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River styles assessment of the Waipā river catchment, Waikato, New Zealand

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River Styles Assessment of the Waipā River Catchment, Waikato, New Zealand

Prepared for Waikato Regional Council

July 2020

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Executive Summary

Waikato Regional Council contracted the joint venture of Aerialsmiths New Zealand Ltd, Hydrobiology Qld Pty Ltd and The University of Auckland to finalise a River Styles assessment of the Waipā River catchment. This study uses the River Styles Framework (Brierley & Fryirs, 2005) to present a coherent overview of the controls on river adjustment to support geomorphologically-informed appraisals of targeted river management and restoration strategies. The assessment builds on an initial River Styles assessment carried out by Wheeler (2019) and valley confinement assessment by Marson (2019). The study focuses on the main stem of the Waipā River and five of its sub-catchments: the Moakurarua Stream (228 km^2), the Mangapū River (445 km^2), the Upper Waipā River (458 km^2), the Pūniu River (561 km^2), and the Mangapiko River (307 km^2). Many of these areas contain priority zones that have been outlined in the Waikato and Waipā Restoration Strategy (Neilson et al., 2018). This report assesses the regional and catchment setting, identifies and maps the diversity of River Styles, and interprets controls on river character and behaviour. The major findings of the assessment include:

- A total of 45 River Styles were identified throughout the Waipā River catchment (Figure 4.12).
- Past geological history and anthropogenic activities have left a strong imprint on the river systems throughout the catchment, dictating the capacity for contemporary geomorphic adjustment in many locations. Each sub-catchment has distinctive characteristics. River diversity is largely a product of past volcanic activity, sedimentary responses, the evolution of the Waikato River Fan, and/or anthropogenic activities that have locally modified channels and their capacity to adjust.
- Most lower reaches within the Waipā River catchment flow within constraints imposed by terraces which were created as a result of long-term incision through Late Pleistocene deposits. Upper reaches are primarily dominated by bedrock margins, the properties of which vary between sub-catchments due to the wide range of landscape factors.
- In general, only relatively short reaches situated in laterally unconfined zones between these upper and lower zones have significant capacity for adjustment and are considered moderate to high sensitivity (in geomorphic terms). However, many of these reaches have been subject to anthropogenic modification in an effort to limit their capacity to adjust and reduce flood risk. Most of the studied reaches are either partly or fully confined (Figure 4.1) and have very low capacity for geomorphic adjustment.
- Only ~3% of river courses in the Waipā catchment were found to have significant capacity for geomorphic adjustment (Section 6.2). Some of the most sensitive reaches include the lower portion of the Upper Waipā River (upstream of Ōtorohanga), the lower Mangatutu Stream, the confluence zone between the Mangawhitikau Stream and Mangapū River, and a mid-reach of the Mangaohoi Stream (Figure 6.1).

In summary, unlike many other river systems in New Zealand, the Waipā Catchment is comprised primarily of geomorphologically resilient rivers, with only localised areas that are sensitive to change. Given the limited geomorphic responses to catchment disturbances in recent decades, off-site impacts are relatively insignificant other than the enhanced conveyance of fine-grained sediments as suspended load materials. Findings from this study can support cost-effective approaches to proactive river management and rehabilitation. For example, the report identifies sensitive reaches that are prone to bank erosion and lateral adjustment. Such reaches are ideally suited for freedom space initiatives that support diverse habitat creation. Also, analysis of River Styles and their catchment-scale patterns can support riparian planting initiatives to reduce suspended sediments in the Waipā River.

Section 1: Introduction

1.1 Aim

Waikato Regional Council contracted the joint venture of Aerialsmiths New Zealand Ltd, Hydrobiology Qld Pty Ltd and The University of Auckland to finalise a River Styles assessment of the Waipā River catchment, the outcomes of which can inform river management decisions within the catchment. This report applies Stage One of the River Styles Framework to undertake a geomorphic assessment of the Waipā River Catchment (3093 km^2).

The River Styles Framework provides a coherent set of procedures with which to integrate a catchment-scale geomorphic understanding of river forms, processes, and linkages, which can be used to describe and explain the distribution of river forms and processes and predict likely future river behaviour (Brierley & Fryirs, 2005). This assessment covers Stage One of the River Styles Framework in detail, highlighting some implications for management applications. Stage One includes an assessment of the regional and catchment setting controls acting on each sub-catchment, defining and mapping the diversity of River Styles within each sub-catchment and interpreting the controls of river character and behaviour.

1.2 Study Area

The study extent is restricted to the main Waipā River channel and all fifth-order sub-catchments greater than 200 km^2 (Figure 1.1). All fourth-order streams and above within each of these sub-catchments are included. The study stream network also extends up the longest flow path to the headwaters of each fourth-order stream to ensure a reasonable number of lower-order streams are represented. This study area aligns with priority zones outlined in the 2018 Waikato and Waipā Restoration Strategy (Neilson et al., 2018).

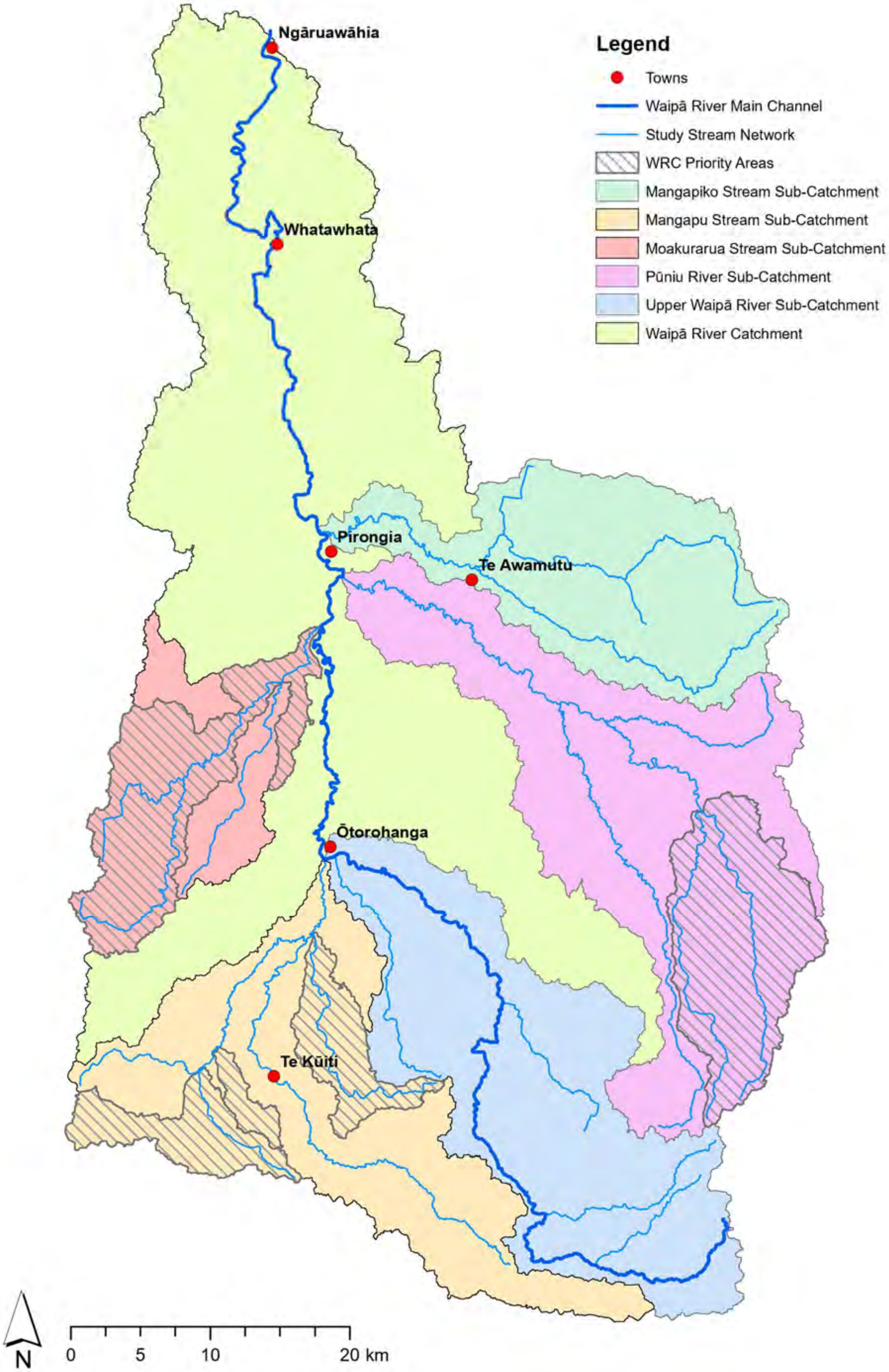

Figure 1.1. Map showing the studied sub-catchments within the wider Waipā Catchment area (MfE, 2010b, 2010a, 2013). Sediment and erosion priority areas, as highlighted in the Waikato and Waipā River Restoration Strategy (Neilson et al., 2018), are also shown.

1.3 Report Structure

The report is structured into the following sections:

- Section 2 – Regional Setting, giving context to the River Styles identified within the sub-catchments
- Section 3 – Methods used to characterise and identify the River Styles in each catchment
- Section 4 – Downstream patterns of River Styles are presented
- Section 5 – Controls on River Styles, providing a broad overview of the imposed and flux boundary conditions which influence the identified River Styles
- Section 6 – Implications of this study
- Section 7 – Concluding comment

Finally, Appendix A summarises the identified River Styles in a table format, with proformas of each River Style presented in Appendix B.

Section 2: Regional Setting

2.1 Introduction

The Waikato region covers much of New Zealand's central North Island (~25,000 km^2) and encompasses approximately 44, 000 kilometres of waterways (Hill, 2011). The Waipā River is a sixth-order river system and is the largest tributary to the Waikato River (Figure 2.1). The headwaters of the Waipā River originate in the Rangitoto Range, east of Te Kūiti and flow northwards through the towns of Ōtorohanga, Pirongia and Whatawhata, before joining the Waikato River at its confluence in Ngāruawāhia (Figure 2.2). Covering approximately 3092 km^2, the Waipā River catchment contains approximately 4825 km of mapped channels (Neilson et al., 2018).

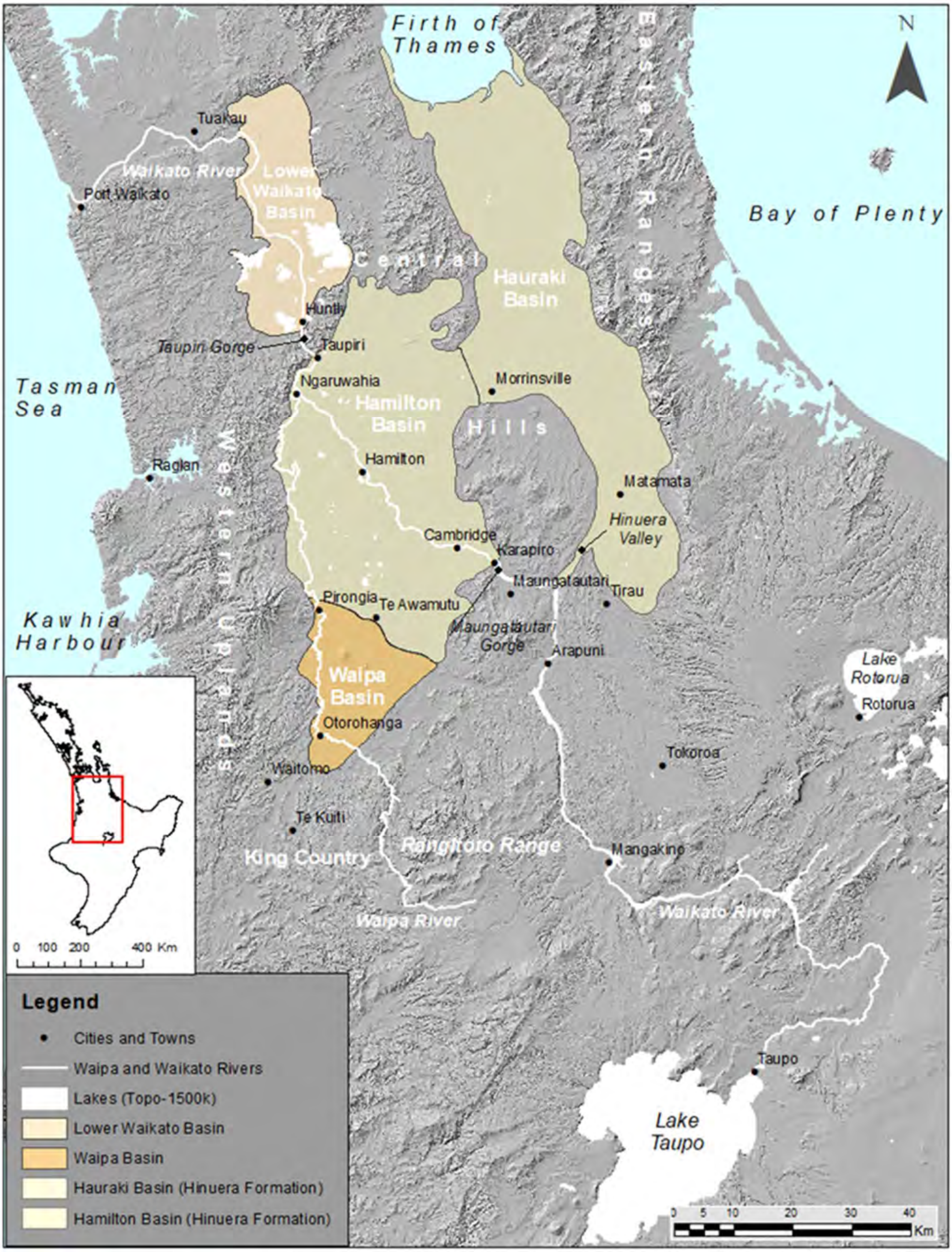

Figure 2.1. The extent of the Waikato and Waipā Rivers in the Central North Island of New Zealand and their corresponding Basin formations (Edbrooke, 2005; Manville & Wilson, 2004; McCraw, 2011).

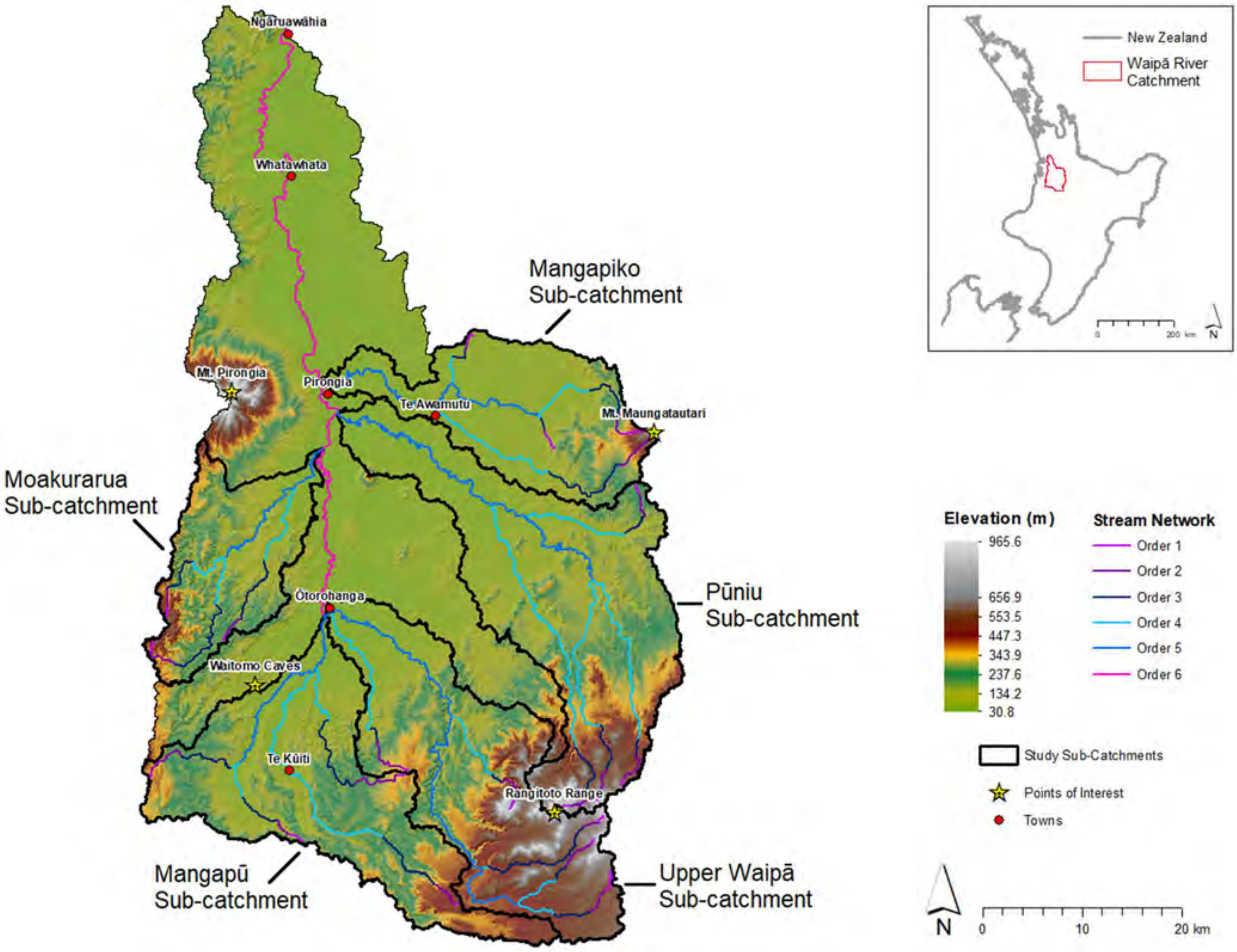

Figure 2.2. The Waipā River catchment, sub-catchments and river channel stream order network analysed in this study. Main towns and key points of interest are also shown.

2.2 Climate and Flood History

The Waipā Catchment receives approximately 1100-2200 mm of rainfall per year (Figure 2.3), the distribution of which is influenced by the topography and prevailing winds (Chappell, 2014). With a predominantly westerly to north-westerly wind flow, the elevated land to the west of the catchment captures a higher volume of the annual rainfall in comparison to the central and eastern lowlands. However, heavy rainfall events can occur during storms with long-duration, intense rainfall commonly inducing localised flooding in low-lying areas (Chappell, 2014). The Waipā River and its tributaries have long been vulnerable to flooding (Hoyle, 2013; Munro, 2002). Over the years, this hazard has been reduced in the broader Waikato river systems by the construction of hydroelectric dams and various flood protection structures, such as stopbanks and embankments (primarily within Ōtorohanga and Te Kūiti respectively), flood gates and pump stations (Edbrooke, 2005; Hurst, 1998a, 1998b).

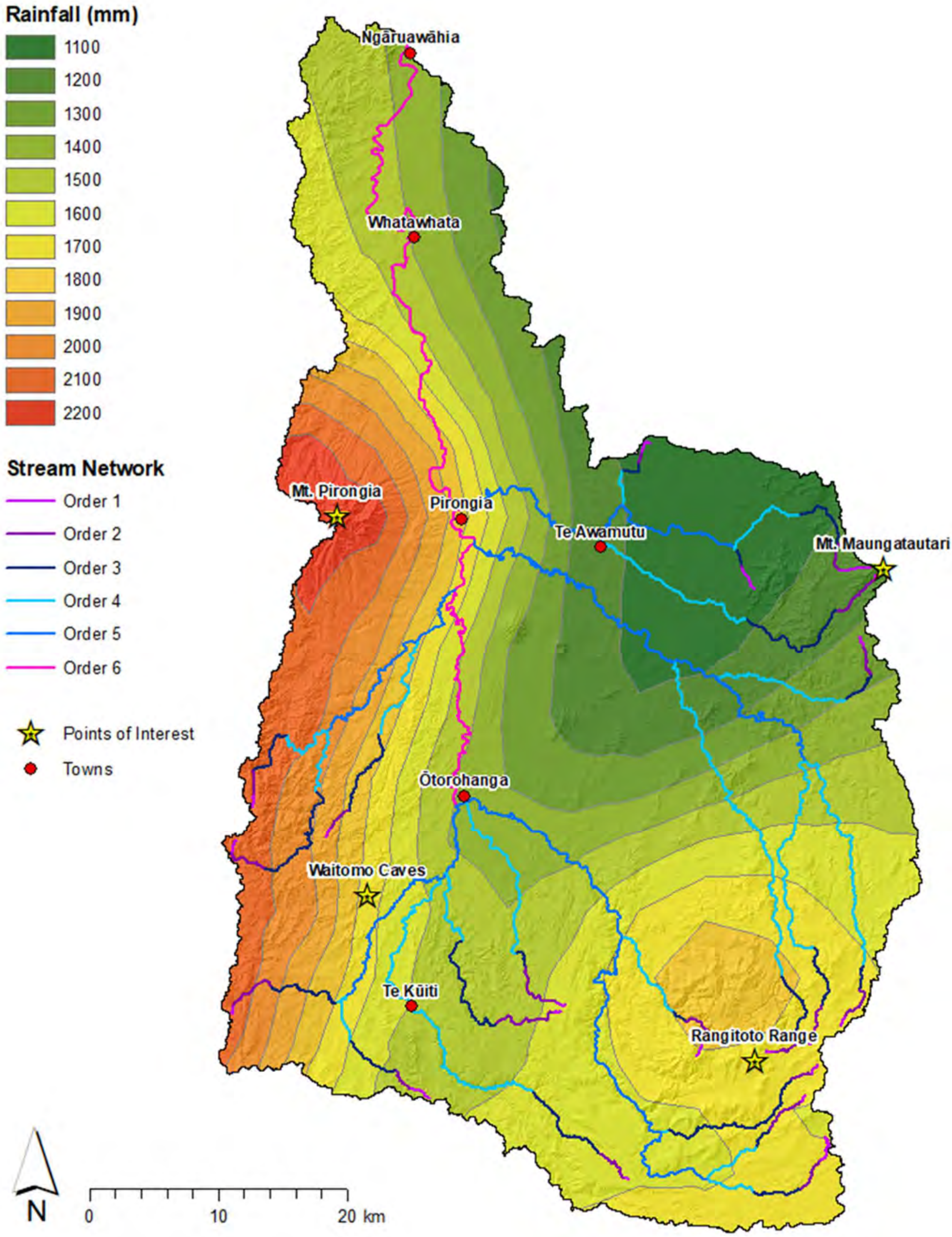

Figure 2.3. Average annual rainfall (1972-2013) across the Waipā River catchment (MfE, 2016a).

2.3 Geology, Lithology and Geomorphic History

The Waikato region lies within the Australian Plate, west of the Australian-Pacific plate boundary, which passes through the West Coast of the South Island and along the Hikurangi Trough off the East Coast of the North

Island (Edbrooke, 2005). Terrestrially, basement rocks of the Australian Plate consist of three fault-bounded tectonostratigraphic terranes that were merged in the late Mesozoic (Mortimer, 2004): Murihiku terrane outcrops in the west, Waipāpa (composite) terrane in the east, and an intervening narrow belt of Dun Mountain-Maitai terrane (Hunt, 1978). A succession of Cretaceous to Holocene aged sedimentary and volcanic rocks overlay these basement rocks (Figure 2.4). Only a small and thin part is represented by Late Eocene to Late Miocene rocks, mainly consisting of marine sedimentary rocks that are locally covered by terrestrial sediments of Pliocene to Holocene age (Edbrooke, 2005). Pliocene to Holocene volcanic activity produced prominent basaltic cones (Pirongia and Karioi volcanoes) southwest of Hamilton, ignimbrites in the east and tephras that mantle much of the region (Edbrooke, 2005).

Overlaying these basement rocks are distinctive patterns of landscape geology units, which vary between the sub-catchments of the Waipā Catchment (Figure 2.4, Table 2.1). The northern part of the Waipā Catchment is characterised by low rolling hills formed predominantly on Quaternary alluvium and distal ignimbrite, with wide intervening valleys filled with volcaniclastic-rich alluvium (Edbrooke, 2005). This alluvium blankets the plain areas (Hinuera surface) and forms part of the Waikato Fan (unconsolidated pumice, clays, silts, sands, tephras, breccias), which covers ~5% of the catchment (Figure 2.4). This alluvium was derived from remobilisation, by the Waikato River, of pyroclastic material following the 26.5 ka Oruanui eruption from Taupō volcano (Manville & Wilson, 2004). Blocked embayments and low areas of the plain in the northeast resulted in the formation of peat mires (~5% of the catchment; Edbrooke, 2005). Higher hills that border the Waipā Basin are formed on weathered basement greywacke, with a discontinuous cover of ignimbrite. Kakepuku volcano and the lower slopes of Pirongia volcano rise from the lowlands in the middle of the catchment, with narrow valleys separated by steep hills and ridges, formed on Tertiary rocks. Much of the catchment (~56%) is draped in ashes older than Taupō pumice, creating distinctive volcanic uplands in the south. The south-western part of the catchment near Waitomo is characterised by uplifted sedimentary rocks of Eocene to Oligocene age, within the Te Kūiti Group (Kear & Schofield, 1959; White & Waterhouse, 1993). Uplifted limestone covers ~5%, while uplifted mudstone ~3% and uplifted sandstone and siltstone consists of ~1.6% of the catchment. Karst landscape formed on upper Te Kūiti Group limestone west of Waitomo is characterised by numerous sinkholes, surrounded by irregular limestone ridges and near-vertical cliffs, commonly with a blocky or knobbly appearance (Orahiri and Ōtorohanga limestone) (Edbrooke, 2005; Kear & Schofield, 1959). The sinkholes convey rainwater into underground cave networks.

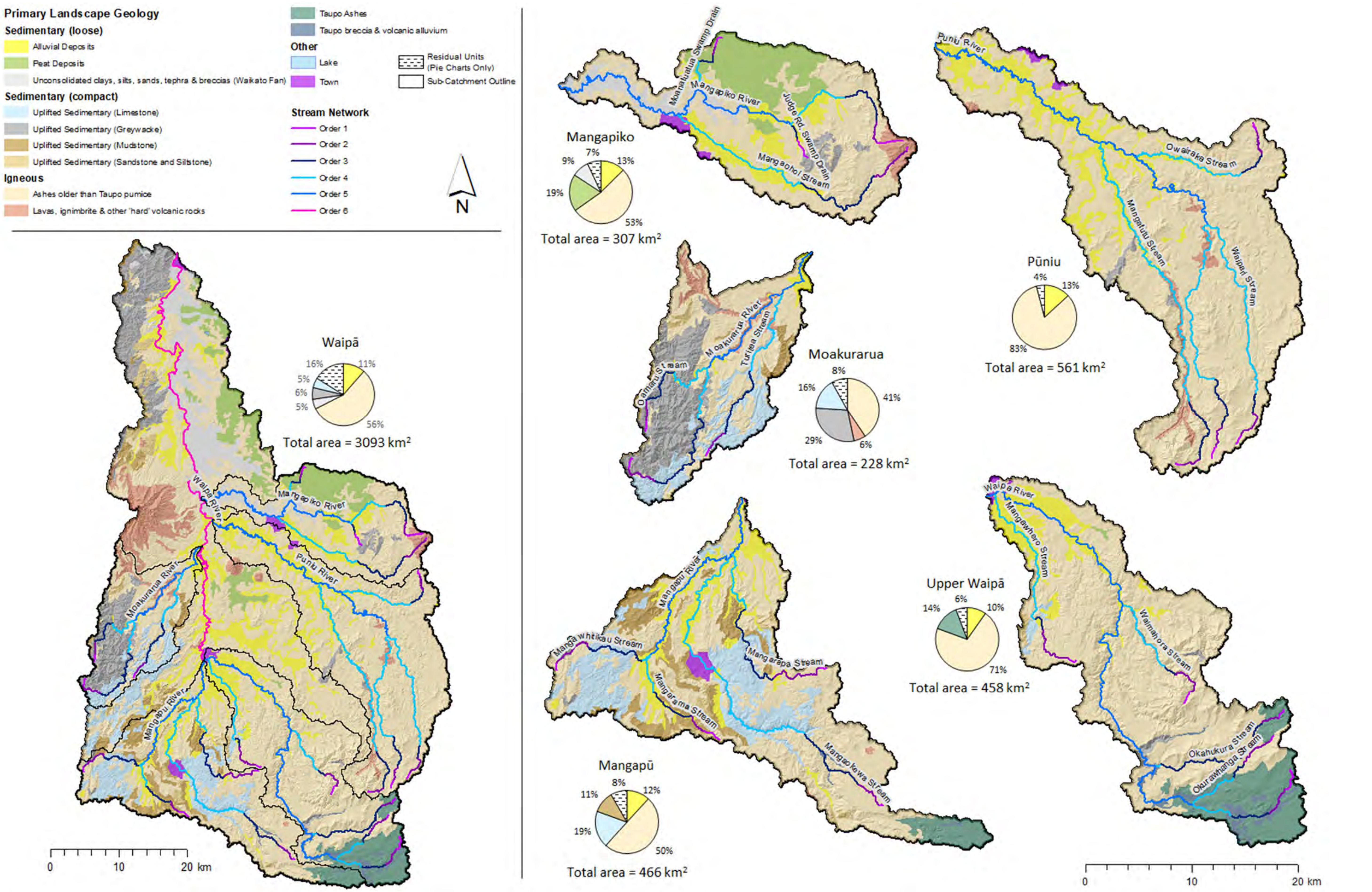

Figure 2.4. Primary landscape geology (landscape unit) maps of the Waipā River catchment and study sub-catchments, with labelled study stream networks. Pie charts show the dominant landscape units in each catchment (>5% of land area) (modified from Landcare Research New Zealand, 2011; Marson, 2019).

Table 2.1. Summary of primary physiographic attributes of study catchments. Note: in this context, “Relief” refers to the maximum vertical distance covered by any single studied stream within each (sub-)catchment.

Catchment	Area (km^2)	Length of Study Streams (km)	Relief (m)	Dominant Lithologies/Landscape Units
Waipā	3093	726	625	Uplifted sedimentary outcrops (upper Western reaches). Old ash/pumice thoughout. Alluvial, peat and unconsolidated, fine-grained material (mid-lower reaches).
Moakurarua	228	81	351	Uplifed greywacke and limestone (upper reaches). Old ash/pumice and localised hard igneous rock (lower reaches).
Mangapū	466	125	403	Uplifted limestone and mudstone (upper-mid reaches). Old ash/pumice and alluvial deposits thoughout.
Upper Waipā	458	141	588	Taupō ashes (upper reaches). Old ash/pumice thoughout. Alluvial deposits (lower reaches).
Pūniu	561	178	625	Old ash/pumice cut down to igneous baserock (upper-mid reaches). Alluvial deposits (mid-lower reaches).
Mangapiko	307	104	487	Old ash/pumice (upper-mid reaches). Alluvial and peat deposits (mid reaches). Unconsolidated, fine-grained material (lower reaches).

Many river systems in the Waipā are influenced by past Quaternary and Holocene changes. This geological history governs much of the contemporary river character and behaviour within the catchment. The Waikato River has switched its course between the Hauraki Plains and the Hamilton Basin several times in the last 100 ka (Manville, 2002; Manville & Wilson, 2004). Avulsion was due to the rapid aggradation of the riverbed as a result of high sediment yields following the large-scale volcanism and contemporaneous climatic deterioration (Manville, 2002). The most recent avulsion occurred at ~19 ka when the river diverted into the Hamilton Basin (McGlone et al., 1978), forming a broad, very low relief fan (Kear et al., 1978). During this fan building phase, the Waikato River avulsed several times across the fan leaving behind several paleochannels, along which some tributaries of the Waipā now flow (McCraw, 1967, 2011). Following the 181 A.D Taupō Eruption, a large breakout flood caused the Waikato River to quickly incise and became entrenched in its present course. This lowered the base level along proximal and medial reaches, causing tributary streams, including the Waipā, to undergo renewed incision as they degraded to the new base level over time, generating paired recessional terraces cut into ignimbrite deposits (Manville, 2002). Once tributary rejuvenation and adjustment to changes in base level ceased, the Waikato River experienced ~1000 years of relative stability following the re-establishment of podocarp forests, before humans settled in this area (Manville & Wilson, 2004).

2.4 Land Use History

Superimposed on geologic landscapes are the different land uses across the Waipā catchment, with much of the land having undergone considerable modification since human settlement. New Zealand has a compressed history of anthropogenic impacts upon landscapes, as it was first settled only 750 years ago (Pawson & Brooking, 2002). Significant human disturbance has occurred in the period since European settlement (~1800 A.D.). By the early 1900s, widespread forest clearance from the coast to well into the hill country by both Māori and Europeans had induced rapid landscape change, with forest coverage decreasing from ~68% to 23% (Ewers et al., 2006). As reported by Glade (2003), land sliding and hillslope erosion were common, particularly in steep hill country comprised of weak lithology. As a result, anthropogenic legacy sediments wield a major influence upon subsequent river channel adjustments (e.g. Kasai, 2006).

However, for parts of the Waipā Catchment, this history is far more compressed and delayed due to the conflict between Māori tribes and between Māori and Europeans. Although some northern parts of the catchment, such as the European town of Alexandra (now Pirongia), had been settled by European missionaries in the early 1800s, the King Country (Te Rohe Pōtae) region (comprising the Ōtorohanga and Waitomo districts and the northern two-thirds of the Ruapehu district) was closed to European settlement until the late 1800s (McLintock, 1966; Pollock, 2015). Although European traders first visited the King Country in the late 1820s and were followed by missionaries in the 1830s, the region was closed to Europeans following the battle of Ōrākau in 1864, with no land confiscated beyond the Aukati (boundary) south of the Pūniu River (Figure 2.5; McLintock, 1966; Pollock, 2015).

Figure 2.5. Map M157: Chapman Map of the Waikato, 1866 (Te Awamutu Museum Trust Board Collection). The Aukati Boundary is shown highlighted in pink (Chapman, 1866).

These lands were largely off-limits to European government and settlers until Ngāti Maniapoto agreed to a survey for the main trunk railway line through Te Rohe Pōtae in 1882 (Pollock, 2015). The railway line, which reached Ōtorohanga and Te Kūiti in 1887 and Taumarunui in 1903, facilitated the opening of the King Country to Pākehā. The first European settlers took up farms in the early 1890s, however, growth did not occur until the early 20th century (McLintock, 1966). Before this European settlement, much of the King Country was covered by extensive conifer-broadleaf forests and was known to Māori as Te Nehe-nehe-nui (The Great Forest; Pollock, 2015). Indeed, much of the Waipā Catchment was dominated by native forest, scrub and tussock (McGlone, 1989). There were also significant wetland areas in the northern areas of the catchment (Figures 2.6 & 2.7). Much of this forest was felled or burned by farmers or cut by sawmillers (Pollock, 2015). Such changes likely induced a legacy of change to the channel adjustment and sediment regimes of streams and rivers in the region.

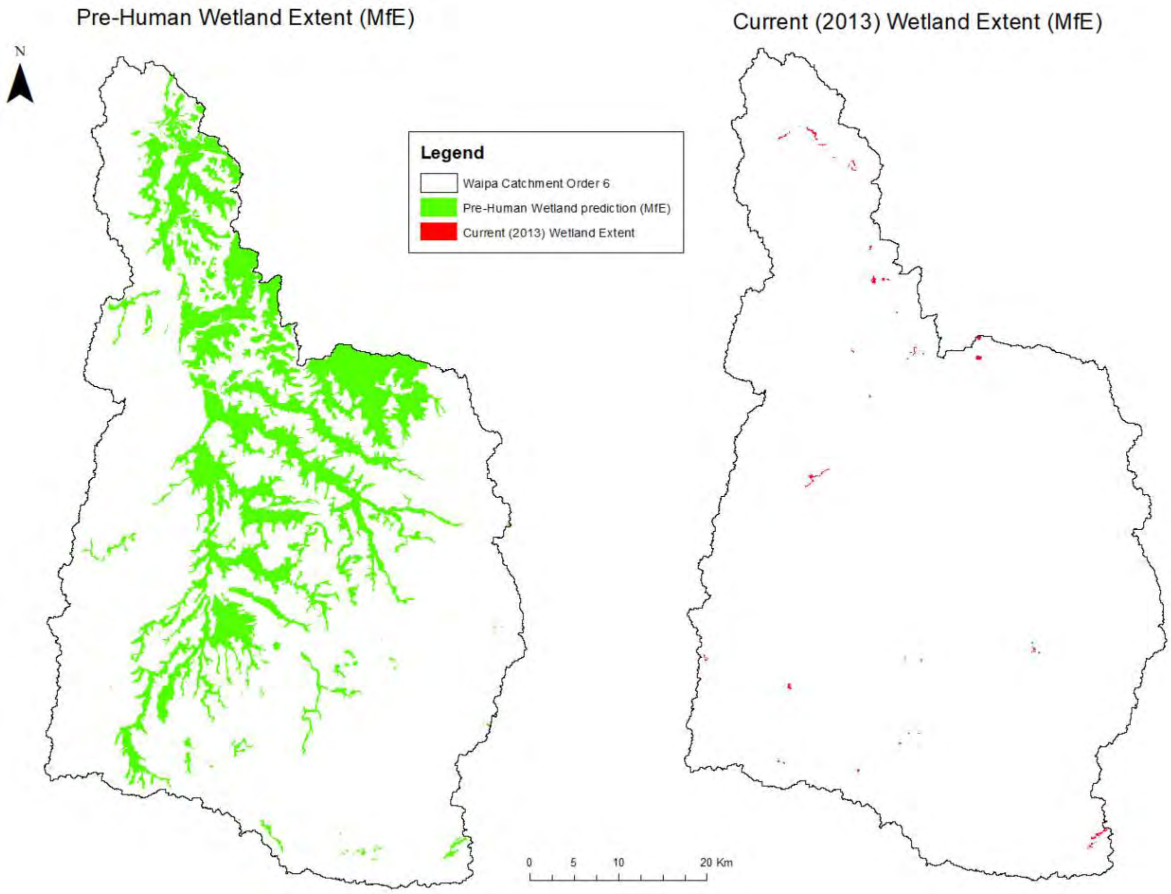

Figure 2.6. Comparison of Wetland extents between Pre-Human settlement and current (2013) coverage for the Waipā Catchment (MfE, 2016b, 2016c).

