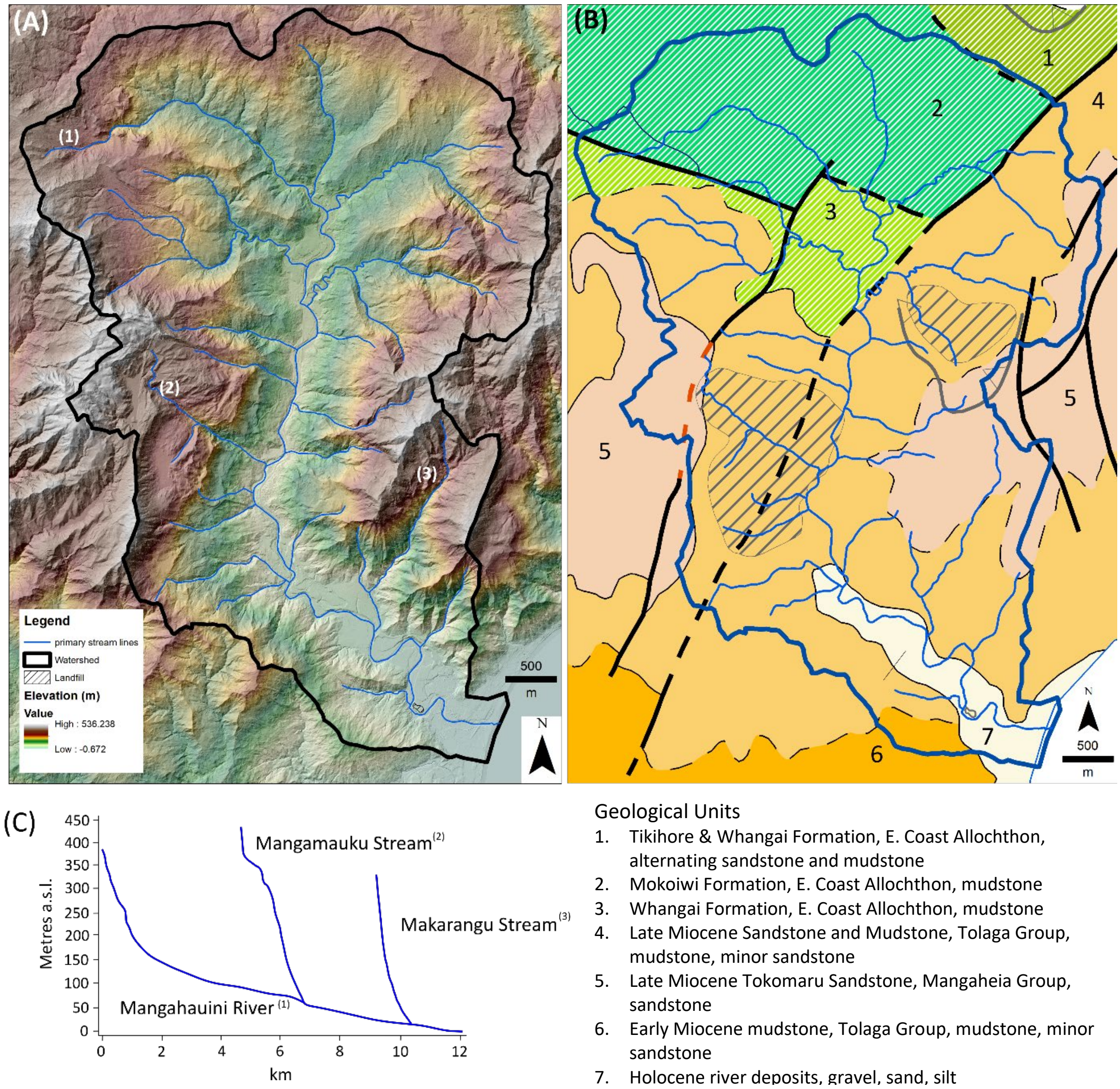

Figure 1. (A) Mangahauini catchment: topography and drainage. Topographic data from Gisborne regional LiDAR. (B) Mangahauini catchment geology sourced from Raukumara QMap. Black lines are inactive fault traces, hatched areas indicate mapped zones of landsliding. (C) Long profiles for the mainstem of the Mangahauini River and Ototo Stream (longest tributary in headwaters), Mangamauku Stream, which is a right-bank tributary rising in the sandstone terrain, and Mākarangū Stream, left-bank tributary (cf. Figure 6).

Sediment generated from these contrasting lithologies is distinctive. The crushed Cretaceous shales and mudstones of the Allochthon, together with the mudstones of the Tolaga Group, generate a high proportion of the suspended sediment yielded from the catchment, with specific suspended sediment yields from the upper catchment estimated to exceed 5000 t km^2 yr^{-1} (Hicks et al., 2019). Bedload calibre material from this sediment source is weak and breaks down quickly, although given the short, steep catchment and short travel distances some of this material may be delivered to the lower river and coast as bedload (sand and fine gravel). Bedload is nevertheless likely dominated by sandstone lithologies (Figures 1b, 2-3).

The short, steep nature of the catchment (Figure 1c), and in particular the location of the highest relief (>500 m) mid-catchment, around 6 km from the river mouth, gives the river sufficient energy to move cobble sized material to the coast (Figure 4). Boulders are also moved in the mainstem of the channel as far downstream as the landfill site during high-energy flow events (Figure 5). This large calibre bedload is likely sourced from adjacent short steep tributaries (e.g. Mākarangū Stream). The steep profiles (Figure 1c) and availability of sediment renders these tributaries potentially prone to debris flow / flood events during extreme rainstorms (Figure 6). Landslides are also likely to deliver large sized material to the channel (cf. Figure 1b).

Figure 2. Sandstone cobbles and shale-dominated fines[1] in the lower Mangahauini, looking upstream from reinforced bank at northern edge of landfill site. The bottom of the pool in the foreground is notably soft, filled with fines, in contrast with the cobbly substrate of the higher bar and channel platform in the middle distance.

[1] Note: no quantitative assessment of sedimentology in the Mangahauini has been undertaken, all statements relating to bed sediment characteristics in this report are based on qualitative observations made during the November 2021 site visit.

Figure 3. Finer-grained bedload, with lack of surface structuring immediately upstream of the landfill (rock revetment to the left of the image). Note protruding earthflow lobe in middle distance.

Figure 4. Mangahauini river mouth: gravel and cobble-sized bedload visible in the channel where it crosses the beach.

Figure 5. Bed sediment in the lower Mangahauini: photo looking downstream, located ~100 m upstream from the landfill site. Note the presence of several sandstone boulders, as well as a high proportion of fines (sand and silt), which also mantle the cobbles in the wetted channel. Boulders

likely to be sourced from localised slope sources and / or nearby short, steep tributaries draining steep sandstone terrain in the catchment.

Figure 6. Mākarangū Stream, principal left-bank tributary. Catchment relief rises to 490 m in under 2 km. Slope erosion visible is on upper slopes below trees on ridgeline, exposing underlying Tolaga Group mudstones. Debris flood deposits (boulders, cobbles, fines) visible in the channel in the foreground, indicating some sandstones are present in the catchment. Sediment load in this tributary had blocked the culvert underneath SH 35, forcing flow over the road and into Tokomaru Bay township during the June 2021 storm (Cave, 2021) (photo 30 November 2021, ICF).

2.1.1 Erosion processes

Active slope erosion in the catchment has the potential to deliver large volumes of sediment to the Mangahauini channel. Gullies and earthflows in the catchment underlain by the Allochthon generate substantial volumes of suspended sediment, as do the mudstones of the Tolaga Group. Much of the coarse sediment load will be delivered to the channel network during storm events via debris flow / debris flood processes (Figure 6), as well as landsliding of both a deep and shallow nature in the Tolaga Group mudstone terrain (Figure 1b).

Newtonian flow in steep tributaries will be competent to move coarse material down steep channel beds. In addition, earthflow activity in Tolaga Group mudstone, notably in the vicinity of the landfill site, is significant and delivery of sediment by this process exceeds the ability of the river to erode it at this location, leading to a diversion of the channel around the earthflow toe (Figure 7).

