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Peria River, Doubtless Bay Restoration

Geomorphic Assessment

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Executive Summary

Morphum Environmental Ltd was engaged by the Department of Conservation (Te Papa Atawhai) to undertake a geomorphic study on a section of the Peria River, a sub-catchment of the Oruru Catchment, Doubtless Bay. The Oruru Catchment is part of the Ngā Awa river restoration programme and Te Paatu ki Kauhanga Trust is working towards restoration of the Peria River and has successfully secured funding from the Ministry for the Environment as part of the Te Mana o te wai programme. In addition, funding has been agreed by Northland Regional Council for fencing and the Department for Conservation Ngā awa programme for planting. Erosion of the stream banks is occurring and there is concern that if erosion of the stream banks is not addressed, or at least considered, it may undermine the restoration efforts. To understand the drivers of erosion along the restoration site and to inform effective planting and fencing efforts, a geomorphic study has been undertaken. This includes an overview of the catchment, in order to provide important context for river trajectory and behaviour. A simple river meander model was applied to provide a sense of the future development of the river's planform, the configuration of the river in plan view based on the number of channels, sinuosity and ability of the channel to adjust laterally.

The Peria River originates in the Maungataniwha Range and flows northward to join with the Pakonga Stream and then the Oruru River where it discharges to the sea at Taipa Bay at the southern end of Doubtless Bay. The site of the restoration project is located along a series of meander bends adjacent to the Kauhanga Marae and is approximately 3 km in length.

Stream bank erosion is occurring throughout the restoration site by fluvial entrainment/erosion (detachment of grains from the surface of bed and banks) and mass/bank slumping (where sections of the banks fall into the channel). This is most pronounced on the outside bank of the meander bends, along the gently curving sections between meander bends, and the inner bends of meanders due to remobilisation of material at high flows. Grain size sampling showed that the stream banks contain approximately 60% sand, 25% silt and less than 15% clay. The low clay content means there is little cohesion of the stream bank material making it susceptible to erosion. Anthropogenically induced erosion is also caused by vehicle and stock access to the stream which destabilises the stream banks, particularly with repeated passage.

An examination of historical features on the valley floor indicated the presence of paleochannels indicative of long-term adjustment of the river during the Holocene. Comparison of aerial photographs from 1950 to today show that the channel has migrated slightly over the past 70 years, with growth at meander bends and a general downstream shift of the channel. This indicates that the restoration site will naturally be eroding as the stream moves on the valley floor, however, forest clearance has likely resulted in enhanced erosion over a vegetated reach.

River evolution modelling was undertaken using the Johannesson and Parker (1989) meander evolution model (JP Meander) which anticipates where we might see erosion in the future. It showed that over time, there is expected to be extension and downstream migration of the meander bends, with their outward growth restricted by the river terraces. The model also indicates a downstream movement of the channel resulting in erosion of the outer edges of the stream banks throughout the channel. The actual extent of erosion may vary from that predicted. Local variations in the river, such as woody debris and bank vegetation can also cause local changes in flow and resultant erosion and deposition. The modelling should therefore be used as a guide to identify vulnerable areas.

The stream banks are generally between 2 to 3 m high, and planting of the riparian edge will have little immediate effect on stream bank stability. While planting alone will not address the geomorphic processes that are driving meander migration and bank erosion, once the roots establish, they will – over the decadal timescale – provide some benefit by increasing soil cohesion of the stream banks and increasing the resistance to erosion. Riparian planting also provides additional benefits such as improvements to habitat heterogeneity/diversity, biodiversity, water quality, and climate change resilience. Rivers are dynamic and allowing the river a corridor where the natural processes of erosion, deposition and flooding can take place will enable the river to self-heal.

In the short term, erosion of the stream banks will continue to occur, particularly on meander bends and in areas with near vertical and/or bare banks. We recommend the establishment of a riparian buffer with a width of 10 m or greater, if, and where possible. Where narrower riparian planting buffers are used this will reduce erosion mitigation and biodiversity benefits. To minimise the loss of plants through erosion over the short term, we recommend that planting be set back from the stream edge by 1 to 2 m where banks are vertical or actively eroding. In other areas, planting can be taken down to the stream edge. Planting in areas that are inundated, such as point bars should include flexible vegetation such as *Carex germinata* or *Cyperus ustulatus*. Elsewhere we recommend fast growing ‘nurse’ species[1] and species that are tolerant of dry soil conditions while also providing good erosion mitigation, such as mahoe, mānuka, kānuka, karo, and cabbage trees.

The stream should be fenced to prevent stock access to the river bank (refer to the Planting and Fencing Strategy Map in Appendix 2). Where riparian planting is undertaken, we recommend that fences be placed 1 m from the edge of the planting on the landward side to avoid stock browsing. If planting does not take place, a setback distance from the top of bank of 5 m is recommended, particularly in areas of active erosion. We also recommend that measures be put in place to manage the use of stream crossings to minimise erosion by stock and vehicles. Fences and gates should be used to prevent stock access to the stream unless being moved between paddocks. Access to a robust and reliable reticulated water supply will be required so stock do not need access to the river for drinking water.

The next step will be to prepare detailed planting and fencing plans which take account of the areas of active erosion, the long-term trajectory of the Peria River and cultural, social, economic and climate benefits of restoration. Consideration should also be given to how restoration of the site can tie into the overall objectives of the Ngā Awa programme and restoration of biodiversity at a catchment scale.

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[1] Hardy trees and shrubs that can tolerate exposed conditions and once established provide micro climatic conditions for more diverse species to establish and survive (either naturally established or planted later). Includes species such as manuka, mahoe and karamu.

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1. Introduction

Morphum Environmental Ltd (Morphum) was engaged by the Department of Conservation Te Papa Atawhai (DoC) to undertake a geomorphic assessment of a section of the Peria River, which is part of Oruru Catchment, Doubtless Bay. Doubtless Bay is one of 14 rivers or catchments in the Ngā Awa river restoration programme administered by the Department of Conservation. The Ngā Awa project employs a whole-of-catchment approach to restoring biodiversity in the rivers and the larger catchment. Te Paatu ki Kauhanga Trust is working towards restoration of the Peria River with te Mana o te Wai funding from the Ministry for the Environment, and additional funding available for planting from DoC and fencing from Northland Regional Council. However, significant erosion of the stream banks is occurring and there is concern that if the erosion is not addressed, or at least considered, it may undermine the restoration efforts.

The Peria River originates in the Maungataniwha Range and flows northward through the Honeymoon Valley to join with the Pakonga Stream and then the Oruru River where it discharges to the sea at Taipa Bay at the southern end of Doubtless Bay. For the purposes of this report, the Peria Catchment extends upstream from the confluence of the Pakonga Stream and the Oruru River (Figure 1) and has a catchment area of 4,576 ha. The site of the restoration project is shown in Figure 1. It is located along a series of meander bends adjacent to the Kauhanga Marae and is approximately 3 km in length.

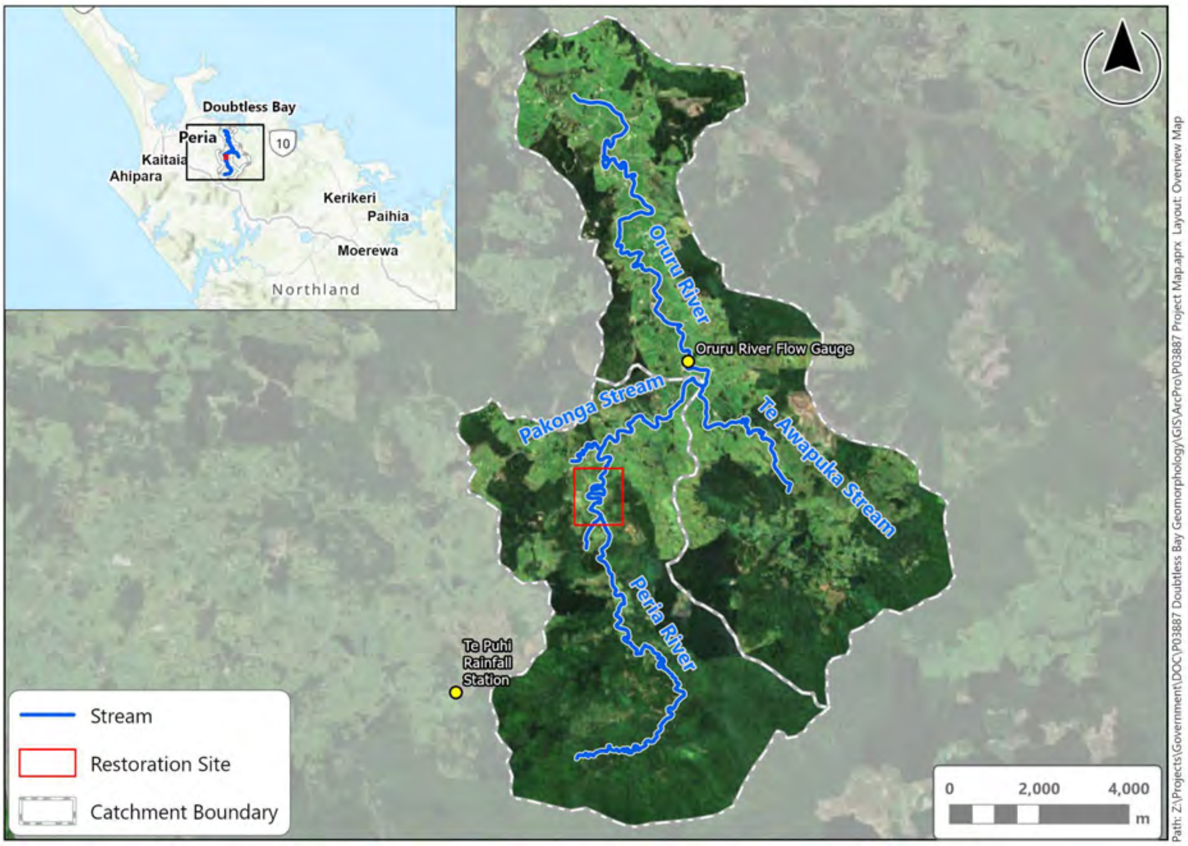

Figure 1: Overview map of the Oruru and Peria River Catchments. The site of the proposed stream restoration is highlighted. The catchment in relation to Doubtless Bay is shown in the inset map.

To understand the drivers of erosion in the Peria River and to inform effective planting and fencing efforts, a geomorphic study has been undertaken along the restoration reach on the Peria River. This includes an overview of the catchment, to provide important context for river trajectory and behaviour. Field observations, and current and historical aerial imagery provide further insight into sedimentary materials and the evolution of channel form. A simple river meander evolution model (Johannesson and Parker, 1989; MeanderJP) was applied to provide a sense of the future development of the river's planform[2]. For additional information on river geomorphology principles, reference can be made to the report by Tunnicliffe and Brierley (2021).

To better support restoration efforts, this work then provides a picture of the likely geomorphic evolution of the meandering river (points of erosion and deposition). Based on this information, recommendations on where planting is likely to be most effective, and the plant species best suited for different river margin environments is provided. The location of bank instability, shown in the Geomorphic Features Map in Appendix 2, can also inform set-back distances for fencing.

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[2] The channel planform is the configuration of the river in plan view and is based on the number of channels, sinuosity and ability of the channel to adjust laterally.

2. Catchment Context

2.1. Geology

The headwaters of the Peria Catchment are underlain by the Tangihua Complex of the Northland Allochthon which comprises basalt pillow lava and subvolcanic intrusive of dolerite (Isaac, 1996). It is Early Cretaceous to Paleocene in age (120 – 55 million years ago) and is believed to be part of oceanic crust that was thrust upon Northland during the Oligocene (25 million years ago) (Haywood, 2017). The northern extent of the Tangihua Complex in the Peria Catchment is demarcated by the northeast- to southwest-trending Maungataniwha thrust fault (Figure 2). The rocks of the Tangihua Complex are harder and more resistant to erosion than other rocks in the Northern Allochthon (Haywood, 2017).