Contemporary land use in the Waipā Catchment is now dominated by intensified agriculture. Since 1840, almost all native vegetation in low-lying areas has been converted to pasture (WRC, 2012). In addition, almost all significant wetland areas have been drained, leaving behind only small residual pockets of wetland and shallow peat lakes (WRC, 2012). Natural forest now only encompasses ~19% of the catchment, with a further 3% planted forest (post-1990), and the area of wetlands in the Waipā Catchment has decreased by about 99% between pre-human settlement and 2013 (Figure 2.6). Figure 2.8 shows that as of 2013, about 62% of the Waipā Catchment consisted of high producing grassland, and about 12% consisted of low producing grassland. Recent land figures show that agriculture is continuing to intensify in the region, with an increase in stocking rates on existing dairy farms (WRC, 2012; WDC, 2013). Following human settlement, forest clearance caused a local increase in sediment yields which resulted in aggradation along the lower Waikato River (Schofield, 1967). However, recent patterns of fluvial responses are far more complex, due to a combination of imposed landscape inheritance, land use patterns and intensities, and cumulative responses to direct forms of anthropogenic modification (i.e. river management practices).

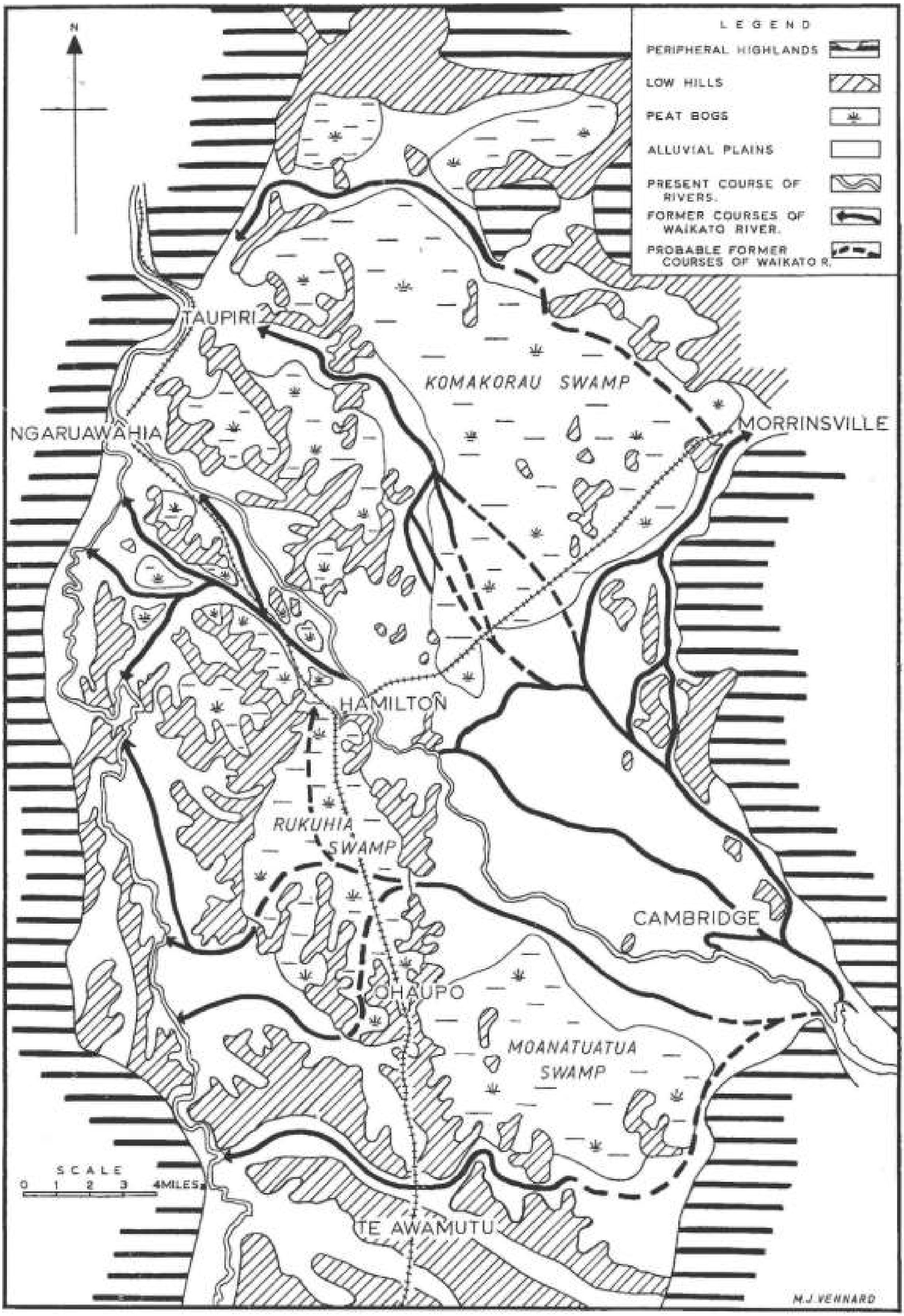

Figure 2.7. Generalised topography and old Waikato River courses of the lower Waipā River catchment. The present-day Waipā River channel can be seen in the left of the drawing, flowing north into Ngāruawāhia (McCraw, 1967).

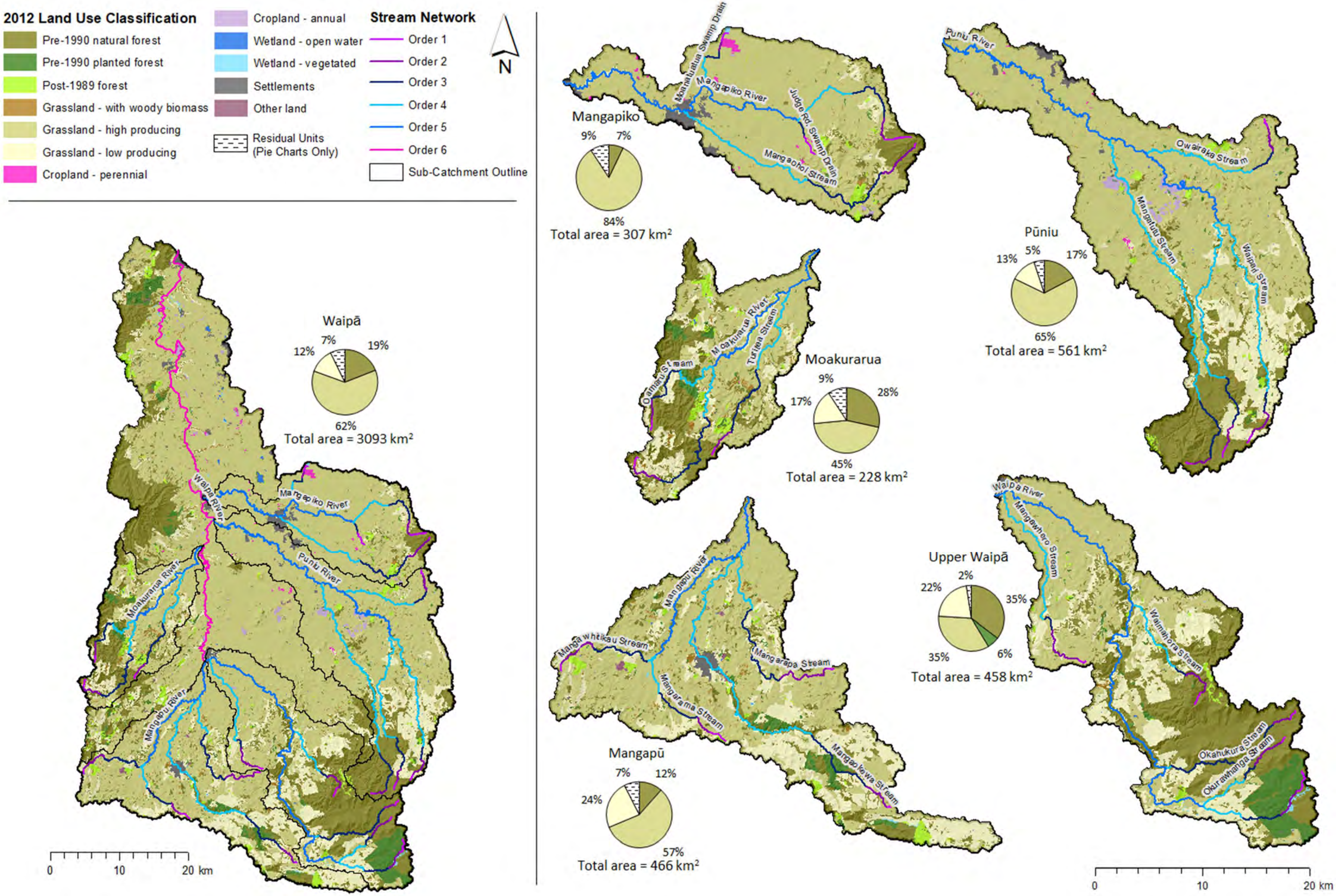

Figure 2.8. Land use maps of the Waipā River catchment and study sub-catchments as of 2012, including labelled study stream networks. Pie charts show the dominant land use units in each catchment (>5% of land area) (MfE, 2019).

2.5 Sediment Regime

Land use change and landscape inheritance exert key boundary controls on the sediment regimes of rivers in the Waipā Catchment, which in turn governs river character, behaviour, and channel adjustment. Sediment production, transfer and deposition have historically been controlled by the geology of the region, with human activities on the land and in the waterways increasingly modifying the sediment regime (Hill, 2011). Therefore, the contemporary sediment regime of the Waipā Catchment largely reflects modification of natural processes under present climate and landscape conditions, including changes in land use, hydro-electric power development on the Waikato River, sand and gravel extraction and channel migration works (Hicks & Hill, 2010).

State of Environment monitoring of soil disturbance and bare soil for the Waikato region in 2002 and 2007 indicated that soil disturbance increased from 10% to 30%, with three-quarters attributed to land use activities and the remaining quarter to natural erosion (Hill, 2011). Along with this hillslope mass movement, streambank erosion is perceived to be a key sediment source in areas of pastoral land use, especially along unfenced banks accessible to stock (WRC, 2012).

Although the upper catchment dominates the sediment yield of the Waipā Catchment by virtue of the high loads it carries during floods, the Mangapū River runs muddier during normal flows, with concentrations up to twice those sampled in the upper Waipā. This is due to the influence of large areas of mudstone in the upper Mangapū catchment (Collier et al., 2010).

Past land use conversion to pasture, involving forest and scrub removal, created large increases in sediment loads, particularly in the basins in the upper Waikato and upper Waipā, which drain Taupō Pumice terrain (Hill, 2011). Therefore, current trends of widespread conversion of exotic forest blocks to intensify dairy farming are likely to induce a repeat phase of high sediment production (Hicks & Hill, 2010).

2.6 Management Interventions

Within the Waipā, many river channels have been highly modified through time, significantly altering their form and behaviour. This anthropogenic imprint sits atop a strong geologic landscape memory, altering geomorphic sensitivity to channel adjustment. Most management works began following the devastating 1958 floods on the Waipā River (Hurst, 1998b). Management works carried out between 1961 and 1966 provided flood protection in Ōtorohanga and Te Kūiti.

Ōtorohanga had developed in low lying land within a meandering loop of the Waipā River, at a confluence zone with the Mangapū River. The town was highly vulnerable to overwhelming flooding during cyclonic storms or when continuous, heavy rainfall occurred in the Waipā Catchment and its tributaries (Hurst, 1998a). As a result of the 1958 flood, the Ōtorohanga Scheme was developed to safely 'control' a flood 50% greater than that of 1958 (Hurst, 1998a), thus able to accommodate a 100-year flood, with 600 mm of freeboard (Munro, 2002).

The scheme included about 2.5 km of channel realignment, construction of pumping stations, gravity outlets, and over 4.5 km of stopbanks, and the installation of a weir to control the bed level of the river at the upstream extent of the stopbanks (Hurst, 1998a; Munro, 2002).

Works in Te Kūiti following the 1958 flood were instigated as the Mangaokewa Stream overtopped its banks through the centre of the town. Management measures included channel straightening and enlargement (excavation), including complete diversion of its bed at the southern end of the town (Hurst, 1998a), and the clearance of the sloping banks above the channel, predominantly on the inside of bends.. These procedures increased the capacity of the stream by 50%, providing a 50-year event protection within Te Kūiti (Hurst, 1998a; Munro, 2002).

The post flood management works also provided protection to about 17,000 ha of previously flood-prone land on the floodplain below Ngāruawāhia in the lower Waikato River valley as part of 'The Lower Waikato – Waipā Control Scheme' (Hurst, 1998a). The scheme incorporated ~150 km of stopbanks, 47 flood gates, 56 pumping stations and several major control structures (Hurst, 1998b; WRC, 2012). Completed in 1983, the scheme also entailed channel straightening, controlled willow clearance and tree planting schemes in headwater areas (Hurst, 1998a).

Section 3: Methods

3.1 River Style Framework: Background

The River Styles Framework provides a coherent set of procedures (stages outlined in Figure 3.1) with which to integrate a catchment-scale geomorphic understanding of river forms, processes, and linkages (Brierley & Fryirs, 2005). Collectively, the application of these principles presents a physical basis with which to describe and explain the distribution of river forms and processes and predict likely future river behaviour and how it may change over time. This spatially and temporally integrative framework appraises contemporary river morphology and formative processes (Stage One) in light of river change, thereby providing critical insights with which to interpret geomorphic river condition (Stage Two). This forms a basis to predict river futures and the potential for geomorphic river recovery (Stage Three). In doing so, the River Styles framework provides a comprehensive geomorphic appraisal of catchments which can guide proactive management schemes (Stage Four).

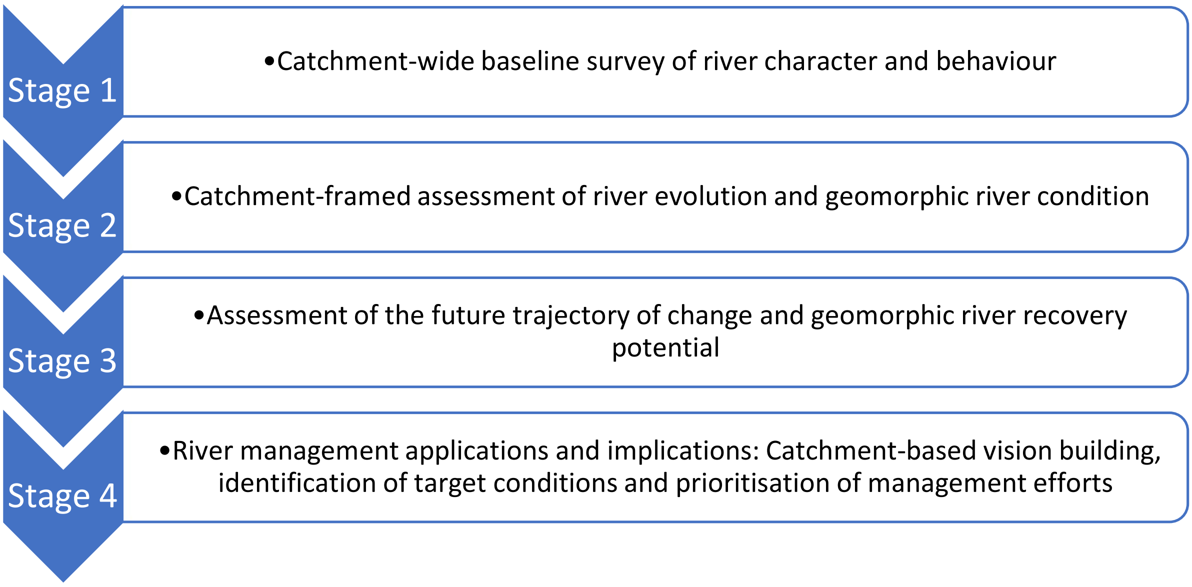

Figure 3.1. Stages and procedures for performing a River Styles Framework assessment of a river catchment (Brierley & Fryirs, 2005).

3.2 River Styles Framework: Stage One

All fourth-order streams and above, extending up the longest flow path to the headwaters of each stream, were analysed throughout the aforementioned Waipā sub-catchments. River Styles were identified according to their valley setting, planform, bed material and assemblage of geomorphic units (Brierley & Fryirs, 2005). The naming convention outlined by Fryirs and Brierley (2018) was applied.

Stage One of the River Styles Framework involves a catchment-wide baseline survey of river character and behaviour (Figure 3.2). It comprises three main steps: assess regional and catchment setting controls, define and map River Styles (analysis of river character and behaviour) and analyse downstream patterns and controls.

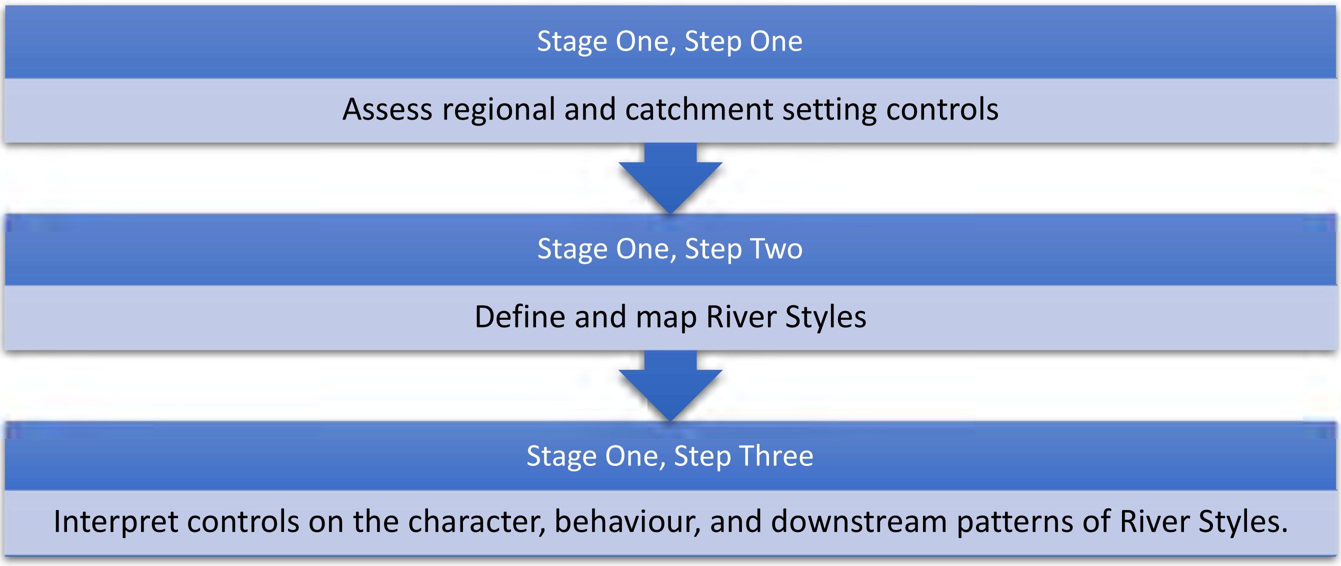

Figure 3.2. The three core steps of Stage One of the River Styles Framework.

3.1.1 Step One - Assess Regional and Catchment Setting Controls

Step one involves background research on regional setting, geology, hydrology, land use history and vegetation associations. This included:

- Landscape units that were identified from a combination of geology datasets (Landcare) and previous landmark surveys (McCraw, 1967, 2011; Schofield, 1965).
- Longitudinal profiles derived using estimated valley slopes along stream polylines extracted from the 8m regional digital elevation model (DEM) (LINZ, 2016) using methods outlined by Jain et al. (2008). This used the flow direction, flow accumulation and interpolate shape tools in ArcMap 10.7.1. The downstream total stream power values (Ω, measured in W m^{-1}) were derived using the following equation:

$$\Omega = y \cdot Q \cdot s$$

  Where y is the specific weight of water multiplied by water density, Q is discharge ($m^3 s^{-1}$) and s is the slope.

- Discharge that was approximated using catchment area, for flows of a 1 in 1-year event or average annual flood recurrence interval. This is calculated using the following equation adapted from McKerchar and Pearson (1990):

$$Q = 1.5\, A^{0.8}$$

  Where A is upstream catchment area measured in km^2.

3.1.2 Step Two - Define and Map River Styles

Step two involved identifying, characterising, and interpreting the behaviour of the myriad of river types, including:

- Preliminary identification of River Styles using the procedural tree in Figure 3.3. Several data sources were used to perform this task, including aerial photography, 1m Regional LiDAR, topographic maps, and Google Earth Imagery (Brierley & Fryirs, 2005).
- Valley confinement assessed using Google Earth and procedures outlined by Fryirs et al. (2016)
- Boundaries and River Styles were adjusted based on field observations (Fryirs & Brierley, 2018). Initial field verification of preliminary mapped River Styles was carried out through multiple field visits from May to October 2018, with final field verifications carried out in February 2020.
- Once finalised, River Styles were differentiated using the naming convention for geomorphic river types by Fryirs and Brierley (2018). This convention uses the same principles of scaffolding to develop both abbreviated and full River Style names. (Figure 3.4).

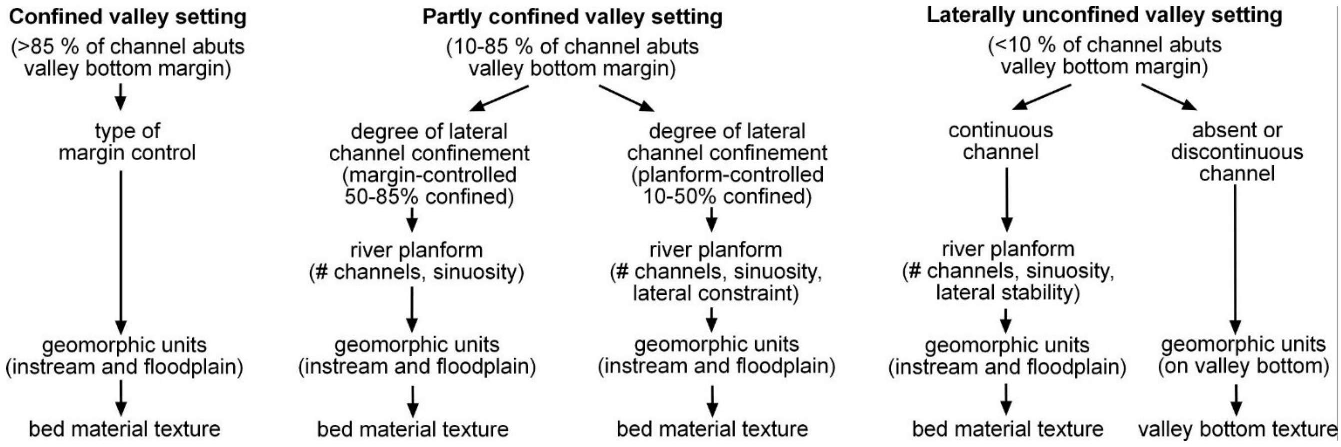

Figure 3.3. Stage One, step one River Styles procedural tree. Hierarchical approach used to identify and differentiate River Styles in the Moakurarua and Mangapū catchments (Brierley & Fryirs, 2005).

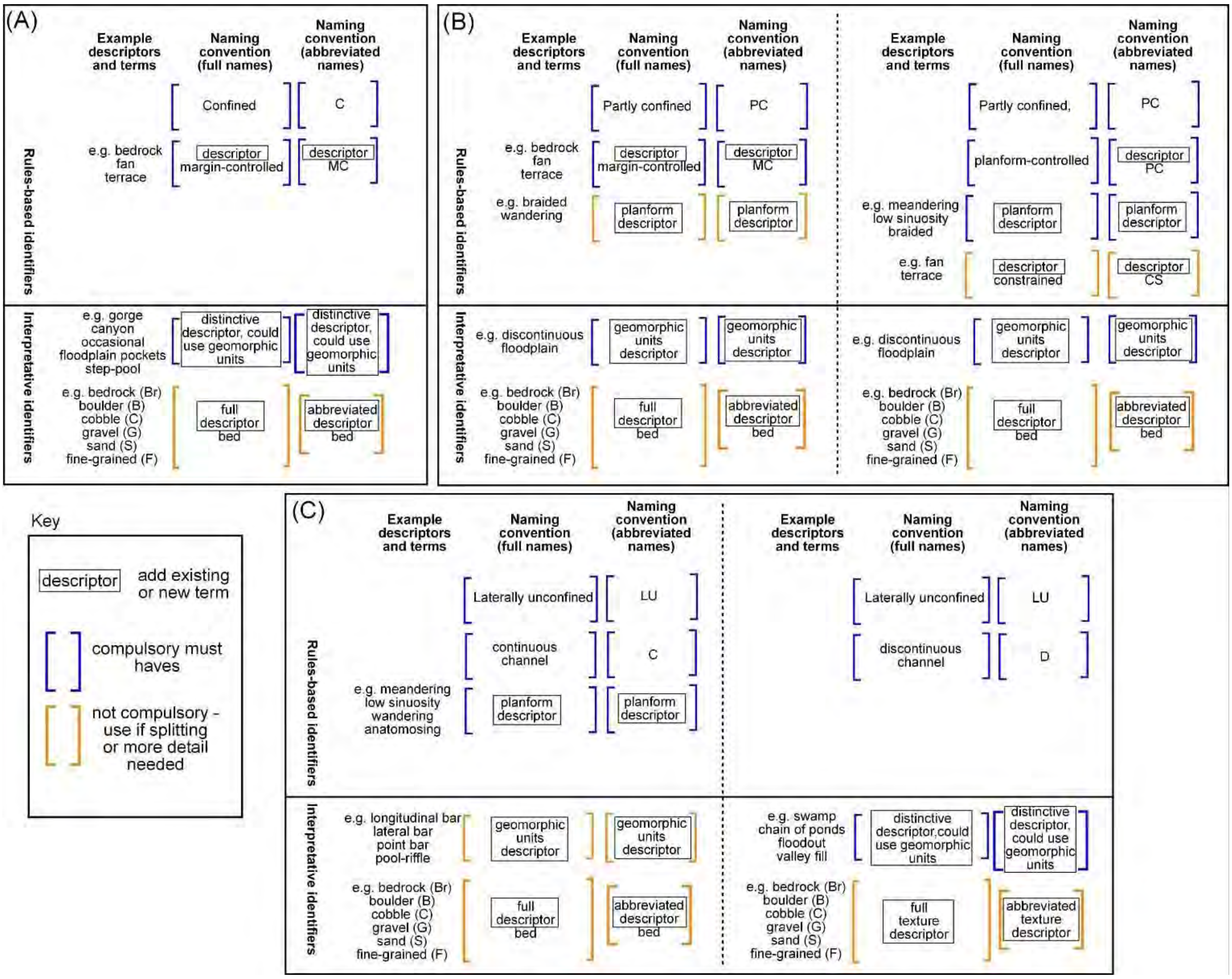

Figure 3.4. The naming convention used for river types (Fryirs & Brierley, 2018). The approach is matched to the River Styles procedural tree (Figure 3.3) and produces full and abbreviated names; A) for confined valley setting, B) for partly confined valley setting and C) for laterally unconfined valley setting.

Primarily, the majority of the above interpretations are made qualitatively by informing geomorphic knowledge and by following the guidelines set out by Brierley & Fryirs (2005). However, it is possible to also quantify some of these variables; techniques we occasionally employed (mainly for confinement and sinuosity) as necessary when certain reaches bordered between two identifiers (Figures 3.5 & 3.6).

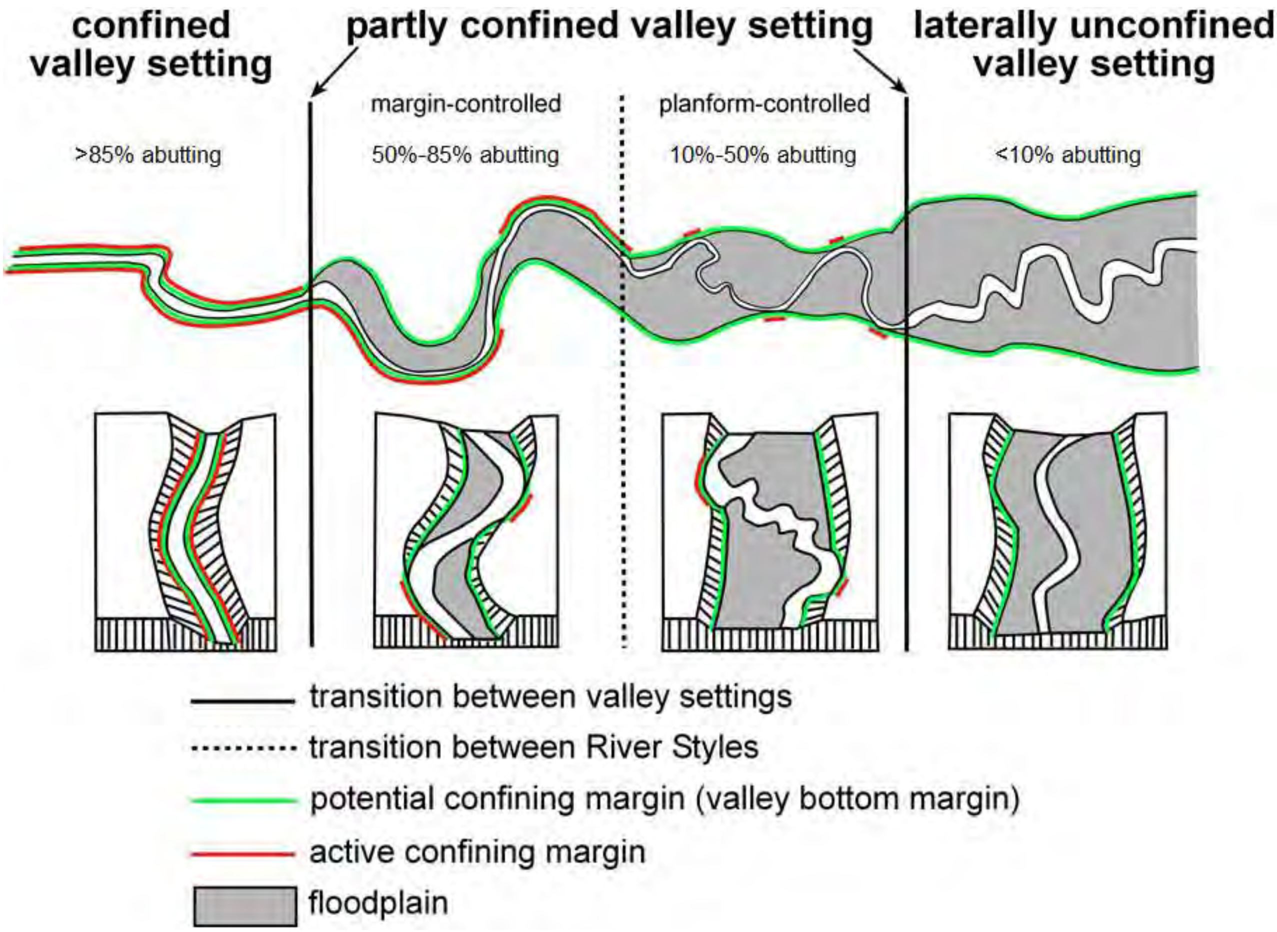

Figure 3.5. Illustration depicting the four categories of valley confinement. Confinement decreases as the length of active channel abutting the valley bottom margin (green) decreases from left to right, resulting in progressively less active confining margin (red). The abutting percentages refer to the percentage of the bankfull channel over a given reach which is abutting the confining margin (O'Brien et al., 2019; Modified from Fryirs & Brierley, 2010).

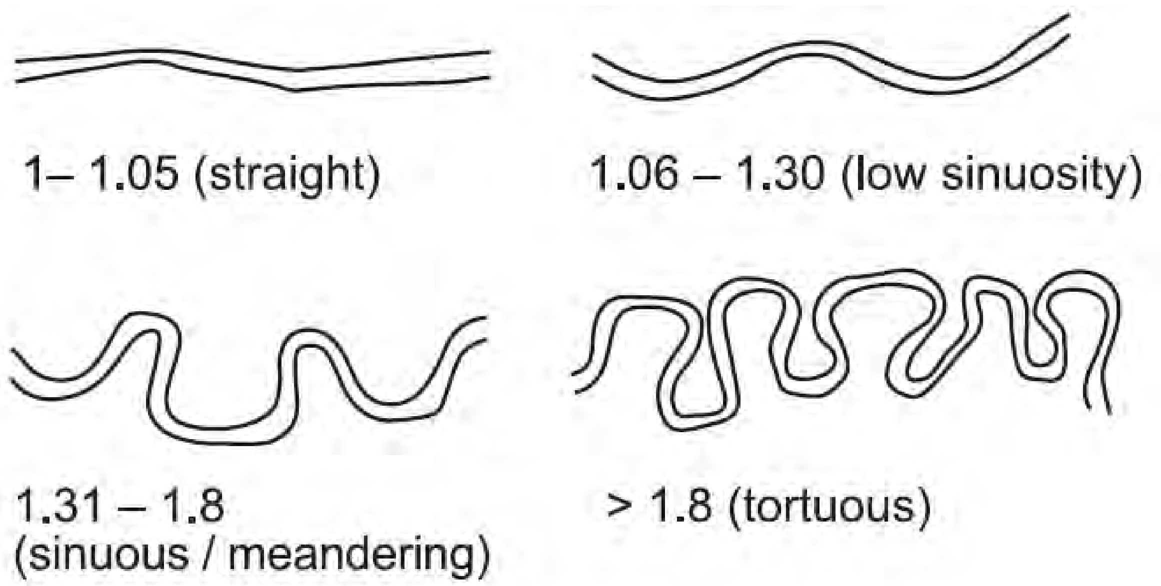

Figure 3.6. Classification of the degree of sinuosity used in analysis of channel planform (Modified from Fryirs & Brierley, 2013).

Confinement is measured as the ratio of active confining margin to potential confining margin for a given reach. Channel sinuosity is measured as the ratio of channel length to valley length for a given reach. Since these values are quantifiable and are dependent upon relatively easily identifiable topographical features, they can be calculated from the results of advanced GIS tools. Marson (2019) previously undertook such GIS analysis within the Waipā River Catchment to calculate catchment-wide confinement measurements by utilising the Valley Bottom Extraction Tool (V-BET) (Gilbert et al., 2016) and the Confinement Tool (O'Brien et al., 2019). These quantifications were used to help determine appropriate identifiers for reaches which bordered between two categories of confinement or sinuosity.

3.1.3 Step Three - Interpret Controls on the Character, Behaviour, and Downstream Patterns of River Styles

Stage One, step three of the River Styles Framework involves the analysis of downstream patterns and controls on rivers. This uses the longitudinal profiles derived in step one as a key tool for analysis and visualisation (Brierley & Fryirs, 2005). This involves:

- The differentiation of river courses that have similar patterns from those that are distinct, by plotting the downstream pattern of river types under the longitudinal profile.
- Analysis of controls conducted by superimposing the sequence of imposed and flux controls, placing river character and behaviour within its catchment-scale context (Brierley & Fryirs, 2005).

This information can form a baseline that can then be used to make forecasts about the geomorphic sensitivity of different river reaches to disturbance.

3.1.3.1 Potential Geomorphic Sensitivity Ranking

Reid and Brierley (2015) developed an approach for assessing the potential sensitivity of different River Styles. Wheeler (2019) built on these methods, applying them to the Waipā River Catchment. An implication of carrying out steps one, two and three of the River Styles Framework is producing the information required for creating potential geomorphic sensitivity rankings. This report further develops Wheeler (2019)'s findings to present potential geomorphic sensitivity rankings for the studied Waipā Catchment watercourses.

As outlined by Brierley and Fryirs (2005), if a channel responds readily and frequently it is considered sensitive and are likely to have high rates of adjustment. If channel responses are negligible and uncommon, the river is considered resilient to change due to their ability to absorb excess energy and minimize the extent of adjustment.

The nested framework developed by Reid and Brierley (2015) classifies the sensitivity of each River Style based on its capacity for adjustment. A similar method was applied in this assessment of the Waipā Catchment. Each

River Style was qualitatively assessed based on its potential range of geomorphic adjustment relative to other types of river (Figure 3.7). Geomorphic sensitivity of each River Style was ranked as High, Medium-High, Medium, Low-Medium, or Low using procedures outlined in Figure 3.8.