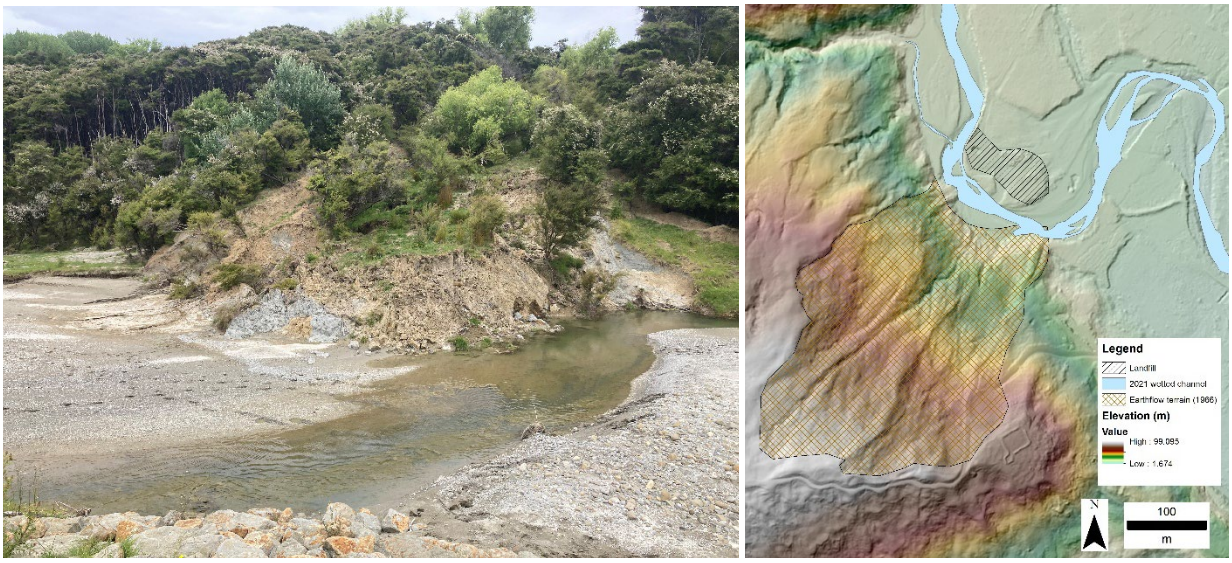

Figure 7. Photograph shows earthflow toe opposite landfill site. Examination of aerial photography and LiDAR digital terrain model suggests this earthflow extends to the catchment divide at the top of the slope (adjacent map) in a portion of the catchment underlain by Early Miocene mudstone of the Tolaga Group (Figure 1b).

2.2 Floodplain and valley floor

Much of the Mangahauini valley floor is narrow, significantly confined by valley sides and characterised by pockets of floodplain alluvium where local valley widening permits sediment storage (cf. Figure 1). Floodplain sediments are coarse grained, with cobbles and boulders overlain by sands, silts and gravels (Figure 8).

Figure 8. Floodplain sediments, lower Mangahauini, looking across to the true right (flow right to left in photo) in the vicinity of Figure 5. Very coarse material (cobbles and boulders) is overlain by predominantly sands and silts, with some gravel clasts evident in these finer alluvial deposits. The floodplain at this location was part of the active channel until at least 1977 (see historic maps below), indicating rapid rates of floodplain formation and sediment deposition (bank face is approximately 1.5-2 m high).

The lower valley broadens and the river becomes partly confined in these lower reaches. Confinement in these lower reaches is exerted by river terraces in addition to the valley side and any active slope failures (cf. Figure 7). River terrace risers have been mapped approximately using the LiDAR DEM in the lower valley in the vicinity of the landfill site (Figure 9). The ages of these surfaces is not known, although QMap identifies this area of the catchment as Holocene (last ~11 ka BP), see Figure 1b. It is possible the highest elevation terrace in the valley floor pre-dates the Holocene, given the prominence of the Waipaoa-1 surface farther south in the Waipaoa catchment, as well as prominent Last Glacial and postglacial terraces in the Waiapu catchment farther north. These valley floor features play a significant role in routing floodwaters along the river corridor. It is notable that the landfill occupies a surface below these terraces (Figure 9).

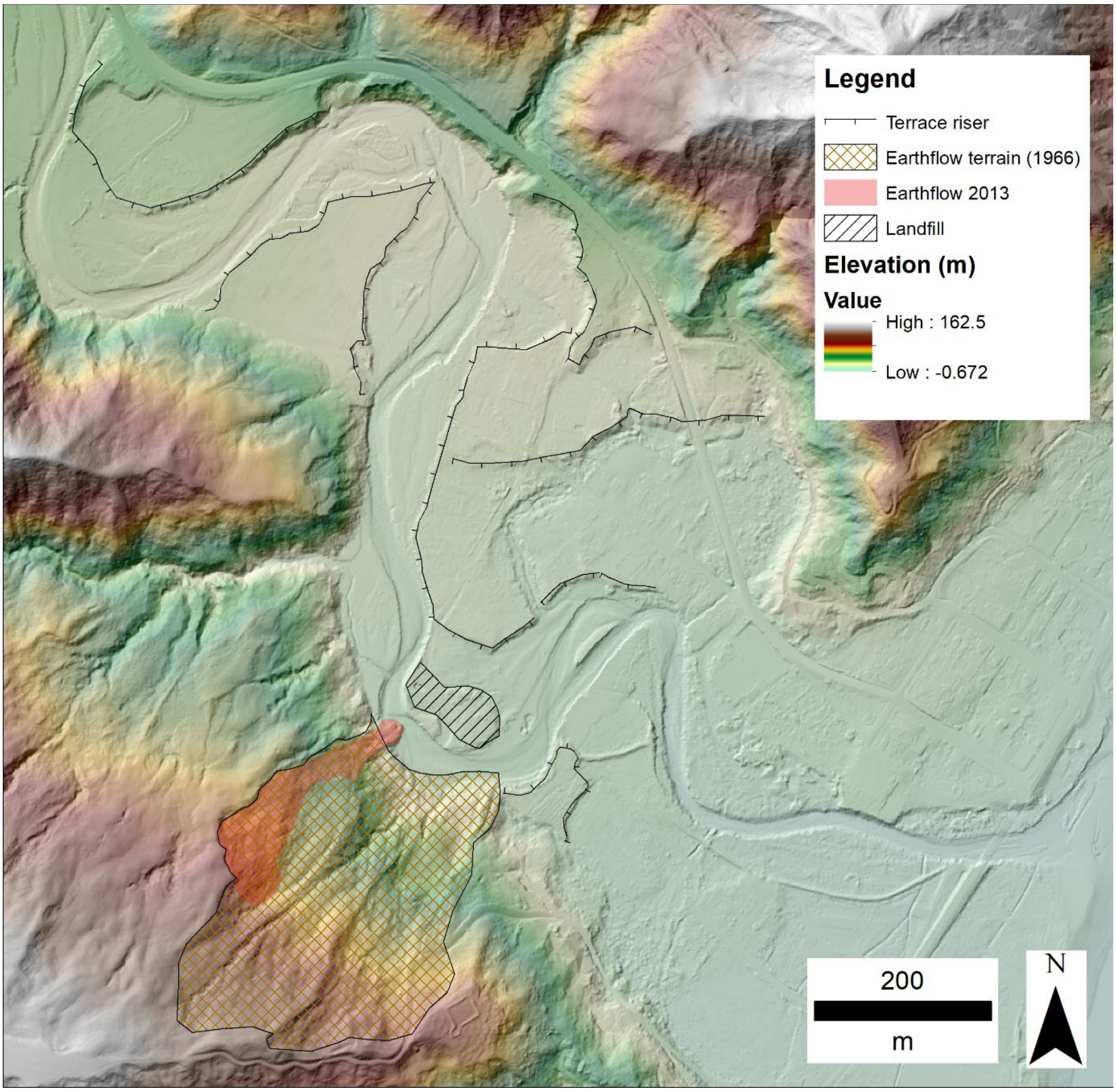

Figure 9. Mangahauini lower valley floor morphology, river terrace risers mapped from LiDAR DEM only.