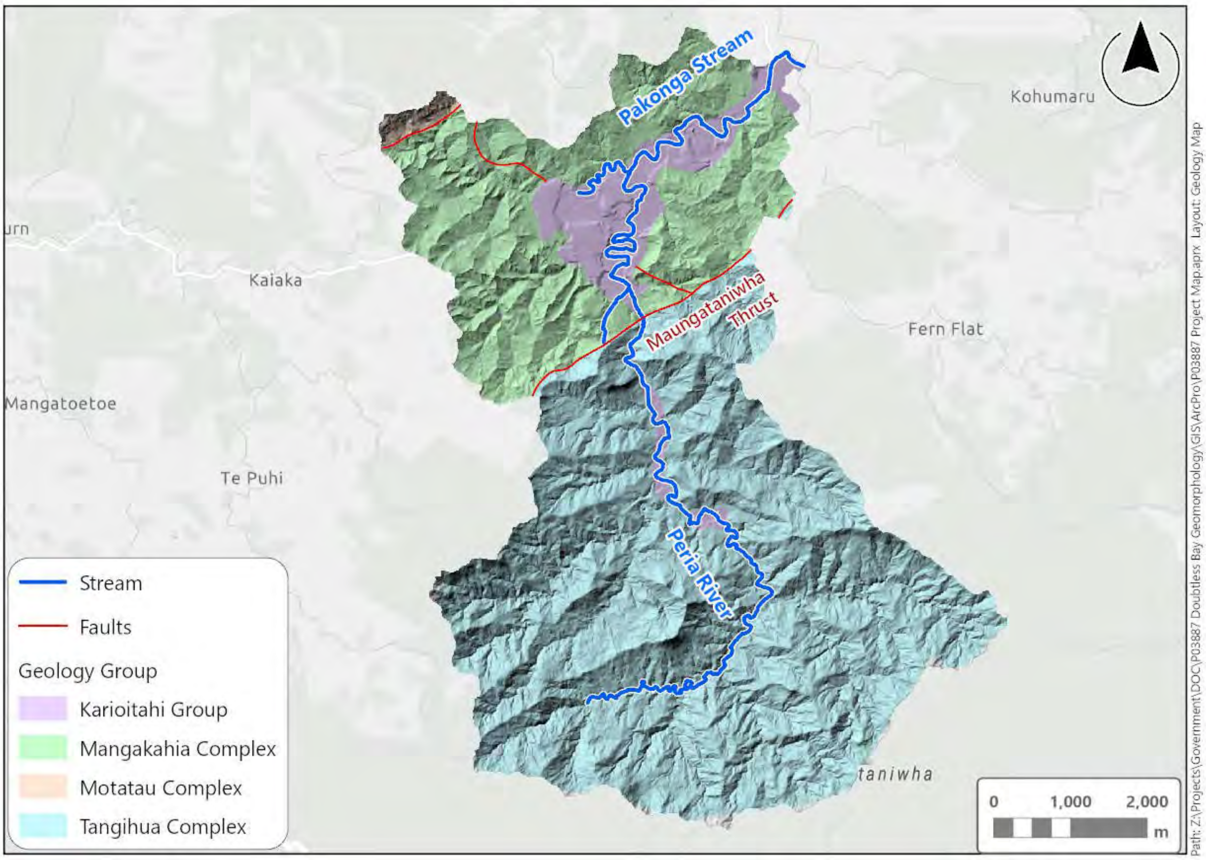

Figure 2: Geology of the Peria Catchment (GNS Science).

To the northwest of the fault is the Whangai Formation (Mangakahia Complex) which comprises siliceous and calcareous mudstone (Isaac, 1996) that are late Cretaceous to Palaeocene in age (80 – 56 million years ago) (Haywood, 2017). It forms the hillslopes on either side of the lower reaches of the Peria River. Late Pleistocene to Holocene (1 million years ago to today) river and swamp deposits (Kariotahi Group) have accumulated on the valley floor (Isaac, 1996). This valley fill has been subsequently reworked by the contemporary river.

Across the Northland region, Pleistocene- and Holocene-aged river terraces have been identified in valley settings similar to the Peria River site. River terraces are landforms which represent the remnants of a former valley floor that has been abandoned as the river gradually incises, typically in response to tectonics, climatic change or base level changes (Leopold et al. 1964). Radiocarbon dating suggests that floodplain aggradation occurred between approximately 7500 calendar years before present (cal. YBP), to 2800, cal. YBP during a period of climatic deterioration. More intense storms and floods increased sediment generation from the catchment. This was followed by a period of channel degradation (incision) from 1900-1200 cal. YBP, as the climate warmed and became more settled (Richardson et al, 2014).

Following Māori and European settlement, there was a period of rapid, fine-grained sedimentation on the lower Holocene surfaces in Northland catchments in response to deforestation (Richardson et al., 2013). Across Northland, the calculated rates of floodplain aggradation over the past 1,000 years is between 3.3 and 10.1 mm/year with a notable increase in the rate of sedimentation post European settlement (Richardson et al., 2013). For example, the sedimentation rate in the Kaeo Catchment was less than 1 mm/year prior to human habitation and increased to 13.5 mm/year following European settlement (Richardson et al. 2014). The suite of terraces observed along the Peria River is similar to those found in other river valleys around Northland, and it is likely that similar climatic and anthropogenic factors (changes brought about by human habitation such as forest clearance) have contributed to their formation.

2.2. Climate

Northland is narrow, with no point greater than 50 km from the sea. This leads to broad exposure to moist oceanic air masses, leading in turn to high ambient air moisture and abundant rainfall. The Peria River has an average annual rainfall of between 1,600 and 1,800 mm a year, with the majority of rainfall occurring during the winter months. Northland can be subject to heavy rainfall, particularly from ex-tropical depressions that results in flooding, including Cyclone Bola of 1988 (Chappell, 2013) and more recently, ex-tropical Cyclone Hale and Cyclone Gabrielle in 2023.

Daily rainfall from January 2003 to December 2022 at the Te Puhi rainfall station, located to the southwest of Peria, is shown in Figure 3. In the last 20 years, there have been five rainfall events exceeding 120 mm in 24 hours. During Cyclone Gabrielle, 130mm of rain was recorded from the 11th to the 14th February, with a maximum of 61 mm of rain falling in 24 hours.

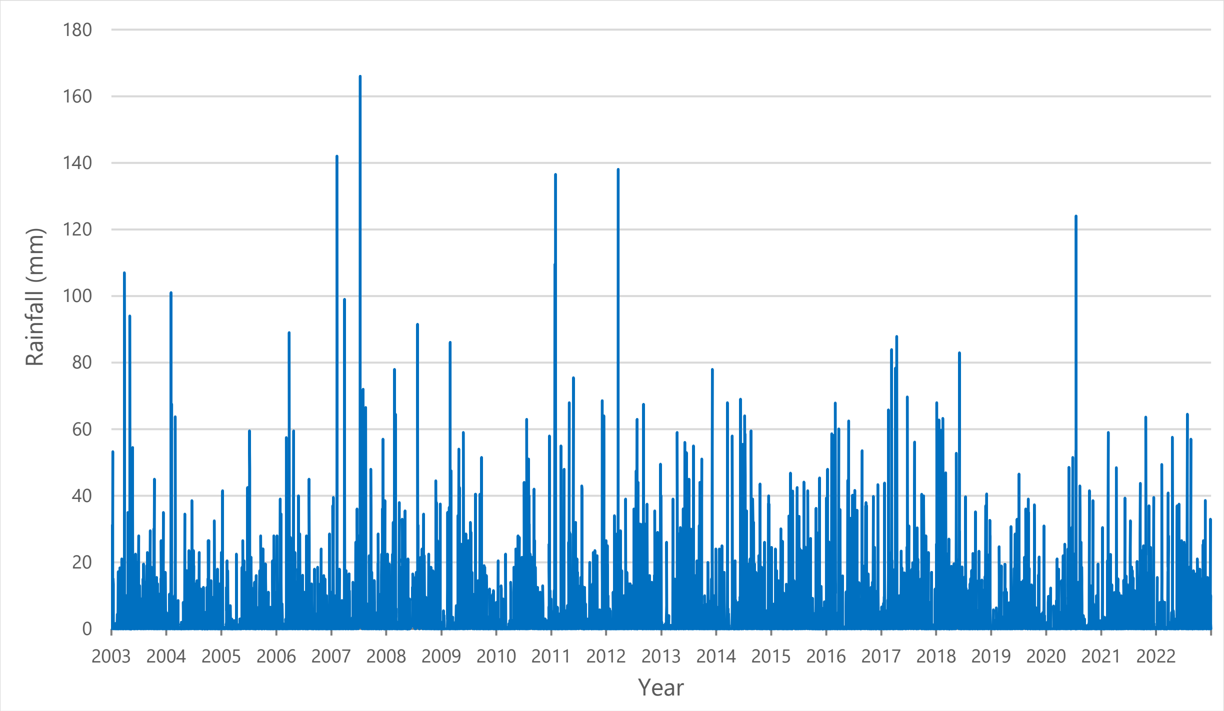

Figure 3: Daily rainfall at Te Puhi, Mangakawakawa Trig.

2.3. Landuse change

The first Māori settlers are believed to have arrived in Taipa about 700 years ago and established settlements throughout the Doubtless Bay area, with the most extensive settlement at Taipa and the Oruru Valley behind it, extending up as far as the fertile Peria Valley, where the Kauahanga Pa is today. The Oruru River provided an easy pathway to the sea and provided excellent garden land (Waitangi Tribunal, 1988).

Captain James Cook first came to the area in 1770. This initial contact was later followed by the arrival of whalers and traders in the early 1790's (Waitangi Tribunal, 1988). The first missionary contact was in 1831. British Admiralty later arrived in the area to fell Kauri, followed by European settlement.

Historical aerial photographs from 1950, sourced from Retrolens.nz, show extensive forest clearance across the Peria Catchment, with forest coverage only remaining in the steep, headwater streams of the Maungataniwha Forest. Based on the New Zealand Landcover Database (LCDB 5.0), as of 2018 the majority of the Peria Catchment is native forestry (61%) concentrated in the upper catchment, with pasture making up 24% of the catchment area, particularly in the lower catchment. Since 1996, the first year of the LCBD, there has been a decrease in pasture and an increase in native forest. The land coverage is shown in Figure 4 and Table 1.