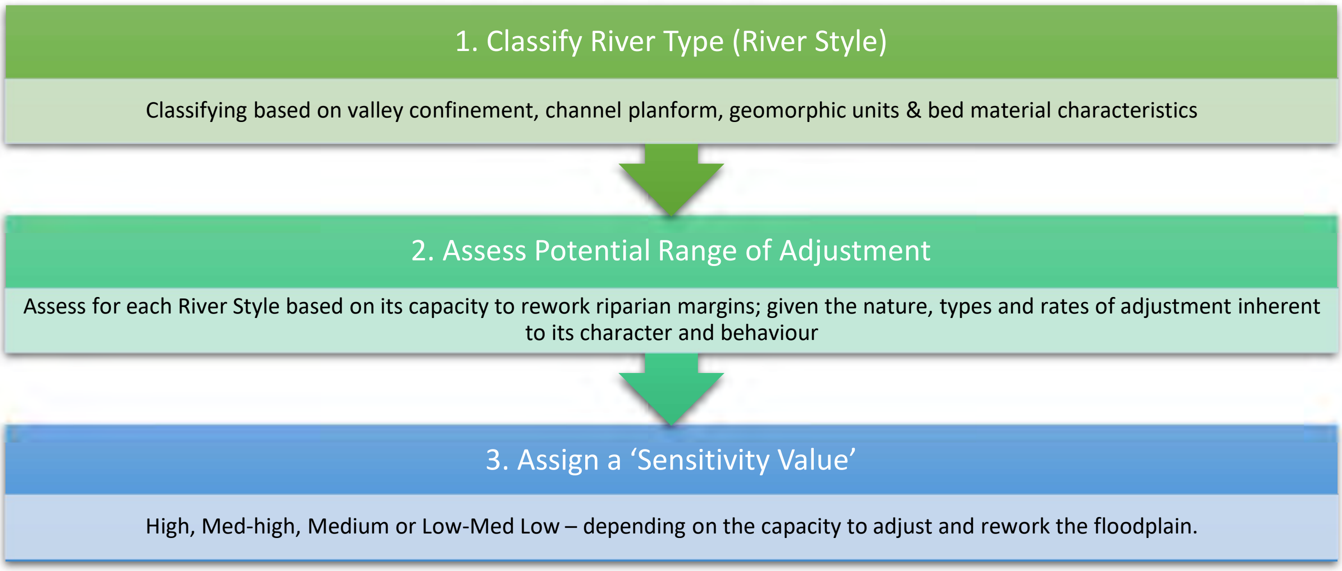

Figure 3.7. Flow chart describing steps used to analyse potential geomorphic river sensitivity (adapted from Reid & Brierley, 2015).

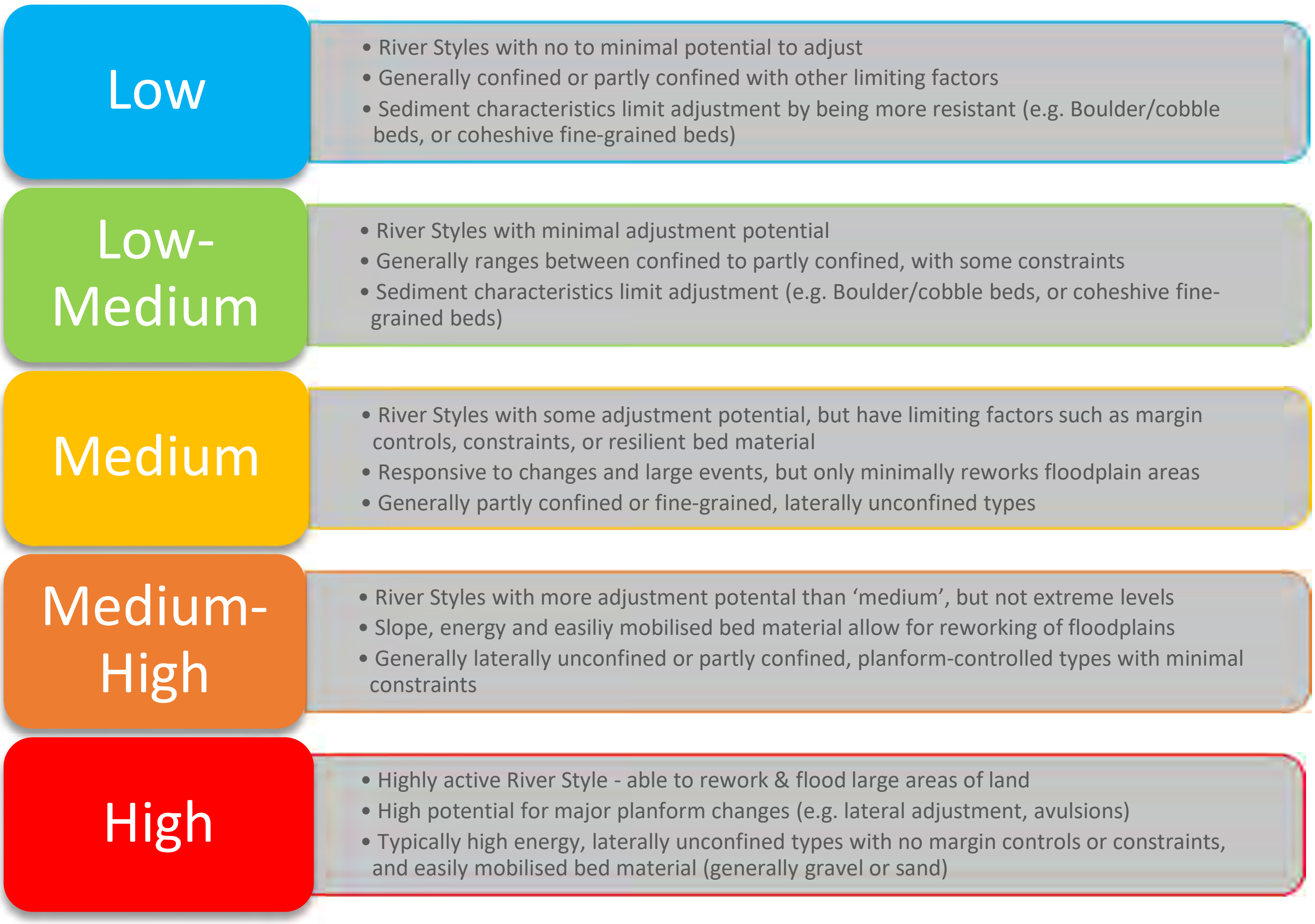

Figure 3.8. An approach to analysing potential geomorphic river sensitivity. This procedure assesses the manner and capacity (ease) of adjustment (the ability of that River Style to rework areas of land) for each River Style and assign a potential sensitivity ranking (adapted from Wheeler 2019).

Section 4: Downstream Patterns of River Styles

4.1 Background

Different patterns of river character and behaviour reflect variability in landscape setting, gradient and energy conditions. In turn, these attributes influence a river's capacity for geomorphic adjustment and the rate at which off-site impacts are conveyed through a catchment. In this section, the downstream patterns of River Styles are presented for each catchment investigated. The diversity of River Styles displayed in each catchment reflects the wide variability in landscape units present throughout the Waipā River Catchment. These landscape units are a product of the geological history of the area.

Overall, it was found that much of the studied stream network within the Waipā River Catchment is highly confined (Figure 4.1), which limits the network's capacity to adjust to only a small proportion of localised reaches. River Style abbreviations are shown in Table A1 in Appendix A. Information on each River Style, including their full names and their distinctive/unique characteristics, are displayed in the associated proformas in Appendix B.

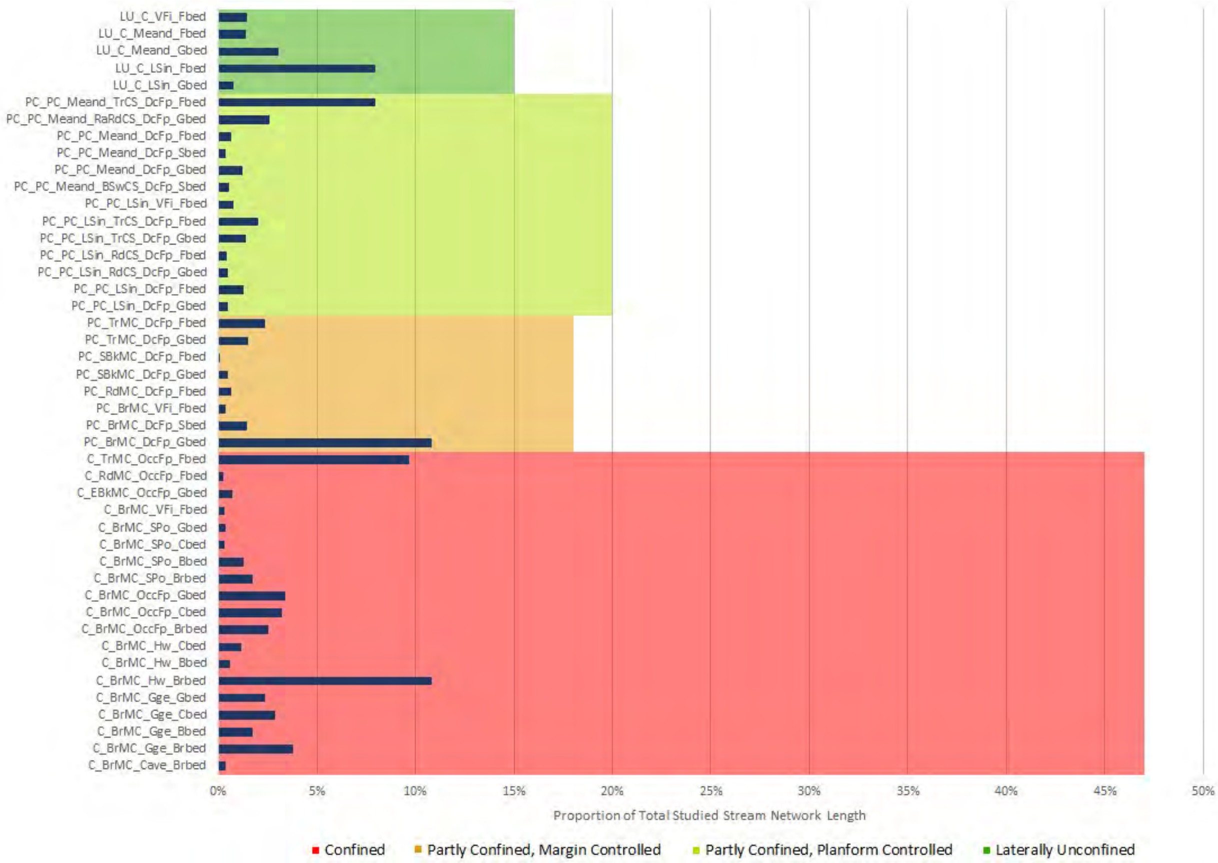

Figure 4.1. Summary bar chart displaying the proportion of each River Style identified within the Waipā River Catchment when compared to the overall study stream network length (see Table A1 for supplementary information). This is overlaid on the similarly calculated proportions of each valley setting found across the study stream network.

4.2 Moakurarua Sub-Catchment

The Moakurakura sub-catchment is located in the south-western portion of the Waipā River Catchment. Upland areas drain volcanic ignimbrite terrain around Mount Pirongia and uplifted sedimentary rocks consisting of sandstone, siltstone and areas interbedded with limestone (Figure 2.4). Downstream variation of the eight different River Styles found in the Moakurarua sub-catchment is shown alongside the longitudinal profile and distribution of total stream power in Figure 4.2. A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is displayed in Figure 4.3. This catchment is dominated by gravel bed rivers, most of which are either fully or partly confined by bedrock margins.

The Moakurarua River originates as a confined, bedrock headwater stream (C_BrMC_Hw_Brbed) and quickly transitions to a partly confined, gravel bed stream (PC_BrMC_DcFp_Gbed) due to a small increase in valley floor width prior to the river going underground. At this point, about 3 km downstream, the Moakurarua River briefly transitions to a confined, bedrock cave (C_BrMC_Cave_Brbed) as it flows through an area of uplifted limestone. Upon exiting the cave, the river becomes a confined, cobbled bed river with occasional floodplain pockets (C_BrMC_OccFp_Cbed). This coincides with a rapid increase (~5 kW m^{-1}) in total stream power due to the sudden increase in gradient following the cave. This stream power gradually decreases over the next 3.5 km, during which the bed material decreases in size from cobble to gravel. The Moakurarua River then remains a confined gravel bed river with occasional floodplain pockets (C_BrMC_OccFp_Gbed) for the next 9.5 km, during which the total stream power gradually increases in conjunction with cumulative drainage area while the gradient of the river bed remains generally constant. Continuing downstream, the valley begins to widen resulting in a change in River Style back to a partly confined, gravel bed river (PC_BrMC_DcFp_Gbed) at about 17 km from the source. At about 20 km downstream, the Ōamaru stream joins the Moakurarua, and the valley widens to a partly confined, planform-controlled setting (PC_PC_Meand_DcFp_Gbed). This coincides with the first major peaks in total stream power of approximtely 11.5 kW m^{-1} and 10.0 kW m^{-1} at about 19 km and 21 km downstream respectively.

Upstream in the Ōamaru Stream, this river has a series of alternating River Styles between partly confined, bedrock margin-controlled settings (PC_BrMC_DcFp_Gbed) and partly confined, planform-controlled settings (PC_PC_Meand_DcFp_Gbed). This reflects a series of natural chokepoints between areas of wider valley settings. Prior to this pattern, the Ōamaru Stream is a confined, gravel bed river with occasional floodplain pockets (C_BrMC_OccFp_Gbed) for about 1 km after having started its course as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed) for 3 km downstream from its source. As the Ōamaru joins the Moakurarua Stream, the locally widened valley setting and relatively high energy conditions, coupled with a river bed consisting of easily mobilised gravels, results in a dynamic River Style that is sensitive to adjustment.

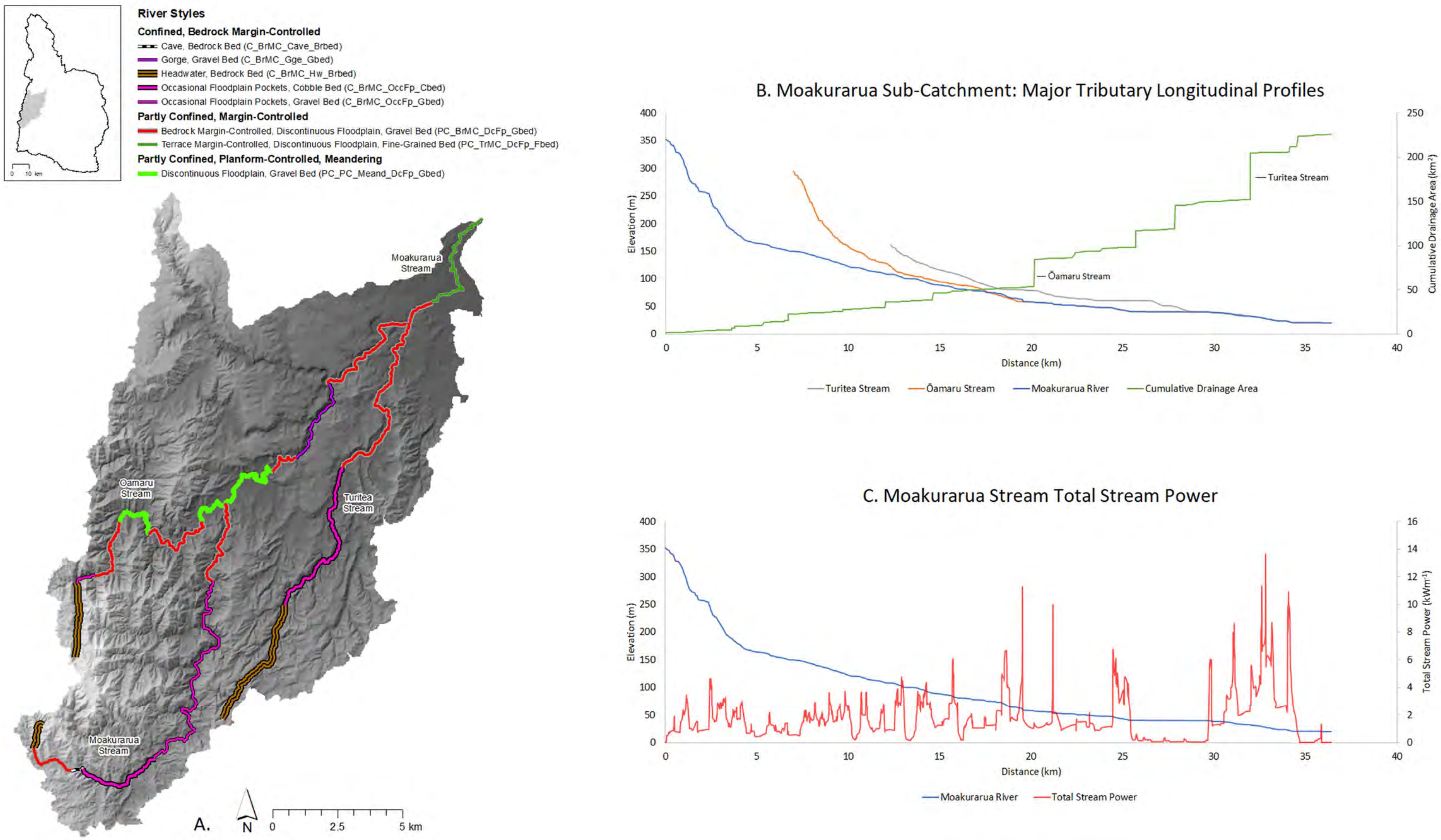

Figure 4.2. A. River Styles identified within the Moakurarua sub-catchment. B. Downstream changes in the longitudinal profiles and cumulative drainage area of the Moakurarua River and major tributaries within the Moakurarua sub-catchment. C. Downstream changes in total stream power along the Moakurarua River.

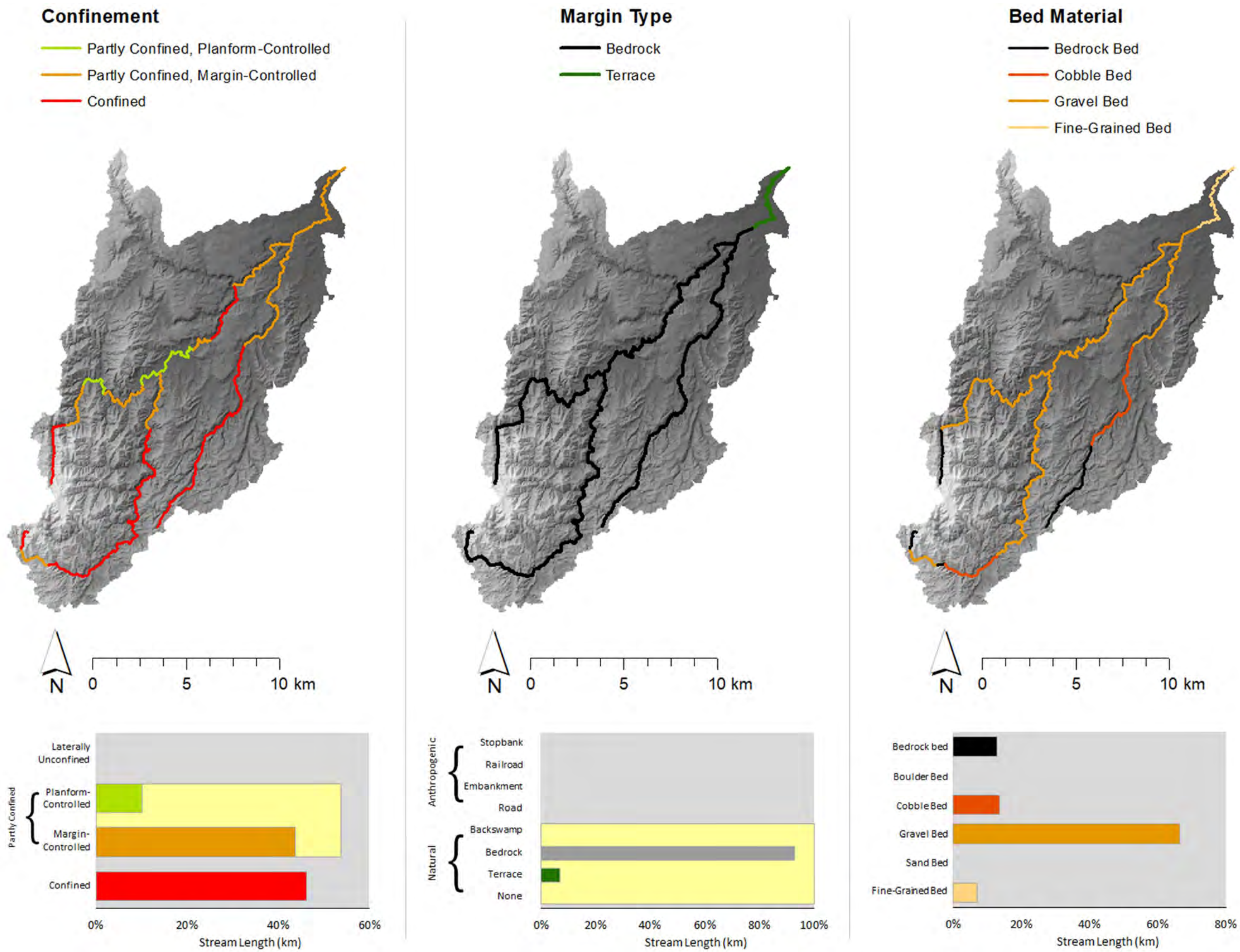

Figure 4.3. Main attributes of River Styles identified in the Moakurarua sub-catchment (degree of confinement, margin type and bed material).

Moving to 22.5 km downstream, the Moakurarua Stream enters a constriction zone imposed by the volcanic bedrock along the flanks of Mount Pirongia. This results in a change back to a partly confined, gravel-bed river (PC_BrMC_DcFp_Gbed) for 1.5 km, before transitioning to a confined, gorge River Style (C_BrMC_Gge_Gbed) at the 24 km mark, with constrained lateral adjustment. Vertical adjustment through this area is also constrained by hard volcanic bedrock (Figure 2.4), which lowers the gradient and reduces total stream power. At 27.5 km downstream, the valley begins to widen, transitioning back to a partly confined, gravel bed river (PC_BrMC_DcFp_Gbed). However, the gradient remains quite flat until the 30 km mark, at which point the gradient increases, causing the total stream power to rise rapidly until it reaches the second major peak of 14 kW m^{-1} at 33 km downstream. The confluence of the Turitea Stream with the Moakurarua Stream at the 32 km mark also contributes to this increase in total steam power.

The Turitea Stream originates as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed) river for 5 km, before transitioning to a confined, cobble bed river with occasional floodplain pockets (C_BrMC_OccFp_Cbed). It then transitions to a partly confined, gravel bed river (PC_BrMC_DcFp_Gbed) at 12 km downstream until its confluence with the Moakurarua Stream. This stream is largely controlled by bedrock margins as the valley and stream follow the Waipā fault.

Shortly after the Turitea Stream confluence, the Moakurarua River becomes slope limited, as it reaches the alluvial plains of Holocene and Late Pleistocene alluvial deposits. This results in lower energy conditions, despite the large cumulative drainage area. The stream is incised into, and becomes confined by, fine-grained terraces and transitions to a partly confined, terrace margin-controlled, fine-grained bed river (PC_TrMC_DcFp_Fbed) at the 33 km mark and flows for 4 km until it reaches the Waipā River. This incision and confinement have been in response to a base level that was set by the Waipā River (discussed above) and acts in conjunction with the cohesive fine-grained bed and bank materials to limit the capacity for adjustment.

4.3 Mangapū Sub-Catchment

The Mangapū sub-catchment drains the south-western region of the Waipā River Catchment. The longest river of this sub-catchment is the Mangaokewa Stream. In its lower reaches, it merges with, and becomes, the Mangapū River, which is the highest order stream in the sub-catchment. The upper reaches of the Mangapū River are split into two main tributaries, referred to here as the Mangapū-Mangawhitikau Stream and the Mangapū-Mangarama Stream for ease of interpretation on the longitudinal profile graphs in Figure 4.4. For this study, the Mangapū-Mangawhitikau Stream is considered the main channel of this sub-catchment due to the lower Mangapū River containing the highest order streams and the Mangaokewa Stream has the longest upstream path out of the two upper Mangapū River tributaries.

The 24 different River Styles in the Mangapū sub-catchment (Figure 4.4) reflect the high level of diversity in landscape units present in this catchment. These range from volcanic ignimbrite uplands in the south to uplifted sedimentary rocks interbedded with limestone that result in karst landscapes in the south-west, as well as a large amount of pumice and alluvial deposits found throughout the sub-catchment (Figure 2.4). A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is shown in Figure 4.5.

The Mangawhitikau Stream goes through several bedrock-controlled River Styles before joining the Mangarama Stream to form the Mangapū River. It originates as a steep, confined, bedrock bed headwater stream (C_BrMC_Hw_Brbed) for 2 km before transitioning to a confined, gravel bed stream with occasional floodplain pockets (C_BrMC_OccFp_Gbed) for 2.5 km. During this reach, the gradient decreases temporarily, reducing total stream power, and allows for the deposition of localised occasional floodplain pockets. Following this, the stream transitions to a confined, gravel bed stream with step-pool features (C_BrMC_SPo_Gbed) for 2 km. During this step-pool reach, the first major peak in total stream power is observed, reaching ~6.5 kW m^{-1} as the gradient suddenly steepens again. Following this, long-term incisional processes have allowed a narrow gorge to form as the stream cuts down into the limestone basement rock (Figure 2.4). This is where the Mangawhitikau Stream transitions to a confined, gorge River Style (C_BrMC_Gge_Gbed) before entering a cave network. The Mangawhitikau Stream then flows underground for 2 km as a confined, bedrock bed, cave River Style (C_BrMC_Cave_Brbed). Upon exiting the cave, the valley widens to a laterally unconfined setting and the stream begins to flow through valley-filled alluvial deposits. The gradient also decreases and remains relatively flat to the end of the Mangapū River, as the bed level is primarily controlled by the base level of the Waipā River, with subsequent occasional peaks in total stream power being attributed to localised adjustments in bed level. The increase in valley width results in a laterally unconfined, meandering, gravel bed River Style (LU_C_Meand_Gbed), which has the potential to be highly sensitive. The gravel bed reflects the high energy of this reach as it transfers this larger material from the upper reaches through this laterally unconfined zone. Approximately halfway down this reach, the Mangarama Stream joins the Mangawhitikau Stream to form the Mangapū River.

The Mangarama Stream has a relatively low elevation profile in comparison to the other Mangapū sub-catchment tributaries. It starts as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed) before quickly transitioning to a laterally unconfined, fine-grained valley fill (LU_C_VFi_Fbed) until it reaches the Mangawhitikau Stream. In between these two reaches is a 1 km transition zone where the stream is classed as a partly confined, fine-grained valley fill River Style (PC_BrMC_VFi_Fbed) as the valley setting gradually widens. This flow path can also be described as an underfit stream, in that the contemporary river did not deposit the alluvial material through which it flows, as it does not have the discharge or sediment source to do so. This suggests that this valley may have been gradually back-filled with alluvial deposits over time, hence the valley-fill classification.

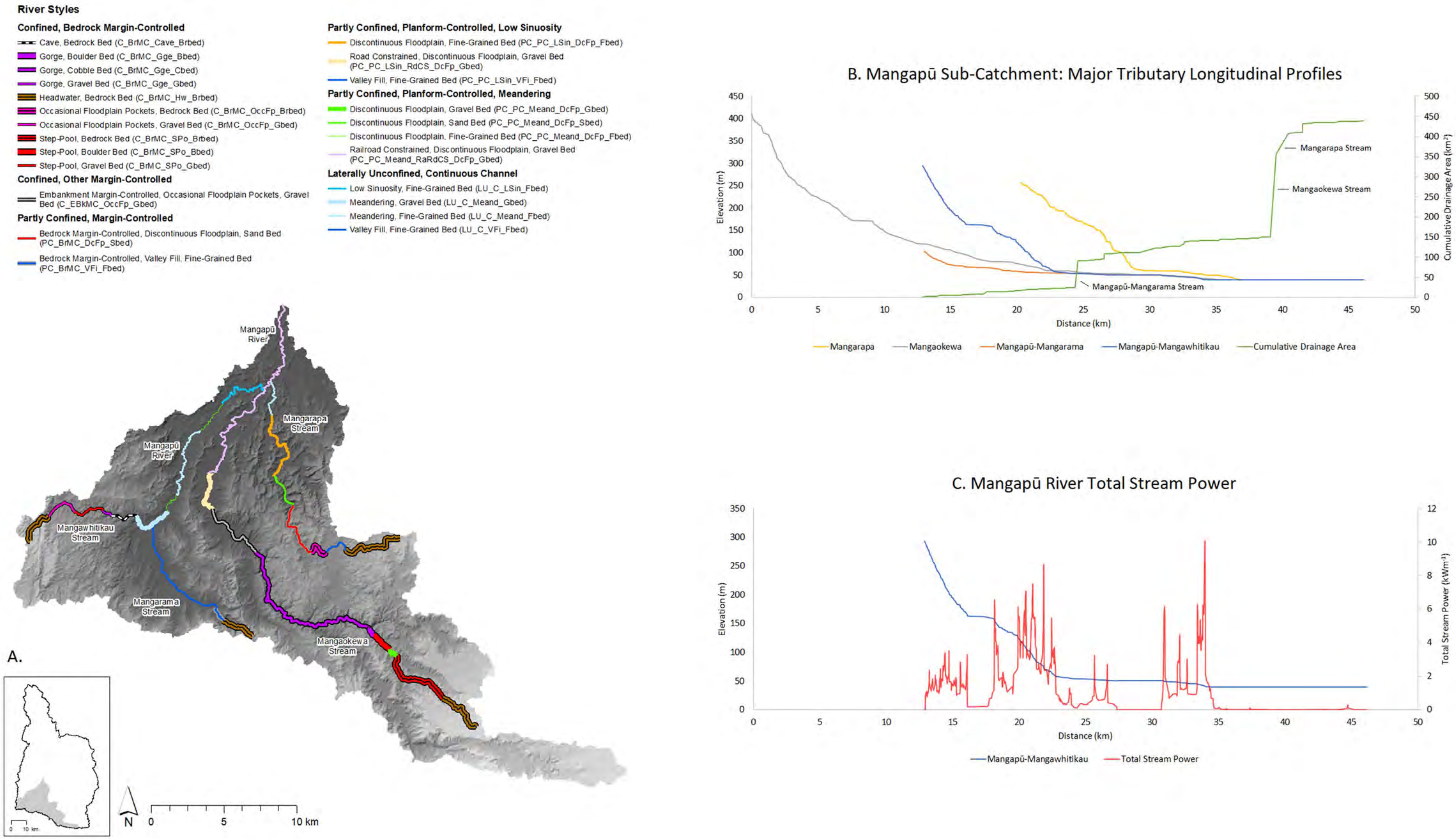

Figure 4.4. A. River Styles identified within the Mangapū sub-catchment. B. Downstream changes in the longitudinal profiles and cumulative drainage area of the Mangapū-Mangawhitikau River and major tributaries within the Mangapū sub-catchment. C. Downstream changes in total stream power along the Mangapū-Mangawhitikau River.

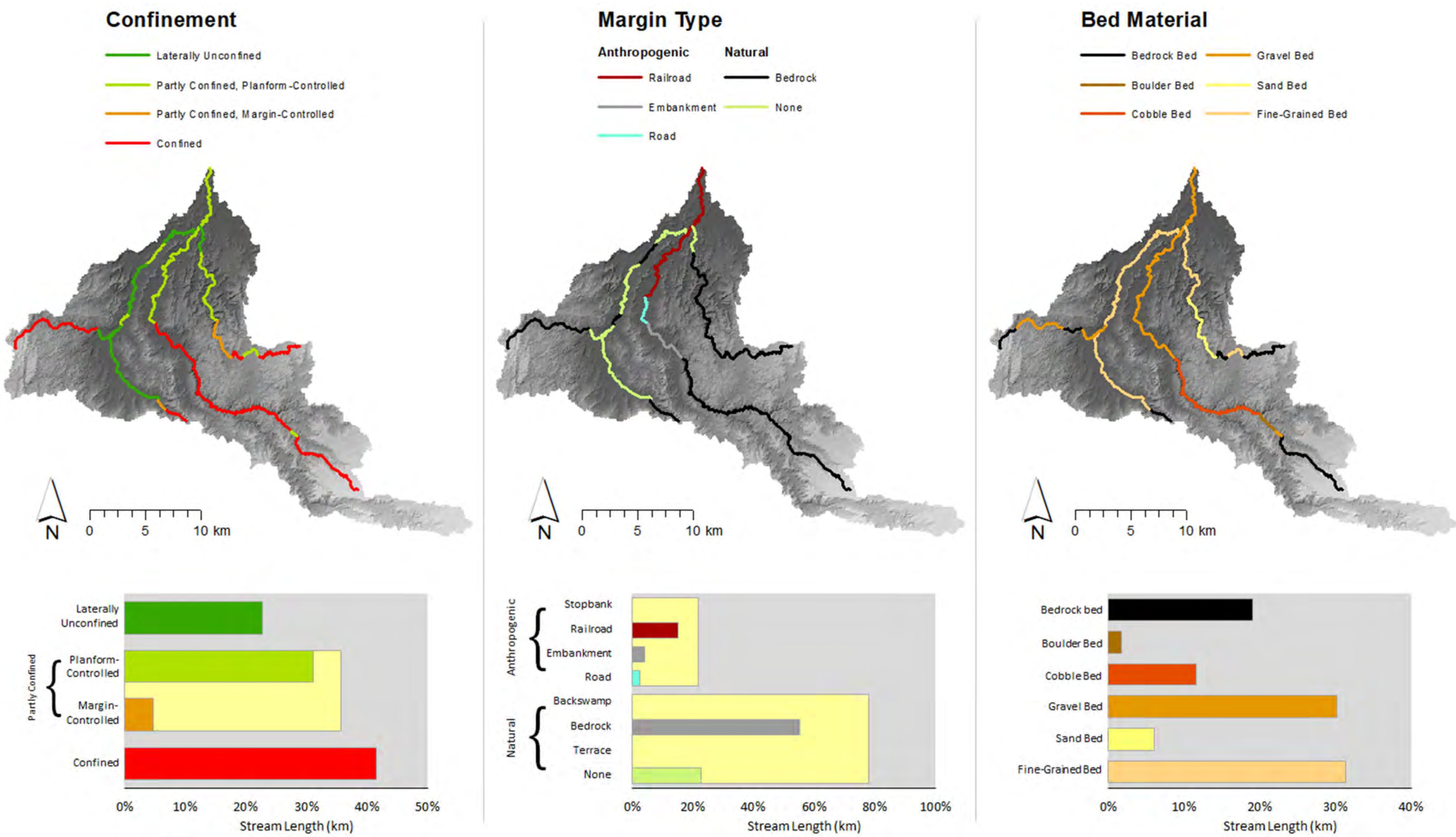

Figure 4.5. Main attributes of River Styles identified in the Mangapū sub-catchment (degree of confinement, margin type and bed material).

Downstream of the confluence between the Mangawhitikau and Mangarama Streams, the Mangapū River alternates between laterally unconfined and a partly confined, planform-controlled setting, with the latter being the result of the river periodically abutting the old, cohesive pumice valley sides which impose the lateral boundaries along the length of the river. Approximately 1 km downstream of the Mangawhitikau-Mangarama Stream confluence, the Mangapū River transitions from a laterally unconfined, meandering, gravel bed river (LU_C_Meand_Gbed) to a partly confined, planform-controlled, meandering, fine-grained bed system (PC_PC_Meand_DcFp_Fbed) for 1.5 km, where it then switches to a laterally unconfined, meandering, fine-grained bed river (LU_C_Meand_Fbed) for almost 6 km, and then back to the partly confined, planform-controlled, meandering, fine-grained bed river (PC_PC_Meand_DcFp_Fbed) for 2.5 km. Following this, the river centralises on the valley floor once more, becoming a laterally unconfined, low sinuosity, fine-grained bed river (LU_C_LSin_Fbed) for 3.5 km until it is joined by the Mangaokewa Stream, alongside which a railroad has been built which periodically constrains the Mangapū to a partly confined, planform-controlled River Style (PC_PC_Meand_RaRdCS_DcFp_Gbed).

The Mangaokewa Stream originates in steep volcanic uplands consisting of ignimbrite basement rock, topped with cohesive pumice. This creates a confined valley, where the stream originates as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed) before transitioning to a confined, bedrock bed river with step-pool features (C_BrMC_SPo_Brbed) about 2.5 km downstream. It eventually transitions to a boulder bed (C_BrMC_SPo_Bbed) at 8.5 km, but not before flowing through a ~700 m pocket of localised valley widening where a prehistoric valley has infilled with Taupō and Kaharoa breccia and other volcanic alluvium. This resulted in this short reach becoming a partly confined, planform-controlled, meandering gravel bed River Style (PC_PC_Meand_DcFp_Gbed). This transition also coincides with a brief decrease in gradient on the longitudinal profile. After this, at the 10 km mark, the gradient steepens again as the Mangaokewa Stream transitions into a 14 km long greywacke/limestone gorge. Initially, the stream is a boulder bed gorge (C_BrMC_Gge_Bbed) for roughly half a kilometre, where the bed is primarily comprised of large, locally-sourced boulders at the head of the gorge. It then transitions to a cobble bed (C_BrMC_Gge_Cbed) through the remainder of the gorge length. The Mangaokewa Stream flows through the town of Te Kūiti at the 23.5 km mark, where the stream is now controlled by anthropogenic margins. The stream becomes a confined, embankment margin-controlled, gravel bed river with occasional floodplain pockets (C_EBkMC_OccFp_Gbed) for 4.5 km through Te Kūiti, after which wide alluvial valleys dominate the landscape. Despite the wide alluvial valleys, the anthropogenic margins continue to affect confinement, with the stream transitioning to a partly confined, planform-controlled, low sinuosity, road constrained, gravel bed river (PC_PC_LSin_RdCS_DcFp_Gbed) for 2.5 km before transitioning to a meandering railroad constrained variant (PC_PC_Meand_RaRdCS_DcFp_Gbed). This River Style continues through the confluence with the Mangapū River at ~38 km downstream, until the Mangapū River joins the main Waipā River channel in Ōtorohanga.