2.3 River morphology and behaviour

The Mangahauini River is gravel-bedded throughout, which means the day-to-day morphology of the channel reflects and responds to bedload sediment flux and storage. The channel is generally wide and shallow throughout (e.g. see Figure 5) Although confined by valley sides, colluvial deposits and river terraces, the river channel remains dynamic. Channel changes in the lower catchment were mapped using archive aerial photography from 1945, 1966, 1977, 2013 and 2018, as well as rectified drone imagery supplied by GDC (Figure 10). The river channel in this reach has been characterised by lateral erosion within a relatively narrow active channel corridor, which is constrained by lateral confinements described above. The channel planform lacks sufficient sinuosity or repeated regularity of bends to be classified as truly meandering, and although some localised flow division occurs, neither is the river braided. As such, the Mangahauini displays the characteristics of a coarse-grained wandering river in this lower reach (Figure 11). Bends in the vicinity of the landfill (upstream and downstream) have nonetheless developed, with classic rotation and migration of the prominent loop prior to the straighter reach to the coast evident over the course of 75 years (Figure 10).

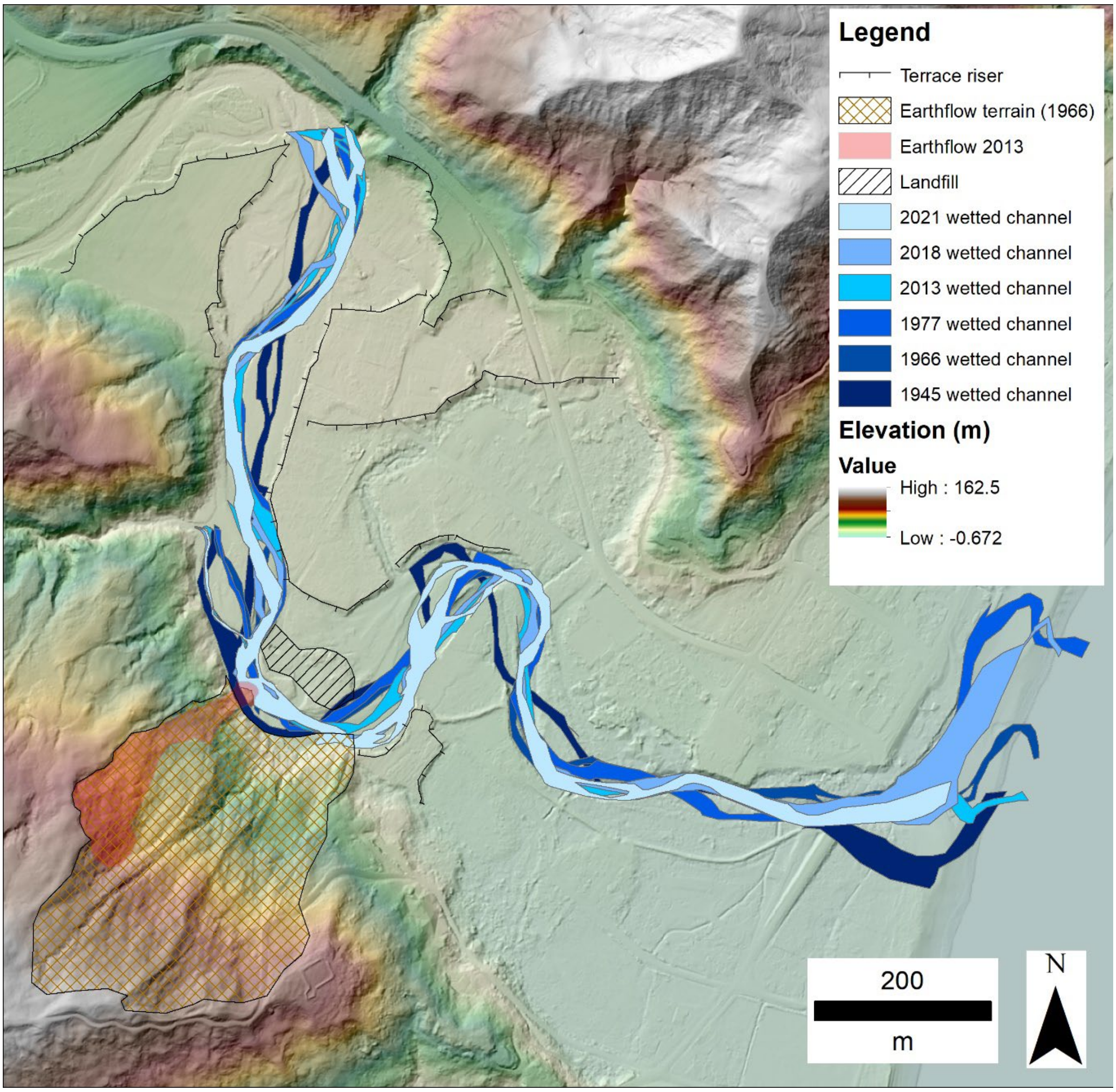

Figure 10. Wetted channel positions 1945-2021 interpreted from archive aerial photography and drone imagery.

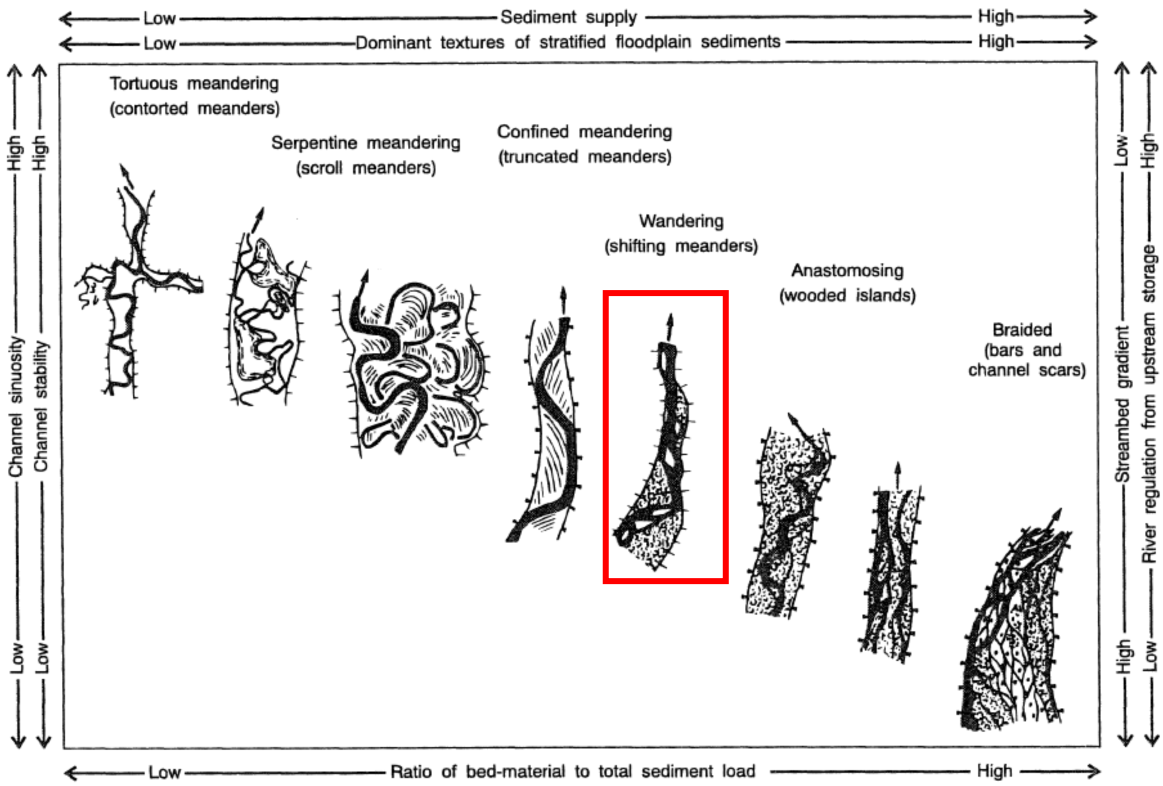

Figure 11. Continuum of river channel types and controlling variables, after Mosley (1992). Mangahauini fits the wandering channel type in this scheme (red box).