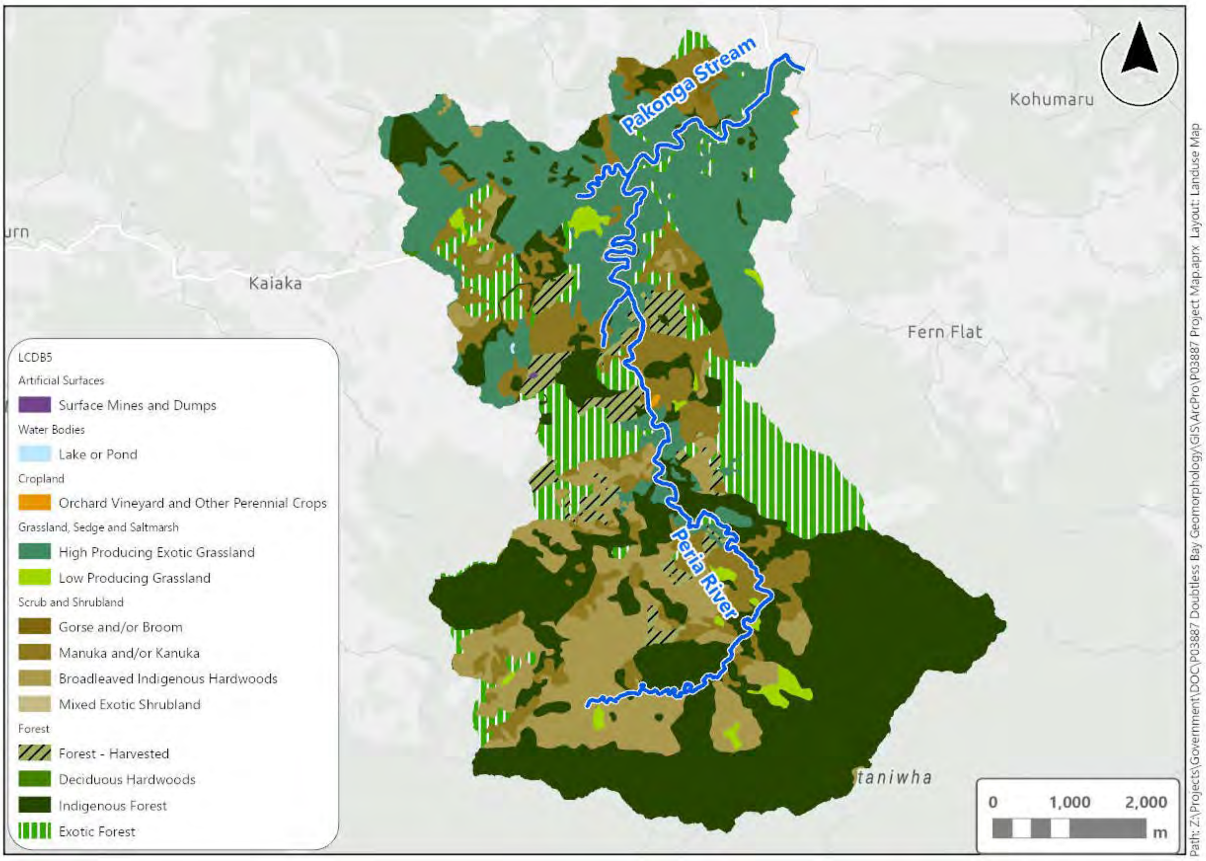

Figure 4: Landuse in the Peria Catchment, 2018 (LCDB 5.0)

Table 1: Comparison of land coverage in the Peria Catchment from 1996 and 2018 from the LCDB 5.0

Land Coverage	**2018**	**1996**
Pasture/Grassland	24%	30%
Indigenous Forest, hardwoods and mānuka/kānuka	61%	57%
Exotic Forest and Harvested Forest	14%	11%
Other	<1%	<3%

2.4. Longitudinal Profile and Stream Power

The Peria River is a steep headwater stream, down to the waterfall located at the Maungataniwha thrust fault. Downstream of the waterfall, as the valley opens, the stream grades gently to the confluence with the Oruru Stream and through to Taipa Bay.

A flow gauge is located on the Oruru River at Saleyards, immediately downstream of Dangen Road (Figure 1) which records hourly discharge rates. A Gumbel flood frequency plot shows the relative likelihood of annual floods of various magnitude (hourly discharge; Appendix 1). By using a discharge to area scaling relationship, the discharge at the end of the Peria restoration site is estimated to be 31.1 m^3/s for a 2-year event and 43.9 m^3/s for a 10-year event (Table 2).

Table 2: Calculated discharge (m^3/s) for flood events of various return intervals, based on the Oruru River flow gauge at Saleyards.

Location	**Area (ha)**	**Return Flood Interval (years)**				
		1	**2**	**10**	**50**	**100**
Oruru Gauge	7,900	30	66	93	119	130
Peria Catchment	4,576	19.4	42.6	60.1	76.9	84.0
Peria Site	3,087	14.1	31.1	43.9	56.1	61.3

Stream power reflects the total energy available in a river for the flowing water to undertake geomorphic work, such as reworking and/or transporting sediment. Stream power is an expression for the rate of potential energy expenditure per unit downstream length based on the volume of water (discharge), channel slope and the specific weight of water (Fryirs and Brierley, 2013).

The stream power profile of the Peria River for a 2-year discharge event was calculated based on channel slope and the discharge (Figure 5). As discharge does not scale linearly with catchment area, to determine the discharge along the longitudinal profile, a discharge scaling factor (McKerchar & Pearson, 1990) was calculated, based on the catchment area and the estimated discharge at the gauge station from the Gumbel plot.

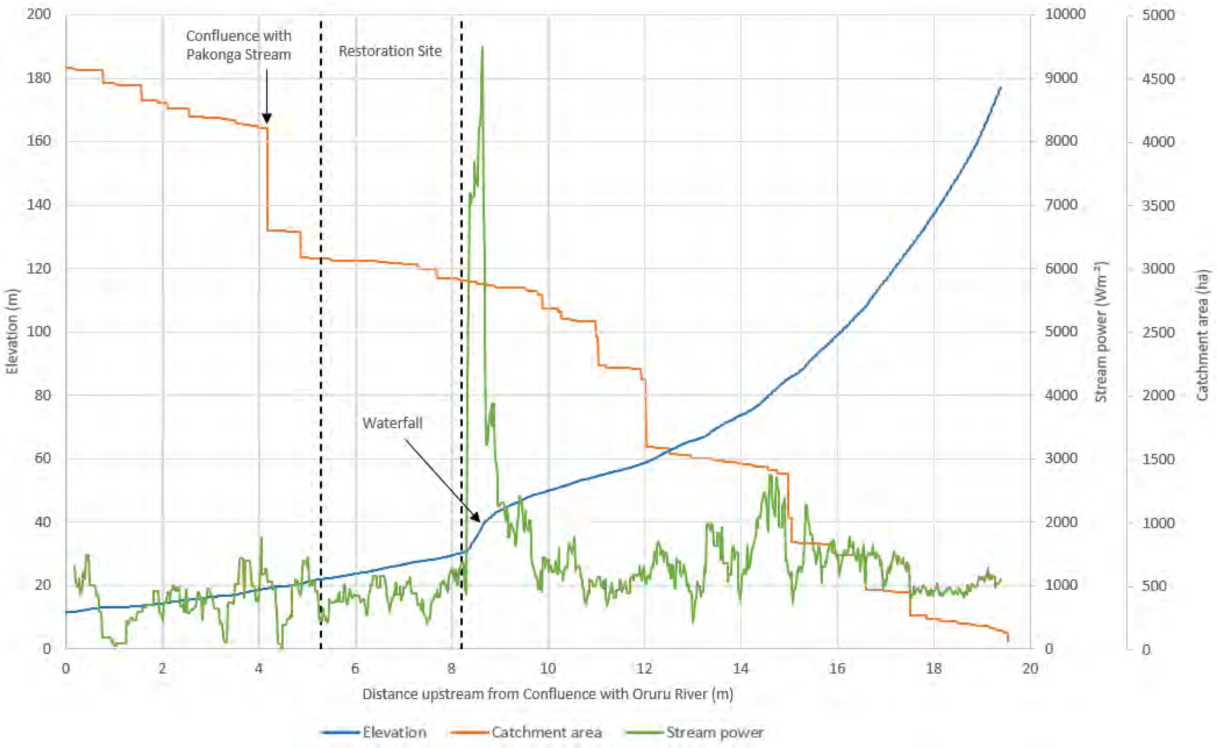

Figure 5: Longitudinal profile, catchment area and stream power for a 2 year discharge event of the Peria River.

The trends in stream power shows a general increase in stream power throughout headwater reaches from 19.5 to 14 km upstream due to the steeper grade and the input of discharge from tributaries. From 14 to 10 upstream, there is a general decrease in stream power as the gradient declines; this also corresponds to the development of valley deposits upstream of the waterfall as stream slope decreases

(Figure 2). Stream power spikes at the waterfall (approximately 8.5 km upstream) due to the steep grade and then reduces markedly through the restoration site to the confluence. The discharge remains relatively constant from downstream of the waterfall through to the confluence with Pakonga Stream, and there is a variable but generally decreasing downstream trend in stream power. Overall, the channel slope has graded itself to the contemporary discharge regime, particularly downstream of the steeper headwaters (above 14 km).

It is notable that broad meanders are only present immediately downstream of the waterfall, which might suggest that the river has somehow sought to adjust its slope and sinuosity in response to the local differential uplift at the Maungataniwha fault (i.e. the waterfall).

2.5. Biodiversity

Northland Regional Council (NRC) undertakes habitat (Rapid Habitat Assessments (RHA) (Clapcott, 2015)) and macroinvertebrate sampling at two sites within the Oruru Catchment:

- Oruru at Oruru Road, mid-way towards the coast downstream of the confluence of the Peria River,
- Peria at Honeymoon Valley Road, upstream of the restoration site in the forested headwaters of the Peria River.

Riverine habitat conditions at the Oruru River site are described as ‘marginal’ based on NRC’s habitat survey programme and had an RHA score of less than 50% (NRC 2016). The river banks are described as relatively unstable and the river shows evidence of high sediment loads (NRC, no date), a description which reflects the conditions of the restoration site. In contrast the Peria at Honeymoon Valley sites had an RHA score of 90%, reflective of the site location in the upper catchment, flowing from subcatchments with mainly native vegetation, plenty of shading, a stony substrate and a variety of instream habitat types (NRC, 2016).

The marginal habitat quality at the Oruru River site is also reflected in a degraded invertebrate community, dominated by pollution-tolerant species such as snails and the pollution-tolerant caddisfly *Oxyethira* (NRC, no date). For the 2014/15 survey the Oruru River, the MCI score was less than 80 indicative of ‘probable severe pollution’. In contrast the Peria at Honeymoon Valley site had an MCI score of greater than 130 indicating ‘clean water’.

The restoration site is located between the two survey sites, however, given the habitat and geomorphic conditions at the restoration site (limited instream habitat diversity, limited riparian vegetation, adjacent pastural land use, and actively eroding river banks) it is anticipated that the habitat values and macroinvertebrate community would be more reflective of the Oruru River site rather than the Peria at Honeymoon Valley site.

The greater Doubtless Bay catchment has records of nine native fish species on the National Freshwater Fish Database. These include longfin eel, shortfin eel, inanga, giant bully, common bully, smelt, torrent fish, redfin bully and banded kokopu. The pest fish gambusia is also recorded in the catchment (NRC, no date). No records are available for the Oruru River Catchment itself, however, records for the nearby Paranui and Owhetu Stream include records of those species identified across the wider catchment. Subject to the effects of any potential downstream barriers to migration, these species may utilise the restoration site, however, the limited quality and quantity of instream habitat is likely to limit abundance and diversity of freshwater fish species.

3. Geomorphic Assessment

3.1. Observations

The Peria River upstream of the Maungataniwha thrust fault is generally a confined, bedrock margin controlled, headwater stream. The bedrock adjacent to the headwater streams ‘confines’ the movement of the river on the valley floor and the steeper grade allows sediment to easily be transported downstream, preventing the development of floodplains except in discrete pockets.

In contrast, downstream of the fault, the Peria becomes a planform-controlled, terrace-constrained, meandering channel with discontinuous floodplains and a sand-to-pebble bed. There is some room for the river to migrate laterally across the valley floor, making it partly confined. The presence of terraces on either side restricts some movement, resulting in a discontinuous floodplain surface. As the channel migration is restricted along less than 50% of the channel length, the valley fill has a greater influence on the nature of channel migration; this is known as a ‘planform controlled’ morphology (Brierley and Fryirs, 2002). The floodplains are inundated during storm events which allows for vertical accretion on the floodplain surface as fine-grained sediment is deposited out of suspension.