At about 1 km downstream of the Mangaokewa Stream confluence, the Mangapū River is joined by the Mangarapa Stream from the East. This tributary begins as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed) in an area dominated by old, cohesive pumice material, before briefly switching to a partly confined, planform-controlled, low sinuosity, fine-grained valley fill (PC_PC_LSin_VFi_Fbed) as the stream flows through an infilled valley comprised of alluvial and peat deposits for 1.5 km. This reach also aligns with a similarly brief flattening out on the longitudinal profile. The valley setting then narrows again, forcing the river into a confined valley with occasional floodplain pockets (C_BrMC_OccFp_Brbed) for another kilometre. After this, the geology of the landscape changes to a combination of uplifted mudstone, fine siltstone, and limestone outcrops, which results in a fining of the bed material, with a transitioning to a partly confined, sand bed River Style (PC_BrMC_DcFp_Sbed) for 4.5 km. For the next 2.5 km, the gradient of the Mangarapa Stream decreases, becoming influenced by the bed level of the Mangapū River, as it meanders through alluvial deposits in a partly confined, planform-controlled valley setting (PC_PC_Meand_DcFp_Sbed). As the energy of the stream becomes further dissipated, it transitions to a partly confined, planform-controlled, low sinuosity, fine-grained river (PC_PC_LSin_DcFp_Fbed) for 5 km and then to a meandering, laterally unconfined River Style (LU_C_Meand_Fbed) as the valley setting widens downstream before joining the Mangapū River.

4.4 Upper Waipā Sub-Catchment

The Upper Waipā sub-catchment is located in the south-eastern portion of the Waipā River Catchment and contains the source of the main Waipā River channel. Upland areas drain a combination of Taupō volcanic material, including ashes, breccia and other volcanic alluvium from the Rangitoto Range (Figures 2.2 & 2.4). The high prevalence of ashes older than Taupō pumice within the sub-catchment (>70%) results in a dynamic incisional landscape, characterised by streams that are influenced by varying basement rock types. This has resulted in a wide range of River Styles, with 17 different styles in the Upper Waipā sub-catchment (Figure 4.6). Landscape units range from volcanic ignimbrite uplands in the south to uplifted sedimentary rocks interbedded with limestone that result in karst landscapes in the south-west, as well as a large amount of pumice and alluvial deposits found throughout the sub-catchment (Figure 2.4). A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is shown in Figure 4.7.

The source of the upper Waipā River is found on the southern plateau of the Rangitoto Range. Initially heading in a south-westerly direction as a confined valley fill River Style (C_BrMC_VFi_Fbed) for a kilometre, the Waipā River soon changes to a partly confined, planform-controlled, low sinuosity, fine-grained River Style in valley fill (PC_PC_LSin_VFi_Fbed) for 3.5 km. Both these early reaches reflect the geology of the area, as they flow through volcanic alluvium and ash-filled volcanic-bedrock valleys. The low initial discharge of the river inhibits the mobilisation of the large volumes of fine-grained cohesive volcanic alluvium and ash found here. As the upper Waipā River turns east, it becomes a confined headwater with boulders (C_BrMC_Hw_Bbed) for 2 km, then transitions to bedrock bed (C_BrMC_Hw_Brbed) for a further 3 km. The boulders found in the first of these two reaches are locally sourced from periodic slips and landslides, possibly accentuated by the forestry practises occurring in the area (see Figure 2.8). The gradient of the river along these upper reaches remains relatively moderate, and the river soon transitions to a confined River Style with step-pool features and boulders (C_BrMC_SPo_Bbed) for 3 km, before transitioning to bedrock (C_BrMC_SPo_Brbed) for a further 8 km as it continues to flow through these volcanic uplands. The first of these two reaches coincides with a relatively small (10 kW m^{-1}) peak in total stream power as the localised step-pool morphology increases the gradient of the bed. Approximately 1.5 km after transitioning to a C_BrMC_SPo_Brbed River Style, another peak in total stream power (13 kW m^{-1}) is observed in response to the increase in cumulative drainage area as the upper Waipā River is joined by the Okurawhanga Stream.

The Okurawhanga Stream begins slightly north of the upper Waipā River and slightly higher up in the Rangitoto Range, originating as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed), before transitioning to a boulder bed (C_BrMC_Hw_Bbed). It then transitions to a River Style with step-pool features (C_BrMC_SPo_Bbed), following a similar downstream pattern to the upper Waipā River as it flows through these volcanic uplands. However, it then transitions to a cobble bed (C_BrMC_OccFp_Cbed) where the terrain allows for a slight increase in accommodation space, leading to the formation of small floodplain pockets before the confluence zone between the Okurawhanga Stream and the upper Waipā River. Approximately 6.5 km downstream of the Okurawhanga Stream confluence, the upper Waipā River begins to decrease in gradient, transitioning to a partly confined, planform-controlled, low sinuosity, gravel bed river constrained by terraces (PC_PC_LSin_TrCS_DcFp_Gbed) for 3 km before entering a steep gorge through a pocket of uplifted greywacke. Transitioning to a gorge (C_BrMC_Gge_Cbed), the total stream power of the upper Waipā River starts to increase rapidly, peaking at just over 75 kW m^{-1} shortly after the Okahukura Stream confluence.

The Okahukura Stream originates very close to the Okurawhanga Stream in the Rangitoto Range and follows a similar downstream transition pattern. Beginning as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed), the Okahukura Stream maintains this style for most of its length before switching to a bedrock bed with step-pool features (C_BrMC_SPo_Bbed), followed by a cobble bed gorge (C_BrMC_Gge_Cbed) before joining the upper Waipā River.

Approximately 3 km downstream of the Okahukura Stream confluence, the Waipā River becomes a gravel bed gorge River Style (C_BrMC_Gge_Gbed). As the gradient of the bed gradually lowers on its way through the gorge, lower total stream powers result in a reduced bedload capacity, allowing the formation of a gravel bed river. Following the occurance of the Tunawaea Landslide in 1992, the geomorphology within this gorge has been significantly impacted as the river has gradually transported landslide material downstream (Hoyle et al., 2015). However, according to Hoyle et al. (2015), the sediment slug associated with the Tunawaea Landslide has not materialized downstream at Ōtewa and much of the sediment has been stabilised by recent remedial works and planting. After flowing through the gorge for 11.5 km, the valley begins to widen into a partly confined setting, at which point the Waipā River transitions to a partly confined, gravel bed River Style (PC_BrMC_DcFp_Gbed) for 4.5 km and alluvial floodplains become more prominent on the valley floor. As it enters the relatively wide valley confluence zone of the Waimahora Stream, the Waipā River temporarily transitions to a partly confined, planform-controlled low sinuosity gravel bed River Style (PC_PC_LSin_DcFp_Gbed) for 3 km.

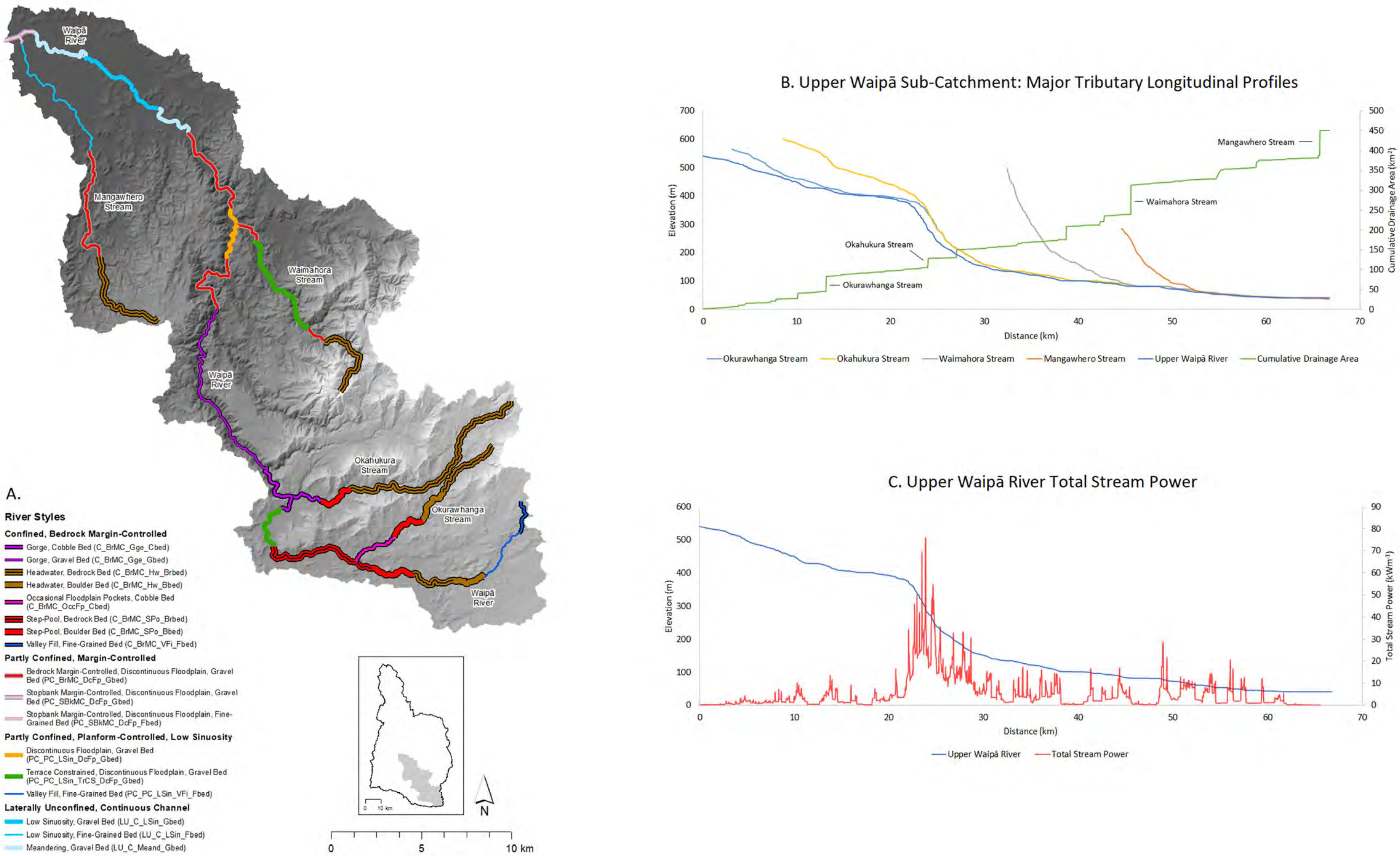

Figure 4.6. A. River Styles identified within the Upper Waipā sub-catchment. B. Downstream changes in the longitudinal profiles and cumulative drainage area of the upper Waipā River and major tributaries within the Upper Waipā sub-catchment. C. Downstream changes in total stream power along the upper Waipā River.

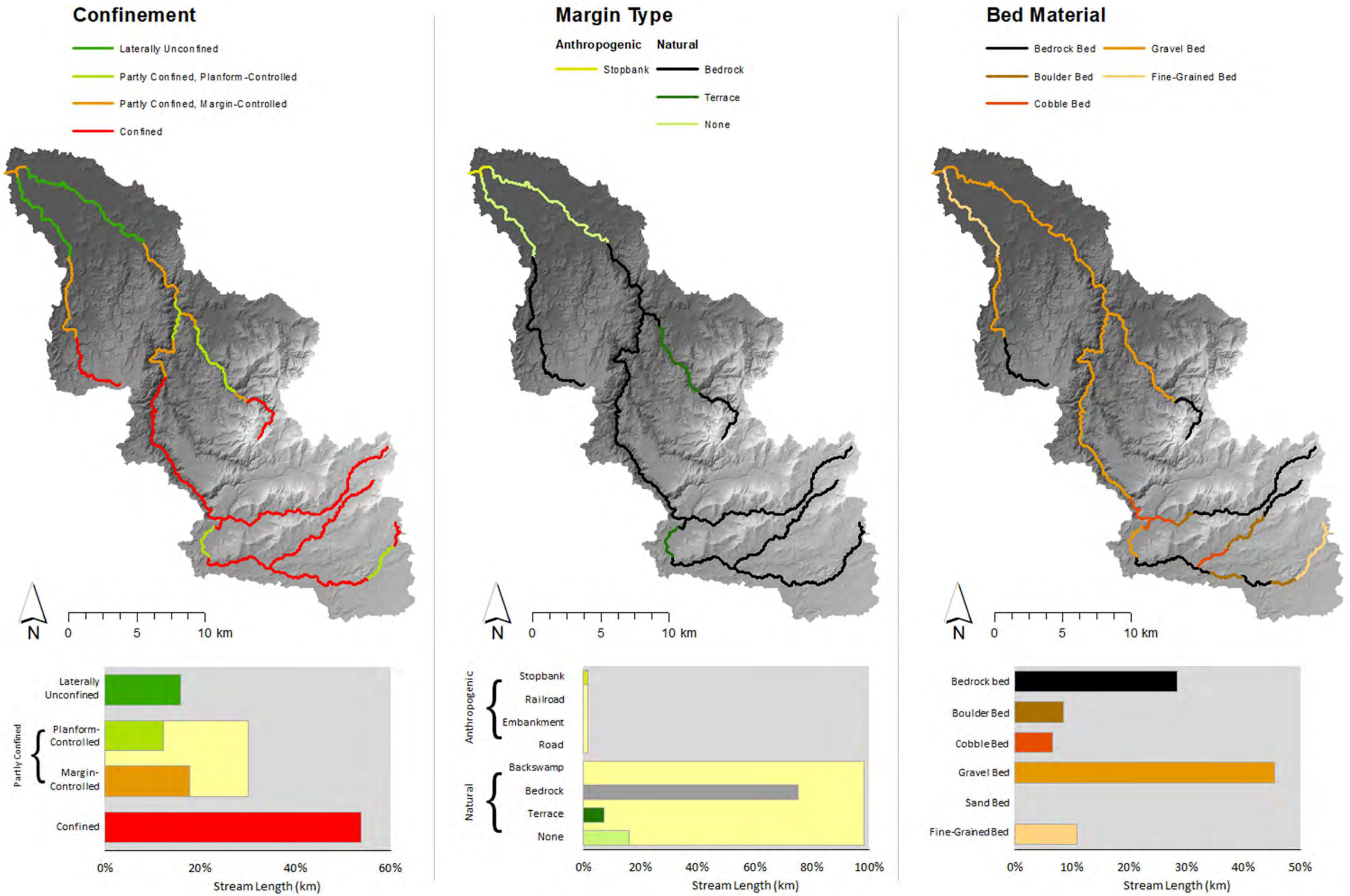

Figure 4.7. Main attributes of River Styles identified in the Upper Waipā sub-catchment (degree of confinement, margin type and bed material).

The Waimahora Stream drains from the northern side of the Rangitoto Range, originating as a steep bedrock bed headwater (C_BrMC_Hw_Brbed), and then switching briefly to a partly confined, gravel bed River Style (PC_BrMC_DcFp_Gbed), before flowing most of its length as a PC_PC_LSin_TrCS_DcFp_Gbed River Style. The initial two reaches are controlled mainly by the lithology and relief of the Rangitoto Range. However, the later reach, flowing through fine-grained fluvial and volcanic alluvium, has been able to moderately incise to form pumice terrace constraints. Before joining the Waipā River, the Waimahora Stream becomes a partly confined, gravel bed River Style (PC_BrMC_DcFp_Gbed) as it enters the Waipā River valley setting.

Soon after this confluence zone, the Waipā River transitions back to a partly confined, gravel bed River Style (PC_BrMC_DcFp_Gbed) for 6 km as the valley setting narrows once more. As the valley setting begins to widen downstream, the Waipā River is granted the accommodation space to become a laterally unconfined, meandering, gravel bed River Style (LU_C_Meand_Gbed) for the next 2.5 km. The gradient and total stream power remain quite high in this area. This allows the river to continue transporting a gravel bedload and also results in a reach that is highly sensitive to lateral migration as the river looks to dissipate its energy in an area characterised by wide areas of accommodation space and alluvial deposits. After this reach, the Waipā River switches to a laterally unconfined, low sinuosity, gravel bed River Style (LU_C_LSin_Gbed) for 7 km, and then back to a LU_C_Meand_Gbed for a further 4 km before reaching the town of Ōtorohanga. The reason for this temporary reduction in sinuosity is not natural, as human-induced channel straightening has occurred over the last few decades in an effort to manage the river and prevent the loss of productive farmland on the floodplains.

In Ōtorohanga, the Waipā River becomes partly confined by anthropogenic stopbanks which have been built to protect the town from flooding, turning the river into a partly confined, stop-bank margin-controlled River Style (PC_SBkMC_DcFp_Gbed). A man-made weir also sets the bed level of the Waipā River as it enters the town. This can be more easily observed on the longitudinal profile of the full Waipā River as a brief decrease in channel gradient between 62 and 67 km downstream from the source (see Figure 4.13). The end of the Upper Waipā sub-catchment is marked by the confluence of the Mangapū River as it flows through Ōtorohanga, about 1 km downstream from the Mangawhero Stream confluence.

The Mangawhero Stream flows in line with the boundary between the Upper Waipā and Mangapū sub-catchments. Its source is very close to the head of the neighbouring Mangarapa Stream, flowing through uplifted sedimentary basement rocks topped with old, cohesive pumice as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed). The Mangawhero then becomes a partly confined, gravel-bed River Style (PC_BrMC_DcFp_Gbed) until it reaches the wide, alluvial plains towards Ōtorohanga. Here it switches to a laterally unconfined, low sinuosity, fine-grained River Style (LU_C_LSin_Fbed), as its relatively low discharge is unable to maintain a gravel bed. Upon reaching the stopbanks of Ōtorohanga, it briefly becomes a partly confined, stopbank margin-controlled, fine-grained bed River Style (PC_SBkMC_DcFp_Fbed) until joining the Waipā River.

4.5 Pūniu Sub-Catchment

The Pūniu sub-catchment drains an area of the eastern side of the Waipā River Catchment and is the largest sub-catchment in this study. Despite this, it is not as diverse as the other large sub-catchments, containing only 14 different River Styles (Figure 4.8). This is due to the relative lack of landscape diversity (Figure 2.4). Most of this catchment is characterised by old pumice overlaid on hard volcanic rock and localised uplifted greywacke. In the lower reaches, alluvial deposits become the primary landscape unit, throughout which terraces have formed in response to long-term incisional processes (Figure 4.9). As a result of the large drainage area and discharge of this sub-catchment, these well-defined terraces impose lateral controls on much of the lower stream network.

The Pūniu River starts its path downstream as a steep, 4 km long confined headwater (C_BrMC_Hw_Brbed), the bed of which is controlled by hard volcanic basement rock. It then becomes a narrow gorge (C_BrMC_Gge_Bbed) for the next 12 km as it makes its way through an area of undulating relief produced by uplifted greywacke topped with old pumice. The total stream power gradually increases to almost 13 kW m^{-1} in this reach. As the gorge-style relief of the terrain becomes less prominent, the total stream power goes through a series of peaks and troughs in response to the varying gradient of the river bed as it is controlled once again by hard volcanic basement rock. Here, the Pūniu River transitions to a confined, bedrock river with occasional floodplain pockets (C_BrMC_OccFp_Brbed) for 6.5 km. As the valley setting widens, it then transitions to a partly confined, gravel bed River Style (PC_BrMC_DcFp_Gbed) for 5.5 km until it is joined by the Waipari Stream.

The Waipari Stream runs parallel to the upper Pūniu River with an almost identical elevation profile, heading north on the eastern side of the sub-catchment. Being controlled by similar changes in landscape units along its path as the upper Pūniu River, it also displays a similar general pattern in downstream transitions of River Style. It starts as a confined, headwater River Style (C_BrMC_Hw_Brbed) and then eventually becomes a gorge further downstream, but not before going through three short River Style reaches along the way. It first transitions to a laterally unconfined, fine-grained valley fill (LU_C_VFi_Fbed) as the stream flows through a small upland pumice-filled valley. It then becomes a partly confined, gravel bed River Style (PC_BrMC_DcFp_Gbed) and then a confined, cobble bed river with step-pool features (C_BrMC_SPo_Cbed). Following this, it becomes fully confined by the narrow gorge, transitioning to a C_BrMC_Gge_Brbed River Style for most of its length. Finally, the Waipari Stream becomes a C_BrMC_OccFp_Brbed as the gorge-style relief becomes more suppressed before meeting the Pūniu River.

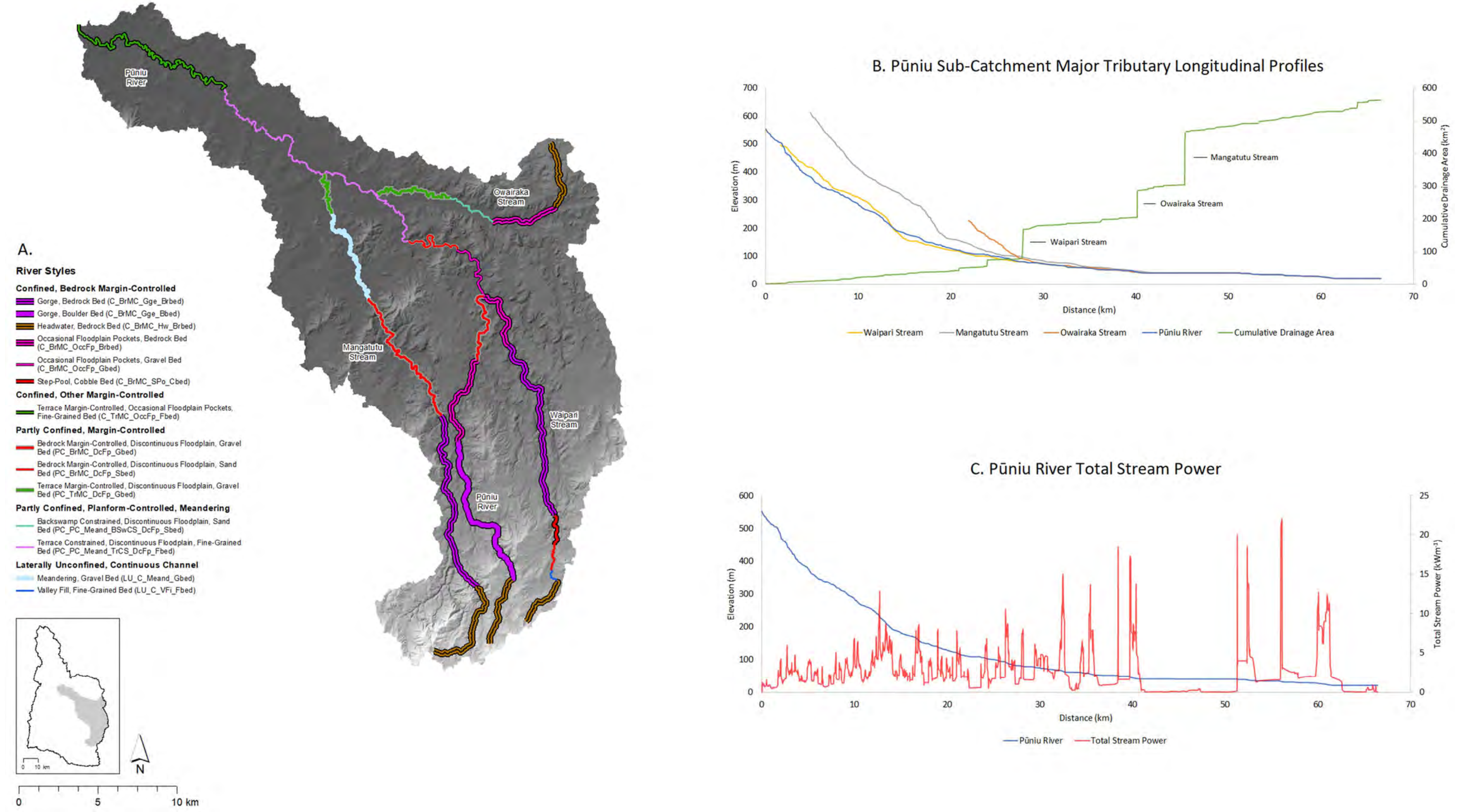

Figure 4.8. A. River Styles identified within the Pūniu sub-catchment. B. Downstream changes in the longitudinal profiles and cumulative drainage area of the Pūniu River and major tributaries within the Pūniu sub-catchment. C. Downstream changes in total stream power along the Pūniu River.

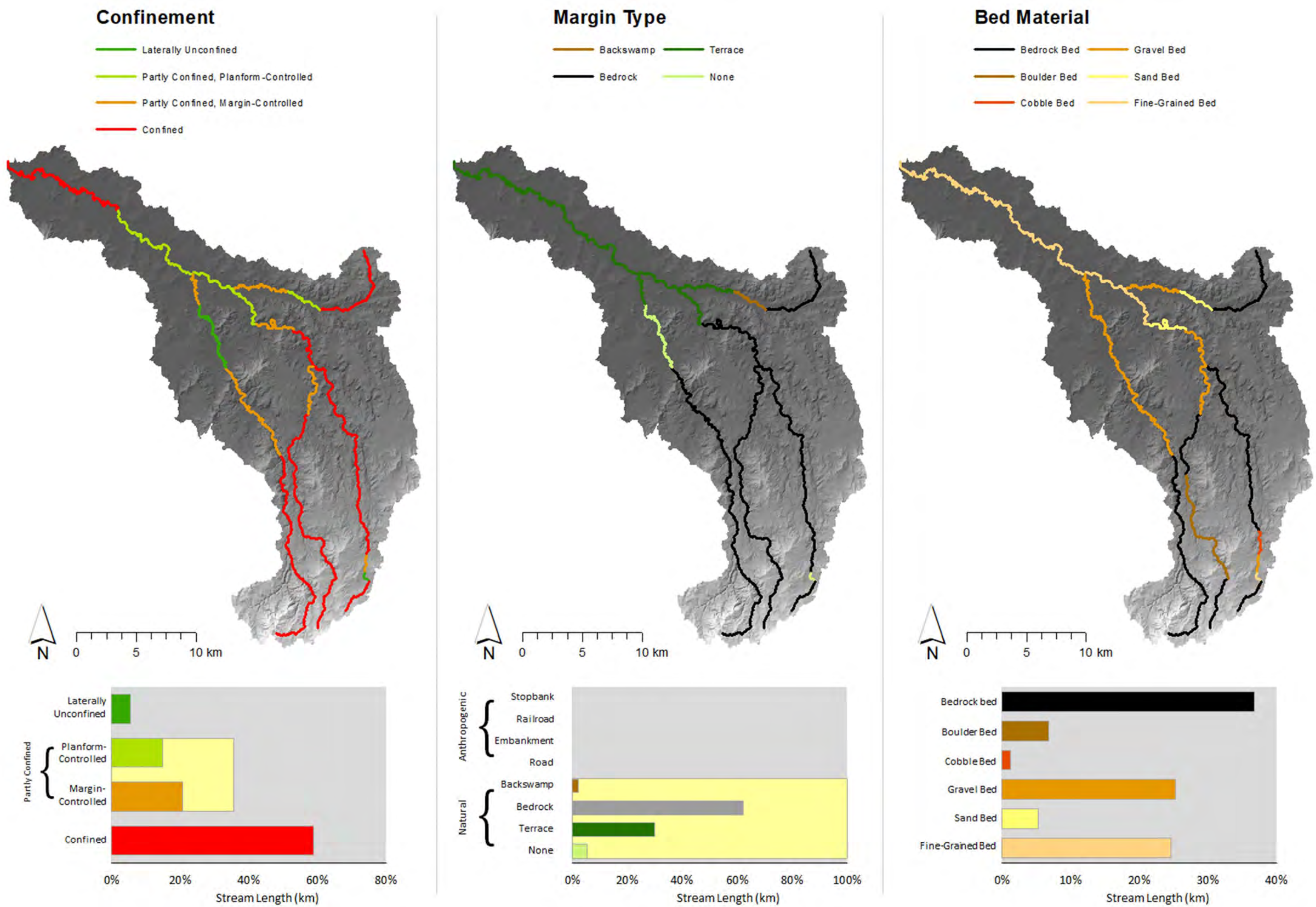

Figure 4.9. Main attributes of River Styles identified in the Pūniu sub-catchment (degree of confinement, margin type and bed material).

After the Waipari Stream confluence, the Pūniu River gradient begins to decrease as it transitions to a confined, gravel bed river with occasional floodplain pockets (C_BrMC_OccFp_Gbed) for 4 km through a narrow valley setting. It then becomes a 5 km long partly confined, sand bed River Style (PC_BrMC_DcFp_Sbed). This marks the transition between the undulating volcanic relief upstream and the relatively flat alluvial plains downstream. As the valley continues to widen, terraces impose constraints on the Pūniu River, changing it to a partly confined, planform-controlled, meandering, fine-grained river constrained by terraces (PC_PC_Meand_TrCS_DcFp_Fbed) for the next 18 km. Along this lower portion of the Pūniu River, sudden large peaks in total stream power mark short, sharp adjustments in bed level, indicating the presence of headcuts moving their way upstream through the fine-grained pumice bed. During this reach, the Pūniu River is joined by the Owairaka Stream and the Mangatutu Stream. The final reach of the Pūniu River is a 12 km long confined, terrace margin-controlled with occasional inset floodplain pockets River Style (C_TrMC_OccFp_Fbed), which continues as it joins the Waipā River.

The Owairaka Stream is a short, low elevation tributary that feeds the Pūniu River from the southern foothills of Mount Maungatautari (Figure 2.2). It starts as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed) and then transitions to a slightly wider valley setting where occasional floodplain pockets form (C_BrMC_OccFp_Brbed). It then reaches the extent of the lowland alluvial deposits, becoming a partly confined, planform controlled, meandering, sand bed river constrained by backswamps (PC_PC_Meand_BSwCS_DcFp_Sbed).

The backswamps in this reach are the product of two main processes. The first is a series of short, very low discharge, ephemeral tributaries that drain the hills either side of this reach. Many of them do not have the energy to fully connect to the main channel, and so they flood out onto the Owairaka Stream floodplain to create localised backswamps. In conjunction with this, the highly sinuous main channel has also formed several meander cut-offs which have gradually infilled with fine sediments over time, forming more backswamps. These backswamps impose localised constraints on the main channel and become reactivated during floods. They can serve as sediment sinks during high flow events, trapping fine-grained sediments as the streamflow overtops the banks of the main channel. They also hold ecological significance, offering a diverse array of freshwater habitats. Downstream of this reach, the Owairaka Stream becomes a partly confined, terrace margin-controlled, gravel bed River Style (PC_TrMC_DcFp_Gbed) as it becomes more incised downstream until it meets the Pūniu River.

Approximately 5 km downstream of the Owairaka Stream confluence, the Pūniu River is joined by the Mangatutu Stream. Like the Waipari Stream, it also flows parallel to the upper Pūniu River, flowing close to the western Pūniu sub-catchment boundary. It also mimics a similar pattern of downstream River Style transitions, indicating a degree of cross-catchment connectivity influenced by the homogeneous landscape units of the area. The Mangatutu Stream begins as a confined, bedrock bed headwater (C_BrMC_Hw_Brbed) before becoming a narrow gorge (C_BrMC_Gge_Brbed). At a similar distance downstream to the Pūniu River, the Mangatutu Stream exits the gorge valley setting to become a partly confined, gravel bed River Style

(PC_BrMC_DcFp_Gbed). It then flows out into the alluvial plains of the lower Pūniu sub-catchment, becoming a laterally unconfined, meandering, gravel bed river (LU_C_Meand_Gbed). The highly sinuous channel laterally dissipates the stream's energy. Although, further downstream, anthropogenic straightening has markedly reduced sinuosity. As the bed level of this stream is set by the Pūniu River, it has not incised along this reach as its elevation profile is already very similar to the Pūniu River bed level. Before joining the Pūniu River, the Mangatutu Stream becomes a partly confined, terrace margin-controlled River Style (PC_TrMC_DcFp_Gbed) as incisional processes from further downstream have made their way up through the lower portion of this stream to create terraces. If channel straightening continues in the prior reach, this will accelerate the rate at which incisional headcuts make their way upstream, increasing the rate of erosion along this section of the river.

4.6 Mangapiko Sub-Catchment

The Mangapiko sub-catchment flows from the eastern region of the Waipā River Catchment and is the second smallest sub-catchment in this study, covering 307 km^2. Upland areas drain the foothills of Mount Maungatautari, with lithologies comprising mainly lavas, ignimbrite and other hard volcanic rocks. However, most of the Mangapiko sub-catchment stream network flows through very flat, low lying terrain, dominated by pumice, peat deposits, and unconsolidated fine-grained material (Figure 2.4), remnants of the old Waikato alluvial fan and the drained Moanatuatua Swamp (Figures 2.1 and 2.7).

The 12 different River Styles in the Mangapiko sub-catchment (Figure 4.10) are a reflection of the diversity in landscape units found in this region, as well as how long term geomorphic and anthropogenic processes have responded to this landscape diversity. A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is shown in Figure 4.11.

The Mangapiko River begins its journey as a steep, confined, cobble-bed headwater (C_BrMC_Hw_Cbed) for 3 km as it flows down the western slopes of Mount Maungatautari. It then turns north, following the terrain for 4.5 km as a confined, gravel bed river with occasional floodplain pockets (C_BrMC_OccFp_Gbed) as the gradient of the river starts to reduce. The Mangapiko River once again alters its course, turning east and becoming a partly confined, gravel bed River Style (PC_BrMC_DcFp_Gbed) for 4 km as the gradient continues to decrease and valley floor width gradually increases. In these three early reaches, the total stream power remains relatively constant as the discharge gradually increases as the gradient decreases, with occasional peaks of 4 – 4.5 kW m^{-1} reflecting localised bed level changes. After this stage of the river, it flows out into the flat, laterally unconfined alluvial and peat deposits left behind from the drained wetlands that used to dominate this region, becoming a laterally unconfined, low sinuosity, fine-grained bed River Style (LU_C_LSin_Fbed) for the next 9 km. Roughly halfway down this reach, the Mangapiko is joined by the first of two unnamed tributaries in the sub-catchment, referred to hereafter as the Judge Road Swamp Drain.

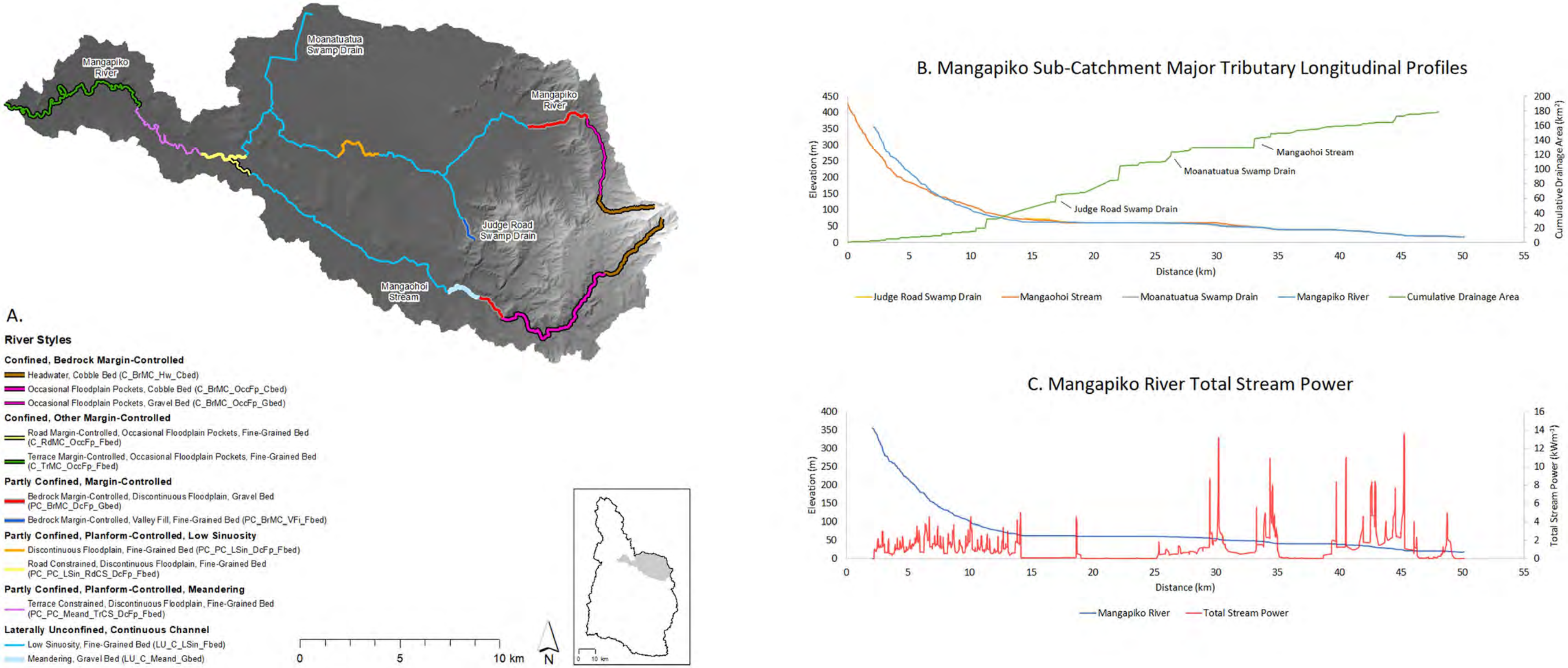

Figure 4.10. A. River Styles identified within the Mangapiko sub-catchment. B. Downstream changes in the longitudinal profiles and cumulative drainage area of the Mangapiko River and major tributaries within the Mangapiko sub-catchment. C. Downstream changes in total stream power along the Mangapiko River.