2.3.1 Channel geomorphology 1945-2021

Interpretive mapping of the active channel corridor using archive aerial photography demonstrates both the assemblage of features and their dynamics over ~75 years. This is important information to inform both risks and recommendations for the landfill site, which is located in what was the active channel corridor in 1945 (Figure 12). Subsequent shifting and contracting of the active channel corridor occurred in the vicinity of the landfill (Figures 13-18). The landfill site was inundated in the June 2021 flood, which is not surprising, given its occupation of the former channel bed. Channel migration of the river immediately upstream of the landfill site over the past 75 years has also increased the likelihood of erosion on the true left bank adjacent to the landfill. Furthermore, the active earthflow on the true right at this location is diverting flow back towards the landfill.

The lateral extent of the June 2021 flood spread was naturally limited by river terraces on the valley floor. This natural confinement of flood flows tends to elevate stream powers relative to inundation of larger areas of valley floor (Fuller, 2008). Further confinement of flows between landfill rock-armour protection and the earthflow is likely to elevate flood powers, contributing to the potential for enhanced erosion at this site. Figures 13-18 indicate the most significant adjustments to channel morphology in this lower reach are in the area in the vicinity and immediately downstream of the landfill site, which is where the active channel is widest, compared with the more naturally confined reach upstream of the landfill. Historically the river has reworked this corridor width. Flatter channel gradients towards the coast appear to have limited the energy for adjustment evident in the last 75 years and this would be a zone of energy dissipation, particularly if flood flows are allowed to spread.