There is a suite of up to four terraces in the Peria catchment which were formed as the ancestral Peria River cut down through the valley fill deposits; these flat, past valley floodplains on the valley floor. The active alluvial surface or valley bottom (Fryirs et al., 2016) represents the active floodplain for the contemporary river that is engaged during high flows. Flows within the active floodplain do not inundate the terraces: Terrace 1 is approximately 1 to 2m above the active floodplain elevation. The principal geomorphic features within the restoration site are shown in the Geomorphic Features Map in Appendix 2; a typical cross-section of the valley floor is shown in Figure 6. The features are also shown in Photo 1; for reference of photograph locations, refer to the Geomorphic Features Map.

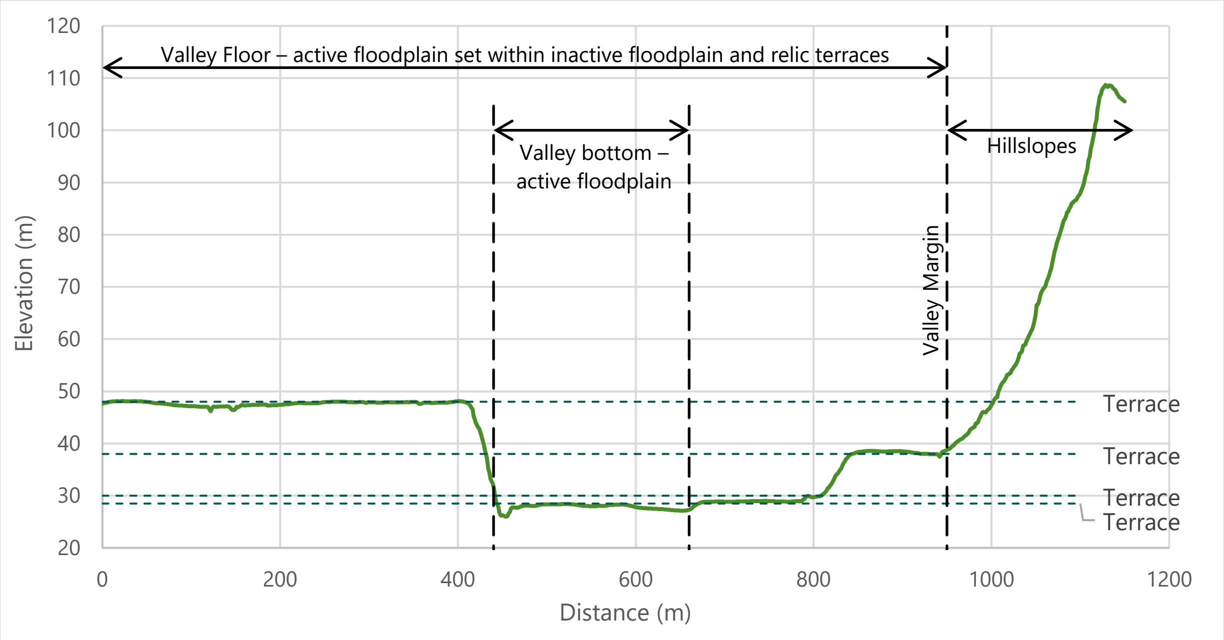

Figure 6: Representative cross section across the valley floor. Terrace levels are indicated. The valley floor includes the active flood plain surfaces (valley bottom) and the terraces. The valley margin represents the boundary between the valley floor and the hillslopes.

Photo 1: The Peria River with the active floodplain and terraces indicated. Note the bare banks where fluvial entrainment is occurring. The red lines indicate the top of terraces. The blue line indicates the base of terrace 1 and the edge of the valley bottom.

The stream banks are generally between 2 m and 3 m above the active channel, with a profile slope that ranges from about 45° to vertical (Photo 2 and Photo 4). The bank material consists mainly of sand and silt, with bedrock exposed, particularly where the river abuts the terrace margins (refer to Section 3.2 for more detail). The stream banks are generally grassed (dominated by kikuyu), with occasional areas of willow (predominantly crack willow; *Salix x fragilis*), exotic weeds (including cape honey flower; *Melianthus major* and Montbretia; *Crocosmia x crocosmiiflora*) and native vegetation (including tutu; *Coriaria arborea*, which appeared to be recently controlled by herbicide), particularly where the river abuts the terrace margins.

Instream geomorphic units include riffle-run sequences (Photo 4), pools (Photo 5), point bars (Photo 6) and the occasional midchannel and lateral bar (Photo 4). Sediment is stored within the bars and is available for reworking at high flows.

Bank erosion is occurring throughout the Peria River restoration site. The mechanisms for erosion include fluvial entrainment/erosion, where individual grains are dislodged by the flow of water, and mass/bank slumping, whereby sections of the stream banks fall into the channel. Ongoing fluvial erosion can undermine the banks and lead to mass slumping. Erosion is more pronounced on the outside of meander bends (outer bank erosion on the Geomorphic Features Map) as the flow is directed into the banks during high flows. This causes the gradual growth and downstream shift of the meander bends (Photo 3 and Photo 5). Fluvial and mass slumping is also occurring along the gently curving stream banks between the larger meanders (Photo 7, Photo 8 and Photo 9).

Bedload material is deposited on point bars on the inner bend of meanders, and this is material is remobilised during high flows. Erosion at these point bars may be accompanied by mass slumping of the exposed edges on the same side of the stream (Photo 6 and Photo 10). Erosion and collapse of the bank material is being exacerbated by stock which trample and loosen sediment on the banks (Photo 11). Farm tracks are also causing localised destabilisation of the stream banks and are also a point of access to the stream for stock (Photo 9).

The floodplains are engaged during high flows and debris, such as leaves and branches, was observed to be caught on fence lines and around vegetation. Surrounding land use is generally grassed pasture with maize crops in the downstream portion of the site. Fences are present along some sections of the stream but are generally in poor repair and are no longer preventing stock access to the stream.

Photo 2: Characteristic run along the Peria River. Note the vertical banks. Looking upstream.

Photo 3: Characteristic run towards a meander bend, looking downstream. Note the graded stream banks and the erosion at the meander bend.

Photo 4: A riffle with upstream pooling behind the riffle and a run. Looking upstream.

Photo 5: Pool formation and erosion on the outside of a meander bend.

Photo 6: Point bar where sediment is stored on the inside of a meander bend. Erosion is occurring on the inside of the point bar and the banks are slumping. Looking downstream.

Photo 7: Fluvial and mass slumping of the stream banks in straighter sections of the stream. Looking upstream.

Photo 8: Fluvial entrainment and mass slumping. Looking upstream.

Photo 9: Ford crossing of the stream has likely contributed to localised bank erosion and sediment bar formation. Looking upstream.

Photo 10: Erosion of material on inside of point bar and slumping. Erosion is likely to have been exacerbated by stock access.

Photo 11: Lateral bar with graded banks where stock can access the stream.

3.2. Sediment Sampling

Sediment sampling was undertaken to determine the grain size distribution of the active alluvial surface within the channel and the floodplain material exposed in the banks. The location of the sediment sampling is shown on the Geomorphic Features Map in Appendix 2.

Sediment sampling for the active alluvial surface was undertaken on bars at the upstream and downstream ends of the study reach (Site 1, Photo 12 and Site 2 Photo 13) to assess the composition of the active surface layer, the gravel fraction that remains on the sediment bar following the removal of the finer portion of material at moderate or waning flow conditions. It gives an indication of the hydraulic roughness in the channel and the calibre of the sediment which is being transported. The material was assessed using the Wolman Pebble Walk methodology (Bunte & Abt, 2001), where a transect was walked across the bar, and a single clast (i.e., a pebble or cobble) was randomly selected at approximately 0.5 m intervals. A total of 100 grains were measured along the b axis (the intermediate axis length), using the modified Udden-Wentworth grain size scale to classify grains at half phi intervals from Φ-3 to Φ-7 (8 to 128 mm) (Blair & McPherson, 1999; Clapcott et al., 2001).

The stream banks provide a cross-section view of the lower terrace material; these typically have a gravel base with fine-grained sediment above (Photo 14). The gravel layer is inferred to be an earlier stream bed at a similar elevation, prior to the deposition of valley fill above. This earlier system was likely filled with material following anthropogenic disturbance. Two samples (Site 3 and 4) (approx. 150 g collected) of the fine-grained bank material were taken. A MasterSizer3000 particle size analyser was used in the University of Auckland laboratory to determine the grain size distribution of the fine-grained samples (approximately 0.25 g of collected sample), refined using the average of four measurements taken from the same sample.

Bedrock was observed in the meander bends where the stream was abutting against the terrace margins (Photo 15), and also at the base of the channel in discrete locations. There was also occasional woody debris in the stream.

Photo 12: Site 1, lateral bar. Looking upstream.

Photo 13: Site 2, point bar. Note erosion of the inside bank. Looking upstream.

Photo 14: Stream bank exposures with gravel in the base and fine-grained sediment above.

Photo 15: Bedrock exposures in stream banks. Looking downstream. Note the woody debris.

The results of the sediment sampling are shown in Figure 7

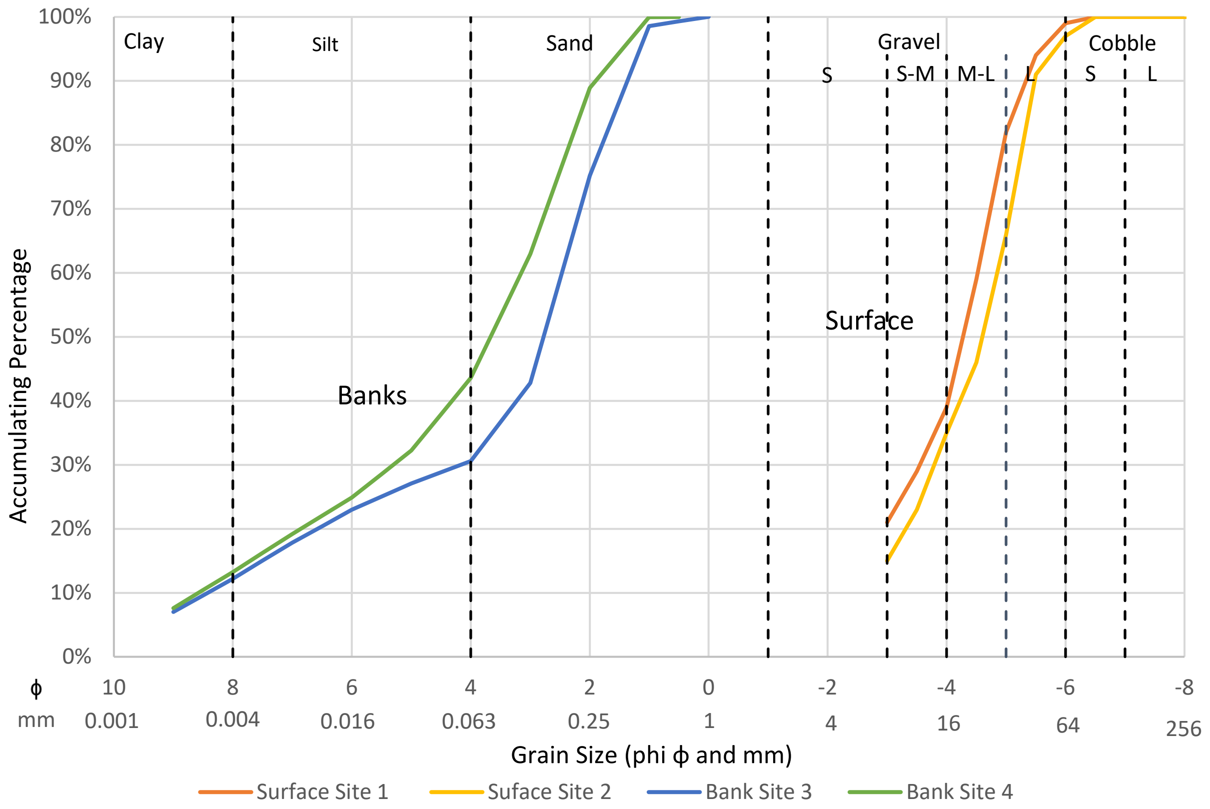

Figure 7: Grain size distribution as accumulating percentage of sediment of the active layer deposits in sediment bars and fine sediment portion of the banks.