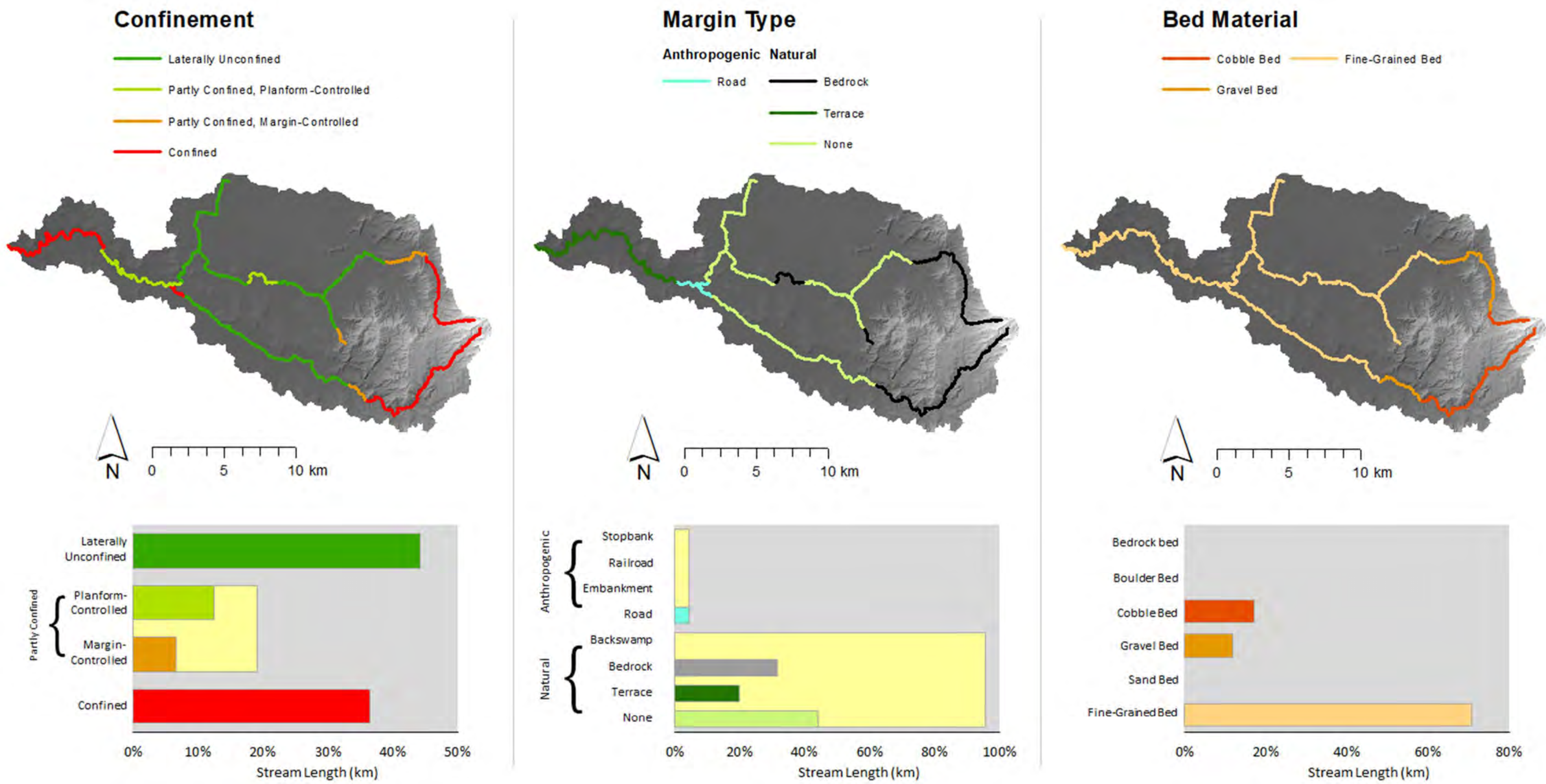

Figure 4.11. Main attributes of River Styles identified in the Mangapiko sub-catchment (degree of confinement, margin type and bed material).

The Judge Road Swamp Drain has a relatively low elevation source coming from the uplifted greywacke foothills on the western side of Mount Maungatautari. It starts as a partly confined, valley fill with fine-grained bed River Style (PC_BrMC_VFi_Fbed) and quickly transitions to a laterally unconfined, low sinuosity, fine-grained bed River Style (LU_C_LSin_Fbed) until joining the Managapiko River. Field verification confirmed that much of this tributary is, in fact, a trench which was dug to drain the pre-existing wetlands to allow the surrounding land to be utilised for agriculture (Figure 2.8).

Approximately 3.5 km downstream of the Judge Road Swamp Drain confluence, the Mangapiko River briefly becomes a partly confined, planform-controlled, low sinuosity River Style (PC_PC_LSin_DcFp_Fbed) for 3 km as it becomes partly confined by the start of the extent of the Hamilton Hills (Figure 2.1). This also marks the boundary along the Mangapiko River between the upstream alluvial and peat deposits and the downstream unconsolidated fine-grained materials of the Hamilton Basin (i.e. the Waikato Fan), deposited by the Waikato River following the Oruanui eruption from Taupō volcano (Manville & Wilson, 2004). Downstream of this reach, the Mangapiko returns to a laterally unconfined, low sinuosity, fine-grained bed River Style (LU_C_LSin_Fbed) until reaching the town of Te Awamutu where it is joined by the second unnamed tributary, referred to hereafter as the Moanatuatua Swamp Drain. Much like the Judge Road Swamp Drain, the Moanatuatua Swamp Drain is a very low slope, trench-like channel that was constructed to drain pre-existing wetlands to allow for agricultural expansion. Many of the tributaries leading into the Moanatuatua Swamp Drain are in fact irrigation channels servicing the farmlands which now dominate the area.

Once reaching Te Awamutu, the Mangapiko River becomes partly confined by the town, changing the river to a partly confined, planform controlled low sinuosity fine-grained river that is constrained by the road (PC_PC_LSin_RdCS_DcFp_Fbed) for 2.5 km. Approximately halfway through Te Awamutu, the Mangapiko River is joined by the Mangaohoi Stream. The Mangaohoi Stream follows a very similar downstream pattern of River Style transitions as the Mangapiko, reflecting a high level of cross-catchment connectivity and consistency in downstream changes of landscape units. However, it does display some slight variations. The first three reaches heading downstream from the source are very similar to the first three reaches of the Mangapiko River, going from confined headwater with cobbles (C_BrMC_Hw_Cbed) to a confined river with occasional floodplain pockets (C_BrMC_OccFp_Cbed) and onto a partly confined, gravel bed River Style (PC_BrMC_DcFp_Gbed). The only difference here is the second reach maintains a cobble bed until becoming partly confined. This is due to the additional length of these initial reaches travelling through this source zone, resulting in a larger input of sediment which allows for the larger sediment size to be maintained for longer until the energy of the stream can rework it downstream. Following this reach, the Mangaohoi Stream flows onto the alluvial plains becoming laterally confined. There is a brief 2 km transition zone where the stream is a laterally unconfined, meandering, gravel bed River Style (LU_C_Meand_Gbed) where it dissipates built up energy by forming a meandering path on the valley floor. This sinuosity quickly decreases as the stream becomes a laterally unconfined, low sinuosity, fine-grained bed River Style (LU_C_LSin_Fbed). It is not until the stream reaches Te Awamutu that it changes to a confined, road margin-controlled River Style (C_RdMC_OccFp_Fbed) as it flows through the town until it meets the Mangapiko River.

As the Mangapiko River exits the constraints of the town downstream, it transitions to a partly confined, planform-controlled, meandering, fine-grained bed River Style with terrace constraints (PC_PC_Meand_TrCS_DcFp_Fbed) for 4.5 km. Here, unconsolidated fine-grained materials are easily mobilised as the flow is constrained by terraces that reflect long-term incisional processes, with the base level set by the main Waipā River. Becoming more incised further downstream, the Mangapiko River becomes a confined, terrace margin-controlled, fine-grained bed river with occasional inset floodplain pockets (C_TrMC_OccFp_Fbed) for the rest of its course to the Waipā River. Occasional short, sharp peaks in total stream power indicate sites where localised bed level adjustments (i.e. headcuts) are occurring. These features will gradually move upstream as the river continues to incise.

The majority of the laterally unconfined reaches of the Mangapiko sub-catchment can be described as underfit rivers/streams. This is because the contemporary watercourse did not deposit the alluvial material through which they flow. This makes many of these reaches highly insensitive to lateral adjustment as they do not have the energy to rework most of the previously deposited material. They are, however, prone to prolonged flooding as the gradient and composition of the floodplains do not allow for large volumes of water to be drained away quickly, especially those like the Moanatuatua Swamp Drain where the incredibly flat land means that it could be drained towards either the Waipā or Waikato Rivers. This can lead to the formation of backswamps and other localised wetlands. Left to their own devices, these lands would likely gradually return to swamps over time.

By concentrating such a large pre-existing wetland into just a few anthropogenic, single-thread channels, these rivers have been encouraged to incise as they flow through unconsolidated, fine-grained materials. This makes this sub-catchment (and others like it) a very high source of fine-grained sediment which is fed into the Waipā River. In addition to this, this sediment load increases as the bed continues to incise as the multiple headcuts make their way upstream. This, in turn, destabilises the banks and produces further erosion and loss of land. Combined with the intensive farming of the area and low discharge of the Mangapiko stream network, this can result in very poor water quality in this sub-catchment.

4.7 Waipā Catchment

This section discusses the downstream transitions along the main Waipā River channel not already covered in the individual sub-catchment sections, from where the Mangapū River meets the upper Waipā River 66.5 km from its source. Despite a diverse array of distinctive River Styles having been displayed in each sub-catchment so far, the rest of the main Waipā River channel is dominated by long-term incisional processes which have limited the range of geomorphic diversity. The result is the existence of only six River Styles along a 70 km stretch of river, two of which are imposed by highly localised anthropogenic controls, meaning only four of these reaches are the result of the geomorphic processes acting along this river (Figure 4.12). Except for the localised anthropogenic margins, the long-term incision along this stretch of river has caused it to be either fully or partly confined by terrace features along its entire length (Figure 4.13).

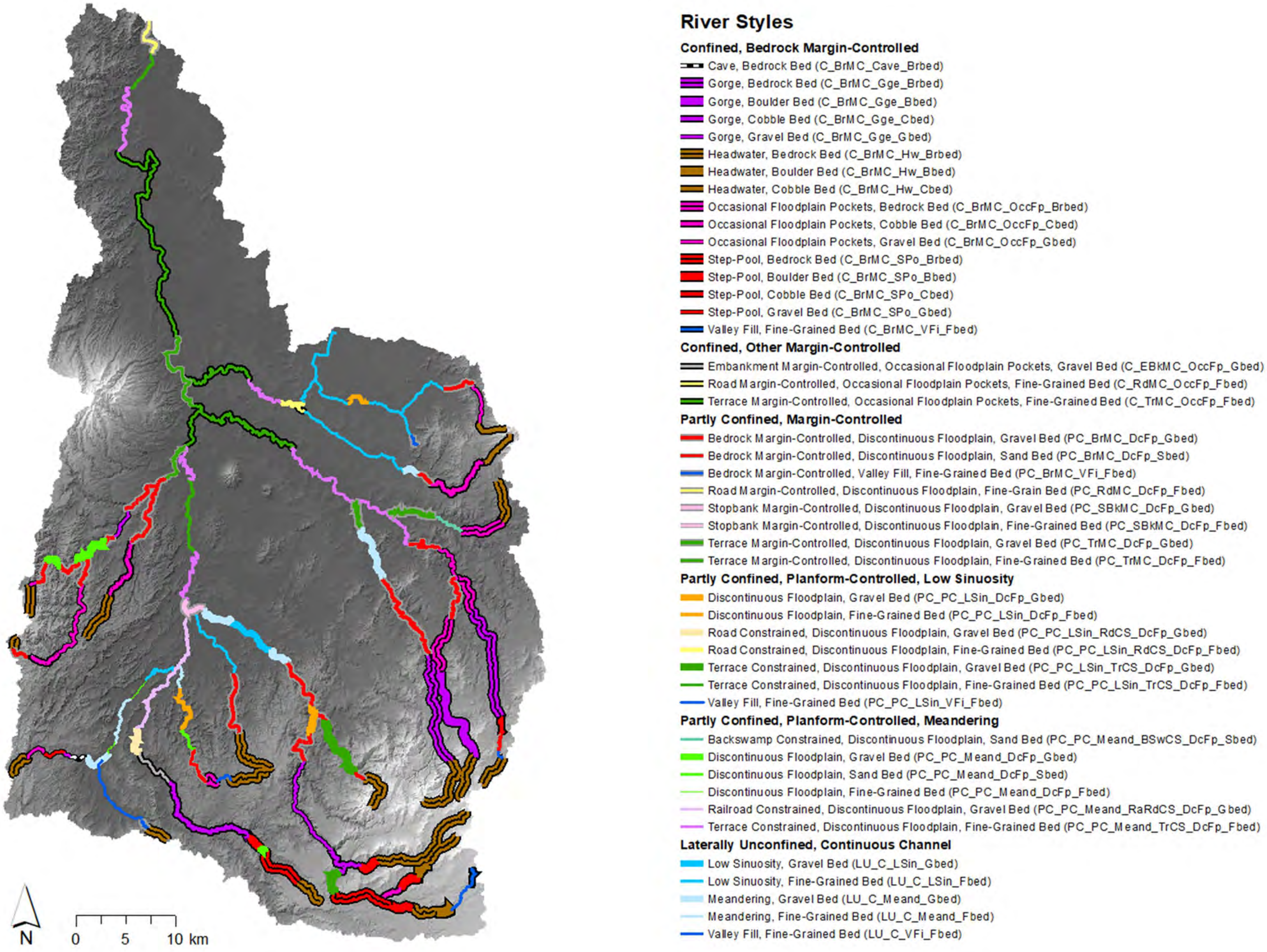

Figure 4.12. A. River Styles identified within the Waipā River Catchment.

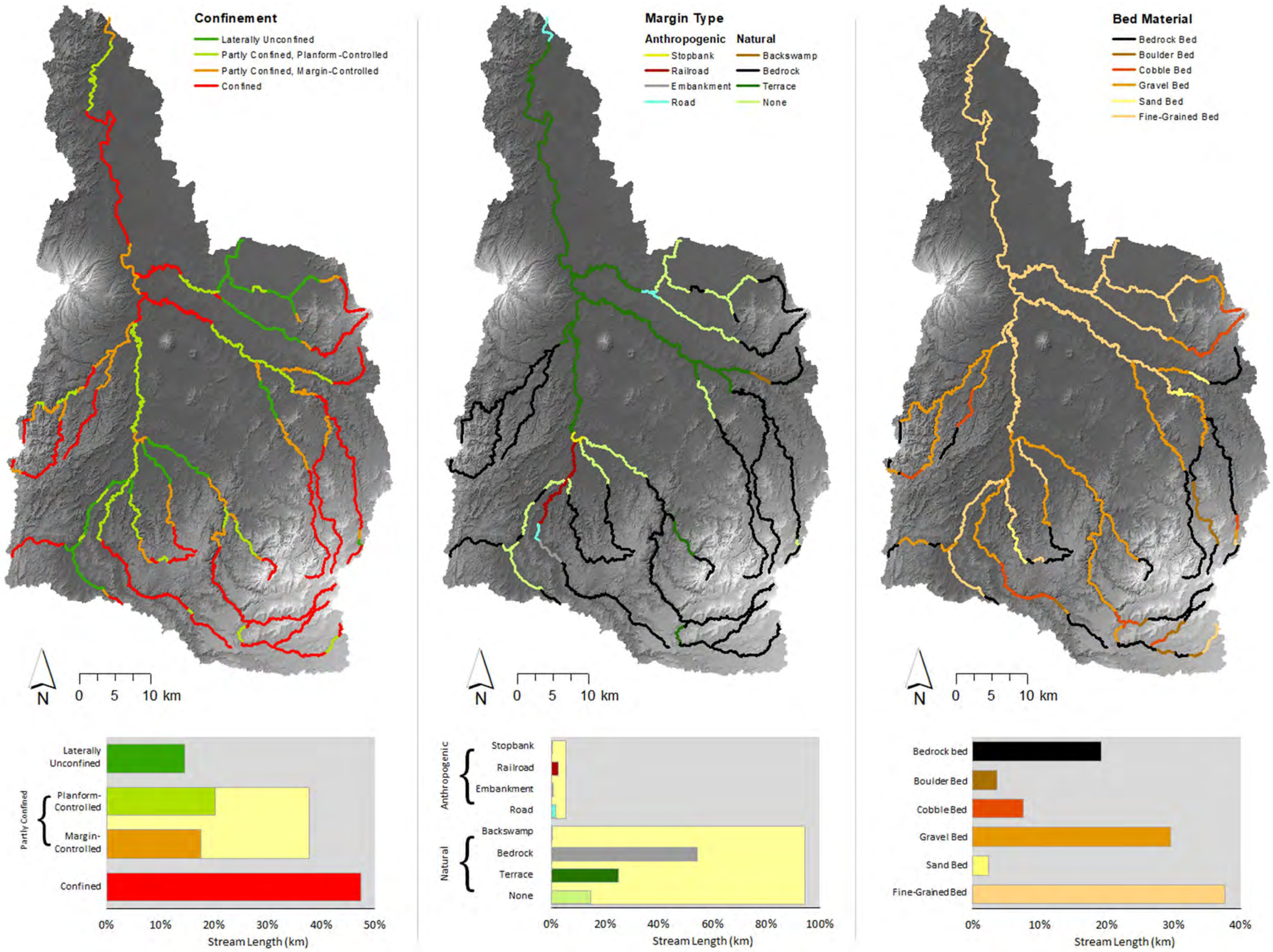

Figure 4.13. Main attributes of River Styles identified in the Waipā River Catchment (degree of confinement, margin type and bed material).

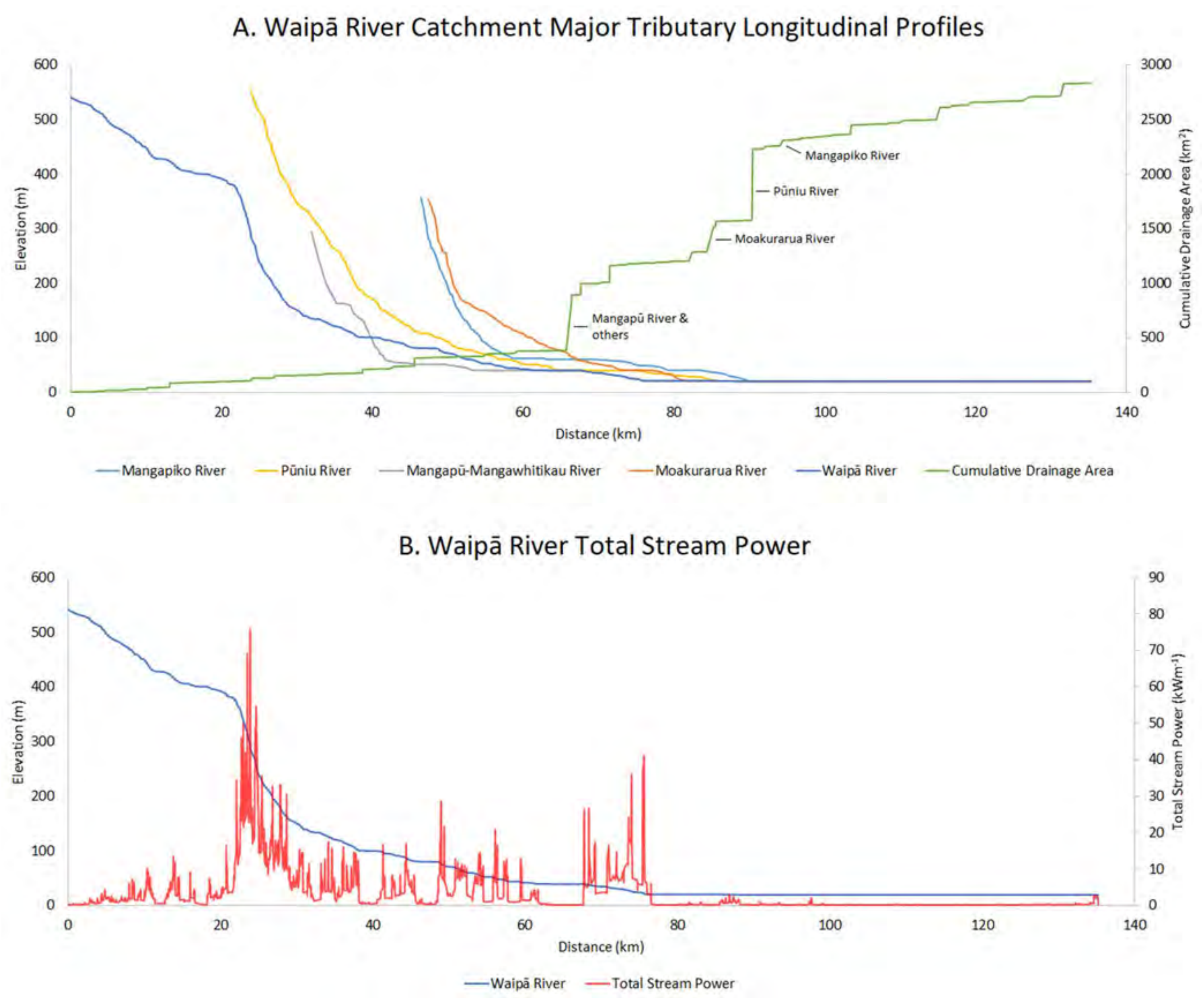

Figure 4.14. Stacked profile plot for the Waipā River main channel, showing the downstream relationship between elevation, cumulative DA (top) and total stream power (bottom). The elevation profiles of the main tributaries from each study sub-catchment are also shown.

After the Mangapū River confluence in Ōtorohanga, a stopbank lined length of the Waipā River flows through the town for 1 km as a partly confined, stopbank margin-controlled, gravel bed River Style (PC_SBkMC_DcFp_Gbed). Stopbanks limit the accommodation space for sediment to be deposited. Hence, any finer-than-gravel sized material is quickly flushed through this reach. The bed level of the river through the town is also managed by past channel works and the weir installed at the upstream extent of the stopbanks (Hoyle et al., 2015; Munro, 2002).

The river then becomes a partly confined, planform controlled, meandering, fine-grained bed river with terrace constraints (PC_PC_Meand_TrCS_DcFp_Fbed) for 6 km. These partly confined, terrace margin-controlled rivers have been able to slowly adjust laterally over time through the scouring and undercutting of their cohesive terrace constraints. This has resulted in what looks like a river channel within a larger river channel along much of their lengths. The river can relatively easily adjust laterally within the terrace constraints, reworking its morphology over time and increasing geomorphic diversity within the terrace boundaries. Allowing the river to do this, dissipates its energy and reduces the capacity of the channel to continue scouring and undercutting the terrace boundaries over time. Despite the meandering form of this reach, it has also been influenced by localised anthropogenic channel straightening in the past, leaving behind a few relatively large oxbow lakes which can become reactivated during over-bank flows.

This reach also coincides with a fairly rapid ~20 m elevation drop along the longitudinal profile (Figure 4.14). This is mainly due to the Ōtorohanga weir and channel works which control the bed level of the river through the town, causing localised aggradation upstream of the town, and then a sudden bed level drop as the river exits the bed level controls to return to the natural bed level of the lower Waipā River. In addition to this, the channel straightening downstream of the town reduces the overall length of the river, further increasing its relative gradient. This gradient increase results in a relatively large and prolonged spike in total stream power between 13.0 kW m^{-1} and 40.5 kW m^{-1}. This may result in excessive pressure placed on the channel geometry throughout this reach, resulting in the scouring and undercutting of banks and terraces and inducing bank instability.

Downstream of this reach, more channel straightening has reduced the sinuosity further, resulting in the next 8.5 km of the river becoming a partly confined, planform-controlled, low sinuosity, fine-grained river with terrace constraints (PC_PC_LSin_TrCS_DcFp_Fbed). It then switches back to a PC_PC_Meand_TrCS_DcFp_Fbed River Style for 3.5 km until it is joined by the Moakurarua River. From here, the Waipā River becomes fully confined by terraces, becoming a 6 km long C_TrMC_OccFp_Fbed River Style. Towards the end of this reach, the river is joined by the Pūniu River before switching to a PC_TrMC_DcFp_Fbed River Style, during which it is also joined by the Mangapiko River. The joining of these two tributaries to the main Waipā River channel also coincides with the upstream extent of the Waikato Fan. Here, the material composition of the land through which the river flows changes from contemporary alluvial deposits to unconsolidated fine-grained material left behind by old Waikato River courses (Figure 2.4 & 2.7). Between the Waipā River mouth and Ōtorohanga, the bed level of the river has incised over time, adjusting to the level of the Waikato River. This incisional influence has also transitioned upstream to the lower portions of the tributaries which join this length of the Waipā River as they flow through similar alluvial landscape units.

Approximately 7 km after being joined by the Mangapiko River, the Waipā River once again becomes fully confined by terraces, switching back to a C_TrMC_OccFp_Fbed River Style for the next 21.5 km. Soon after passing through Whatawhata, it then spends 7 km as a PC_PC_Meand_TrCS_DcFp_Fbed as long-term lateral migration has developed enough accommodation space within the terrace boundaries for confinement to drop below 50%. This particular reach is also characterised by former courses of the Waipā and Waikato Rivers (Figure 2.7) which now carry underfit streams which drain the large confluence zone between these two rivers. Further downstream, the river's sinuosity drops as it approaches the Waikato confluence at Ngāruawāhia, becoming a short partly confined, planform controlled, low sinuosity, fine-grained bed with terrace constraints (PC_PC_LSin_TrCS_DcFp_Fbed). As the extent of the Ngāruawāhia township begins to exert anthropogenic controls on the Waipā River, it transitions to a partly confined, road margin-controlled River Style(PC_RdMC_DcFp_Fbed) before finally completing its journey and joining the Waikato River.

Section 5: Controls on River Styles

5.1 Background

In the five sub-catchments and the broader Waipā Catchment, the variable extent of River Styles reflects a distribution of inherited controls across different scales. Imposed and flux boundary conditions exert significant control on river character, behaviour, and sensitivity to geomorphic change. This following section provides a broad overview of the main controls acting on River Styles within the Waipā Catchment.

5.2 Geology and Geomorphic History (Imposed)

5.2.1 Topography and Valley Setting

Geologic and geomorphic history has left a strong landscape imprint (memory) on the Waipā Catchment, influencing contemporary river character and behaviour and the pattern of River Styles that result. Notions of landscape memory encapsulate principles of antecedence, inheritance, persistence and preservation (Brierley, 2010).

Geological controls upon landscape inheritance determine the relief, topography, and erodibility of a landscape. This, in turn, determines the energy conditions and exerts a primary control upon the effectiveness of erosional processes and the resulting degree of landscape dissection (Brierley, 2010). At a smaller scale, such geologic factors exert a primary influence upon the distribution of sediment source, transfer and accumulation zones (Schumm, 1977). Additionally, geologic controls on valley width fashion the pattern of accommodation space (Brierley, 2010).

In the Waipā Catchment, Quaternary and Holocene geomorphic history has resulted in a large proportion of rivers in the lower catchment being confined by terraces and paleochannels, severely restricting the capacity for adjustment. Additionally, in the upper reaches of the Waipā, many river courses are confined by bedrock margins within uplifted volcanic and sedimentary rock. Therefore, it is only in localised areas behind the Waikato Fan where locally aggraded, laterally unconfined reaches have significant capacity to adjust. These areas make up only a small proportion (~3%) of river length in the Waipā Catchment.

5.2.2 Lithology and Bed Material

Lithology affects the erodibility of bedrock (i.e. its resistance to erosion and the breakdown products that are made available to be reworked). In the lower Waipā, most River Styles consist of fine-grained sediments, as many of the plains are comprised of fine-grained, cohesive, clays and silts, incised within former lakes or drained swamp land (McCraw, 1967, 2011). This has led to channels that have an inherent resilience to geomorphic adjustment, with boundaries that are not easily deformable. In the upper reaches, much of the bedrock has a volcanic origin, and many reaches have bedrock or boulder beds consisting of resistant greywacke, ignimbrite, and sandstone. These reaches also have limited capacity for geomorphic adjustment.

5.2.3 Configuration and Planform

Inter-relationships between river morphology and stream power influence geomorphic river sensitivity. Local channel configuration and planform geometry influence the concentration of flood energy (e.g. Fuller, 2007; Miller, 1995). In lower reaches of the Waipā Catchment, localised adjustment is evident along the outer bends of meandering entrenched rivers and along occasional floodplain pockets between terrace margins (Wheeler, 2019). Channel sinuosity also exerts a strong control on variability in within-reach sensitivity. Along the Waipā, more sinuous meander bends experienced the highest migration rates, as well as reaches directly downstream of meander cut-offs (Wheeler, 2019). These findings aligned with other channel migration studies (Constantine et al., 2014; Sylvester et al., 2019).

5.3 Climate – Magnitude-Frequency Relationships, Geomorphic Effective Floods (Flux)

Large magnitude decadal flood events exert a strong control on geomorphic adjustments on localised reaches that are inherently sensitive to change within the Waipā Catchment. Some major floods produce catastrophic change and accomplish large amounts of geomorphic work (Miller, 1995), while others result in little change (e.g. Costa & O'Connor, 1995; Magilligan et al., 1998). Miller (1995) suggested that if 'catastrophic' floods can be described as those exceeding thresholds of instability, zones can be detected along a drainage system where thresholds may be attained. Magilligan (1998) and Miller (1995) concluded that minimum values of 100 N m^{-2} for shear stress and 300 W m^{-2} for unit stream power are not rigidly absolute thresholds, but closely approximate minimum thresholds.

Analysis of sensitive sites by Wheeler (2019) showed that such sites had unit stream power conditions close to these thresholds under normal flow conditions. As these thresholds are likely to be exceeded regularly, these sites are inherently sensitive to change. This reflects catchment context, as such sensitive sites are in relatively steep alluvial environments, with significant upstream drainage area, that results in high energy conditions. Miller (1995) suggested that large floods in steep mountain valleys are more likely to leave a lasting imprint on the landscape than floods of comparable magnitude in broad, low-gradient, low energy valleys. This, therefore, exerts a strong control on the highly localised nature of channel adjustment and sensitivity in the Waipā Catchment (Wheeler, 2019).

5.4 Highly Modified Systems – (Imposed) Anthropogenic Controls

Geomorphic adjustment and sensitivity in the Waipā Catchment have been strongly affected by anthropogenic factors, as many reaches have been highly modified. Indirect response to vegetation changes and drainage of swamps laid the foundations for disturbance responses to human impacts, prompting significant human actions in recent decades.

In the 1950s and 1960s, management works were carried out in response to the 1958 floods on the Waipā River. This included diversions, channel straightening, cut-offs, and the construction of stopbanks, embankments and a weir. Some channels were also excavated to accommodate larger flood flows. This changed the character and behaviour of many reaches. Additionally, gravel extraction practices that commenced in the late 1970s and 1980s resulted in bed degradation, altering adjustment regimes. Anthropogenic margin controls or constraints (e.g. stopbanks, infrastructure and roading networks) restrict the capacity for adjustment. Additionally, many lowland rivers flow through drained peat and swampland, often within human-made channels.

In recent years, several management schemes introduced by WRC have been directed towards reducing bank erosion and channel migration through hard engineering structures such as large vegetation groynes installed into the floodplain, rock revetments on bends, and flow control structures. These actions have limited the capacity for lateral adjustment, constraining flows within narrow channels. In some areas, soft engineering approaches, such as fencing and riparian planting rehabilitation initiatives, have been applied. The later applications grant space for natural adjustment. This promotes an increase in geomorphic diversity that enhances the range of potential habitats that are important for ecological rejuvenation (Fryirs & Brierley, 2016). Collectively, a suite of anthropogenic activities has been superimposed upon landscape attributes, influencing the River Styles that ensue and their resulting sensitivity to geomorphic adjustment.

5.5 Riparian Vegetation (Flux)

Site-scale analysis carried out by Wheeler (2019) revealed that riparian vegetation exerts a strong control on the stabilisation of banks and limits channel migration. For example, sites along the Waipā and Ōamaru reaches underwent a degree of stabilisation in bank migration and channel narrowing in response to riparian planting and the colonisation of geomorphic units. Such responses are commonly reported in the literature (Abernethy & Rutherfurd, 2000; Rinaldi, 2003). Therefore, riparian initiatives currently underway in the Waipā Catchment are likely to influence future geomorphic adjustment and sensitivity to change.

5.6 Summary

A suite of geomorphic, geologic, climatic, and anthropogenic controls influences the types and patterns of River Styles. This sets the physical template for ecosystems, as well as influencing geomorphic sensitivity in the Waipā Catchment. A strong landscape memory means that only a few localised reaches and bends are sensitive to geomorphic adjustment. Given these localised adjustments and the pattern of River Styles, responses to contemporary disturbance events are accommodated relatively easily in the Waipā Catchment relative to other river systems in Aotearoa New Zealand (cf., Fryirs et al., 2007).

Section 6: Implications of this Study

6.1 Diversity

The wide range of landscape units found throughout the Waipā Catchment results in considerable diversity of River Styles. In many instances, human disturbance has suppressed the range of instream geomorphic diversity, impacting upon the functionality of the physical habitat mosaic of the river. It is recommended that management strategies work with river processes to allow for river diversity, enhancing the formation of instream geomorphic units which are vital for physical habitat variety.

The dynamic physical mosaic of a river system creates and regenerates habitats for freshwater organisms and associated ecosystems (Florsheim et al., 2008; Piégay et al., 2005; Trush et al., 2000). Hence, reaches that are sensitive to geomorphic adjustment may be especially important from an ecological perspective and their identification is important for river rehabilitation and restoration strategies. Used effectively, principles from geomorphology provide the fundamental template with which to frame river management applications, supporting programmes to achieve biodiversity management goals (Brierley & Hooke, 2015; Death et al., 2015; Fuller et al., 2019).

Static banks do not sustain healthy ecosystems (Florsheim et al., 2008; Piégay et al., 2005). In the Waipā Catchment, many channel straightening and hard engineering management initiatives in sensitive zones have altered the geomorphic capacity for adjustment, changing river behaviour and reducing geomorphic diversity. Such activities are not sustainable over longer timeframes, working against ecologically framed rehabilitation initiatives. Understandings of geomorphic sensitivity and prospects for freedom space management interventions are a critical component of integrative approaches to river management.

All too often, bank stabilisation and flood protection measures seek to maintain rivers in place (Biron et al., 2014; Buffin-Bélanger et al., 2015). However, this approach may enhance risk into the future, especially in light of climate change (Stocker et al., 2013). Such measures are unsustainable in economic and ecological terms (Kline & Cahoon, 2010; Kondolf, 2011; Piégay et al., 2005). Bank stabilisation and flood protection measures such as stopbanks tend to “fossilise” rivers by preventing channel adjustment, migration and limiting connection with the floodplain (Kondolf, 2011). They also require frequent maintenance (Kline & Cahoon, 2010) and may be damaging to habitat diversity (Kondolf, 2011). Buffin-Bélanger et al. (2015) applied a cost-benefit analysis to demonstrate savings made by allowing the river to freely migrate. Savings achieved through removing construction and maintenance costs of structures far outweighed the costs associated with loss of productivity for farmers and loss of property that are part of the corridor. In addition to this, the removal of stopbanks has been proven to be an effective method for restoring geomorphic diversity to the river system (Williams et al., 2020). Hence, providing space for natural migration and flooding appears to be a sensible approach to the sustainable management of flood and erosion risk, and enhancing overall river restoration (Biron et al., 2014; Kondolf, 2011; Piégay et al., 2005).

Application of such principles relies on the identification of spaces necessary for rivers to adjust (and flood) to ensure both public security and ecological services (Biron et al., 2014). Catchment-scale analysis of reaches that are sensitive to geomorphic adjustment and change underpins these efforts. In catchments such as the Waipā, only certain reaches are sensitive to geomorphic adjustment. These locations are highlighted in the following section which can be used to apply rehabilitation initiatives.

6.2 Sensitivity

Figure 6.1 shows the small proportion of the Waipā Catchment that has significant capacity for geomorphic adjustment. This largely reflects an imprint of landscape units. Many upper reaches are confined by bedrock margins as channels descend from the volcanic plateau and uplifted highlands. Additionally, many of the lower reaches are entrenched in Late Pleistocene or Waikato Fan alluvium or constrained by anthropogenic margins (e.g. stopbanks). Therefore, only a small proportion of the Waipā Catchment has the accommodation space that is required to create River Styles that are sensitive to geomorphic adjustment. Hence, the catchment is considered to be a resilient system, with only localised reaches that are sensitive to change (Wheeler, 2019). Where this is paired with high stream power, as well as easily mobilised sediments, dynamic rivers result.