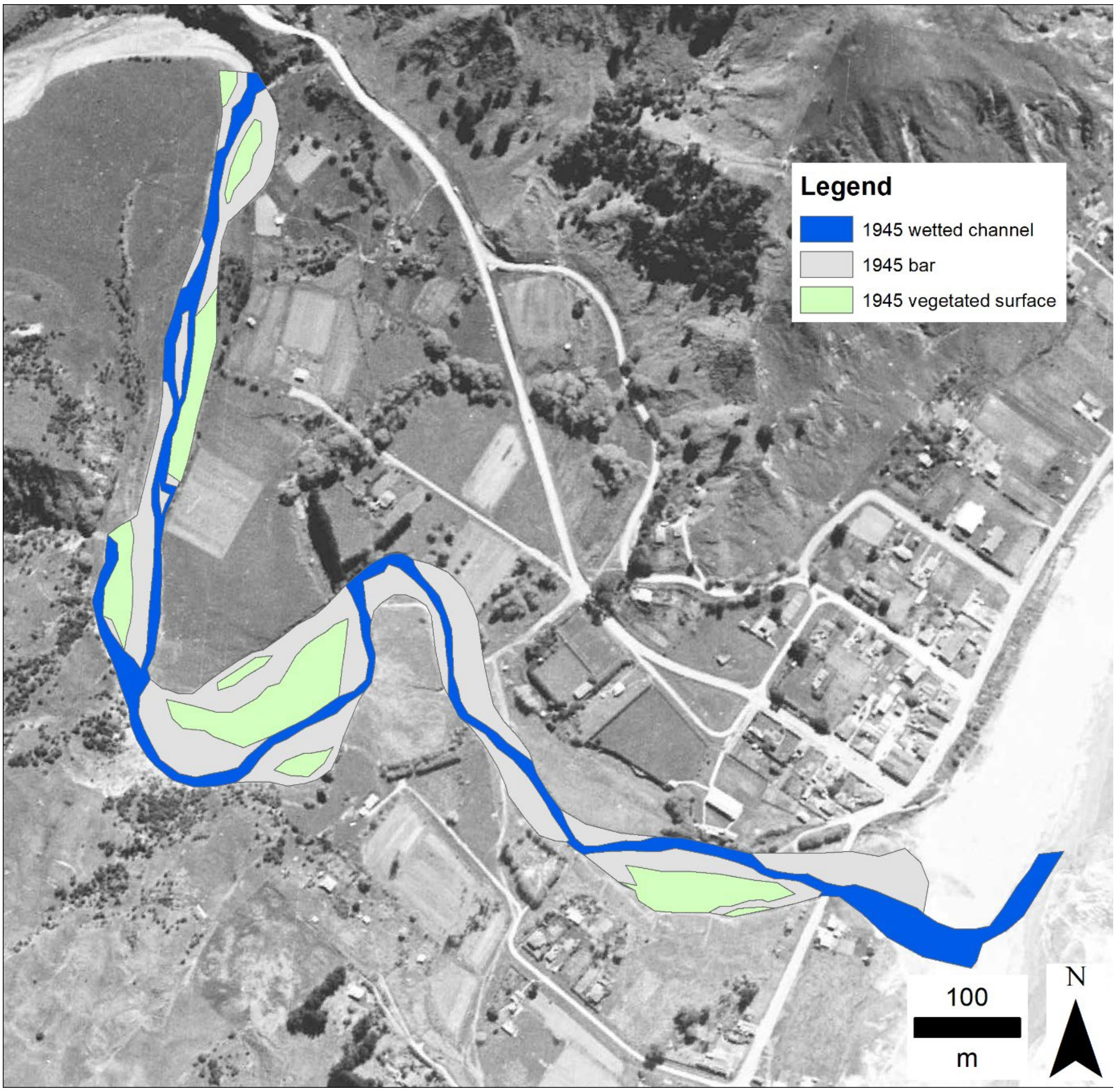

Figure 12. Mangahauini active river corridor, 1945

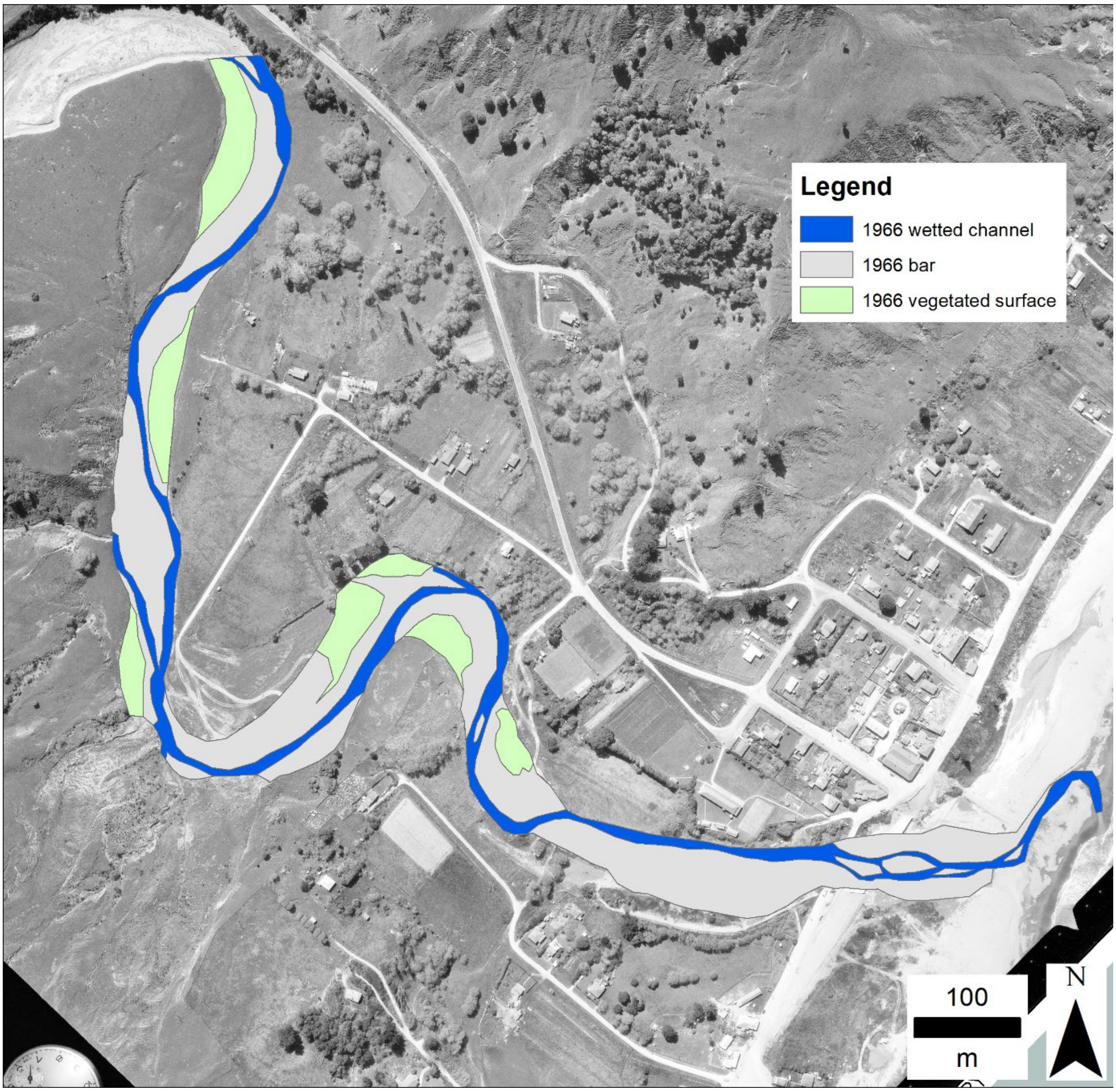

Figure 13. Mangahauini active river corridor, 1966

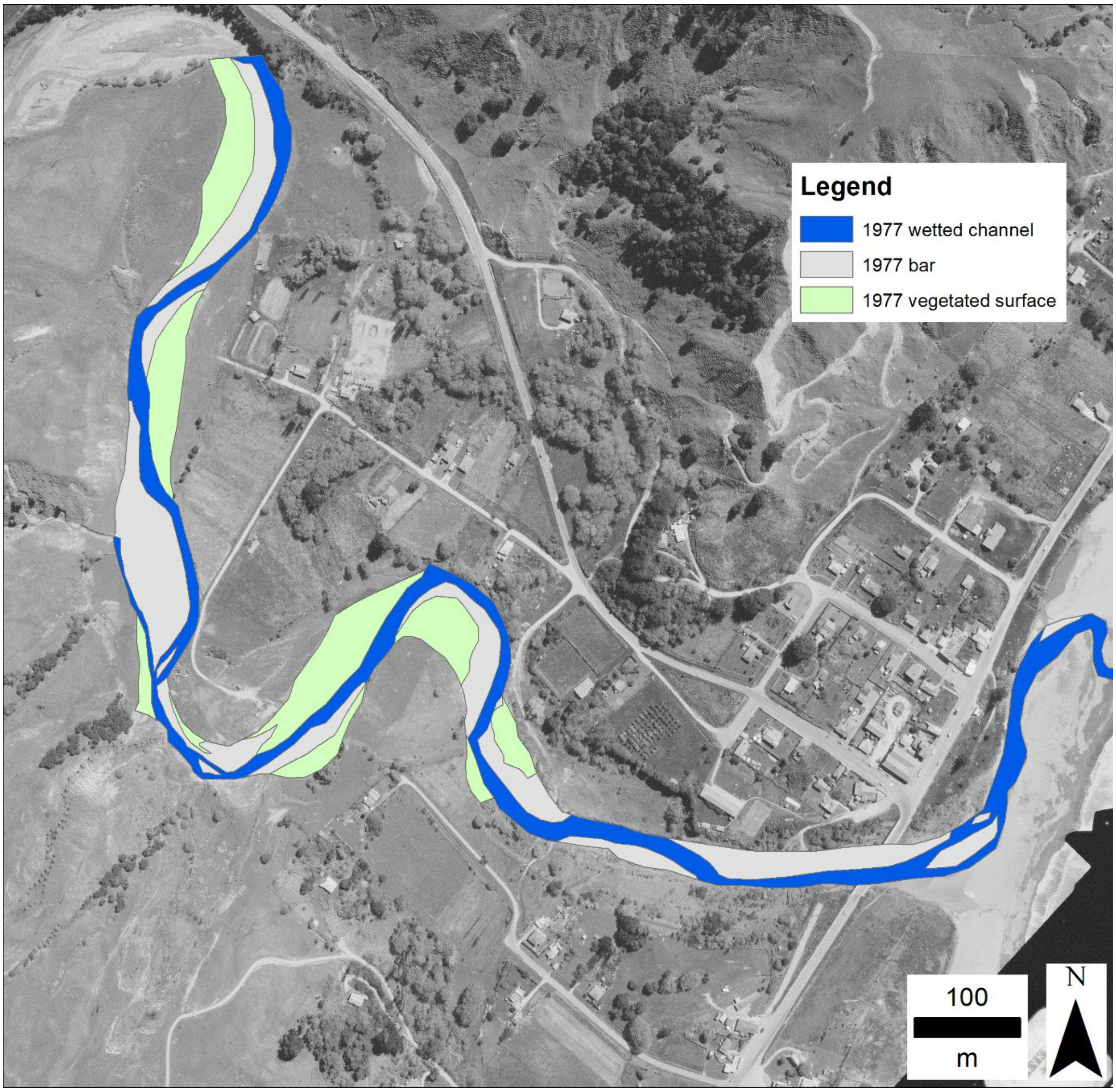

Figure 14. Mangahauini active river corridor, 1977

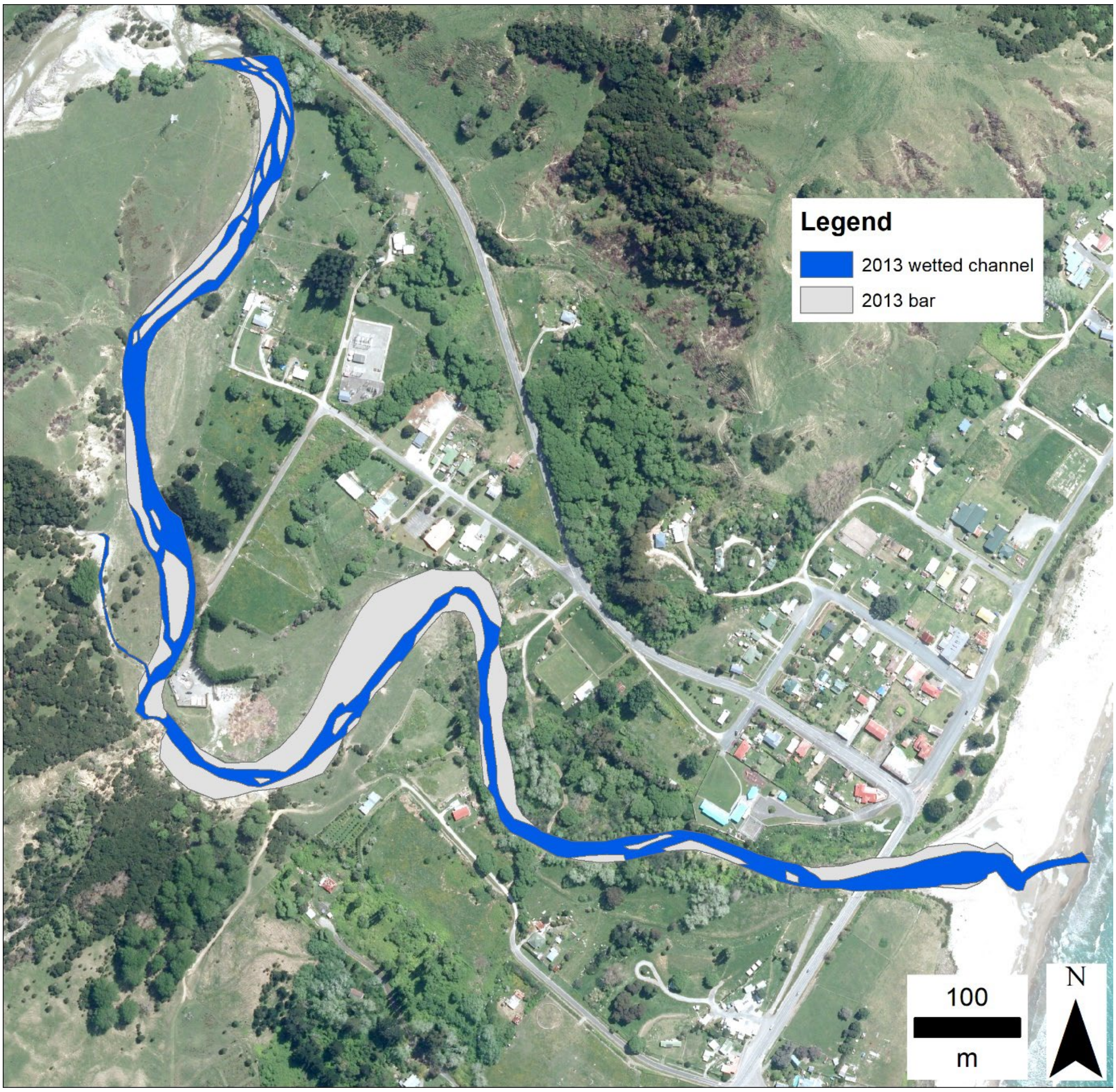

Figure 15. Mangahauini active river corridor, 2013

Figure 16. Mangahauini active river corridor, 2018

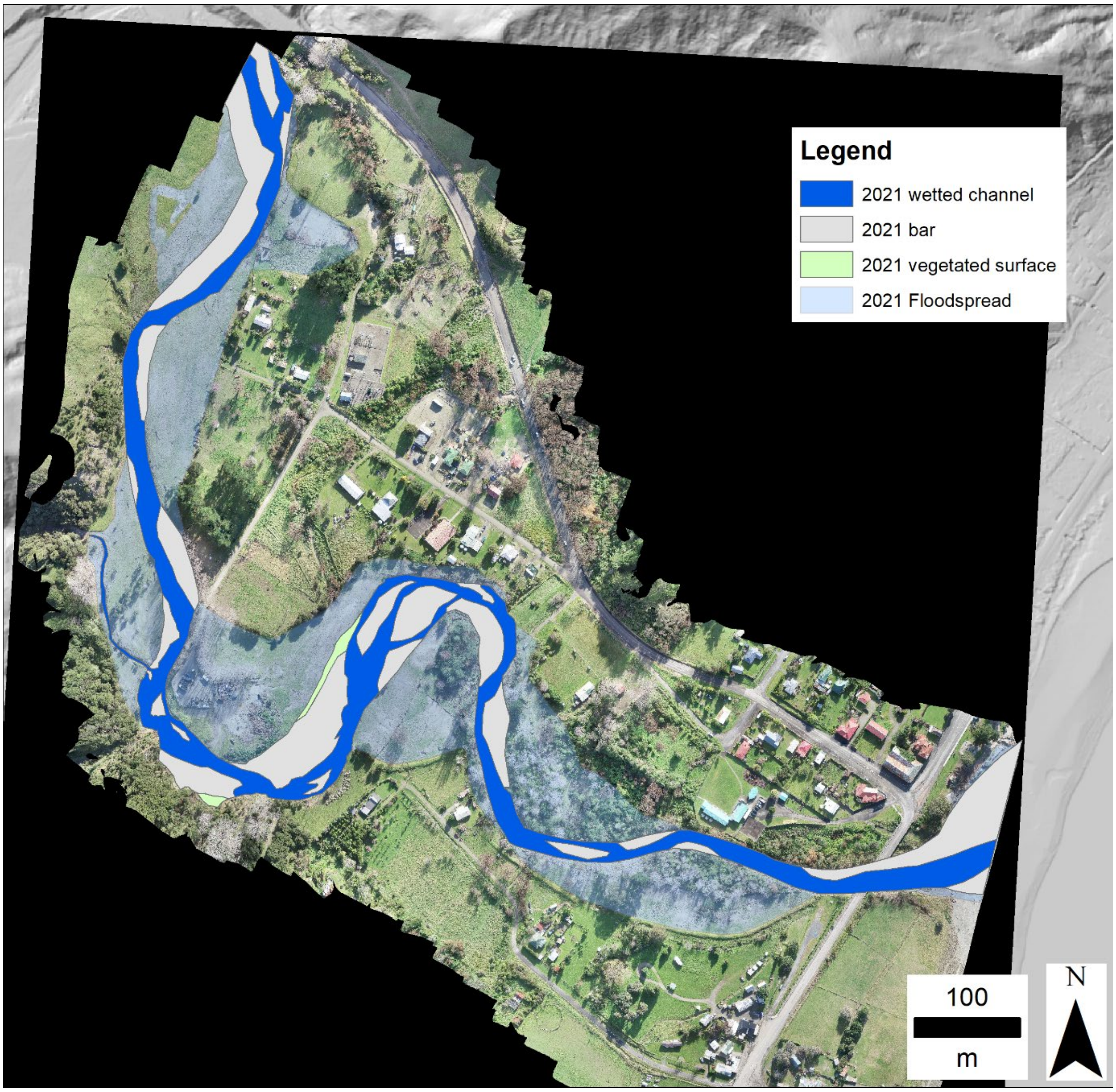

Figure 17. Mangahauini active river corridor, 2021

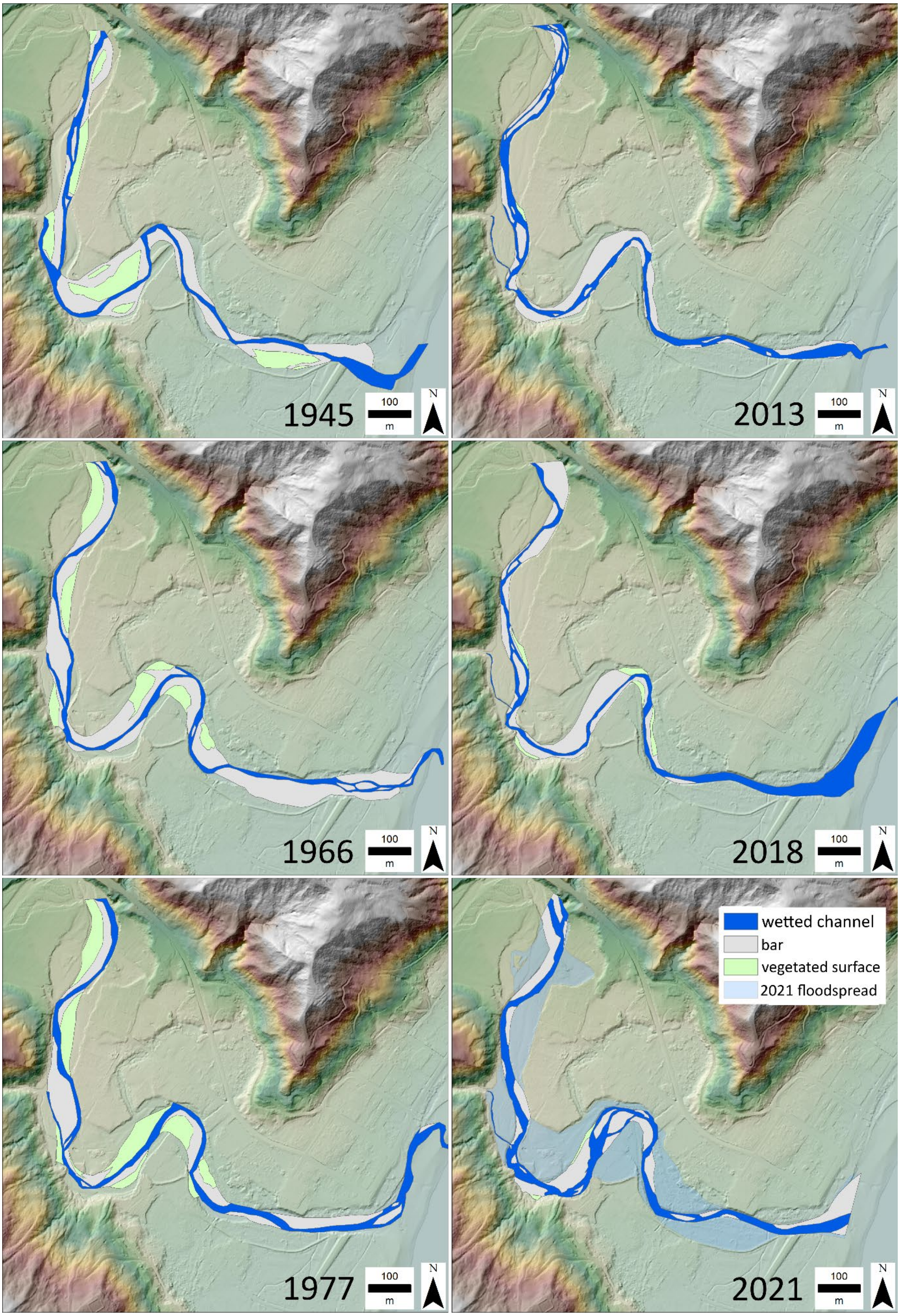

Figure 18. Mangahauini river corridors compared.

3. Landfill risks: river and coast

3.1 Landfill damage

The dynamics and behaviour of the Mangahauini River outlined in Section 2 pose a significant threat to the Tokomaru Bay landfill site located in the river corridor. Construction of rock revetment on the upstream boundary of the landfill is intended to prevent erosion of this left-bank. However, alignment of the channel at this location directs the full power of flow into this bank, and some damage was sustained during the June 2021 storm (Figure 19). In addition, floodwaters washed over the landfill site, recruiting surficial waste into the river and down to the coast (Cave, 2021). Prior to the June 2021 storm, an assessment report on the Tokomaru Bay legacy landfill (GDC 28 May 2021) identified erosion of the landfill and discharge of waste to the environment.

Figure 19. Left: damage to rock revetment protecting landfill site, photo: 30 November 2021 (ICF); right: washover of approach road to landfill site, photo: 20 June 2021 (Murry Cave).

3.1.1 Risks from the Mangahauini River

Discharge in the Mangahauini River is not gauged, so the quantum of flow contributing to the damage in Figure 19 and flood spread in Figures 17 and 18 is not known. However, assessment and analysis of rainfall in the catchment during the event by Cave (2021) suggests that the local 12-hour rainfall accumulation of 160 mm recorded informally in Tokomaru Bay had a recurrence interval of 13.5 yr. This ARI statistic could be used tentatively to inform the likely ARI for flow in the Mangahauini during this event, although it is difficult to extrapolate from a single rainfall statistic to discharge, but if this is approximately correct, it suggests that the Mangahauini flood was not particularly extreme. The geomorphic evidence would certainly corroborate this interpretation, because erosion of the channel margin was generally localised: floodplains were inundated, but not eroded. This contrasts with the geomorphic impacts of much larger ARI floods that have been described in scientific literature, where channel changes in rivers of similar nature to the Mangahauini (steep, coarse-grained, wandering) have been significant, even catastrophic (Fuller, 2008, Milan, 2012, Buraas et al., 2014, Surian et al., 2016, Scorpio et al., 2018). The inference for the Mangahauini and the risk it poses to