4. Trajectory of Change

4.1. Historical Features

Historical aerial photographs reveal how the stream has adjusted over the recent past. Aerial photographs from 1950 (SN1363-30 and SN1363.32) were sourced from Retrolens.nz and the stream alignment was compared to today (Figure 8). This shows that over the last 70 years, there has been a gradual extension (outward growth) of the meander bends with rotation occurring (deflection and shift of the pathway of bend migration) where their growth is restricted by the terrace margins.

The straighter sections of stream between meanders have generally followed the same alignment through this time, however there are some areas of minor adjustment. These could be a result of localised forcing elements such woody debris or bank slumps which alter stream flow over a decadal timescale, resulting in a localised change in deposition or erosion.

Figure 8: 1950 aerial photo of the Peria River. Current alignment of the Peria River is shown in blue.

A relative elevation model (REM) highlights important features on the valley floor (See Relative Elevation Model Map in Appendix 2). This indicates previous paleochannels on the valley floor, including one meander loop at the downstream end that has been cut off. This indicates that over the geomorphic time scale (thousands of years), the river has been adjusting its course and reworking the valley fill deposits.

The historical imagery suggests that the Peria River has adjusted over decadal to century timescales through downstream meander migration. Natural erosion should therefore be expected in the Peria

River, particularly on the outside of meander bends, both on the larger meanders, and the gently curved sections between meander bends. However, forest clearance and transition to pastural land use has likely resulted in enhanced erosion above what would be expected in a reach with shrubs and mature trees in the riparian margins and surrounding subcatchment.

4.2. River Evolution Modelling

To assess the future trajectory of change for the Peria River and to determine areas susceptible to erosion, a meander evolution model has been prepared using MeanderJP (Johannesson & Parker, 1989, Larson, et al., 2002, Larson et al., 2006), using the iRIC platform (ESSA Technologies Ltd). The model is used to anticipate where we might see erosion in the future, with erosion occurring on the outside of meander bends, and accumulation of sediment on point bars and inside banks. The rate of migration is proportional to the tightness of the bends, with greater erosion occurring through tighter bends. While centreline migration models such as MeanderJP are based on relatively simple rules of river hydraulics and sediment movement (our understanding of meander migration remains, arguably, incomplete), such models have been shown to effectively reproduce the meandering trajectory of river systems under simple and uniform conditions, at least to a first order approximation (c.f. Seminara, 2006; Zolezzi et al., 2009; Bogoni 2017). It is speculative to use this for prediction in more complex field conditions, but we feel it is helpful to understand the overall trajectory of the Peria River pattern.

The JP Meander model set up uses the stream centreline at the 2 year recurrence interval, channel characteristics/geometry and the 2 year discharge. The terraces were assumed to be less susceptible to erosion and were given a higher erodibility factor than the valley floor. A variable discharge rate was applied based on the daily flow record from the Oruru gauge station which was proportionally adjusted to the subject site using an area scaling relationship.

The 1950 centreline was used to calibrate the model by comparing the results from the model output with the river centreline today. These parameters were then used to assess the evolution over the river over the next fifty years (2021-2071), based on the date of the most recent aerial photograph. The results of the model, including the 1950 centreline, centreline at 2021, and the potential centreline at 2071 are shown on the River Evolution Pathway 1950 – 2071 Map in Appendix 2.

The Peria River has not shown much change since 1950, however, to visualise the potential range of motion of the Peria River and the localities where the most erosive flows are acting, the model was rerun using more erosive material and for a longer time frame (100 years). The results are shown in the Long-Term River Evolution Pathway Map in Appendix 2.

The model output indicates an overall downstream shift of the Peria River meander pattern. The tight bends also tend to force erosion and stimulate continued evolution of the system. This is a natural process for rivers, optimising channel gradient and therefore sediment transport processes. This in turn leads to important renewal of substrate in the channel and floodplain, with many attendant ecological benefits. The terrace margins restrict growth of the meanders outwards in some places, and there is instead a bend rotation and shift downstream. Even within the straighter sections between meander bends, there is a progressive downstream adjustment which will result in erosion of the down-valley portion of the bank and gradual deposition on the upstream side.

The long-term evolution of the river (centuries), indicates that ongoing erosion may eventually lead to a cut off of meander bends forming oxbows. This would then lead to extensive readjustment of the river's longitudinal bed profile due to abrupt steepening of the grade (i.e., the bed slope) along the reduced stream length, and a change in the sediment regime. The most vulnerable area for a meander cut off to occur is at the downstream most meander where there is only approximately 25 m separation (located at photo point 1 - see Appendix 1, Geomorphic Features Map). A river's energy gradient is strongly linked to the intensity (tortuousness) of the meandering. The meander ratio (channel length vs valley length) through the restoration site is approximately 2 and this high sinuosity reduces the energy to transport sediment.

This model provides an indication of the potential erosion pathway of the Peria River through time. However, the actual extent of erosion over the 50 year time frame may vary from that shown. By understanding the overall development of the channel planform pattern, the significance of local sites of erosion can be interpreted: for instance, are these part of meander bend migration? Or are other, local factors influencing erosion, such as woody debris and bank vegetation influencing this? Excess loads of debris can cause local changes in flow, resulting in erosion and deposition. Natural systems are not closed: rivers, in particular, are known for their complex responses to changes within the system. Their behaviour may vary widely as a result of conditioning from prior events (Fryirs & Brierley, 2013). As such, this model should be used as a guide to indicate what *could* occur in the Peria River into the future and to highlight areas which may be most vulnerable to change.

5. Stream Remediation Strategy

5.1. Overview

The Peria River has a long-term history of incision (lowering of the channel bed) with the river cutting down through the valley fill deposits and creating the river terraces on either side of the valley floor. Anthropogenic disturbances can bring about excess flow energy which destabilises a system and leads to channel incision (i.e., deepening) (Simon & Rinaldi, 2006). Forest clearance following European settlement released fine sediments (i.e., clay and silt) and changed the balance of roughness elements on the valley floor (i.e., elements such as wood and vegetation that slow the velocity of flow). This likely initiated a period of incision in the Peria River which caused deepening and widening of the stream channel. No obvious knickpoint (abrupt changes in grade) were observed during the site walkover, and bedrock was noted in the channel which suggest that the system is no longer incising through knickpoint propagation[3]. The stream is thought to have reached a new state of quasi- equilibrium (Stage VI) in the channel evolution cycle (Figure 9: Channel evolution cycle showing how the channel incises and widens to reach a new equilibrium condition following disturbance. The Peria River at the restoration site is at Stage IV (Simon & Rinaldi, 2006).Figure 9). Currently, the dominant driver of erosion is through meander migration.

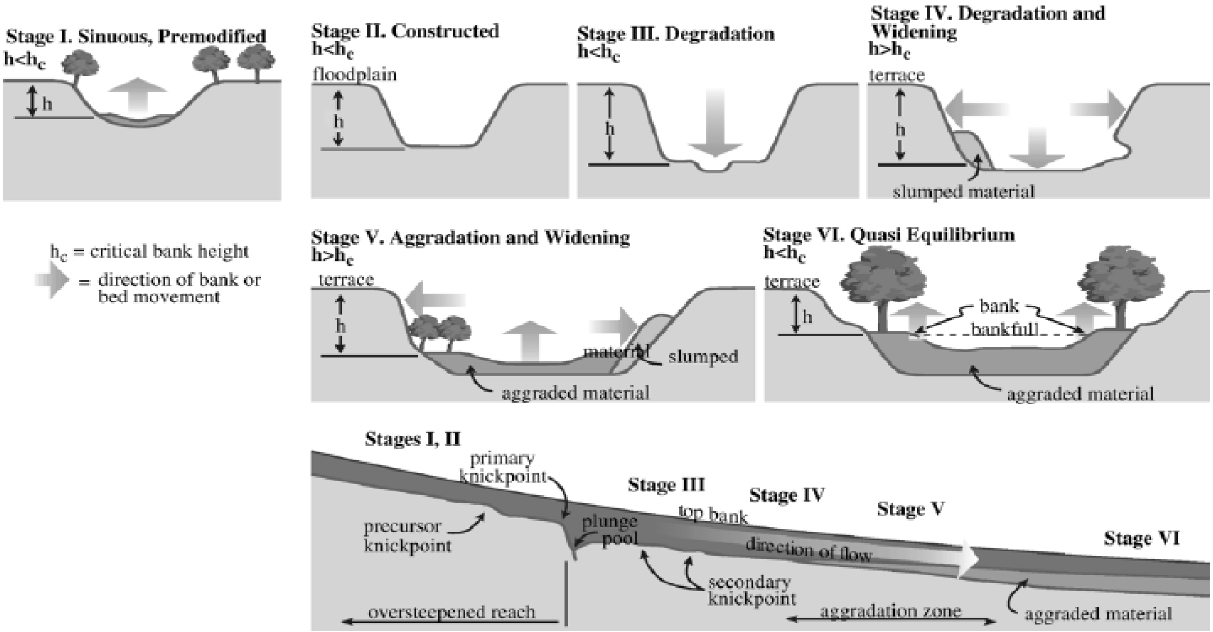

Figure 9: Channel evolution cycle showing how the channel incises and widens to reach a new equilibrium condition following disturbance. The Peria River at the restoration site is at Stage IV (Simon & Rinaldi, 2006). h = actual bank height, h_c = critical bank height.

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[3] Knickpoints are locations where stream bed erosion is enhanced due to the abrupt change in grade concentrating flow energy and creating a plunge pool. The knickpoint will continually migrate upstream through erosion of the headwall on the upstream side of the plunge pool.

The contemporary channel today is meandering across the valley floor through meander migration, and river evolution modelling indicates that over time, there will be a downstream shift in the meander bends with erosion on the outside of bends and deposition on the inside of bends. The bank materials have low cohesion and are readily eroded, resulting in mass slumping along the channel.

As well as natural erosion expected in a meandering system, anthropogenic disturbance of the river banks through river fording (vehicles and stock), and the lack of fencing to prevent stock from accessing the stream bank edges and bars is exacerbating bank erosion.

5.2. Planting

The banks are up to 3 m high in places and planting of the riparian edge will have little immediate effect on stream bank stability as the roots will not penetrate deep enough to provide additional cohesion for the soil to improve bank strength in the short term. The digging of closely spaced holes for planting may also result in destabilisation of the top of the banks. Regrading of the stream banks will provide for better stabilisation with vegetation; however, at this site, this would require considerable removal of material and associated cost and is not considered feasible.

In the short term, erosion of the stream banks will continue to occur, particularly on meander bends and in areas with near vertical and/or bare banks. While planting alone will not address the geomorphic processes that are driving meander migration and bank erosion, it will, in the longer term (decadal timescale), provide some benefit by increasing the cohesion of the soils and reducing the rate of erosion. Strategic riparian planting will also support improving habitat heterogeneity, biodiversity, and water quality.