Spatial patterns of sensitivity also vary between the sub-catchments due to the variation in landscape units. For instance, the Moakurarua and Pūniu sub-catchments are considered to be resilient catchments, with only localised areas that have significant capacity to adjust. This is representative of large extents of bedrock or terrace margin-control valley settings. In addition, the Moakurarua and Pūniu channels both become entrenched in Late Pleistocene and Holocene alluvium (Waikato Fan) as they join the Waipā, limiting their capacity for adjustment. Reaches that are potentially sensitive to adjustment in the Moakurarua sub-catchment are restricted to partly confined planform-controlled variants at the confluence of the Ōamaru and Moakurarua Streams, where energy conditions and valley setting permit significant capacity for adjustment. Whereas in the Pūniu sub-catchment, only a single laterally unconfined reach is considered to be highly sensitive. This reach lies towards the lower end of the Mangatutu Stream as it exits the upland bedrock margin areas and flows out onto the lower alluvial plains. As its bed level already matches the bed level of the Pūniu

River along this reach, it has not incised. However, it would be highly susceptible to incision if any cross-catchment bed level adjustments were to occur.

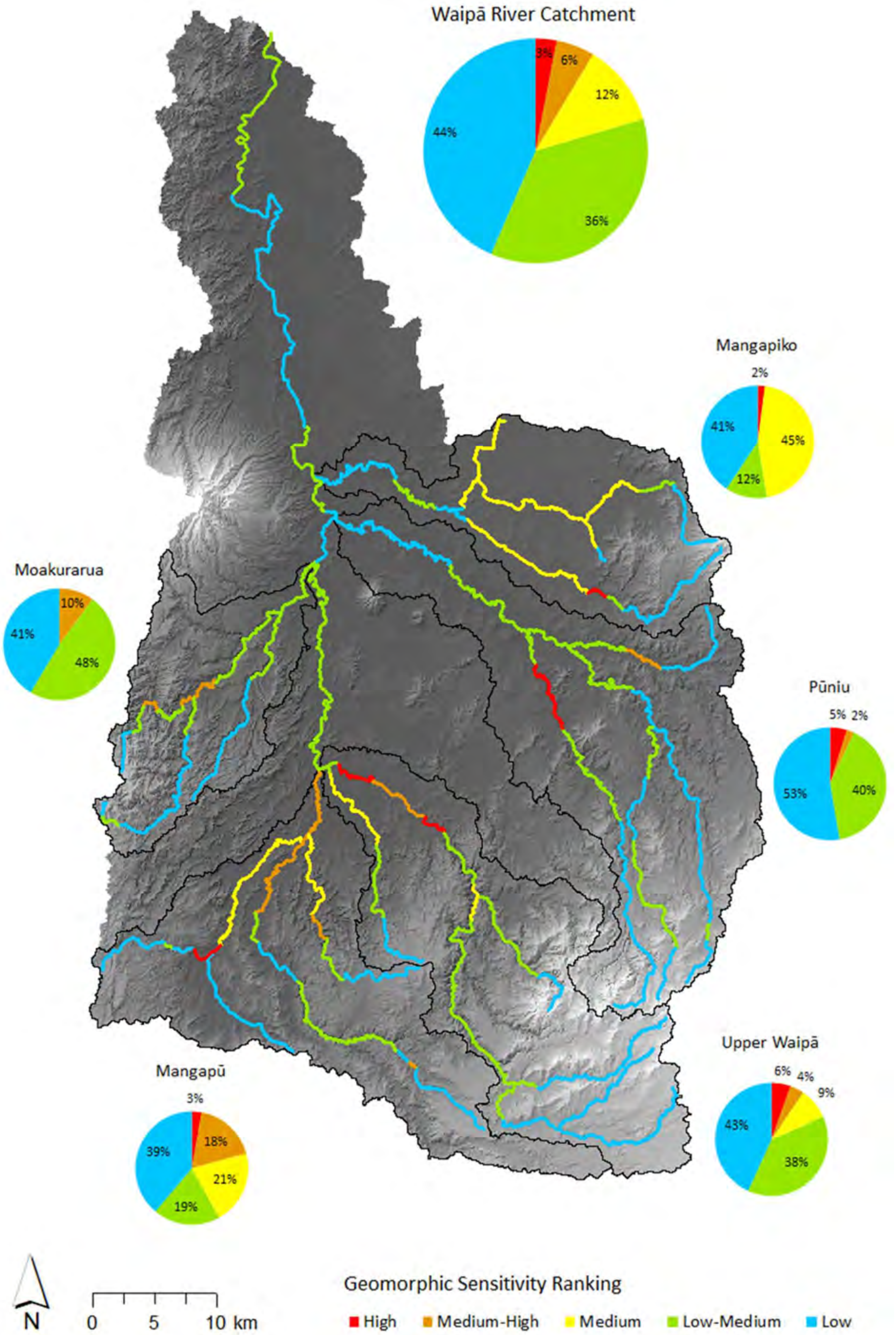

Figure 6.1. Geomorphic sensitivity rankings of the Waipā Catchment and study sub-catchments. Pie charts show the proportion of each sensitivity ranking within each catchment.

In the Mangapū and Mangapiko sub-catchments, larger proportions of reaches have a greater capacity for adjustment compared with the Moakurarua and Pūniu sub-catchments. However, most reaches remain resilient to adjustment as they flow within confined and partly confined bedrock or terrace margin-control settings. In addition, reaches through Te Kūiti and Te Awamutu are constrained by anthropogenic constraints and reaches downstream are highly entrenched. The large proportion of laterally unconfined reaches in the Mangapiko sub-catchment are responsible for the proportionate number of moderately sensitive reaches found here, as the lack of lateral constraints grants these channels with large amounts of accommodation space. However, the flatness of the terrain in this region means that these rivers lack the energy to rework floodplains quickly, even when floods occur.

As the Upper Waipā sub-catchment can maintain a relatively high stream power due the steep descent from the volcanic plateau, even as it enters the flatter alluvial plains towards the lower portion of the region it can produce some moderate to high sensitivity reaches. This is especially evident where these characteristics coincide with laterally unconfined settings. Yet, the system in general, much like the rest of the Waipā catchment, is very resilient to lateral geomorphic change. The high proportion of confined and partly confined bedrock River Styles limit its capacity for adjustment. However, a weir which has been installed just before the river enters Ōtorohanga has altered the bed level, creating a prominent elevation step shown approximately halfway along the Waipā River elevation profile (Figure 4.13). This weir has caused this sub-catchment to become disconnected from the rest of the Waipā catchment. This sub-catchment also contains some of the most sensitive reaches found along the studied Waipā stream network (Figure 6.1). These localised ‘geomorphic hotspots’ (cf., Czuba & Foufoula-Georgiou, 2015) are found where some of the first laterally unconfined valley settings coincide with high energy conditions and high gravel sediment loads (e.g. downstream of steep gorges), resulting in the ‘perfect storm’ for geomorphic adjustment where such zones are highly sensitive to change (Wheeler, 2019). Such reaches are an example of where initiatives mentioned previously (Section 6.1) could be applied.

6.3 Emerging Technology

Emerging technology and techniques are transforming how we see riverscapes, changing approaches to systematic catchment-scale analyses of river processes. However, great care must be taken in the application and use of these geomorphic tools (Marson, 2019). Often, geomorphic understanding is required to make sensible interpretations of tool outputs (Blue & Brierley, 2016; Fryirs et al., 2019). Many tools tend to be rather simplified, as they are designed for use by non- geomorphologists. This can lead to misrepresentation or misinterpretation if used by non- experts (Hooke, 2019). In addition to this, the lack of accurate and reliable informing data with sufficient spatial coverage limits the capability of such tools to appraise to the pattern of downstream and cross-catchment processes for entire catchments in Aotearoa New Zealand (Marson, 2019). Hence, effective use of emerging technologies entails awareness of their limitations, applying them alongside field-based appraisals of the landscape.

However, as is the case with most modern-day technology, progress in this area is constantly moving forward. Open-source GIS-based tools and the utilisation of machine learning are quickly evolving in this area of research and making geomorphic mapping and assessment tools increasingly accessible and easy to use (Brown & Pasternack, 2019; Guillon et al., 2020; O'Brien et al., 2019). Furthermore, with higher resolution data becoming increasingly more available over time, combined with the fundamental ability to transfer and quantify the informing principles that underly the River Styles Framework approach to geomorphic interpretations of riverscapes, automated tools will continue to be developed which will be able to extract and map detailed catchment-scale appraisals of river form and sensitivity. Such tools will prove incredibly useful to future river managers for highlighting areas of focus across their entire area of responsibility in a very timely manner.

Section 7: Concluding Comment

Application of Stage One of the River Styles Framework provides catchment-wide understandings of geomorphic diversity, as well as the controls on river character and behaviour. This provides insight into the physical template of the river, underpinning interrelationships with ecosystem health. In this study, sub-catchments of the Waipā Catchment were found to have a diverse array of River Styles, reflecting the strong diversity of landscape units within the catchment. This influences the character and behaviour of different rivers and their sensitivity to geomorphic adjustment. This is inferred to influence their aquatic biodiversity.

Findings show that the Waipā Catchment comprises primarily geomorphologically resilient rivers, with only localised areas that are sensitive to change. As geomorphic responses to catchment disturbances in recent decades have been limited and not especially pronounced, off-site impacts are likely to be insignificant other than the enhanced conveyance of fine-grained sediments as suspended load materials. Findings from this study can support cost-effective approaches to proactive river management and rehabilitation. For example, highlighting sensitive reaches that are prone to bank erosion and lateral adjustment could be used to apply freedom space initiatives that support diverse habitat creation. Also, areas to focus riparian planting initiatives can be highlighted in an effort to reduce suspended sediment yields in the Waipā River.

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Appendix A: River Styles

Table A1. Summary of River Styles identified within the Waipā River Catchment study stream network. The overall length of each River Style and their representative proportions are also presented (supplementary to Figure 4.1).

River Style (Abbreviated & Full names)	Key Characteristics and Geomorphic Features	Length (km)	Percentage (of rivers analysed)
C_BrMC_Cave_Brbed Confined, bedrock margin-controlled, cave, bedrock bed.	Underground cave network in limestone karst landscape with stalactites, stalagmites, cascades and step-pool sequences.	2.66	0.37%
C_BrMC_Gge_Brbed Confined, bedrock margin-controlled, gorge, bedrock bed.	Incised gorge with bedrock and boulder steps, cascades, rapids, runs, pools and boulder bars.	27.40	3.77%
C_BrMC_Gge_Bbed Confined, bedrock margin-controlled, gorge, boulder bed.	Incised gorge with bedrock and boulder steps, waterfalls, cascades, runs, rapids, pools and boulder bars.	12.62	1.74%
C_BrMC_Gge_Cbed Confined, bedrock margin-controlled, gorge, cobble bed.	Incised gorge with bedrock and cobble steps, cascades, runs, pools, bedrock-controlled islands and bank-attached gravel bars. Small occasional floodplain pockets present.	20.86	2.87%
C_BrMC_Gge_Gbed Confined, bedrock margin-controlled, gorge, gravel bed.	Incised gorge with cascades, gravel longitudinal/lateral bars, point bars, pools and riffles. Small occasional floodplain pockets present, with pumice terrace features present in the Upper Waipa.	17.06	2.35%
C_BrMC_Hw_Brbed Confined, bedrock margin-controlled, headwater, bedrock bed.	Headwater stream with bedrock steps and bedrock induced pools. Very small occasional floodplain pockets present.	78.56	10.82%
C_BrMC_Hw_Bbed Confined, bedrock margin-controlled, headwater, boulder bed.	Headwater stream with bedrock steps and boulder-forced pools.	4.47	0.61%
C_BrMC_Hw_Cbed Confined, bedrock margin-controlled, headwater, cobble bed.	Headwater stream with bedrock steps and bedrock induced pools, cascades and runs.	8.59	1.18%
C_BrMC_OccFp_Brbed Confined, bedrock margin-controlled, occasional floodplain pockets, bedrock bed.	Single thread channel with bedrock induced pools and steps, riffles, point bars and uniform glides. Occasional floodplain pockets present.	18.31	2.52%
C_BrMC_OccFp_Cbed Confined, bedrock margin-controlled, occasional floodplain pockets, cobble bed.	Single thread channel with cascades, bedrock-forced step pool features, vegetated lateral bars, cobble point bars and lateral bars. Occasional floodplain pockets present.	23.43	3.23%
C_BrMC_OccFp_Gbed Confined, bedrock margin-controlled, occasional floodplain pockets, gravel bed.	Single thread channel with cascades, vegetated lateral bars, point bars and mid-channel bars. Occasional floodplain pockets present.	24.57	3.38%
C_BrMC_SPo_Brbed Confined, bedrock margin-controlled, step-pool sequences, bedrock bed.	Single thread channel with step-pool sequences, bedrock cascades, waterfalls and possible cave network (Upper Waipa). Occasional floodplain pockets present.	12.78	1.76%
C_BrMC_SPo_Bbed Confined, bedrock margin-controlled, step-pool sequences, boulder bed.	Single thread channel with step-pool sequences, bedrock and boulder cascades, waterfalls and coarse bars. Occasional floodplain pockets present, with older terrace (pumice in places) features.	9.22	1.27%

C_BrMC_SPo_Cbed Confined, bedrock margin-controlled, step-pool sequences, cobble bed.	Single thread channel with step-pool sequences, bedrock and cobble cascades, waterfalls and coarse bars. Small occasional floodplain pockets present.	2.24	0.31%
C_BrMC_SPo_Gbed Confined, bedrock margin-controlled, step-pool sequences, gravel bed.	Single thread channel with step-pool sequences, riffles, glides, runs and cascades. Very small occasional floodplain pockets present in places.	2.50	0.34%
C_BrMC_VFi_Fbed Confined, bedrock margin-controlled, valley fill, fine-grained bed.	Valley fill with backswamps and sculpted runs, with bedrock outcrops.	2.19	0.30%
C_EBkMC_OccFp_Gbed Confined, embankment margin-controlled, occasional floodplain pockets, gravel bed.	Entrenched single thread channel within man-made embankments, deprived of in-channel geomorphic units, but some occasional lateral bars. Occasional inset floodplain pockets and older disconnected urbanised floodplain.	5.25	0.72%
C_RdMC_OccFp_Fbed Confined, road margin-controlled, occasional floodplain pockets, fine-grained bed.	Entrenched single thread channel within road margins, deprived of in-channel geomorphic units, but with some occasional lateral bars. Occasional inset floodplain pockets and older disconnected urbanised floodplain.	1.67	0.23%
C_TrMC_OccFp_Fbed Confined, terrace margin-controlled, occasional floodplain pockets, fine-grained bed.	Entrenched single thread slot channel within terrace margins, with meander cut-offs from channel straightening practices. Occasional sculpted point bars and localised large woody debris forced pools. Occasional inset floodplain pockets, with disconnected terrace floodplain (Waikato Fan).	70.52	9.71%
PC_BrMC_DcFp_Gbed Partly confined, bedrock margin-controlled, discontinuous floodplain, gravel bed.	Single thread channel with pools, riffles, gravels bars (point, lateral/bank attached bars with chute channels), benches, point benches and ledges. Discontinuous floodplain present.	78.68	10.83%
PC_BrMC_DcFp_Sbed Partly confined, bedrock margin-controlled, discontinuous floodplain, sand bed.	Single thread channel with pools, riffles, runs and small sand bars. Discontinuous floodplain present.	10.41	1.43%
PC_BrMC_VFi_Fbed Partly confined, bedrock margin-controlled, valley fill, fine-grained bed.	Valley fill with sculpted runs.	2.50	0.34%
PC_RdMC_DcFp_Fbed Partly confined, road margin-controlled, discontinuous floodplain, fine-grained bed.	Entrenched single thread channel within road margins, deprived of in-channel geomorphic units. Discontinuous inset floodplain pockets and older disconnected urbanised floodplain.	4.62	0.64%
PC_SBkMC_DcFp_Gbed Partly confined, stopbank margin-controlled, discontinuous floodplain, gravel bed.	Entrenched single thread channel within stopbank margins, deprived of in-channel geomorphic units, but some occasional lateral bars present. Discontinuous inset floodplain pockets and older disconnected urbanised floodplain.	3.31	0.46%
PC_SBkMC_DcFp_Fbed Partly confined, stopbank margin-controlled, discontinuous floodplain, fine-grained bed.	Entrenched single thread channel within stopbank margins, deprived of in-channel geomorphic units, but some occasional lateral bars present and localised large woody debris forced pools. Discontinuous inset floodplain pockets and older disconnected urbanised floodplain.	0.52	0.07%
PC_TrMC_DcFp_Gbed Partly confined, terrace margin-controlled, discontinuous floodplain, gravel bed.	Entrenched single thread channel within terrace margins, with benches, ledges, occasional bank-attached lateral bars and point bars. Discontinuous inset floodplain pockets and older disconnected terrace floodplain (Waikato Fan).	10.80	1.49%
PC_TrMC_DcFp_Fbed Partly confined, terrace margin-controlled, discontinuous floodplain, fine-grained bed.	Entrenched single thread channel within terrace margins, with benches, ledges, occasional bank-attached lateral bars, point bars, riffles and sculpted pumice bedrock outcrops. Discontinuous inset floodplain pockets and older disconnected terrace floodplain (Waikato Fan).	17.16	2.36%
PC_PC_LSin_DcFp_Gbed	Single thread channel with mid-channel bars, point and lateral bars, forced pools, ledges and benches. Discontinuous floodplain present.	3.59	0.49%

Partly confined, planform-controlled, low sinuosity, discontinuous floodplain, gravel bed.			
PC_PC_LSin_DcFp_Fbed Partly confined, planform-controlled, low sinuosity, discontinuous floodplain, fine-grained bed.	Single thread channel, with long uniform glides but deprived of other in-channel geomorphic units. Discontinuous floodplain present.	9.50	1.31%
PC_PC_LSin_RdCS_DcFp_Gbed Partly confined, planform-controlled, low sinuosity, road constrained, discontinuous floodplain, gravel bed.	Single thread channel constrained by the road in places, with long glides, woody debris forces pools, ledges and benches, but deprived of other in-stream geomorphic units. Discontinuous floodplain present.	3.31	0.46%
PC_PC_LSin_RdCS_DcFp_Fbed Partly confined, planform-controlled, low sinuosity, road constrained, discontinuous floodplain, fine-grained bed.	Incised single thread channel constrained by the road in places, with long glides but deprived of other in-channel geomorphic units. Discontinuous floodplain present.	2.90	0.40%
PC_PC_LSin_TrCS_DcFp_Gbed Partly confined, planform-controlled, low sinuosity, terrace constrained, discontinuous floodplain, gravel bed.	Single thread channel constrained by terraces, with long glides and occasional woody debris forced pools, but deprived of other in-channel geomorphic units. Discontinuous floodplain with occasional backswamps and flood channels present.	10.14	1.40%
PC_PC_LSin_TrCS_DcFp_Fbed Partly confined, planform-controlled, low sinuosity, terrace constrained, discontinuous floodplain, fine-grained bed.	Incised single thread channel with some terrace constraints, with long glides and occasional woody debris forced pools, but deprived of other in-channel geomorphic units. Discontinuous floodplain present.	14.61	2.01%
PC_PC_LSin_VFi_Fbed Partly confined, planform-controlled, low sinuosity, valley fill, fine-grained bed.	Single thread channel within valley fill with sculpted runs.	5.67	0.78%
PC_PC_Meand_BSwCS_DcFp_Sbed Partly confined, planform-controlled, meandering, backswamp constrained, discontinuous floodplain, sand bed.	Single thread channel constrained by backswamps in places, with occasional mid-channel islands, woody debris and in-channel vegetation forced bars and islands. Discontinuous floodplain present.	3.80	0.52%
PC_PC_Meand_DcFp_Gbed Partly confined, planform-controlled, meandering, discontinuous floodplain, gravel bed.	Single thread channel with mid-channel bars, point bars, point benches, ledges, man-made riffles and rock groynes. Discontinuous floodplain present with natural oxbow cut-offs and paleochannels.	8.98	1.24%
PC_PC_Meand_DcFp_Sbed Partly confined, planform-controlled, meandering, discontinuous floodplain, sand bed.	Single thread channel with mid-channel bars, point bars, point benches and ledges. Discontinuous floodplain present with oxbow cut-off and paleochannels.	2.86	0.39%
PC_PC_Meand_DcFp_Fbed Partly confined, planform-controlled, meandering, discontinuous floodplain, fine-grained bed.	Single thread channel with mid-channel bars, point bars, point benches and ledges. Discontinuous floodplain present with paleochannels from channel straightening practices and backswamps.	4.88	0.67%
PC_PC_Meand_RaRdCS_DcFp_Gbed Partly confined, planform-controlled, meandering, railroad constrained, discontinuous floodplain, gravel bed.	Incised single thread channel with railroad constraints, with long glides, ledges and forced pools, but deprived of other in-channel geomorphic units. Discontinuous floodplain present.	18.77	2.58%
PC_PC_Meand_TrCS_DcFp_Fbed Partly confined, planform-controlled, meandering, terrace	Incised single thread channel with some terrace constraints, with ledges, forced pools and occasional point bars, but deprived of other in-channel geomorphic units. Discontinuous floodplain present with oxbow cut-offs and paleochannels from channel straightening practices.	57.75	7.95%

constrained, discontinuous floodplain, fine-grained bed.			
LU_C_LSin_Gbed Laterally unconfined, continuous channel, low sinuosity, gravel bed.	Single thread channel with ledges, mid-channel bars, point bars and forced pools. Continuous floodplain present with oxbow cut-offs and paleochannels from channel straightening.	5.73	0.79%
LU_C_LSin_Fbed Laterally unconfined, continuous channel, low sinuosity, fine-grained bed.	Single thread channel with long glides but deprived of other in-channel geomorphic units. Continuous floodplain present with oxbow cut-offs and paleochannels from channel straightening.	58.00	7.99%
LU_C_Meand_Gbed Laterally unconfined, continuous channel, meandering, gravel bed.	Single thread channel with ledges, mid-channel bars, point bars, forced pools and occasional man-made groyne structures. Continuous floodplain present with oxbow cut-offs and paleochannels from channel straightening.	22.06	3.04%
LU_C_Meand_Fbed Laterally unconfined, continuous channel, meandering, fine-grained bed.	Single thread channel with benches, ledges, pools, in-channel islands and large woody debris forced pools. Continuous floodplain with benches, ledges, pools, mid-channel islands and large woody debris forced pools.	10.25	1.41%
LU_C_VFi_Fbed Laterally unconfined, continuous channel, valley fill, fine-grained bed.	Single thread channel within valley fill with sculpted runs and ledges, but deprived of other in-channel geomorphic units.	10.43	1.44%

Appendix B: River Style Proformas

B.1. Confined, Bedrock Margin-Controlled, Cave, Bedrock bed (C_BrMC_Cave_BrBed)

Location(s): Moakurarua River and Mangawhitikau Stream

Distinguishing attributes: This River Style is set in a confined setting within a limestone karst landscape, where the channel flows into an underground cave network and is fed by multiple sinkholes. The channel abuts bedrock 100% of the time and is trapped underground within limestone bedrock. Some gravels are transported through the system. Adjustment is in the form of long term degradational dissolution processes.

Figure B.1. Photograph showing the Mangawhitikau Stream entering the Mangawhitikau Cave network, representative of the C_BrMC_Cave_BrBed River Style.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°19'34.57"S, 175° 4'27.94"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of a fully enclosed, bedrock cave.
Channel Planform	Channel abuts bedrock 100% of the time and channel configuration is dictated by long term dissolution of limestone bedding plains in this karst landscape.
Bed material texture	Bedrock bed with gravels
Channel geometry	Limestone cave
Geomorphic Units	Within-channel • Cave – stalactites and stalagmites • Some cascades, step-pool sequences • Channel is narrow and confined by bedrock Floodplain • n/a
Vegetation associations	n/a

RIVER BEHAVIOUR
Low Flow Behaviour
The river flows underground, with pooling behind some disruptions, with occasional cascades occurring.
Bankfull Behaviour

The gravel sediment is mobilised, and sediments may be flushed through the cave network. Channel is very stable due to bedrock control. Some localised erosion may occur, through both scour and dissolution processes. **Overbank Behaviour** n/a

CONTROLS	
Landscape Setting and within-catchment position	Found in the upper catchment area, within limestone karst landscape.
Valley Morphology	Undulating karst, with sinkholes that feed the underground cave network
Process Zone	Sediment source/transport zone
Channel Slope	Unknown
Upstream Catchment Area	20 km^2 on the Mangawhitikau Stream, 19 km^2 on the Mangapū Stream

B.2. Confined, Bedrock Margin-Controlled, Gorge, Bedrock Bed (C_BrMC_Gge_BrBed)

Location(s): Mangatutu Stream and Waipari Stream

Distinguishing attributes: This River Style is set within a highly confined valley setting, set within a gorge. The channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor. The channel configuration is dictated by valley alignment. The bed material consists mainly of bedrock, with some larger clasts overlaid.

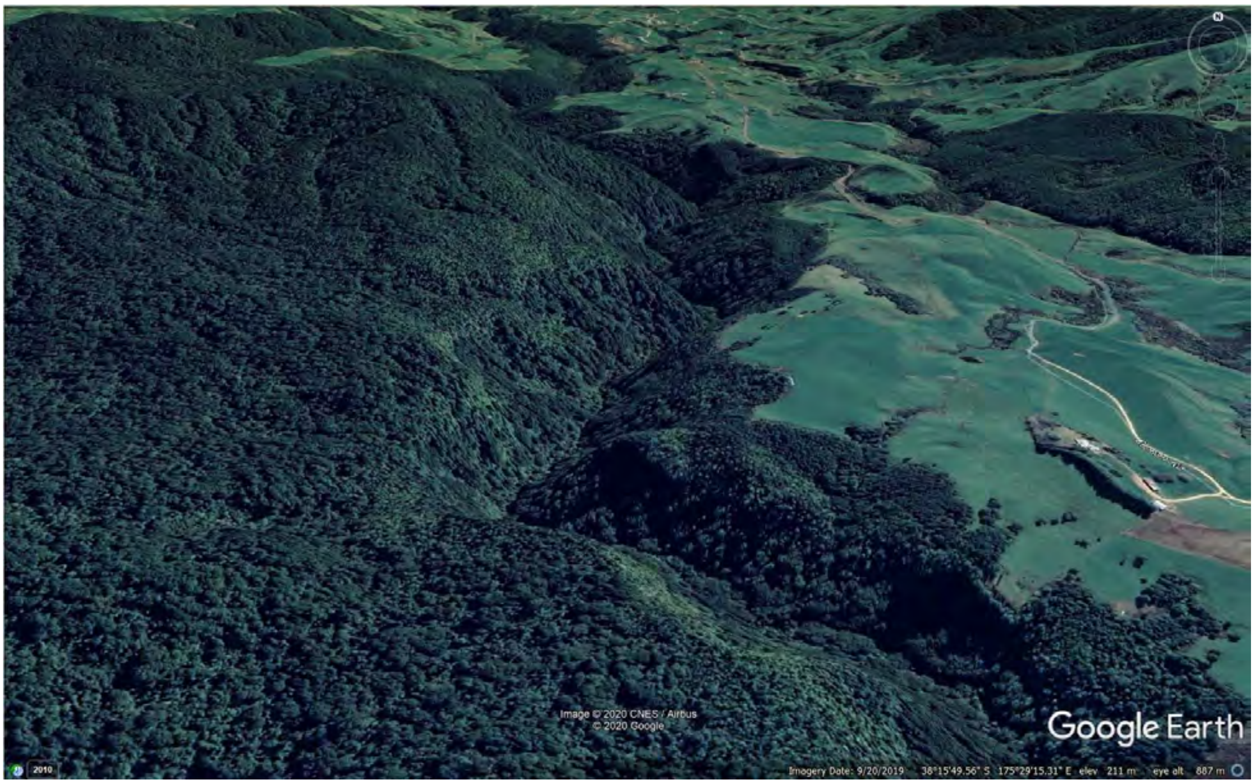

Figure B.2. Google Earth image showing a reach of the Mangatutu Stream, a representative reach of the C_BrMC_Gge_BrBed River Style.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°15'52.81"S, 175°29'12.24"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of steep, gorge faces, which can be unstable in places and be prone to slips.

Channel Planform	Set within a V-shaped valley, with no floodplain. Stable single channel with low sinuosity. Morphology is imposed by valley shape.
Bed material texture	Predominantly bedrock, overlaid by large clasts
Channel geometry	Irregular, bedrock confined with a continuous channel.
Geomorphic Units	Within-channel • Bedrock and boulder steps • Cascades, runs and rapids • Bedrock controlled pools • Boulder bars Floodplain – not present
Vegetation associations	Valley sides are covered in native bush.

RIVER BEHAVIOUR
Low Flow Behaviour Low flow occurs over irregular bedrock bed and around coarse substrate producing significant hydraulic diversity. Extremely stable channel setting, with limited capacity for adjustment. Steep, fast-flowing bedrock-confined river with limited sediment storage. **Bankfull/Overbank Behaviour** As bedrock valley margins form the channel margin, there is no room for lateral movement or floodplain formation. Very high stream powers can move coarse bedload and re-arrange the geomorphic unit assemblage and the channel bed. In general, the assemblage of geomorphic units is dominated by high energy bedrock and larger clast sculpted features. The type formed is dependent on substrate character, slope, and the arrangement of coarse substrate on the valley floor. In extremely high flow events, the valley sides can be undercut which can lead to landslides which produce the boulders and coarse sediments present on the valley floor.

CONTROLS	
Landscape Setting and within-catchment position	Typically found in rugged settings in the upper catchment positions.
Valley Morphology	50-100 m wide with steep bedrock valley margins, up to 50 m deep
Process Zone	Source zone
Channel Slope	0.065 m/m (Mangatutu Stream), 0.031 m/m (Waipari Stream)
Upstream Catchment Area	22 km^2 (Mangatutu Stream), 24 km^2 (Waipari Stream)

B.3. Confined, Bedrock Margin-Controlled, Gorge, Boulder bed (C_BrMC_Gge_Bbed)

Location(s): Pūniu River and Mangaokewa Stream

Distinguishing attributes: This River Style is found in a confined gorge valley setting. It has a steep, confined channel with bedrock margins and no floodplain. The very coarse gravels and boulders which make up the bed material are reflective of the high stream power through this River Style.

Figure B.3. Photograph representative of the C_BrMC_Gge_Bbed River Style along the Mangaokewa Stream.

Figure B.4. Photograph representative of the C_BrMC_Gge_Bbed River Style along the Mangaokewa Stream.

Figure B.5. Google Earth image showing a representative reach for the C_BrMC_Gge_Bbed River Style along the Mangaokewa Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Mangaokewa: 38°27'46.23"S, 175°20'42.25"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of steep, gorge faces, which can be unstable in places and be prone to slips.
Channel Planform	Set within a V-shaped valley, with no floodplain. Stable single channel with low sinuosity. Morphology is imposed by valley shape.
Bed material texture	Bedrock, with angular boulders up to 2 m (b-axis).

Channel geometry	Irregular, bedrock confined with channel up to 10 m wide.
Geomorphic Units	Within-channel • Bedrock and boulder steps • Cascades, runs and rapids • Waterfalls • Bedrock-controlled pools • Boulder bars Floodplain – not present
Vegetation associations	Occasional pockets within the channel where boulders can shelter them from high flow events. Valley sides are well vegetated with native bush.

RIVER BEHAVIOUR
Low Flow Behaviour Low flow occurs around coarse substrate producing significant hydraulic diversity. Extremely stable channel setting, with limited capacity for adjustment. Steep, fast-flowing bedrock-confined river with limited sediment storage. **Bankfull/Overbank Behaviour** As bedrock valley margins form the channel margin, there is no room for lateral movement or floodplain formation. Very high stream powers can move coarse bedload and re-arrange the geomorphic unit assemblage and the channel bed. In general, the assemblage of geomorphic units is dominated by high energy bedrock and boulder sculpted features. The type formed is dependent on substrate character, slope, and the arrangement of boulders on the valley floor. The river acts as a sediment throughput zone. In extremely high flow events, the valley sides can be undercut which can lead to landslides which produce the boulders present on the valley floor and form a sediment supply to the reaches downstream.

CONTROLS	
Landscape Setting and within-catchment position	Typically found in rugged settings in the upper catchment positions.
Valley Morphology	50-100 m wide with steep bedrock valley margins, up to 100 m deep
Process Zone	Sediment source
Channel Slope	0.039 m/m (Mangaokewa Stream), 0.024 m/m (Pūniu River)
Upstream Catchment Area	50 km^2 (Mangaokewa Stream), 18 km^2 (Pūniu River)

B.4. Confined, Bedrock Margin-Controlled, Gorge, Cobble bed (C_BrMC_Gge_Cbed)

Location(s): Mangaokewa Stream and Okahukura Stream/Waipā River confluence

Distinguishing attributes: This River Style is found in a confined valley setting. It has a steep, confined channel with bedrock margins and occasional small pockets of floodplain in places where the valley is locally wider. Very coarse gravel/cobble bedload, representative of a high energy system. As the Mangaokewa stream approaches Te Kūiti, the valley widens as it transitions into a partly confined setting.

Figure B.6. Google Earth image showing a representative reach of the C_BrMC_Gge_Cbed River Style along the Mangaokewa Stream.

Figure B.7. Google Earth image showing a representative reach of the C_BrMC_Gge_Cbed River Style along the upper Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Mangaokewa: 38°21'50.70"S, 175°11'52.37"E; Waipā: 38°24'42.59"S, 175°22'53.63"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of steep, gorge faces, which can be unstable in places and be prone to slips.

Channel Planform	Set within a V-shaped valley, with occasional small pockets of floodplain. Stable single channel with low sinuosity. Morphology is imposed by valley shape.
Bed material texture	Angular cobble-sized gravel.
Channel geometry	Irregular, bedrock confined with channel up to 15 m wide.
Geomorphic Units	Within-channel • Bedrock and cobble steps • Cascades and runs (10-20 m long) • Bedrock-controlled pools • Bedrock-controlled islands (up to 30 m long) • Occasional side-attached gravel bars (up to 50 m long) Floodplain • Small occasional floodplain pockets up to 50 m wide and 100 m long dependent on valley width. Located in areas of local widening.
Vegetation associations	Dense native bush on valley margin walls and patchy coverage on occasional floodplain pockets.

RIVER BEHAVIOUR
Low Flow Behaviour Bedrock induced step-pool-run sequences may be prominent under low flow conditions. Flow occurs around coarse substrate. **Bankfull Behaviour** Relatively stable channel due to bedrock control. High stream powers are capable of transporting cobbles and large boulders, and reworking bars via bed level aggradation and degradation. Most geomorphic units found in the channel zone are high energy features, with the assemblage dictated largely by the occurrence of boulder and cobble accumulations. **Overbank Behaviour** Floodplains are formed in areas of locally wider valley width, where accommodation space allows their formation via vertical accretion processes. Floodplain pockets are often scoured or stripped during high flow events. Limited scope for river adjustment given the confined nature of the valley. Where floodplain exists, the channel may degrade and widen in response to the removal of riparian vegetation and/or coarse woody debris. Under such circumstances, the floodplain itself may be reworked by scouring and/or flood channels. High stream powers may also undercut the valley walls, leading to landslides and sediment generation. These landslide events can be large, producing a significant sediment load to the reaches downstream

CONTROLS	
Landscape Setting and within-catchment position	Typically found in the rugged settings in middle to upper catchment positions.
Valley Morphology	Regular, 100 -250 m wide
Process Zone	Sediment source and transfer zone
Channel Slope	0.011 m/m (Mangaokewa), 0.072 m/m (Waipā)
Upstream Catchment Area	150 km^2 (Mangaokewa), 130 km^2 (Waipā)

B.5. Confined, Bedrock Margin-Controlled, Gorge, Gravel bed (C_BrMC_Gge_Gbed)

Location(s): Moakurarua River, Mangawhitikau Stream and Waipā River

Distinguishing attributes: This River Style is set within a highly confined valley setting. The channel abuts bedrock >90% of the time, as much of this River Style is trapped within a gorge. The channel takes up most of the valley floor and is generally comprised of cascades, point bars, mid-channel, lateral and longitudinal gravel bars. In the upper Waipā, there are occasional floodplain pockets as well as pumice terrace features.

Figure B.8. Google Earth image showing the representative reach of the C_BrMC_Gge_Gbed River Style along the Moakurarua River.

Figure B.9. Google Earth image showing a representative reach of the C_BrMC_Gge_Gbed River Style along the upper Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth - Moakurarua Stream: 38° 7'14"S, 175° 7'27"E; Waipā River: 38°22'51.36"S, 175°21'4.06"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of steep, gorge faces, which can be unstable in places and be prone to slips.