the landfill is that a small-to-moderate flood as occurred in June 2021 is sufficient to damage the site and recruit waste into the river system. The report on the landfill (GDC May 2021) corroborates this interpretation: small floods erode the landfill site. When a larger flood occurs, the frequency of which is likely to increase with climate change projections, far more significant damage and distribution of waste to the river and adjacent coast can be expected. Erosion of the Fox Glacier landfill during a flood event with an estimated ARI of 20 yr in March 2019, which distributed landfill waste along the river to the coast and contaminated ~60 km of coastline, is a warning of what could happen at Tokomaru Bay.

The risks posed to the environment by the location of the landfill are not confined to the waste and contaminants contained therein. Rock revetment at the landfill deflects flow essentially at a right-angle towards the true right of the river corridor. This deflection means flow is directed to the base of the earthflow on that slope. Erosion of the earthflow toe by the river over time (which occurs during flood events) continues to debuttress this slope, facilitating further failure and delivery of material into the river corridor, pushing flow back towards the landfill. It is perhaps notable that when the approach of the river around this bend in 1945 was more oblique, there was no evidence for fresh earthflow deposits in the river corridor and apparently less evidence of activity on the slope, at least compared with 1966 (cf Figures 12 and 13). The presence of the landfill, which requires flow to be directed into the toe of the earthflow will continue to propagate slope instability and delivery of this sediment to the channel. Earthflow deposits are fine grained sands and silts (Figure 7), which likely further degrade water quality in the Mangahauini River, as well as increasing erosion risk to the downstream part of the landfill site, which was acknowledged by GDC (2021).

3.1.2 Risks to the coast

The short distance from the landfill to the river mouth along a straighter, albeit flattening river channel (cf. Figure 1c) means that any waste recruited from the landfill by river erosion or washover is likely to be conveyed very efficiently to the coastal zone. The consequence is potentially significant contamination of the local beach and wider bay by physical wastes and potentially soluble leachate. The Fox Glacier event referred to above reveals how efficiently transfer of waste along river corridors to the coast can be.

4. Landfill erosion in context

4.1 New Zealand landfills