Rivers are dynamic and allowing the river a corridor where the natural processes of erosion, deposition and flooding can take place will enable the river to self-heal (Biron et al., 2014; Kondolf, 2011). Bank erosion and the loss of vegetation into streams can be perceived as an adverse effect, however, woody debris provides stable substrate for organisms, food and shelter, it also changes channel complexity enabling pool formation and flow diversion (Photo 16) (Florsheim et al., 2008). The pools offer habitat diversity for instream organisms and ‘flow refugia’ (i.e., stable substrates in high flows) can be created downstream of woody debris. Following restoration planting, the banks will continue to erode, but this ongoing, natural erosion will create an input of woody debris to the stream (Photo 17) which allows for local variations to instream habitat (Florsheim et al., 2008; Kondolf, 2011).

Photo 16: Woody debris at stream edge trapping fine grained sediment on downstream side. A stable undercut has formed below the stump, providing shelter and shade for fish or invertebrates.

Photo 17: Instream woody debris which facilitates sediment accumulation and scouring to form deeper pools around the wood.

Likewise, bare surfaces on the stream bed (i.e., point bars) initiate the creation of successional vegetation assemblages, where pioneer species can establish on the bare earth and as the channel migrates, so too does the vegetation assemblages (Gurnell et al., 2012; Kondolf, 2011). The Peria River has areas of deposition in lower energy environments such as point bars and behind woody debris. Flood processes can also strip the floodplain of vegetation resulting in bare earth for successional vegetation assemblages to develop over time.

Considerations for riparian planting along the Peria River to help mitigate bank erosion are discussed below. Riparian planting focusses on the active channel area; the terrace margins have lower erosion rates and are generally already vegetated. We appreciate that the existing land use along the restoration site may provide a constraint to applying best practice riparian planting. We suggest a strategic approach with variable riparian buffer widths, and where possible, the areas of enhanced erosion should be targeted as a priority and given stronger consideration of applying best practice riparian planting standards. Proposed areas for planting are shown on the Planting and Fencing Strategy Map in Appendix 2.

- We recommend a 10 m width of riparian edge planting be undertaken (or wider if possible) to provide additional stability to the stream banks, as well as habitat diversity and biodiversity values. A riparian planting width of 10 m (on each bank) also provides for a level of resilience against pest plant incursion and will reduce maintenance costs in the long-term (i.e., wider riparian buffers of native plants have a greater chance of being self-sustaining with minimal maintenance). Where this width is not practicable, a reduced width of minimum 5 m could be adopted. As the width of planting reduces, so does the erosion mitigation and biodiversity values it provides. It also requires a higher level of ongoing maintenance to keep the area free of pest plants and the natural regeneration of indigenous species is limited (Lewis et al., 2015). A 10 m riparian planting zone is shown on the Planting and Fencing Strategy Map.
- Where banks are vertical and eroding, a planting setback distance of approximately 1 m should be allowed (allow up to 2 m if the banks are undermined or actively slumping). This will minimise the loss of plants from the stream bank edge in the short term (1 to 2 years) and allow for the roots to establish. The areas where setbacks are recommended is shown in the River Restoration map (Appendix 2) based on observed erosion, and the areas shown to be at risk of future erosion based on the river evolution modelling.

- Where banks are currently grassed, are at a gentler grade and appear stable, planting can be undertaken down to the stream edge.
- The inside of the meander bends should be planted with flexible vegetation such as *Carex geminata* or *Cyperus ustulatus*. This will allow high flows to pass through the vegetation, while also providing a roughness element to reduce flow velocity. The rhizomatous growth of species such as *Carex geminata* may also provide for greater mitigation of bank erosion.
- Elsewhere in the riparian margin, we recommend fast growing 'nurse' species and species that are tolerant of dry soil conditions while also providing good mitigation to erosion. Species such as mahoe, mānuka, kānuka, karo, and cabbage tree are appropriate (NRC, 2020). We note that mānuka and kānuka can provide additional economic benefits via honey and oil production (Kaval, 2021).
- Flax should be avoided at the stream edge as it is a heavy plant with a solid mass and wide leaves which often results in erosion around the plant, followed by bank failure into the stream.
- The Tī kōuka/cabbage tree has recently been identified as a native species with a root structure that best enhances stream bank stability (Te Paiaka - Native Root Project) (Kaipara Moana Remediation (2022).
- We recommend that the exotic species (i.e., willows) remain in place for the short term as they are currently providing stabilisation (as well as periodic channel shading and both terrestrial and instream habitat values,). As the riparian planting establishes, the willows can then be drilled and poisoned, with the root ball to remain in place. Root balls stabilise the stream bank and root mats that extend into the stream offer important shelter for invertebrates (e.g., juvenile freshwater crayfish, and fish).

5.3. Fencing

Fencing of the stream banks will prevent stock access to the stream and trampling of the stream edge. If the fences are placed too close to the stream edge, they are at risk of being undermined from stream erosion in the short term as vegetation establishes. The Resource Management (Stock Exclusion) Regulations (2020) and Northland Regional Council Plan Rule C8.1.2 state that fences are to be set back a minimum of 3 m from the edge of the stream at its annual full flow.

The following should be considered when developing fencing plans (refer to Planting and Fencing Strategy Map in Appendix 2):

- Where possible, fences should be placed on the crest of terraces and outside of the floodplain (represented by the valley bottom on Geomorphology Features map). The terraces are less susceptible to erosion than the valley fill and fences should be placed to meet the requirements of NRC, or be located at the crest of the terrace, whichever is the greater distance.
- Where riparian planting is undertaken, the fences should be placed of the landward side of the planting. The fence should be placed at least 1 m from the edge of the planting to allow space for the vegetation to grow and minimise grazing from stock.
- In areas where planting does not take place, a minimum set back distance of 5 m is recommended in areas of active bank slumping and erosion.. This includes the outer banks of meander bends, the inside of meander bends on the point bar, and banks which are actively slumping, particularly on the downstream edges.
- In areas which are currently stable, and are not planted, such as where no active erosion is occurring, we recommend a set-back distance of 3 m minimum from the edge of the stream.

- Fences in floodplains trap debris during high flows which can result in damage to the fences as well as diversion of flow which may exacerbate erosion. Where possible, fences should be located above the active floodplain.
- Areas of concentrated overland flow or minor channelised drainage channels can act as 'hot spot' pathways for nutrients and contaminants to enter the waterway. It is recommended that these areas are identified (e.g., using an Overland Flow Path model supported by on the ground assessment) and the fencing is set-back further from the stream in these areas to provide a greater level of filtration of contaminants.

Fording of the river by stock and vehicles is causing localised areas of increased erosion. To enable stock movement across the river and prevent stream bank erosion, single span bridges (a bridge that spans across the watercourse without any central piers in the water for support) would be the most effective solution, however, these are likely cost prohibitive. Culverts can constrain flow and alter the flow dynamics, often causing enhanced erosion on the downstream side. Given the site has high susceptibility to channel erosion, even the use of large, embedded culverts which enclose the channel bed and banks are not recommend.

To minimise the erosion caused by stock and vehicles at stream crossings, we recommend that measures be taken to manage their use. This includes:

  - Managing stock movement between paddocks to reduce the number of times stock cross the river;
  - Reducing the number of crossings of the fords by vehicles;
  - Fencing of fords and ensuring gates are closed at all times so stock cannot access the river unless they are being moved between paddocks;
  - Ensure that stock have access to a robust and reliable reticulated water supply so they do not need to access the river for drinking water.

5.4. Improving Biodiversity

The Peria River has habitat diversity with riffles and runs, pools, shallow sand and gravel bars and woody debris, however, these features are not abundant throughout the restoration site. There is also a lack of vegetation along much of the reach which reduces the shading in the stream, the formation of stable undercuts and input of additional woody debris. The banks are eroding which is adding silt and fine sand into the stream. In places, fine sediment fully blankets the stream bed, filling the interstitial spaces between the coarse sediment that would otherwise provide habitat for invertebrates and fish.

If erosion continues, it could impact on habitat quality by:

- Increasing sediment input, smothering the bed in fine sediment.
- Creating a more homogenous system as flow energy changes limit the development of bar and riffle formation and create longer areas of runs.

Riparian planting and reducing erosion will improve the existing biodiversity of the stream and surrounding area. It will provide shade to the stream which helps keep water temperatures low. It will also provide an input of woody debris to the stream which creates instream habitat diversity, as well as adding roughness elements to the stream and floodplain which reduces velocity. It will provide additional cohesion to the stream banks which will reduce erosion in the long-term and the input of fine sediments into the stream where they smother benthic habitat. Riparian planting will also improve the filtering capacity of the riparian margins reducing contaminants such as fine sediments and faecal bacteria entering the watercourse from the adjacent pastoral land use.

No barriers to fish passage were noted within the subject reach, however, natural or artificial barriers may be present within the catchment either up or downstream.

5.5. Cultural, Social, and Climate Change Benefits

The focus of this investigation was to inform recommendations that secure restoration activities from risk of erosion, with consideration of associated biodiversity benefits.

Wide, healthy riparian buffers, however, also offer numerous social and cultural benefits by the inclusion of culturally important species improving the aesthetics of riverine environments and sites accessed for recreational use. Wider plantings can be used to intercept overland flows that carry sediment, associated nutrients (e.g., phosphorus) and faecal bacteria, thus improving the safety and desirability of harvesting mahinga kai downstream (e.g., watercress/wātakirihi, freshwater crayfish/kōura, īnanga). Protection and enhancement of any wetland areas may also support numerous benefits such as flood mitigation, nutrient and sediment removal, and habitat diversity (e.g., mudfish and bird habitat). Advancing the restoration of the river will also increase its long-term resilience to climate change impacts such as extreme weather events (i.e., floods and droughts).

The understanding potential cultural values and how these might be optimised in the detailed planning phase would need to be led by Mana Whenua. The planning would need to balance the optimisation of recreational access, harvesting and other cultural benefits with a better understanding of water quality conditions and risk.

6. Conclusion

The restoration site on the Peria River is actively eroding through natural meandering migration. The river has incised over the geomorphic timeframe though the valley fill to form river terraces. These terraces are now creating a confining margin that limits lateral migration of the contemporary channel across the valley floor. Paleochannels and meander cut offs on the valley floor indicate that the channel has been actively meandering over the geomorphic timescale and reworking the active floodplain surface. Since 1950, there has been a gradual extension of the meander bends and downstream adjustment of the channel.

River evolution modelling indicates that the natural downstream meander migration pattern will continue to occur with enhanced erosion on the outside of meander bends, and deposition on the inside of meander bends. The rate of erosion has likely increased following forest clearance, and the planting of the banks will reduce the rate of erosion by providing additional cohesion to the stream bank. However, it will take time for planting to establish and in the short term, on-going erosion of the stream banks will occur. Even after the establishment of vegetation, the natural meander migration pattern will continue, albeit at a reduced rate. Regardless, planting will provide additional benefits such as shading, filtering of sediment and nutrients, and an input of woody debris which creates instream habitat diversity improving biodiversity and water quality. Fencing will also assist with reducing anthropogenic erosion due to stock access to the stream banks.