Channel Planform	Channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor. Channel configuration is dictated by valley alignment and is low sinuosity.
Bed material texture	Gravel with occasional cobbles
Channel geometry	Generally symmetrical channel in long, straight sections. Can become asymmetrical where the bedrock margins force the channel to change direction.
Geomorphic Units	Within-channel • Cascades (up to 5 – 10 m long) • Channel is relatively wide (up to 10 m) compared to valley bottom width (approx. 40 m) • Longitudinal/lateral bars (~ 100 m long) with chute channels • Point Bars • Pools • Riffles Floodplain • Small pockets of floodplain in areas of accommodation space. • Pumice terraces (upper Waipā River).
Vegetation associations	Hillslopes are too steep in places for vegetation to take hold in the Moakurarua Stream. Elsewhere, forestry is prevalent with regular harvests taking place. Grass occupies any remaining space as well as the occasional non-native trees along the channel margins. In the Waipā catchment, there is native bush on the valley walls.

RIVER BEHAVIOUR
Low Flow Behaviour Largely undisrupted flow, with occasional cascades occurring. Flow moves around coarse geomorphic units. **Bankfull Behaviour** The gravel sediment is mobilised. Channel is relatively stable due to bedrock control, however gravel geomorphic units such as lateral, longitudinal, and mid-channel bars are constantly reworked with chute channels becoming activated. Localised bank erosion may occur, and channel shift may occur in places of floodplain pockets where accommodation space allows movement. **Overbank Behaviour** The channel can undercut the valley margins on the outside of bends, which over time, may induce landslides and widen the gorge. These landslides may be particularly large in the upper Waipā, which form a major sediment source for the river system. Bars are reworked.

CONTROLS	
Landscape Setting and within-catchment position	Found in rugged settings, in the upper catchment areas
Valley Morphology	Regular, typically 50 m wide
Process Zone	Sediment source and transfer
Channel Slope	0.014 m/m (Moakurarua), 0.042 m/m (Mangawhitikau), 0.019 m/m (Waipā River)
Upstream Catchment Area	119 km^2 (Moakurarua Stream), 20 km^2 (Mangawhitikau), 175 km^2 (Waipā River)

B.6. Confined, Bedrock Margin-Controlled, Headwater, Bedrock Bed (C_BrMC_Hw_Brbed)

Location(s): All rivers, except any in the Mangapiko sub-catchment

Distinguishing attributes: This River Style is set within a highly confined valley setting, with a steep single thread headwater channel that is confined by bedrock margins. The channel abuts bedrock >90% of the time. Only very small pockets of floodplain exist in areas where the valley is locally wider, but for the most part, there is no floodplain. Set within a V-shaped valley, the channel is stable with low sinuosity. The bed material consists of mostly bedrock, overlaid with large, angular clasts, including some boulders.

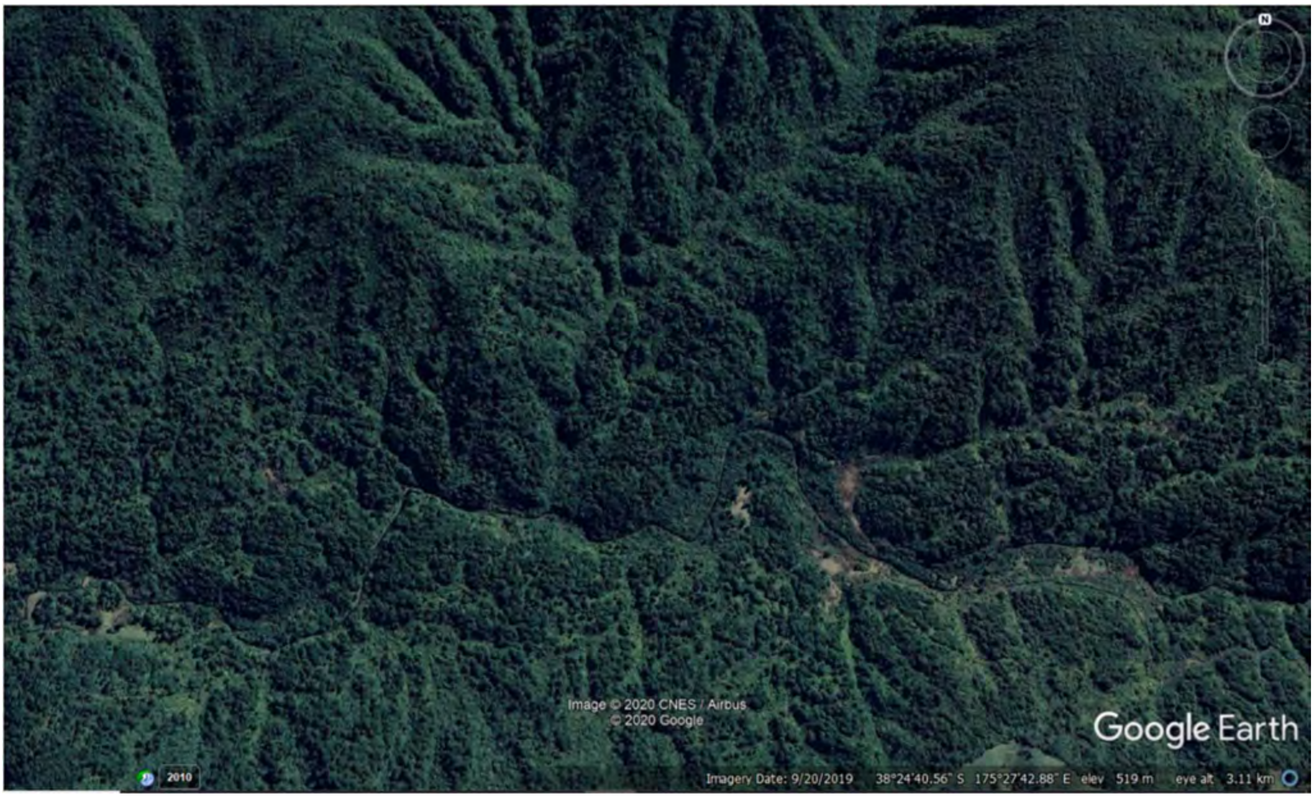

Figure B.10. Google Earth image showing a representative reach of the C_BrMC_Hw_Brbed River Style along the Okahukura Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°24'44.93"S, 175°27'15.89"E

RIVER CHARACTER	
Valley-setting	Confined. Valley margins comprise of steep, undulating, bedrock hills.
Channel Planform	Channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor. Channel configuration is dictated by valley alignment and is low sinuosity.
Bed material texture	Predominantly bedrock, overlaid by larger size classes.
Channel geometry	Irregular, bedrock confined headwater channel.
Geomorphic Units	Within-channel • Bedrock steps • Bedrock induced pools • Pebble clusters Floodplain • Almost no floodplain, only very small pockets of floodplain exist in areas where the valley is locally wider.
Vegetation associations	Steep valley walls are covered in dense native bush or forestry.

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, flow moves over bedrock steps and around coarse substrate, producing hydraulic diversity. With an extremely stable channel setting where bedrock valley margins form the channel margin, there is almost no room for lateral movement or much floodplain formation. **Bankfull/Overbank Behaviour** During bankfull and overbank flows, gravels and finer grain sizes can be mobilised and flushed out of these headwaters. Lack of upstream catchment area means the discharge is still too low to move coarse bedload (i.e. boulders) very far. Larger clasts may be dislodged and roll short distances downstream. Located in a steep landscape, this River Style acts as a source zone of sediment to downstream reaches.

CONTROLS	
Landscape Setting and within-catchment position	Found at the headwaters in the upper catchment areas.
Valley Morphology	Irregular, typically <25 m wide.
Process Zone	Sediment Source
Channel Slope	Typically, ~0.1 m/m
Upstream Catchment Area	Typically, <20 km^2

B.7. Confined, Bedrock Margin-Controlled, Headwater, Boulder Bed (C_BrMC_Hw_Bbed)

Location(s): Okurawhanga Stream, and Waipā River

Distinguishing attributes: This River Style is set within a highly confined valley setting, with steep single thread headwater channel that is confined by bedrock margins. The channel abuts bedrock >90% of the time. For the most part, there is no floodplain. Set within a V-shaped valley, the channel is stable with low sinuosity. The bed material consists of mostly locally sourced, angular boulders which trap smaller clasts between them.

Figure B.11. Google Earth image showing a representative reach of the C_BrMC_Hw_Bbed River Style along the upper Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°27'29.46"S, 175°30'1.30"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of steep, undulating, bedrock hills.
Channel Planform	Channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor. Channel configuration is dictated by valley alignment and is low sinuosity.
Bed material texture	Predominantly boulders, with gravels trapped between them.
Channel geometry	Irregular, bedrock confined headwater channel.
Geomorphic Units	Within-channel • Bedrock steps • Boulder-forced pools • Pebble clusters Floodplain • n/a
Vegetation associations	Steep valley walls are covered in dense native bush (Okurawhanga Stream) or forestry (Waipā River).

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, flow moves around boulders and other coarse substrates, producing hydraulic diversity. With an extremely stable channel setting where bedrock valley margins form the channel margin, there is next to no room for lateral movement or much floodplain formation. **Bankfull/Overbank Behaviour** During bankfull and overbank flows, gravels and finer grain sizes can be mobilised and flushed out of these headwaters. Lack of upstream catchment areas means the discharge is still too low to move coarse bedload (i.e. boulders) very far. Larger clasts may be dislodged and roll short distances downstream. Located in a steep landscape, this River Style acts as a source zone of sediment for reaches downstream.

CONTROLS	
Landscape Setting and within-catchment position	Found at the headwaters in the upper catchment areas.
Valley Morphology	Irregular, typically <25 m wide.
Process Zone	Sediment Source
Channel Slope	Typically, ~0.04 m/m
Upstream Catchment Area	13 km^2 (Okurawhanga Stream), 29 km^2 (Waipā River)

B.8. Confined, Bedrock Margin-Controlled, Headwater, Cobble Bed (C_BrMC_Hw_Cbed)

Location(s): Mangaohoi Stream, Mangapiko River

Distinguishing attributes: This River Style is set within a highly confined valley setting, with a steep single thread, low energy, headwater channel that is confined by bedrock margins. The channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor, resulting in almost no accommodation space for floodplains to form. Channel configuration is dictated by valley alignment. Bed material texture comprises predominantly of cobbles.

Figure B.12. Google Earth image of a representative reach of the C_BrMC_Hw_Cbed River Style along the Mangaohoi Stream.


Figure B.13. Photographs of the downstream end of the C_BrMC_Hw_Cbed River Style along the Mangaohoi Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Mangaohoi: 38° 2'50.84"S, 175°32'44.36"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of steep, undulating, bedrock hills
Channel Planform	Channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor. Channel configuration is dictated by valley alignment and is low sinuosity.
Bed material texture	Predominantly cobbles, with gravels and fines also present.
Channel geometry	Irregular, bedrock confined headwater channel.
Geomorphic Units	Within-channel (all small, <5 m long) • Bedrock steps • Bedrock induced pools • Cascades and runs • Pebble clusters Floodplain • Almost no floodplain, only very small pockets of floodplain exist in areas where the valley is locally wider.
Vegetation associations	In the upper headwaters, the steep valley walls are covered in dense native bush or forestry. Towards the downstream end of the River Style in both the Mangaohoi Stream and Mangapiko River, this transitions to pasture.

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, flow moves over bedrock steps and around coarse substrate, around cobble bars, producing hydraulic diversity. With an extremely stable channel setting where bedrock valley margins form the channel margin, there is next to no room for lateral movement or much floodplain formation, other than in areas of small accommodation space where the valley is locally wider.
Bankfull/Overbank Behaviour During bankfull and overbank flows, high stream powers can move coarse bedload and re-arrange the coarse geomorphic unit assemblage. In general, the assemblage of geomorphic units is dominated by high energy cobble bar features. Located in a steep landscape, this River Style acts as a source zone for sediment. During extremely high flow events, the valley sides may be undercut.

CONTROLS	
Landscape Setting and within-catchment position	Found at the headwaters in the upper catchment areas.
Valley Morphology	Irregular, typically <25 m wide.
Process Zone	Source Zone
Channel Slope	Typically, ~0.1 m/m
Upstream Catchment Area	Typically, ~5 km^2

B.9. Confined, Bedrock Margin-Controlled, Occasional Floodplain Pockets, Bedrock Bed (C_BrMC_OccFp_Brbed)

Location(s): Mangarapa Stream, Pūniu River, Waipari Stream and Owairaka Stream

Distinguishing attributes: This River Style is set within a highly confined valley setting. The channel abuts bedrock >90% of the time. This limits the Style's accommodation space to occasional floodplain pockets which form within the valley margins where the valley is locally wider. The channel is generally comprised of bedrock induced geomorphic units, such as cascades and step-pools. The bed material consists of mostly bedrock, overlaid with larger size clasts.

Figure B.14. Photographs of a representative reach of the C_BrMC_OccFp_Brbed River Style along the upper Pūniu River.

Figure B.15. Google Earth image of a representative reach of the C_BrMC_OccFp_Brbed River Style along the Pūniu River.

Figure B.16. Google Earth image of a representative reach of the C_BrMC_OccFp_Brbed River Style along the Waipari Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Pūniu: 38°12'21.52"S, 175°30'10.97"E; Waipari: 38° 9'32.32"S, 175°31'7.72"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of undulating, bedrock hills.
Channel Planform	Floodplain pockets occur along the channel in irregular sections. Channel abuts bedrock >90% of the time. Channel configuration is dictated by valley alignment and is low sinuosity.
Bed material texture	Bedrock bed, with localised overlaid larger size clasts and sand/slit.
Channel geometry	Generally symmetrical channel in long, straight sections. Occasionally alternates between valley margins but is pinned to one or the other.
Geomorphic Units	Within-channel • 8-10 m long riffle features • Bedrock induced pools and steps • Silt/fine gravel point bars attached to floodplain pockets (~5 m long) • Generally featureless, with planar bedrock bed Floodplain • Generally featureless, long, and thin occasional floodplains attached to bedrock, up to 30 m wide in places. • Ledges
Vegetation associations	Pasture, with occasional weeds and localised invasive/planted vegetation

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, flow moves undisrupted over underlying bedrock. Some cascades and runs occur where bedrock steps are present, providing hydraulic diversity. Very low flows can cause fine-grained sediments and silts to drop out of suspension and drape over the channel bed. **Bankfull Behaviour** During bankfull flows, any cobble-sized sediment overlying the bedrock becomes mobilised via traction, and smaller gravels by saltation. Fine sediments are flushed through this reach. However, the channel remains relatively stable due to the high degree of bedrock control. Some scouring of banks along floodplain pockets occurs, developing ledge features. **Overbank Behaviour** Pockets of floodplain are formed by vertical accretion processes. Limited capacity for river adjustment given the valley confinement and high degree of bedrock control. Where floodplains exist, the channel may widen, especially since vertical adjustment is restricted by the bedrock bed. Floodplain pockets also typically undergo stripping and scour processes during overbank flows.

CONTROLS	
Landscape Setting and within-catchment position	Found in rugged settings, in the upper catchment areas
Valley Morphology	Irregular, typically 50 to 80 m wide
Process Zone	Sediment transfer
Channel Slope	Typically, 0.005 to 0.01 m/m
Upstream Catchment Area	40 to 55 km^2

B.10. Confined, Bedrock Margin-Controlled, Occasional Floodplain Pockets, Cobble bed (C_BrMC_OccFp_Cbed)

Location(s): Turitea Stream, Upper Moakurarua River, Mangaohoi Stream and Okurawhanga Stream

Distinguishing attributes: This River Style is set within a highly confined valley setting. The channel abuts bedrock >90% of the time, as much of this River Style is trapped within fault lines (Turitea Stream, Upper Moakurarua). This limits the Style's accommodation space to occasional floodplain pockets within the locally wider valley margins. The channel is generally comprised of bedrock induced geomorphic units, such as cascades and step-pools.

Figure B.17. Google Earth image of a representative reach of the C_BrMC_OccFp_Cbed River Style along the Turitea Stream.

Figure B.18. Photographs showing the C_BrMC_OccFp_Cbed River Style along the Turitea Stream looking upstream (left) and downstream (right).

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38° 8'38"S, 175° 8'5"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of undulating, bedrock hills. Steep bedrock walls occur along localised sections where the channel flows along a fault line (i.e. Turitea Stream)
Channel Planform	Floodplain pockets occur along the channel in irregular sections. Channel abuts bedrock >90% of the time and is low sinuosity. The channel configuration is dictated by valley alignment, which in turn is defined by a prominent fault line.
Bed material texture	Primarily cobble-sized sediments with occasional boulders and pebble/gravel deposits.
Channel geometry	Generally symmetrical channel in long, straight sections. Occasionally alternates between valley margins, but is pinned to one or the other for long stretches (up to 200-300 m)
Geomorphic Units	Within-channel • Cascades (0.5 – 5 m long) • Small step-pools (up to 30 cm steps with 50 cm wide pools) • Occasional bedrock-forced pools (up to 1.5 m in diameter) • Occasional small vegetated lateral bars (1 m wide, 4 m long) • Cobble bars (point bars, lateral bars) Floodplain • Generally featureless, long, and thin floodplains attached to bedrock (up to 50 m wide and 200 m long in places) • On wider sections, backswamps can form (up to 20 m wide and 50 m long) • A road has been built along the length of most of the floodplain surfaces, constraining the channel further (Turitea Stream)
Vegetation associations	Hillslopes and floodplains have been stripped of native vegetation and replaced with pasture (Turitea and Moakurarua). Some native patches and forestry are present along the Mangaohoi. Localised stretches of native planting has occurred as part of the Turitea Stream Riparian Enrichment Project, however, this is limited to within 5 – 20 m of the channel on floodplain pockets presumably too small to be utilised as farmland.

RIVER BEHAVIOUR
Low Flow Behaviour Cascades prominent, separated by step-pools. **Bankfull Behaviour** Cobble-sized sediment can become mobilised via traction, smaller gravels by saltation. Channel is relatively stable due to bedrock control. Cobble bars (point bars, lateral bars) may be reworked during these flows. **Overbank Behaviour** Floodplains formed by vertical accretion (sediment can be found left on road surfaces on the floodplains). Limited capacity for river adjustment given the valley confinement. Where floodplains exist, the channel may degrade and widen in response to the removal of riparian vegetation. The reactivation of backswamps can occur, with the possibility of flood runners forming.

CONTROLS	
Landscape Setting and within-catchment position	Found in rugged settings, in the upper catchment areas
Valley Morphology	Regular, but incised into narrow fault lines, typically 50 – 100 m wide
Process Zone	Sediment transfer

Channel Slope	0.013 m/m (Moakurarua River and Mangaohoi Stream), 0.006 m/m (Turitea and Okurawhanga Streams)
Upstream Catchment Area	14 km^2 (Moakurarua River), 27 km^2 (Turitea Stream), 30 km^2 (Mangaohoi Stream), 22 km^2 (Okurawhanga Stream)

B.11. Confined, Bedrock Margin-Controlled, Occasional Floodplain Pockets, Gravel bed (C_BrMC_OccFp_Gbed)

Location(s): Upper Moakurarua Stream, Ōamaru Stream, Mangawhitikau Stream, Mangapiko River and Pūniu River

Distinguishing attributes: This River Style is set within a highly confined valley setting. The channel abuts bedrock >90% of the time, as much of this River Style is trapped within fault lines or bedrock margins. This limits the Style's accommodation space, where occasional floodplain pockets form within the valley margins only where the valley is locally wider. The channel is generally comprised of geomorphic units such as cascades and mid-channel bars. However, the relatively wide nature of the channel compared to the valley bottom width limits the capacity for adjustment and the formation of geomorphic units, as sediments are flushed through this River Style reasonably quickly or because geomorphic units are constantly being reworked under high energy conditions.

Figure B.19. Google Earth image of the representative reach of the C_BrMC_OccFp_Gbed River Style along the Moakurarua River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°11'20"S, 175° 5'4"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of steep, undulating, bedrock hills.
Channel Planform	Floodplain pockets occur along the channel in irregular sections. Channel abuts bedrock >90% of the time and is low sinuosity. The channel configuration is dictated by valley alignment, which in turn is defined by a prominent fault line.
Bed material texture	Gravel with occasional cobbles

Channel geometry	Generally symmetrical channel in long, straight sections. Occasionally alternates between valley margins, but is pinned to one or the other for long stretches (up to 500 m)
Geomorphic Units	Within-channel • Small cascades (0.5 – 2 m long) • Occasional vegetated lateral and point bars (up to 4 m wide, 10 m long) • Occasional mid-channel bars comprised of gravel deposits • Channel is relatively wide (up to 10 m) compared to valley bottom width (approx. 40 – 50 m) Floodplain • Generally featureless, attached to bedrock (up to 20 m wide and 100 m long) • Floodplain position is dictated by the valley morphology and channel position, which alternates between margins
Vegetation associations	Hillslopes are largely occupied by pasture, native bush, or forestry practices (Moakurarua River only). Floodplains have been stripped of native vegetation and replaced with pasture. Weeds and other invasive species occupy some of the banks where pasture is present.

RIVER BEHAVIOUR
Low Flow Behaviour Largely undisrupted flow, with occasional cascades occurring. **Bankfull Behaviour** The gravel sediment can become mobilised. Channel is relatively stable due to bedrock control. Mid-channel point and lateral bars can be reworked. The mid-channel bars are particularly susceptible to frequent reworking. **Overbank Behaviour** Floodplains formed by vertical accretion. Limited capacity for river adjustment given the valley confinement. Where floodplains exist, the channel may degrade and widen in response to the removal of riparian vegetation.

CONTROLS	
Landscape Setting and within-catchment position	Found in rugged settings, in the upper catchment areas
Valley Morphology	Regular, controlled by narrow fault lines (Moakurarua River only), or bedrock. Typically, ~50 m wide
Process Zone	Sediment transfer
Channel Slope	0.006 m/m to 0.008 m/m (Upper Moakurarua Stream, Ōamaru Stream, Mangawhitikau Stream and Pūniu River), 0.032 m/m (Mangapiko River)
Upstream Catchment Area	5 km^2 to 10 km^2 (Ōamaru Stream, Mangawhitikau Stream and Mangapiko River), 49.5 km^2 (Moakurarua River), 181 km^2 (Pūniu River)

B.12. Confined, Bedrock Margin-Controlled, Step-Pool, Bedrock Bed (C_BrMC_SPo_Brbed)

Location(s): Upper Waipā River and Mangaokewa Stream

Distinguishing attributes: This River Style is found in a confined valley setting on top of a volcanic plateau. It has a confined channel with bedrock margins, and older terrace features, where occasional small waterfalls and cascades make descents down bedrock resulting in step-pool features. There are small occasional pockets of inset floodplain. The channel is relatively stable, with low sinuosity and bedrock bed.

Figure B.20. Photographs showing a representative reach of the C_BrMC_SPo_Brbed River Style along the Upper Waipā River.

Figure B.21. Google Earth image of a representative reach of the C_BrMC_SPo_Brbed River Style along the Upper Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°26'52.35"S, 175°25'40.57"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of undulating, bedrock hills and outcrops.
Channel Planform	Channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor. The channel configuration is dictated by valley alignment and is low sinuosity. Small pockets of inset floodplain are present, as well as terrace features.
Bed material texture	Predominantly bedrock bed. Some larger clasts overlaid in places.
Channel geometry	Single thread, low sinuosity channel.
Geomorphic Units	Within-channel • Bedrock cascades and runs (up to 50 m long) • Bedrock small waterfalls • Possible cave network (Upper Waipā River reach - difficult to determine with limited access) • Bedrock steps • Bedrock induced pools (~ 50 m long) Floodplain • Small occasional pockets of inset floodplain • Older terrace features, pumice terraces in places • Some backswamps and flood channels present on areas of inset floodplain
Vegetation associations	Some parts covered in native bush; other parts devoid of vegetation used for pasture. Swamp vegetation present in backswamp areas on inset floodplain.

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, bedrock induced step-pool-run sequences are prominent. Flow occurs around coarse substrates and over irregular bedrock steps, producing significant hydraulic diversity. However, the style has an extremely stable channel setting, with limited capacity for vertical or lateral adjustment due to the high degree of bedrock control. Additionally, older terrace features limit the capacity of contemporary adjustment. **Bankfull Behaviour/Overbank behaviour** During bankfull and overbank flows, very high stream powers can move coarse bedload and re-arrange coarser geomorphic units. Finer sediments are flushed downstream and the river acts as a sediment transfer zone. The channel is susceptible to widening where pockets of inset floodplain provide accommodation space for adjustment. During extremely high flow events, valley sides may be undercut in places and inset floodplain surfaces may be scoured and stripped. Backswamps and flood channels are reactivated.

CONTROLS	
Landscape Setting and within-catchment position	Upper catchment
Valley Morphology	Irregular, with widths ranging from 20 – 60 m
Process Zone	Source and Transfer Zone
Channel Slope	0.010 to 0.035 m/m
Upstream Catchment Area	14 km^2 (Mangaokewa Stream), 83 km^2 (Upper Waipā River)

B.13. Confined, Bedrock Margin-Controlled, Step-Pool, Boulder Bed (C_BrMC_SPo_Bbed)

Location(s): Mangaokewa Stream, Okahukura Stream, Okurawhanga Stream and Upper Waipā River

Distinguishing attributes: This River Style is set within a highly confined valley setting. The channel takes up most available space on the valley floor and abuts bedrock >90% of the time. Only small, very occasional floodplain pockets occur where the valley is locally wider. The channel generally comprises of step-pool sequences induced by bedrock, with boulder features present, as well as other coarse sediment clasts.

Figure B.22. Google Earth image showing a representative reach of the C_BrMC_SPo_Bbed River Style along the Upper Waipā River.

Figure B.23. Google Earth image showing a representative reach of the C_BrMC_SPo_Bbed River Style along the Okurawhanga Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Upper Waipā River: 38°27'20.81"S, 175°27'9.66"E; Okurawhanga: 38°25'47.24"S, 175°27'59.03"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of undulating, bedrock hills.
Channel Planform	Channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor. The channel configuration is dictated by valley alignment and is low sinuosity. Rare, small pockets of floodplain occur where the valley is locally wider.
Bed material texture	Large boulder features overlaid on top of bedrock, as well as other coarse sediment clasts.
Channel geometry	Single thread, low sinuosity channel. Channel morphology is dictated by valley alignment.
Geomorphic Units	Within-channel • Bedrock and boulder cascades • Small bedrock waterfalls • Bedrock steps • Bedrock induced waterfalls • Coarse sediment cluster bars in places Floodplain • Rare, small pockets of floodplain occur where the valley is locally wider.
Vegetation associations	Mostly native bush and/or forestry on the valley walls, with pasture in some areas.

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, bedrock and boulder induced step-pool-run sequences are prominent. Flow occurs around boulders and coarse substrate and over irregular bedrock steps, producing significant hydraulic diversity. However, the style has an extremely stable channel setting, with limited capacity for vertical or lateral adjustment due to the high degree of bedrock control and coarse boulder sediments. **Bankfull Behaviour/Overbank behaviour** During bankfull and overbank flows, very high stream powers can move coarse bedload and re-arrange coarser geomorphic units. The channel is susceptible to widening where rare, small pockets of inset floodplain provide accommodation space for adjustment. However, lateral adjustment is mostly limited by the high degree of bedrock control. During extremely high flow events, inset floodplain surfaces may be scoured and stripped, and valley walls may be undercut, resulting in landslide events and block failure that contribute to boulder and coarse sediments.

CONTROLS	
Landscape Setting and within-catchment position	Typically found in rugged, upper catchment settings.

Valley Morphology	Irregular, ~50 m wide
Process Zone	Source Zone
Channel Slope	Typically, 0.02 m/m to 0.03 m/m
Upstream Catchment Area	31 km^2 (Waipā, River), 27 km^2 (Mangaokewa Stream), 15 km^2 - 18 km^2 (Okahukura and Okurawhanga Streams)

B.14. Confined, Bedrock Margin-Controlled, Step-pool, Cobble bed (C_BrMC_SPo_Cbed)

Location(s): Waipari Stream

Distinguishing attributes: This River Style is set within a highly confined valley setting. The channel takes up most available space on the valley floor and abuts bedrock >90% of the time. Only small, very occasional floodplain pockets occur where the valley is locally wider. The channel generally comprises of step-pool sequences induced by bedrock, with the bed material predominantly consisting of cobble sediments.

Figure B.24. Google Earth image showing a representative reach of the C_BrMC_SPo_Cbed River Style along the Waipari Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°17'25.61"S, 175°34'4.93"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of steep bedrock walls.
Channel Planform	Channel abuts bedrock >90% of the time and takes up most of the available space on the valley floor. The channel configuration is dictated by valley alignment and is low sinuosity. Rare, small pockets of floodplain occur where the valley is locally wider.
Bed material texture	Bed comprised of predominantly coarse cobble-sized gravels, with occasional bedrock.
Channel geometry	Single thread, low sinuosity channel. Channel morphology is dictated by valley alignment.
Geomorphic Units	Within-channel • Bedrock and boulder cascades • Small bedrock waterfalls • Bedrock steps • Bedrock induced waterfalls

	• Coarse pebble clusters in places Floodplain • Rare, small pockets of floodplain occur where the valley is locally wider.
Vegetation associations	Patches of native bush with invasive shrubs and trees mainly on valley margins and floodplain surfaces.

RIVER BEHAVIOUR
Low Flow Behaviour Bedrock induced step-pool sequences prominent under low flow conditions. Flow occurs around coarse substrate. Some gravels mobilised. Larger clasts can trap smaller sediments, especially as the flow level drops after an event, forming pebble clusters. **Bankfull Behaviour/Overbank Behaviour** Relatively stable channel due to bedrock control. High stream powers are capable of transporting gravel and large cobbles. Pebble clusters can become dislodged and reworked, causing the sediment to be transported in pulses through the reach. Localised floodplains are formed via vertical accretion processes but are often scoured or stripped under high flow events. Limited scope for river adjustment given the confined nature of the valley.

CONTROLS	
Landscape Setting and within-catchment position	Found in rugged settings in upper catchment positions.
Valley Morphology	Irregular, 20 - 60 m wide
Process Zone	Sediment transfer zone
Channel Slope	0.059 m/m
Upstream Catchment Area	17 km^2

B.15. Confined, Bedrock Margin-Controlled, Step-pool, Gravel bed (C_BrMC_SPo_Gbed)

Location(s): Mangawhitikau Stream

Distinguishing attributes: This River Style is set within a confined valley setting. The channel abuts bedrock >90% of the time. Occasional floodplain pockets occur behind bedrock spurs or at tributary confluences where the valley is locally wider. The channel comprises of step-pool sequences induced by bedrock but predominantly consists of gravel sediments.

Figure B.25. Google Earth image showing a representative reach of the C_BrMC_SPo_Gbed River Style along the Mangawhitikau Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°19'20.03"S, 175° 3'42.65"E

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of undulating, bedrock hills.
Channel Planform	Floodplain is almost non-existent. Channel abuts bedrock >90% of the time. Channel configuration dictated by valley alignment and is low sinuosity.
Bed material texture	Bed comprised of predominantly coarse gravels, with occasional bedrock.
Channel geometry	Irregular and 2-7 m wide
Geomorphic Units	Within-channel • Bedrock step-pool sequences • Pools (up to 10 m long) • Riffles (up to 10 m long) • Glides and runs (up to 50 m long) comprised of gravels and bedrock • Cascades and small waterfalls at bedrock steps Floodplain • Almost none. Those that are present tend to develop around sheltered bedrock spur toes, attached to bedrock and are very narrow. Their form is dependent on valley morphology.
Vegetation associations	Narrow patches of shrubs and trees line the bottom of the valley, with pasture dominating elsewhere.

RIVER BEHAVIOUR
Low Flow Behaviour Bedrock induced step-pool sequences prominent under low flow conditions. Flow occurs around coarse substrate, creating hydraulic diversity. **Bankfull Behaviour/Overbank Behaviour** Relatively stable channel due to bedrock control. Limited scope for river adjustment given the confined nature of the valley. High stream powers are capable of transporting gravels, and large cobbles via traction, resulting in the reworking of geomorphic unit assemblages. Scouring of floodplain banks can occur. Floodplains are formed during overbank flows around spur toes via vertical accretion processes, but they can also be scoured or stripped under high flow events. The low upstream catchment area limits discharge potential, so geomorphic units and bed material tend to remain stable for long periods.

CONTROLS	
Landscape Setting and within-catchment position	Found in rugged settings in the upper catchment.
Valley Morphology	Irregular, up to 20 m wide
Process Zone	Sediment source and transfer zone
Channel Slope	0.0088 m/m
Upstream Catchment Area	14 km^2

B.16. Confined, Bedrock Margin-Controlled, Valley Fill, Fine-Grained Bed (C_BrMC_VFi_Fbed)

Location(s): Upper Waipā River (source)

Distinguishing attributes: This River Style is set within a confined valley setting. The channel abuts bedrock >90% of the time, generally staying on only one side of the valley (eastern edge). Located upon the southern plateau of the Rangitoto Range, the valley is in-filled with Taupō tephra, pumice, and other volcanic alluvium and fallout. This has created a fine-grained valley-fill which forms the valley floor, which has a relatively low slope given its upland catchment position. Adjoining tributaries in this area also contain upland swamps, typical of cut-and-fill streams found in upland plateaus, as well as evidence of pumice quarrying practices having occurred here in the past. The valley-fill acts as the floodplain, although during large rainfall events, it becomes waterlogged and drains poorly, which can lead to the formation of backswamps.

Figure B.26. Google Earth image showing a representative reach of the C_BrMC_VFi_Fbed River Style along the upper Waipā River. Polyline indicates approximate channel position, flowing downstream from the left of the image to the right.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°25'30.05"S, 175°32'26.03"E

RIVER CHARACTER	
Valley-setting	Confined, continuous channel. Valley margins comprise of volcanic bedrock hills in-filled with fine-grained material
Channel Planform	Floodplain is almost non-existent. Channel abuts bedrock >90% of the time. Channel configuration dictated by valley alignment, as well as being imposed by the valley-fill which forces the channel to stay on one side of the valley floor.
Bed material texture	Bed comprised of fine-grained material, with occasional bedrock outcrops
Channel geometry	Regular, almost a slot channel in most locations. Only 1 – 2 m wide.
Geomorphic Units	Within-channel • Sculpted runs • Bedrock outcrops • Localised, narrow ledges along valley-fill banks Floodplain • The valley-fill can act as a floodplain during high flow events. However, it drains poorly and can lead to the formation of backswamps
Vegetation associations	Deforested and prepped for forestry practices in the past. However, new planting has not occurred, allowing for the resurgence of shrubs and young trees (presumably invasive).

RIVER BEHAVIOUR
Low Flow Behaviour Undisrupted flow. Suspended sediments are flushed through this reach. **Bankfull Behaviour** Channel banks can be scoured and/or undercut inducing bank collapse (i.e. slump formations) and the formation of ledges. Over time, this can cause channel widening and lateral migration. Although, this is a very slow, localised process along this River Style given the degree of confinement and cohesive nature of the floodplain/valley-fill material. **Overbank Behaviour** The valley-fill can become waterlogged which can take a long time to drain, promoting the formation/reactivation of backswamps. The preferential flow is retained within the contemporary channel rather than forming flood channels. Suspended sediments are deposited on the floodplain/valley-fill surface, causing it to vertically accrete over time.

CONTROLS	
Landscape Setting and within-catchment position	Found in upland volcanic plateau areas.
Valley Morphology	Irregular, up to 100 m wide in places, in-filled with tephra and other volcanic alluvium
Process Zone	Sediment source zone
Channel Slope	0.037 m/m
Upstream Catchment Area	2 km^2

B.17. Confined, Embankment Margin-Controlled, Occasional Floodplain Pockets, Gravel Bed (C_EBkMC_OccFp_Gbed)

Location(s): Mangaokewa Stream

Distinguishing attributes: This River Style flows through the township of Te Kūiti and is set in a confined setting, where the channel abuts man-made embankment margins >90% of the time. These embankments were created following the 1958 flood, during which time the channel was widened, deepened, and straightened in sections to better convey flood flows. Some of the channel banks have been cemented in place to protect the town from lateral migration of the channel. The channel is entrenched with a low width to depth ratio. There are occasional inset floodplain pockets between the channel and the artificial embankments, while the older highly urbanised floodplain surface has been disconnected from the channel. The bed material comprises of gravels.

Figure B.27. Google Earth image of a representative reach of the C_EBkMC_OccFp_Gbed River Style along the Mangaokewa Stream.

Figure B.28. Photographs showing representative reaches and features of the C_EBkMC_OccFp_Gbed River Style along the Mangaokewa Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°20'5.11"S, 175°10'7.13"E

RIVER CHARACTER	
Valley-setting	Confined
Channel Planform	Channel abuts anthropogenic margins (predominantly embankment margins, as well as roads and concrete) >90% of the time. This results in a highly stable channel position.
Bed material texture	Predominantly gravels, with some sand and fines
Channel geometry	Symmetrical, entrenched
Geomorphic Units	Within-channel • Entrenched single thread channel, deprived of in-channel geomorphic units • Occasional lateral bars • Low channel width to depth ratio prevents the formation of in-stream geomorphic units • Concrete walls in places Floodplain • Occasional inset floodplain pockets between the channel and embankments. • The larger external older floodplain surface is highly urbanized and is disconnected from the contemporary channel.
Vegetation associations	Channel is lined by non-native trees in short sections through the township. Inset floodplain pockets consist predominantly of mown lawn. The wider older disconnected floodplain is highly urbanised, with floodplains that are not built upon comprising of pasture.