The situation at Tokomaru Bay is not unique. The problem of potential landfill erosion in river and coastal locations is widespread throughout New Zealand. According to a media article published in March 2021 at least 321 old landfills are at risk from either river or coastal erosion. The MfE *National Climate Change Risk Assessment Report* (MfE 2020) notes that, "Active and closed landfills and contaminated sites across New Zealand are currently at risk from extreme weather events and sea-level rise, as well as coastal and inland flooding, erosion and rising groundwater", and, "Site failure can cause pollutants to mobilise, with potentially cascading consequences for public health, ecosystems and the economy" (p.87). MfE (2020) identifies risks to landfills as being moderate at present and will likely increase. However, "there is a limited understanding of the location and characteristics of…landfills" (MfE 2020, p.88) and "research is required to understand the locations of landfills and the associated risk across New Zealand" (MfE 2020, p.106). In 2001 MfE reported the exact number of closed landfills throughout the country is unknown, but could be in excess of 1000. Not all of these are at risk of erosion, but more research is evidently needed on the extent of the problem in New Zealand. However, this does not downplay the significance of the risk to the environment posed by potential erosion of the Tokomaru Bay landfill, situated in the active river corridor of the Mangahauini River.

4.2 Landfills overseas

The extent of the risks posed by landfill erosion is better developed overseas. Disposal of solid waste in landfills became common practice in Europe and North America towards the end of the nineteenth century (Louis, 2004). In Austria, out of 1064 landfills investigated, 312 (30%) were located within flood zones (Laner et al., 2009). Flood zones in the Austrian context were identified as at risk of flooding in a 200 year ARI flood event, which was used to take into account the long residence time of a landfill and therefore consider flood events of low probability occurrence (0.5% AEP). In England 4,759 or 24% of 19,635 known historic landfills were found to be sited in the UK Environment Agency's flood zone 3, which has a 1% probability of fluvial flooding and/or 0.5% probability of coastal flooding (Brand et al., 2018).

Landfills have historically been located alongside rivers and coasts, given their proximity to population centres, ease of access, and low land value (Brand et al., 2018, Neuhold, 2013). Recent increases in storm frequency and magnitude have exposed the vulnerability of these sites to becoming a significant source of environmental contamination in otherwise 'clean' locations. Coastal landfill sites are at risk from erosion exacerbated by a combination of sea level rise and frequency and magnitude of storm surges. The storminess of the early twenty-first century contrasts with the relative climate quiescence of the twentieth century (Naylor et al., 2017). With the anticipated effects of climate change, further increases in magnitude and frequency of storms and their associated floods and storm surges imply that erosion of landfill sites is likely to become more frequent and more severe, world-over (cf. Brand et al., 2018).