Considering the above we recommend the following as key aspects of the remediation strategy:

- Riparian buffer planting of 10 m width where possible with fencing on the landward side offset by 1 m to reduce stock grazing while plants are establishing.
- Where 10 m plantings are not practicable, we recommend strategically varying planting widths (down to a minimum of 5 m) to prioritise wider plantings at areas of active erosion (allowing 1-2 m planting setbacks from the stream), and at overland flow paths (see Appendix 2 Plan and Fencing Strategy Map).
- Fences along the crest of terraces and outside the floodplain are also recommended for their long-term benefits, and the reduction of losses due to flood damage.
- Where banks are currently grassed, gently graded and stable, planting can be undertaken down to the stream edge with minimal setbacks and selection of suitable plant species.
- Where planting does not take place, fencing should be located at least 5 m from the stream edge in areas of active bank erosion, and 3 m from the stream edge in stable areas.
- Stock movement between paddocks should be managed to minimise erosion at fords and prevent stream access by stock. Access to a robust and reliable reticulated water supply should be provided in paddocks so stock do not need to access the river for drinking water.
- Riparian plantings can include native species that provide economic and cultural benefits (e.g., mānuka and kānuka for honey and oil, plus flaxes for weaving).
- Flaxes should not be planted close to the waterways as they stimulate erosion.

The next step is to prepare detailed planting and fencing plans which take account of the areas of active erosion and the long-term trajectory of the Peria River. Consideration should also be given to how restoration of the site can tie into the overall objectives of the Ngā Awa programme and increase biodiversity in the whole of the catchment.

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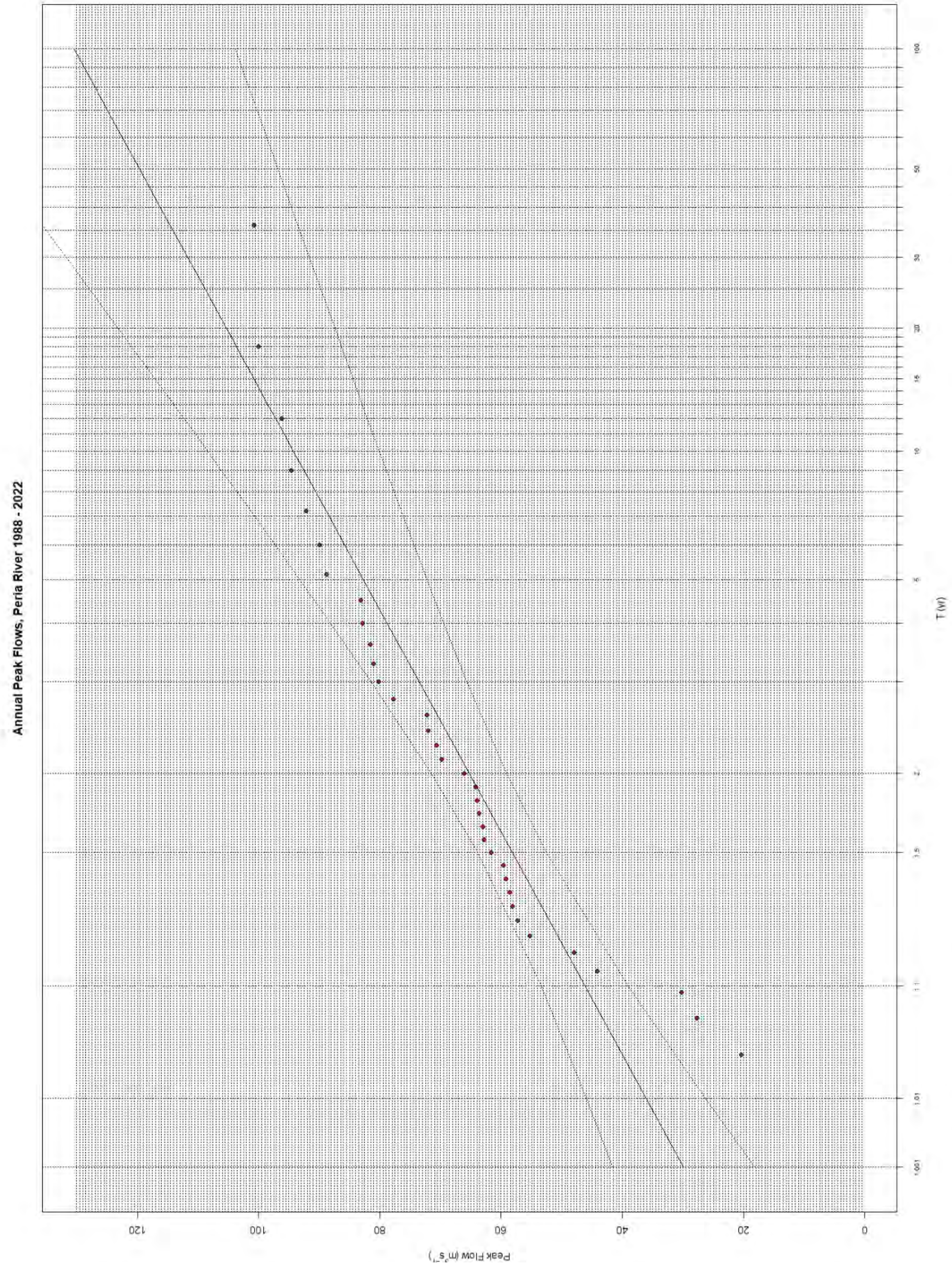
Appendix 1 Gumbel Analysis

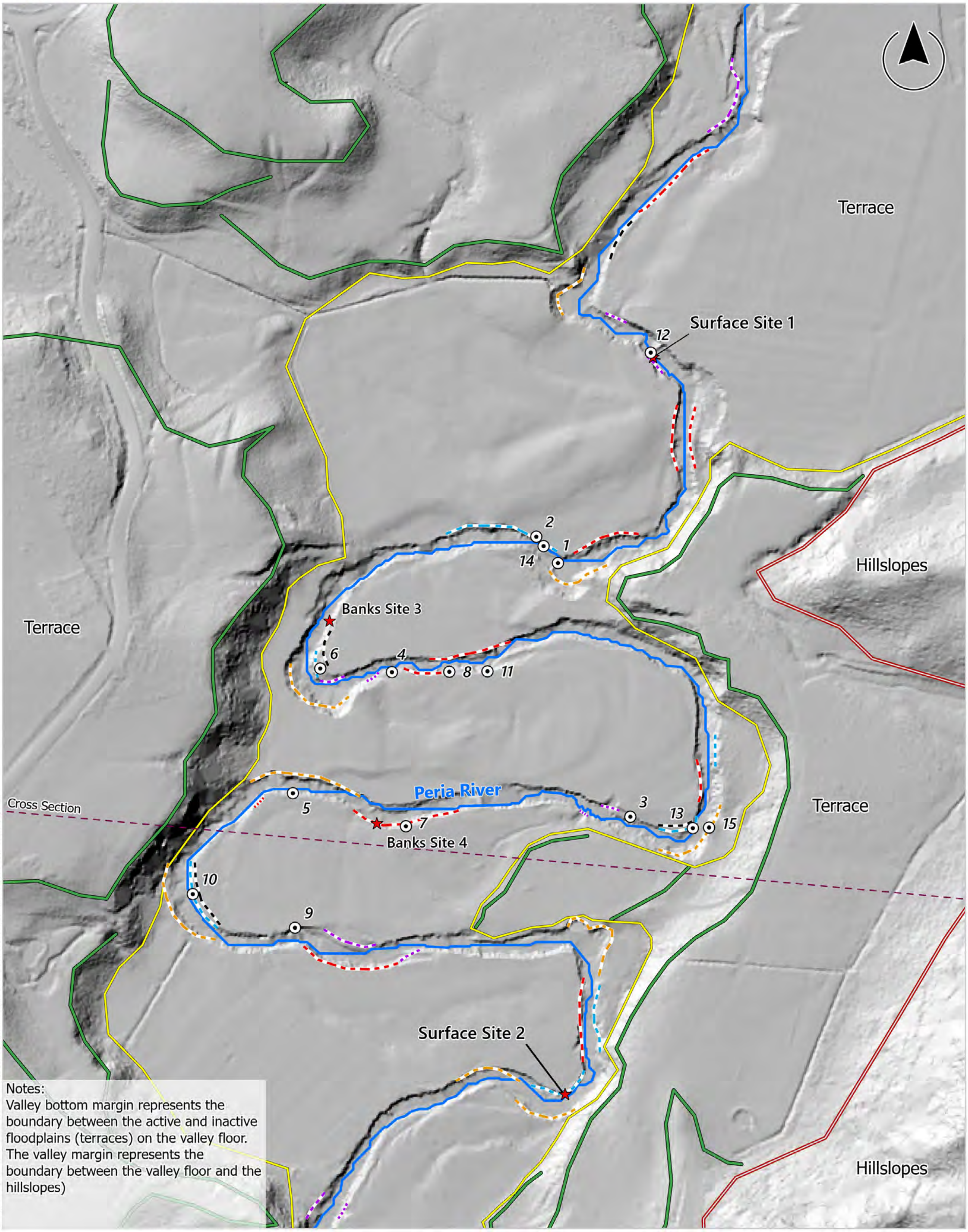


Appendix 2 Maps

Geomorphic Features Map
Relative Elevation Model Map
River Evolutionary Trajectory Map 1950 - 2071
Long-term River Evolutionary Trajectory Map
Plant and Fencing Strategy Map

PERIA RIVER - GEOMORPHIC FEATURES

MORPHUM environmental



Notes:
Valley bottom margin represents the boundary between the active and inactive floodplains (terraces) on the valley floor. The valley margin represents the boundary between the valley floor and the hillslopes)

Z:\Projects\Government\DOC\P03887 Doubtless Bay Geomorphology\GIS\ArcPro\P03887 Project Map Layout: Geomorphology Map

★ Sediment Sampling Sites
⊙ Photo Points
— Stream
— Terrace
— Valley Bottom Margin
═ Valley Margin
- - Cross Section

Bank Erosion

ErosionType
- - Bank Slumping
- - Farm Track
- - Fluvial Erosion
- - Outerbank Erosion
- - Stock Erosion