International studies recognise the complexity of the risks posed by landfill erosion (Arrighi et al., 2018). Erosion of material is not limited to inert physical waste, but also entails release of leachate, heavy metals, asbestos, and other toxins when capping materials are disturbed by erosion processes. Furthermore, there is a recognition that more research is required to understand what happens when wastes become flooded (Laner et al., 2009).

4.3 Mitigation of environmental impacts

Given the significant risk of releasing toxins to the environment from eroding landfills, Brand et al. (2018) refer to a range of strategies to mitigate the risk of contaminant release from historic landfills, including excavation, relocation or incineration of waste. These approaches are being used at sites in, for example, Alaska and Switzerland (e.g. Alaska Department of Environmental Conservation, 2008; (Weber et al., 2011)). However, Brand et al. (2018) note that these strategies would be prohibitively expensive if applied to multiple large-capacity landfill sites. They argue that it is necessary to identify sites with the greatest pollution risk in order to prioritise resource allocation. However, for small-scale, local sites such as Tokomaru Bay removal of waste would be potentially more readily achievable, although still requiring allocation of sufficient resource. The alternative to removal is to improve defences against erosion, but in light of forecast changes in flooding and the location of the site in the middle of the river corridor, this is simply delaying the inevitable. Recommendations are discussed in Section 5.

5. Recommendations

In light of the existing and potentially worsening impacts of the Tokomaru Bay landfill, sited in the active corridor of the Mangahauini River as flood magnitudes and frequencies increase, removal of waste from this site is the safest and most responsible course of action. Limitations of defensive options are outlined below.

5.1 Defensive options

Improving site flood defences as suggested by Options One and Two in GDC (2021) could be used as a short-term measure to shore-up protection, but these approaches only realistically defend against small-medium size floods and have a limited lifespan.

5.1.1 Option One: gabion baskets

Gabion basket lining of the banks around the entirety of the landfill site suggested in Option One are rightly recognised as being vulnerable to failure during floods and failure of one gabion basket compromises the integrity of the whole structure. There is a significant risk of failure of such structures since they will be located in the middle of an active river corridor and face significant flood powers. The realistic lifespan of gabion baskets is (at best) 20-30 years (GDC, 2021), requiring repeated structural intervention, as well as ongoing maintenance. The landfill will outlast this defensive option.

5.1.2 Option Two: rock revetment

Rock revetment has already been established and the suggestion is to continue this around the landfill site. The lifespan of rock revetment is identified in the GDC 2021 report as 50-100 years, which is longer than the gabion baskets of Option One, but the landfill still outlasts this option. Repairs can be effected without compromising the entire structure, but any damage risks discharge of waste to the environment. It is notable that despite the confidence shown in this approach by GDC (2021), damage during the June 2021 flood occurred, releasing waste into the environment from the landfill.

5.1.3 Limitations of any defensive option

Retaining the site in the active river corridor risks a significant flood breaching any improved or re-engineered defences leading to an environmental and community catastrophe. Both options are vulnerable to failure in any flood that exceeds design specifications. The question must be asked, if pursuing a defensive option, what level of risk is the community willing to accept in this design, what flood is to be defended against: 1%? 0.5%? Future climate changes and associated change in flood magnitude and frequency must also be accommodated in any design.

Furthermore neither Option One or Two deal with the risk of flood scour by floodwaters passing over the top of the landfill site. Banks would need to be substantially re-engineered to prevent lateral scour, and raised to prevent wash over. This approach would create significant disturbance in the active channel given the footing required for sufficiently high engineered stopbanks, which would also further limit flood capacities in the channel. In turn, high energy flood waters would be directed towards the unstable earthflow slope on the true right, exacerbating the erosion problem there. The scale of engineering works required to properly defend this true right bank and shore up an active earthflow are likely to be prohibitive. It should be noted that the entirety of this true right bank opposite the landfill is backed by earthflow terrain (see Figure 7) and the entirety of this bank would therefore need to be defended to the same standard: protection proposed in GDC (2021) Figure 4 does not show this required continuity. It is probably unlikely that there is sufficient space between the toe of the earthflow slope and margin of the landfill to adequately defend either.

I suggest that defensive options are simply not realistic in this location. The alternative is landfill removal, discussed below.

5.2 Landfill removal

GDC (2021) reports removal of the landfill as a viable option (Option Three), noting the river will gain more width and reduce pressure on the banks, reducing the rate of erosion, with which I agree. It is also noted that removal of the landfill will also remove any further threat of contamination and leachate being discharged into the Mangahauini River and the Pacific Ocean, with which I also agree.

5.2.1 Geomorphic impacts

The geomorphic impacts of removal of the landfill from the river corridor are likely to be beneficial to the functioning of the river. By removing the landfill, an obstruction to the laterally dynamic channel is removed from what was the active channel in 1945. This will provide the river more room to move and adjust its position within the active corridor and an opportunity to move away from the active earthflow slope, which may contribute to slowing of earthflow activity. Essentially removal of the landfill allows the river to reoccupy its pre-1945 course. Although the wetted channel in 1945 was located towards the southern margin (true right) of the river corridor at this location, the pattern of bar vegetation cover in the wider corridor indicates a recently abandoned channel towards the true left (cf. Figure 12). In providing the river more room to move and adjust, this allows for more effective dissipation of flood energies during high flow events and removes a distinct 'pinch point' between earthflow lobe and landfill rock revetment.

The act of excavating waste from the landfill will inevitably result in a short-term disturbance to this part of the river corridor. However if managed carefully, there is no need for the removal process to result in contamination of the river itself, or the lower reaches and coast, noting the need to conduct the work in dry weather and low flows and prevent, as far as possible, incursion of flow into the active excavation site. GDC (2021) suggests that removal of the landfill will result in a cavity that will need to be filled, however aerial photos of the early landfill do not appear to show any pit. Excavation may need to extend a little way below the current bed level of the river to ensure all contaminated material is removed, but given the high sediment load and dynamics of the river described in Section 2, this will likely rapidly fill with sediment naturally deposited by the river during higher flows.

5.2.2 Downstream and coastal impacts

Carefully managed removal of the landfill from the riverbed is unlikely to have any impact on the river mouth or beach because its removal is restoring natural function in the river corridor and capacity of the river to adjust its position. The adaptive capacity of the river will be improved, increasing river resilience to disturbance in larger floods. This is not, therefore, introducing a new regime to the river-coastal system, but rather improves resilience of the system. The river mouth is characterised by frequent adjustment in response to both water and sediment discharge from the river, as well as coastal processes (Cave, 2019). Removal of the landfill will not, in my opinion, therefore affect either the long-term stability of the river or the adjacent coastline. Flattening of the river gradient in the final ~500 m approach to the river mouth (including the SH 35 Bridge) (cf. Figure 1c) also serves to reduce stream powers in this reach. However, it is noted that the river corridor in this distal zone has been narrowed over time (cf. Figure 18), which will likely raise flood energies due to artificial confinement, but it is this narrowing of the corridor, rather than any adjustment upstream at the landfill site, that is likely to pose any threat to the bridge abutments and alignment of the river through this reach.

5.2.3 Te Mana o te Wai

Removal of the landfill from the river corridor returns the land to the riverbed, which it last was in 1945. From a te ao Māori perspective, this respects the rights of the awa and restores its mana and improves the health of the river. As such, removal of the landfill is in keeping with the principles of Te Mana o te Wai.

Acknowledgements

This work was supported by discussion with Dr. Alastair Clement and Dr. Sam McColl during a field visit to Tokomaru Bay in November 2021 and in subsequent weeks while they were working at Massey University. Dr. Murry Cave facilitated the site visit in November and initiated this work.

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24 August 2022

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