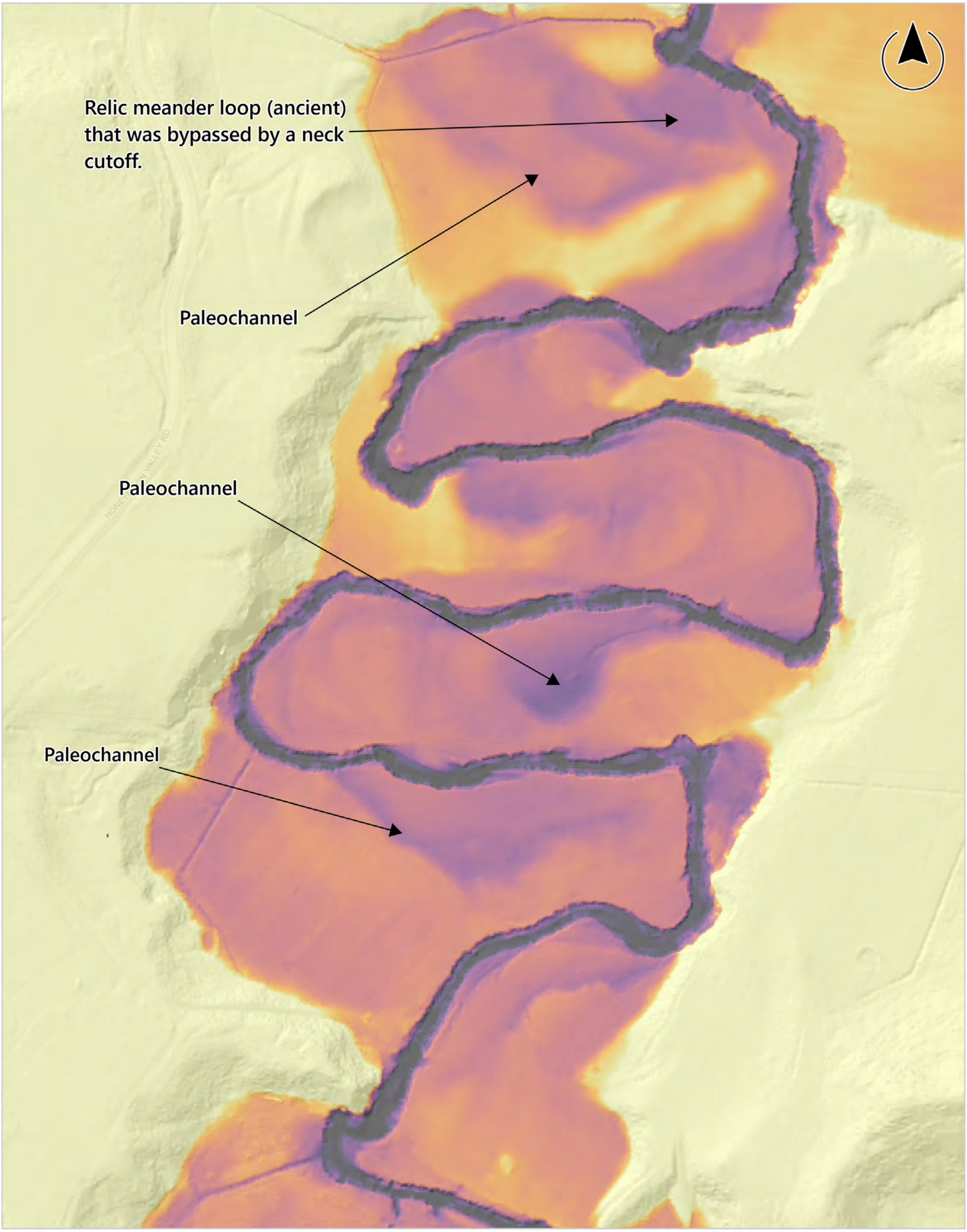
DEM
255
0

Client DEPARTMENT OF CONSERVATION
Project **PERIA RIVER GEOMORPHOLOGY**

0 50 100 m

Project no	P03887
Date	03 Mar 2023
Drawn	PZ
Approved	JM

PERIA RIVER - RELATIVE ELEVATION MODEL



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Peria REM

4.5 m

0 m

Note: 'Relative' elevation is relative to the wetted river bank elevation in the LiDAR dataset

Client DEPARTMENT OF CONSERVATION

Project **PERIA RIVER GEOMORPHOLOGY**

0 50 100 m

Project no. P03887

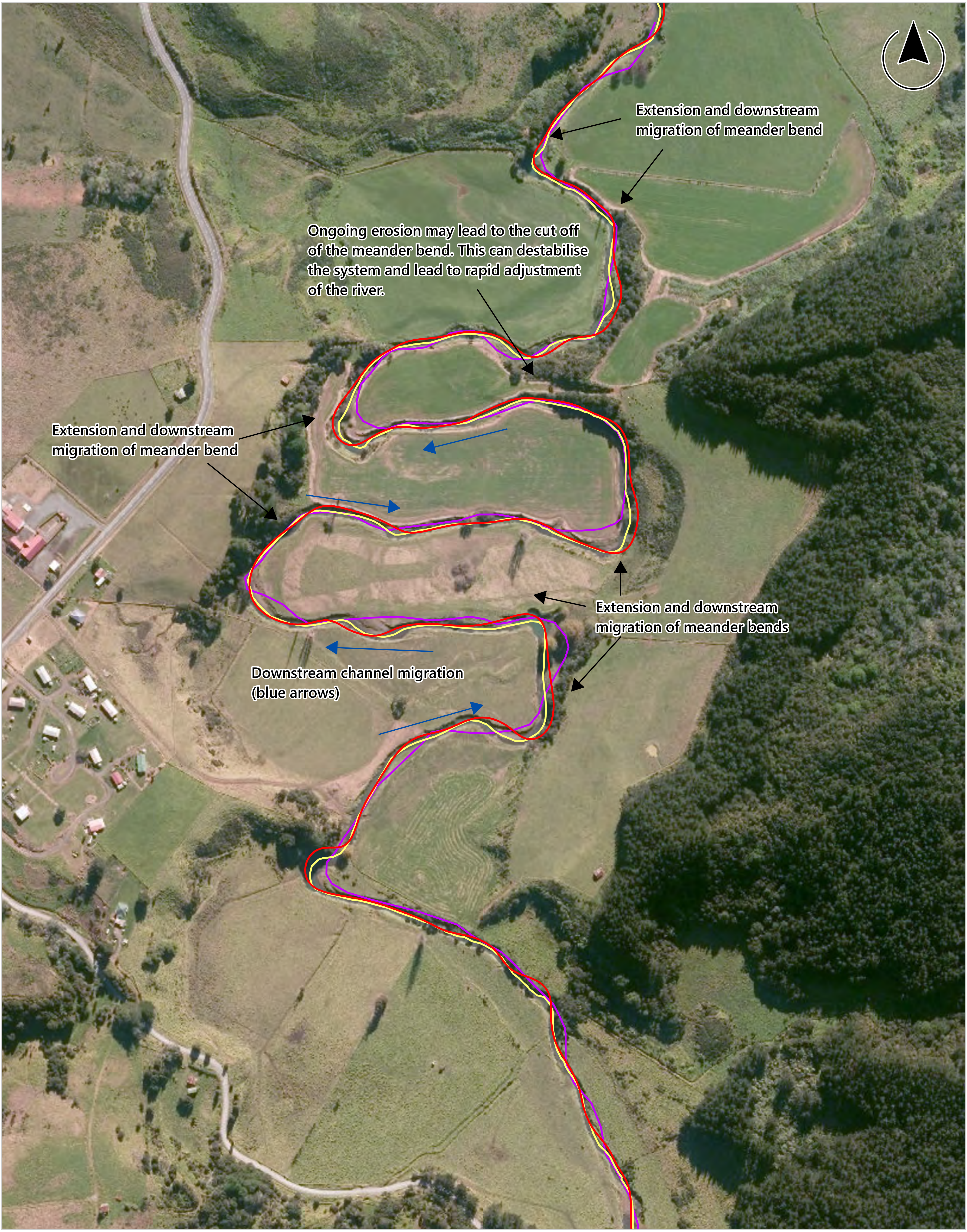
Date 03 Mar 2023

Drawn PZ

Approved JM

PERIA RIVER - RIVER EVOLUTIONARY TRAJECTORY 1950 - 2071

MORPHUM environmental



🟥 2071 Projected Centreline
🟨 2021 Centreline
🟪 1950 Centreline

Client DEPARTMENT OF CONSERVATION
Project **PERIA RIVER GEOMORPHOLOGY**

0 100 200 m

Project no.	P03887
Date	03 Mar 2023
Drawn	PZ
Approved	JM

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PERIA RIVER - LONG-TERM RIVER EVOLUTIONARY TRAJECTORY

MORPHUM environmental

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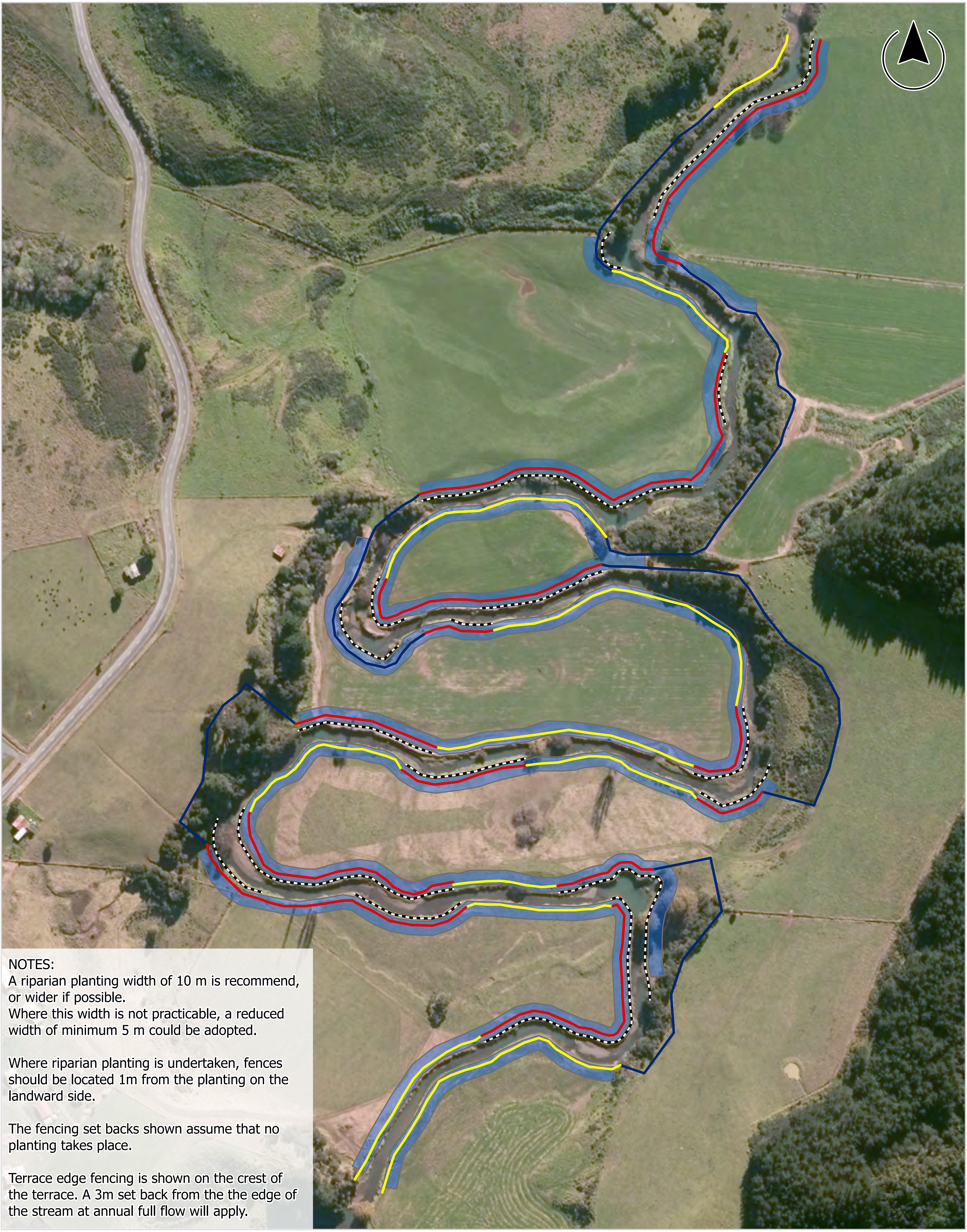
- - - Long-term evolutionary trajectory
━ 2071 Projected Centreline - higher rate of erosion
━ 2021 Centreline

Client DEPARTMENT OF CONSERVATION
Project **PERIA RIVER GEOMORPHOLOGY**

0 100 200 m

Project no.	P03887
Date	10 Apr 2023
Drawn	PZ
Approved	JM

PERIA RIVER - PLANTING AND FENCING STRATEGY



NOTES:
A riparian planting width of 10 m is recommend, or wider if possible.
Where this width is not practicable, a reduced width of minimum 5 m could be adopted.

Where riparian planting is undertaken, fences should be located 1m from the planting on the landward side.

The fencing set backs shown assume that no planting takes place.

Terrace edge fencing is shown on the crest of the terrace. A 3m set back from the the edge of the stream at annual full flow will apply.

Fencing

Set Back Distance

🟨 3m

🟥 5m

🟦 Terrace Edge

▪▪▪ Planting Set back

▨ Planting - 10m width

Client DEPARTMENT OF CONSERVATION
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0 50 100 m

Project no.	P03887
Date	03 Mar 2023
Drawn	PZ
Approved	JM

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