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, flow moves undisrupted through these reaches, with little hydraulic diversity. The channel remains highly stable, confined by numerous anthropogenic margins. **Bankfull Behaviour** During bankfull flows, cohesive banks may be scoured. Low sinuosity and deep channel indicate that bed incision is the dominated process. High channel capacity allows for sediment to be easily flushed through this reach, acting like a flume, resulting in a lack of in-stream geomorphic diversity. Occasional bar surfaces are reworked and mobilised during these flows. Lateral adjustment is limited, as the channel is fixed in place by the town and embankment margins. **Overbank Behaviour** During overbank flows, the inset floodplain pockets may be built up via vertical accretion processes but are more likely to be stripped and scoured as the flow is concentrated between the embankments. Only in extremely large, rare events are the embankments overtopped, resulting in the spread of flow onto the urbanised floodplain and the deposition of fines.

CONTROLS	
Landscape Setting and within-catchment position	Found in the lower-mid catchment areas through townships.
Valley Morphology	Regular, >1 km wide. Anthropogenic margins can be as narrow as 10 - 20 m along most of the reach length.
Process Zone	Sediment transfer/accumulation zone.
Channel Slope	0.0015 m/m
Upstream Catchment Area	181 km^2

B.18. Confined, Road Margin-Controlled, Occasional Floodplain Pockets, Fine-Grained Bed (C_RdMC_OccFp_Fbed)

Location(s): Mangaohoi Stream

Distinguishing attributes: This River Style flows through the township of Te Awamutu and is set in a confined setting, where the channel abuts man-made margins (predominantly roads, along with other man-made structures) >90% of the time. The channel is entrenched in fine-grained alluvium. Te Awamutu is built on the older disconnected floodplain. Only occasional pockets of inset floodplain now exist between the road margins and the channel banks. The bed material comprises of fine-grained materials.

Figure B.29. Google Earth image showing a representative reach of the C_RdMC_OccFp_Fbed River Style along the Mangaohoi Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38° 0'24.34"S, 175°19'34.98"E

RIVER CHARACTER	
Valley-setting	Confined
Channel Planform	Channel abuts anthropogenic margins (predominantly roads) >90% of the time. This results in a stable channel position.
Bed material texture	Predominantly fine-grained material. Some fine gravels are also present in localised deposits

Channel geometry	Single thread, moderately sinuous. Irregular at meander bends, generally symmetrical along straight sections
Geomorphic Units	Within-channel • Entrenched single thread channel, generally deprived of in-channel geomorphic units • Occasional lateral bars, comprised of fine gravel • Low channel width to depth ratio prevents the formation of in-stream geomorphic units Floodplain • Occasional inset floodplain pockets between the channel and roads. • The larger external disconnected floodplain is highly urbanised.
Vegetation associations	Channel is lined by non-native trees in short sections through the township. Inset floodplain pockets consist predominantly of mown lawn. The wider floodplain is highly urbanised, with floodplains that are not built upon comprising of pasture.

RIVER BEHAVIOUR
Low Flow Behaviour The flow moves undisrupted through these reaches, with little hydraulic diversity. The channel remains highly stable, confined by numerous anthropogenic margins. **Bankfull Behaviour** During bankfull flows, cohesive banks may be scoured. The moderate sinuous and deep channel indicates scouring would be focused on the outside of meander bends, and that bed incision is also prevalent. High channel capacity allows for sediment to be easily flushed through this reach, acting like a flume, resulting in a lack of in-stream geomorphic diversity. Occasional bar surfaces are reworked and mobilised during these flows. Lateral adjustment is limited, as the channel is fixed in place by the town and embankment margins. **Overbank Behaviour** During overbank flows, the inset floodplain pockets may be built up via vertical accretion processes but are more likely to be stripped and scoured as the flow is concentrated between the embankments. Only in extremely large, rare events are the road margins overtopped, resulting in the spread of flow onto the urbanised floodplain and the deposition of fines.

CONTROLS	
Landscape Setting and within-catchment position	Found in the lower-mid catchment areas through townships.
Valley Morphology	Regular, >1 km wide. Anthropogenic margins can be as narrow as 20 m.
Process Zone	Sediment transfer/accumulation zone.
Channel Slope	0.004 m/m
Upstream Catchment Area	94 km^2

B.19. Confined, Terrace Margin-Controlled, Occasional Floodplain Pockets, Fine-Grained Bed (C_TrMC_OccFp_Fbed)

Location(s): Waipā River, Mangapiko River and Pūniu River

Distinguishing attributes: Channel abuts terrace margins >90% of the time, hence channel morphology and alignment are controlled significantly by terrace extent. Contemporary inset floodplain pockets occur in wider areas between terrace margins. The channel is sinuous, but lateral adjustment is restricted by terrace margins. The channel is generally narrow and is set within a fine-grained floodplain and cohesive terrace margins. Very low gradient as the river has incised through unconsolidated, fine-grained material deposited by the Waikato Fan, to match the bed level set by the Waikato River.

Figure B.30. Photographs showing representative reaches of the C_TrMC_OccFp_Fbed River Style along the Pūniu River (left) and Waipā River (right).

Figure B.31. Google Earth image showing a representative reach of the C_TrMC_OccFp_Fbed River Style along the Pūniu River.

Figure B.32. Google Earth image showing a representative reach of the C_TrMC_OccFp_Fbed River Style along the Mangapiko River.

Figure B.33. Google Earth image showing a representative reach of the C_TrMC_OccFp_Fbed River Style along the Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Pūniu: 38° 1'21.89"S, 175°16'8.63"E; Mangapiko: 37°59'1.39"S, 175°12'42.53"E; Waipā: 37°47'54.25"S, 175° 9'3.78"E

RIVER CHARACTER	
Valley-setting	Confined, fine-grained terraces delineate the valley margins
Channel Planform	Channel abuts terrace margins >90% of the time. This results in a relatively stable channel position.
Bed material texture	Fine-grained
Channel geometry	Single thread, low sinuosity, slot channel with low width to depth ratio. The channel looks highly sinuous; however, this sinuosity is dictated by the terrace planform. The channel has low sinuosity overall. Irregular channel geometry at meander bends, generally symmetrical along straight sections
Geomorphic Units	Within-channel • Occasional sculpted point bars • Localised large woody debris creates forced sculpted pools • Low channel width to depth ratio prevents the formation of in-stream geomorphic units Floodplain • Inset contemporary floodplain pockets between channel and terrace margins (Waikato fan material) • Disconnected elevated terrace floodplain (Waikato fan) • Flood channels • Terrace point ledges • Occasional backswamps • Meander cut-offs due to channel straightening practices along some reaches, some of which have been left to develop into wetlands/oxbow lakes
Vegetation associations	Pasture dominates, with local pockets of invasive or planted trees and shrubs along channel banks and dotted along floodplains.

RIVER BEHAVIOUR
Low Flow Behaviour Largely undisrupted flow except where large woody debris causes local hydraulic diversity, which induces some minor scouring to occur, preventing forced pools to become in-filled with sediment. Fine-grained material is carried in suspension. Some fine grains are dropped out of suspension during extremely low flow periods (i.e. during the peak of summer). **Bankfull Behaviour** Scouring occurs along the bed and banks, particularly on the outside of meander bends. Point bars are sculpted from the surrounding sediment. Accretion of these bars occurs during the waning stage of flow. Slot channel form indicated bed incision to be the dominating process. **Overbank Behaviour** Floodplains develop through vertical accretion but can also be scoured by particularly high flow events, reactivating and developing flood channels. Flood channels, as well as the preferential channel flow, scour the terrace margins and form terrace ledges over time. The terraces can be undercut and cause instability along the terrace banks. However, this type of erosion is a slow process given the infrequency of these types of events and the cohesive nature of the terrace composition making them relatively resistant to erosional processes. Large woody debris can be dislodged and redeposited elsewhere, leading to the localised reworking of forced, sculpted pools.

CONTROLS	
Landscape Setting and within-catchment position	Found in the lower-mid catchment areas through alluvial deposits left behind by the Waikato Fan
Valley Morphology	Regular, generally 20 - 50 m wide, up to 100 m wide at meander bends. Terrace flats are >1 km wide.
Process Zone	Sediment transfer and accumulation zone. Fine-grained suspended sediment load is also sourced from scouring and bed incision.
Channel Slope	< 0.001 m/m
Upstream Catchment Area	2540 – 2930 km^2 (lower Waipā River), 1530 – 2150 km^2 (mid-Waipā), 300 km^2 (Mangapiko), 560 km^2 (Pūniu)

B.20. Partly Confined, Bedrock Margin-Controlled, Discontinuous Floodplain, Gravel Bed (PC_BrMC_DcFp_Gbed)

Location(s): Ōamaru Stream, Moakurarua River, Turitea Stream, Mangawhero Stream, Waipā River, Waimahora Stream, Mangatutu Stream, Pūniu River, Waipari Stream, Mangaohoi Stream and Mangapiko River.

Distinguishing attributes: Channel abuts valley margin >50% of the time, hence channel morphology and alignment are controlled to a significant degree by the sinuous or irregular valley morphology. Discontinuous floodplains occur where sinuous valleys locally widen at tributary confluences, alternating between either valley side as the channel position changes on the valley floor, and forming in irregular valleys where they locally widen behind bedrock spurs. Bars and islands are often irregular. This River Style displays a high level of geomorphic diversity compared to other River Styles in the Waipā catchment.

Figure B.34. Photograph showing a representative reach of the PC_BrMC_DcFp_Gbed River Style along the Ōamaru Stream.

Figure B.35. Google Earth image showing a representative reach of the PC_BrMC_DcFp_Gbed River Style along the Ōamaru Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38° 9'32.80"S, 175° 4'1.46"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Typically, single-channelled with moderate sinuosity, in a valley which is generally more sinuous. This produces alternating irregular pockets of floodplain along the valley. The channel may locally divide around islands at bends. Despite channel enlargement and floodplain stripping, the channel is moderately stable, as It is pinned against the valley margin, but some downstream translation of bends is possible in floodplain pockets.
Bed material texture	Bed materials range from sands to coarse gravels; banks are commonly composite, with a gravel base and fine-grained upper units.
Channel geometry	Highly variable, ranging from compound channels with multiple floodplain surfaces on insides of bends to symmetrical in some straight reaches. Typically, channels are 5 – 20 m wide; frequently bounded by bedrock valley margin on one side, with benches or ledges on the other.
Geomorphic Units	Within-channel • Channel <20 m wide within an irregular valley which ranges from 50 -250 m wide • Pools up to 10 m wide and up to 30 m long • Riffles up to 10 m wide and 50 m long • Runs ranging from 100 to 300 m • Bars or islands (typically point or lateral/bank-attached bars with chute channels) up to 8 m wide and 30 m long • Benches and point benches up to 10 m wide, and between 20 – 100 m long • Ledges up to 10 m wide, and between 20 – 50 m long Floodplain • Floodplain is up to 150 m wide and 200 m long dependent on valley width. May be multileveled, comprising several stripped floodplain surfaces and valley marginal terraces • Paleochannels and oxbow cut-offs present, with flood channels up to 20 m wide and up to 2 m deep running along the valley margin and obliquely across floodplains
Vegetation associations	Pasture on floodplains and terraces. Patches of native vegetation on bedrock slopes adjacent to the channel, but slopes are dominated by forestry in the upper sections of the sub-catchment.

RIVER BEHAVIOUR
Low Flow Behaviour At low flow stage, the thalweg is aligned along the concave banks of bends and exposed compound point bars will occur on the inside banks for bends. Flow occurs over riffles and fills pools. **Bankfull Behaviour** As high stream powers can be generated at the bankfull stage, the channel is subjected to significant adjustment where there is the accommodation space to do so. Benches can form on the insides of bends, and ledges may form under degradation along runs. Over widened channels permit extensive point bar formation. When colonised by vegetation, this may promote island formation. Bars are commonly dissected at high flow stage. Bend adjustment may occur via downstream bend translation in floodplain pockets and oxbow cut-offs may occur when the flow short circuits the meander. **Overbank Behaviour** The floodplain is built up via vertical accretion processes. In other cases, bends can translate downstream producing lateral accretion features. Floodplains comprise of multiple stripped surfaces. Paleochannels and oxbows are reactivated.

CONTROLS	
Landscape Setting and within-catchment position	Typically found in the rugged settings in middle to upper catchment positions.
Valley Morphology	Irregularly shaped or sinuous valley produces discrete floodplain pockets
Process Zone	Sediment transfer zone
Channel Slope	Generally, ranges between 0.003 and 0.01 m/m
Upstream Catchment Area	20 - 40 km^2 in upper sub-catchment zones, 40 - 200 km^2 in middle-lower sub-catchment zones

B.21. Partly Confined, Bedrock Margin-Controlled, Discontinuous Floodplain Pockets, Sand Bed (PC_BrMC_DcFp_Sbed)

Location(s): Mangarapa Stream and Pūniu River

Distinguishing attributes: Channel abuts valley margin >50% of the time, hence channel morphology and alignment are controlled to a significant degree by the sinuous or irregular valley morphology. Discontinuous floodplains occur where sinuous valleys locally widen at tributary confluences, alternating between either valley side as the channel position changes on the valley floor, and forming in irregular valleys where they locally widen behind bedrock spurs. The channel consists mainly of sands, with relatively cohesive banks.

Figure B.36. Photograph showing a representative reach of the PC_BrMC_DcFp_Sbed River Style along the Mangarapa Stream.

Figure B.37. Google Earth image showing a representative reach of the PC_BrMC_DcFp_Sbed River Style along the Mangarapa Stream.

Figure B.38. Google Earth image showing a representative reach of the PC_BrMC_DcFp_Sbed River Style along the Pūniu River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Mangarapa: 38°20'2.88"S, 175°13'10.54"E; Pūniu: 38° 7'37.63"S, 175°28'57.05"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	The channel abuts bedrock margins >50% of the time with low-moderate sinuosity. Alternating irregular pockets of floodplain occur along the valley. The channel is moderately stable, as it is pinned against the valley margin and floodplain banks consist of cohesive fines.
Bed material texture	Dominant bed material consists of sands, with some gravels present. Banks are commonly composite, with fine-grained upper units.
Channel geometry	Mostly symmetrical channels. Typically, channels are 1 – 3 m wide; frequently bounded by bedrock valley margin on one side, and floodplain on the other.
Geomorphic Units	Within-channel • Channel <3 m wide within an irregular valley, ranging from 100 – 300 m wide • Pools up to 2 m wide and 20 m long • Riffles up to 2 m wide and 20 m long • Runs up to 40 m long • Small sand bars present in some areas Floodplain • Floodplain is up to 200 m wide and 200 m long dependent on valley width. May be multileveled, comprising several floodplain surfaces and valley marginal terrace risers.
Vegetation associations	Pasture on floodplains and terrace risers. Patches of native vegetation on bedrock slopes.

RIVER BEHAVIOUR
Low Flow Behaviour At low flow stage, the thalweg is aligned along the concave banks of bends and exposed small sand point bars occur on the inside banks of bends. Flow occurs over riffles and fills pools. **Bankfull Behaviour** Due to the relatively small upstream drainage area, stream powers remain relatively low at bankfull stage relative to other parts of the catchment. However, the channel is prone to some degradation and widening. Some bend adjustment may occur via downstream bend translation over long time frames. **Overbank Behaviour** The channel is relatively stable, with little capacity for lateral adjustment. This reflects both the small upstream drainage area and that the channel is commonly pinned against bedrock valley margins. In general, the floodplain is built up via vertical accretion processes. This likely reflects sedimentation from suspension.

CONTROLS	
Landscape Setting and within-catchment position	Typically found in rugged settings in middle to upper catchment positions.
Valley Morphology	Irregularly shaped or sinuous valley produces discrete floodplain pockets.
Process Zone	Sediment transfer zone
Channel Slope	0.025 m/m (Mangarapa), 0.005 m/m (Pūniu)
Upstream Catchment Area	22.5 km^2 (Mangarapa), 198 km^2 (Pūniu)

B.22. Partly Confined, Bedrock Margin-Controlled, Valley Fill, Fined-Grained Bed (PC_BrMC_VFi_Fbed)

Location(s): Mangarama Stream and Judge Road Swamp Drain (Source)

Distinguishing attributes: This River Style is set within a partly confined valley setting. The channel abuts bedrock >50% of the time. These reaches are close to, if not are, the source of low discharge tributaries in flat, upland tabletop areas, where bedrock valleys have become backfilled with fine-grained material. This has created a fine-grained valley-fill which forms the valley floor, which has a relatively low slope given its upland catchment position. Poor drainage, due to the low gradient, can cause the valley-fill floodplains to become saturated during rainfall events, turning them into swamp-like areas and promoting the formation of backswamps. The channel is generally continuous but is discontinuous in places where local man-made dams have been constructed for farmland irrigation practices.

Figure B.39. Google Earth image showing a representative reach of the PC_BrMC_VFi_Fbed River Style along the Mangarama Stream.

Figure B.40. Google Earth image showing a representative reach of the PC_BrMC_VFi_Fbed River Style along the Judge Road Swamp Drain.

DETAILS OF ANALYSIS	
Map(s) used: Google Earth – Mangarama: 38°23'9.35"S, 175° 9'35.37"E; Judge Road Swamp Drain: 38° 1'50.88"S, 175°27'28.32"E	
RIVER CHARACTER	
Valley-setting	Partly confined, mostly continuous channel. Valley margins comprise of uplifted sedimentary bedrock hills in-filled with fine-grained material.
Channel Planform	The valley-fill acts as the floodplain in this River Style. However, the low drainage area and discharge of these streams, along with the lack of upstream fine-grained sediment source, prevent them from supplying fine-grained material to the floodplains from upstream. Therefore, these are back-filled valleys. The channel abuts bedrock >50% of the time. The channel configuration is primarily dictated by valley alignment, as well as being imposed by the valley-fill which pins the channel to on one side of the valley floor or the other as the channel switches sides.
Bed material texture	Bed comprised of fine-grained material
Channel geometry	Regular, low width to depth ratio results in a slot channel. Only 1 – 2 m wide.
Geomorphic Units	Within-channel • Sculpted runs • Localised, narrow ledges along valley-fill banks Floodplain • Valley-fill acts as a floodplain, but it was not deposited by the contemporary stream • Becomes saturated during rainfall events, leading to the formation of backswamps
Vegetation associations	Pasture dominates with wetland-type vegetation close to the channel on the valley floor

RIVER BEHAVIOUR
Low Flow Behaviour Undisrupted low flow. Suspended sediments are flushed through this reach. **Bankfull Behaviour** Channel banks can be scoured and cause slumping and the formation of ledges. Over time, this can cause channel widening and lateral migration. Although, this is a slow, localised process along this River Style given the degree of confinement, cohesive nature of the floodplain/valley-fill material and relatively low energy system due to the small upstream catchment area. **Overbank Behaviour** Valley-fill and floodplains can become waterlogged which can take a long time to drain, promoting the formation/reactivation of backswamps. The preferential flow is retained within the contemporary channel rather than forming flood channels.

CONTROLS	
Landscape Setting and within-catchment position	Found in upland plateau areas.
Valley Morphology	Irregular, 100 - 120 m wide, in-filled with fine-grained alluvium
Process Zone	Sediment source zone
Channel Slope	0.02 - 0.04 m/m
Upstream Catchment Area	1.5 - 3.5 km^2

B.23. Partly Confined, Road Margin-Controlled, Discontinuous Floodplain, Fine-Grained Bed (PC_RdMC_DcFp_Fbed)

Location(s): Waipā River (mouth)

Distinguishing attributes: This River Style flows through the township of Ngāruawāhia and is in a partly confined setting, where the channel abuts man-made margins (predominantly roads, along with other man-made structures) >50% of the time. The channel is entrenched in fine-grained alluvium. Ngāruawāhia is built on the floodplain/confluence zone between the Waipā and Waikato Rivers. The bed material comprises of fine-grained materials.

Figure B.41. Google Earth image showing a representative reach of the PC_RdMC_DcFp_Fbed River Style along the Waipā River before it joins the Waikato River.

Figure B.42. Photograph showing a representative reach of the PC_RdMC_DcFp_Fbed River Style along the Waipā River, looking upstream from the Waikato River confluence.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 37°40'5.37"S, 175° 8'33.43"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Channel abuts anthropogenic margins (predominantly roads) >50% of the time. Combined with banks comprised of cohesive, fine-grained material, this results in a stable channel position.
Bed material texture	Fine-grained material.
Channel geometry	Symmetrical, single thread, low sinuosity channel.
Geomorphic Units	Within-channel • Entrenched single thread channel, deprived of in-channel geomorphic units • Low channel width to depth ratio prevents the formation of in-stream geomorphic units Floodplain • Discontinuous floodplains between the channel and roads. • Some older terrace features in places. • The larger external floodplain is highly urbanized and largely disconnected from the contemporary channel.
Vegetation associations	Channel is lined by non-native trees in short sections through the township. Inset floodplain pockets consist predominantly of mown lawn. The wider floodplain is highly urbanised, with floodplains that are not built upon comprising of grass.

RIVER BEHAVIOUR
Low Flow Behaviour The flow moves undisrupted through this reach, with little hydraulic diversity. The channel remains highly stable, due to the numerous anthropogenic margins and cohesive banks. **Bankfull Behaviour** During bankfull flows, cohesive banks may be scoured. Although, vegetation protects most of the banks from excessive erosion. High channel capacity allows for sediment to be easily flushed through this reach, acting like a flume, resulting in a lack of in-stream geomorphic diversity. **Overbank Behaviour** Overbank flows are now very rare and almost non-existent, as the flow of the Waikato River is controlled by several upstream dams. This allows it to flow lower than it would do otherwise during storm events, making it able to draw out and accommodate excess

flow from the lower Waipā river. If overbank flows were to occur, the floodplains would be built up via vertical accretion processes and Ngāruawāhia would be flooded, causing large amounts of flood damage to the town. Only in extremely large, rare events are the road margins overtopped, resulting in the spread of flow onto the urbanised floodplain and the deposition of fines.

CONTROLS	
Landscape Setting and within-catchment position	Found in the lower catchment area (Waipā River mouth) through townships.
Valley Morphology	Regular, >1 km wide. Anthropogenic margins can be as narrow as 120 m.
Process Zone	Sediment transfer/accumulation zone.
Channel Slope	<0.001 m/m
Upstream Catchment Area	3093 km^2

B.24. Partly Confined, Stop Bank Margin-Controlled, Discontinuous Floodplain, Gravel Bed (PC_SBkMC_DcFp_Gbed)

Location(s): Waipā River (Ōtorohanga)

Distinguishing attributes: This River Style flows through the township of Ōtorohanga and is in a partly confined setting, where the channel abuts man-made margins (stopbanks) >50% of the time. The channel is entrenched in fine-grained alluvium. The bed material comprises of gravels with some interbedded sand and fines. Ōtorohanga is built on the floodplain/confluence zone between the Waipā River, Mangapū River, and Mangawhero Stream. This large confluence zone between several prominent watercourses makes the area highly susceptible to flooding during storm events, hence the construction of stopbanks to mitigate the potential flood risk to the town.

Figure B.43. Google Earth image showing a representative reach of the PC_SBkMC_DcFp_Gbed River Style along the Waipā River.


Figure B.44. Photographs showing features (stopbanks, left) and a representative reach (right) of the PC_SBkMC_DcFp_Gbed River Style along the Waipā River at Ōtorohanga.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°11'32.43"S, 175°12'23.30"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	The channel abuts stopbank margins >50% of the time. This results in a highly stable channel position. Discontinuous floodplain surfaces accommodate the limited space present between the channel and stopbank margins as the channel alternates between each side of the valley floor.
Bed material texture	Predominantly gravels, with some interbedded sand and fines
Channel geometry	Symmetrical along straight sections, irregular along bends
Geomorphic Units	Within-channel • Entrenched single thread channel, generally deprived of in-channel geomorphic units • Occasional lateral gravel bars • Low channel width to depth ratio prevents the formation of in-stream geomorphic units • Concrete/rock walls in places Floodplain • Discontinuous inset floodplains between the channel and stopbanks • The larger external floodplain is highly urbanised (now disconnected from contemporary river processes due to stopbanks)
Vegetation associations	Channel is lined by non-native trees in long sections through the township. Inset floodplains between the channel and stopbank margins consist predominantly of mown lawn. The wider floodplain is highly urbanised, with floodplains that are not built upon comprising of pasture.

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, flow moves undisrupted through this reach, with little hydraulic diversity. The channel remains highly stable, confined by anthropogenic margins. **Bankfull Behaviour** High channel capacity allows for sediment to be easily flushed through this reach, acting like a flume, resulting in a lack of in-stream geomorphic diversity. Occasional bar surfaces are reworked and mobilised during these flows. **Overbank Behaviour** During overbank flows, the inset floodplains are built up via vertical accretion processes. During extremely high flow events, floodplains can be stripped and scoured as the flow is concentrated between the stopbanks. Only in extremely large, rare events are the embankments overtopped, resulting in the spread of flow onto the urbanised floodplain and the deposition of fines.

CONTROLS	
Landscape Setting and within-catchment position	Found in the mid catchment area through townships.
Valley Morphology	Regular, >1 km wide. Anthropogenic margins constrain the river to a valley floor of 100 – 130 m wide.
Process Zone	Sediment transfer zone.
Channel Slope	<0.001 m/m

Upstream Catchment Area	390 - 918 km^2 (this reach has two major tributaries which join it as the Waipā River flows through Ōtorohanga, giving it a large drainage area difference between its upstream and downstream extents)

B.25. Partly Confined, Stop Bank Margin-Controlled, Discontinuous Floodplain, Fine-Grained Bed (PC_SBkMC_DcFp_Fbed)

Location(s): Mangawhero Stream (Ōtorohanga)

Distinguishing attributes: This River Style flows through the township of Ōtorohanga where it joins the Waipā River. It is in a partly confined setting, where the channel abuts man-made margins (stopbanks) >50% of the time. The channel is entrenched in fine-grained alluvium. The bed material comprises of fine-grained material. Ōtorohanga is built on the surrounding floodplain/confluence zone. This large confluence zone between several prominent watercourses makes the area highly susceptible to flooding during storm events, hence the construction of stopbanks to mitigate the potential flood risk to the town.

Figure B.45. Photographs showing the representative reach of the PC_SBkMC_DcFp_Fbed River Style along the Mangawhero Stream looking upstream (left) and downstream (right).

Figure B.46. Google Earth image showing the representative reach of the PC_SBkMC_DcFp_Fbed River Style along the Mangawhero Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°11'37.71"S, 175°12'51.33"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	The channel abuts stopbank margins >50% of the time. This results in a highly stable channel position. Discontinuous floodplain surfaces accommodate the limited space present between the channel and stopbank margins as the channel alternates between each side of the stopbank margins.
Bed material texture	Fine-grained sediment
Channel geometry	Symmetrical along straight sections, irregular around bends
Geomorphic Units	Within-channel • Entrenched single thread channel, generally deprived of in-channel geomorphic units • Occasional sculpted forced pools around trapped woody debris • Low channel width to depth ratio prevents the formation of in-stream geomorphic units Floodplain • Discontinuous inset floodplains between the channel and stopbanks • The larger external floodplain is highly urbanised (now disconnected from contemporary river processes due to stopbanks)
Vegetation associations	Channel is lined by non-native shrubs and weeds. Floodplains consist predominantly of pasture. The wider disconnected floodplain is highly urbanised, with floodplains that are not built upon comprising of pasture.

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, flow moves undisrupted through this reach, with little hydraulic diversity. The channel remains highly stable, confined by anthropogenic margins. **Bankfull Behaviour** Slot channel form is indicative of incisional processes dominating. The bed and banks are scoured during high flow events. However, bank-lined vegetation helps mitigate bank erosion. Sediment is easily flushed through this reach, acting like a flume, resulting in a lack of in-stream geomorphic diversity. **Overbank Behaviour** During overbank flows, the floodplains are built up via vertical accretion processes. During extremely high flow events, floodplains can be stripped and scoured as the flow is concentrated between the stopbanks. Only in extremely large, rare events are the embankments overtopped, resulting in the spread of flow onto the urbanised floodplain and the deposition of fines.

CONTROLS	
Landscape Setting and within-catchment position	Found in the mid catchment area through townships.
Valley Morphology	Regular, >1 km wide. Anthropogenic margins constrain the river to a valley floor of 20 – 80 m wide.
Process Zone	Sediment transfer zone.
Channel Slope	<0.028 m/m
Upstream Catchment Area	64 km^2

B.26. Partly Confined, Terrace Margin-Controlled, Discontinuous Floodplain, Gravel Bed (PC_TrMC_DcFp_Gbed)

Location(s): Mangatutu Stream and Owairaka Stream

Distinguishing attributes: Channel abuts terrace margins >50% of the time, hence channel morphology and alignment are controlled to a significant degree by terrace extent. Contemporary, discontinuous floodplains occur in wider areas between terrace margins. The channel is sinuous, but lateral adjustment is restricted by terrace margins. The channel is characterised by a gravel bed and is generally narrow, set within a fine-grained floodplain and cohesive terrace margins.

Figure B.47. Photograph showing a representative reach of the PC_TrMC_DcFp_Gbed River Style along the Mangatutu Stream.

Figure B.48. Google Earth image showing a representative reach of the PC_TrMC_DcFp_Gbed River Style along the Mangatutu Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38° 5'58.55"S, 175°23'47.52"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Channel abuts terrace margins >50% of the time, hence alignment is controlled by terrace extent. The channel is sinuous and contemporary discontinuous floodplains occur in wider areas between terrace margins, as the channel alternates between valley margins.
Bed material texture	Gravel bed with interbedded fine-grained sediment. Banks are comprised of cohesive fine-grained material.
Channel geometry	Symmetrical slot entrenched channel in straight sections, and asymmetrical on bends. Channel is up to 10 m wide.
Geomorphic Units	Within-channel • Benches elevated 1 – 5 m above the channel • Ledges associated with degradation • Occasional bank-attached lateral and point bars • Highly incised and entrenched channel, with limited instream geomorphic units Floodplain • Discontinuous fine-grained contemporary floodplain between terrace margins • Backswamp areas in the contemporary floodplain • Elevated terrace floodplains consisting of Late Pleistocene alluvium
Vegetation associations	Mostly pasture on the contemporary floodplain and terraces. Banks are highly vegetated with weeds and invasive trees and shrubs.

RIVER BEHAVIOUR
Low Flow Behaviour During low flows, flow moves undisrupted through this reach, with little hydraulic diversity. The channel remains highly stable, confined by terrace margins. **Bankfull Behaviour** The channel generally has a low width to depth ratio due to the cohesive, fine-grained floodplain sediments. The cohesive fine-grained floodplains and terrace margins mean that bank erosion occurs at relatively low rates and restricts lateral migration. Dominant forms of bank erosion processes are slumping and block failure. Bankfull flow will rework bank-attached bars. **Overbank Behaviour** In overbank flow, flow spills out over contemporary floodplains and fills the area between the terrace margins. Contemporary floodplains are formed by vertical accretion processes. Only under large flow events (i.e. 1 in 50- or 100-year event) are the terrace margins overtopped.

CONTROLS	
Landscape Setting and within-catchment position	Located in lowland plain settings.
Valley Morphology	Irregular, 50 – 150 m between terrace margins
Process Zone	Sediment accumulation zone.
Channel Slope	0.001 – 0.002 m/m
Upstream Catchment Area	85 km^2 (Owairaka Stream), 112 km^2 (Mangatutu Stream)

B.27. Partly Confined, Terrace Margin-Controlled, Discontinuous Floodplain, Fine-Grained Bed (PC_TrMC_DcFp_Fbed)

Location(s): Moakurarua River and Waipā River

Distinguishing attributes: Channel abuts terrace margins >50% of the time, hence channel morphology and alignment are controlled to a significant degree by terrace extent. Contemporary discontinuous floodplains occur in wider areas between terrace margins. The channel is sinuous, but lateral adjustment is restricted by terrace margins. The channel is generally narrow and is set within a fine-grained floodplain and cohesive terrace margins.

Figure B.49. Photograph showing a representative reach of the PC_TrMC_DcFp_Fbed River Style along the Waipā River.

Figure B.50. Google Earth image showing a representative reach of the PC_TrMC_DcFp_Fbed River Style along the Moakurarua River.

Figure B.51. Google Earth image showing a representative reach of the PC_TrMC_DcFp_Fbed River Style along the Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Moakurarua: 38° 3'47.55"S, 175°11'13.62"E; Waipā: 37°59'41.24"S, 175°11'35.57"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Channel abuts terrace margins >50% of the time, hence alignment is controlled by terrace extent. The channel is sinuous and contemporary floodplain pockets occur in wider areas between terrace margins.

Bed material texture	Fine-grained sediment, with some gravel in the bed. Banks are predominantly comprised of cohesive fine-grained material.
Channel geometry	Symmetrical slot entrenched channel in straight sections, and asymmetrical on bends. Channel is up to 20 m wide.
Geomorphic Units	Within-channel • Benches elevated 1 – 5 m above the channel • Ledges associated with degradation • Highly incised and entrenched channel, with limited instream geomorphic units • Riffles up to 50 m long • Pools can be up to 200 m long and as wide as the channel • Occasional lateral and point bars • Sculpted pumice bedrock outcrops Floodplain • Discontinuous fine-grained contemporary floodplain between terrace margins • Backswamp areas in the contemporary floodplain • Elevated terrace floodplains consisting of Late Pleistocene alluvium
Vegetation associations	Mostly pasture on the contemporary floodplain and terraces, with some small patches of other vegetation.

RIVER BEHAVIOUR
Low Flow Behaviour Low gradients and broad elevated terrace floodplains make for low energy systems. Flow occurs over fine-grained sculpted geomorphic units and fills pools. **Bankfull Behaviour** The channel generally has a low width to depth ratio due to the cohesive, fine-grained floodplain sediments. The cohesive fine-grained floodplains and terrace margins mean that bank erosion occurs at relatively low rates and restricts lateral migration. Dominant forms of bank erosion processes are slumping and block failure. Bankfull flow will sculpt bank-attached bars and scour pools along the concave banks of bends. **Overbank Behaviour** In overbank flow, flow spills out over contemporary floodplains and fills the area between the terrace margins. Contemporary floodplains are formed by vertical accretion processes. Only under large flow events (i.e. 1 in 50- or 100-year event) are the terrace margins overtopped.

CONTROLS	
Landscape Setting and within-catchment position	Located in lowland plain settings.
Valley Morphology	Irregular, 50 – 150 m between terrace margins
Process Zone	Sediment accumulation zone.
Channel Slope	Generally, <0.001 m/m
Upstream Catchment Area	228 km^2 (Moakurarua), 2150 – 2520 km^2 (Waipā)

B.28. Partly Confined, Planform-Controlled, Low Sinuosity, Discontinuous Floodplain, Gravel Bed (PC_PC_LSin_DcFp_Gbed)

Location(s): Waipā River

Distinguishing attributes: The channel abuts the valley margin <50% of the time. The channel is shallow with a high width to depth ratio. Discontinuous floodplains are present, as the low sinuosity channel regularly switches from one side of the valley to the other. The channel position is moderately sensitive to geomorphic adjustment, as stream power is relatively high and there is accommodation space available for lateral migration. Bank instability is promoted along the outside of meander bends, where the fine-grained cohesive banks are scoured and undercut during high flow events, inducing lateral migration of the channel over time. However, bank composition and planted vegetation help to mitigate excessive erosion rates.

Figure B.52. Google Earth image showing the representative reach of the PC_PC_LSin_DcFp_Gbed River Style along the Waipā River.

Figure B.53. Photographs showing a representative reach of the PC_PC_LSin_DcFp_Gbed River Style along the Waipā River looking upstream (top) and downstream (bottom).

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°16'55.33"S, 175°21'6.37"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Channel abuts the valley margins <50% of the time and alternates between the two valley sides, with relatively low sinuosity, causing discontinuous floodplains to form. The channel position is moderately sensitive to geomorphic adjustment, as stream power reasonably high and there is accommodation space available for lateral migration
Bed material texture	Gravel
Channel geometry	Symmetrical along straight sections, asymmetrical around meander bends
Geomorphic Units	Within-channel • Mid-channel bars (up to 80 m long and 30 m wide) • Point and lateral bars (up to 60 m long and 15 m wide) • Forced pools around hardwood trees on the riverbank • Ledges and benches along the outside and inside of meander bends respectively (indicative of lateral migration processes) Floodplain • Floodplains are generally flat and up to 300 m wide, multi-levelled in places • Occasional flood channels are present, which tend to remain wet/boggy most of the time • Primarily occupied by farmland
Vegetation associations	Floodplains comprise mainly of pasture. Riverbanks are planted with non-native trees.

RIVER BEHAVIOUR
Low Flow Behaviour Undisrupted flow with fine-grained suspended sediments being transported through this reach. **Bankfull Behaviour** Although partly confined by bedrock margins, bed and banks can be scoured during bankfull flows, and channel adjustment can occur in the form of downstream bend translation where there is accommodation space associated with discontinuous floodplain. Low sinuosity and deep channel indicate that bed incision is the dominating process. High channel capacity allows for fine sediments to be easily flushed through this reach, while geomorphic unit assemblages of gravel bars and islands are reworked at this flow stage. . **Overbank Behaviour** Fine-grained sediments are dropped out of suspension in blankets over the flat floodplains. This sediment deposition causes the floodplains to vertically accrete over time. Flow is highly concentrated within the contemporary channel.

CONTROLS	
Landscape Setting and within-catchment position	Found in the mid catchment areas
Valley Morphology	Regular
Process Zone	Sediment transfer/accumulation zone
Channel Slope	0.007 m/m
Upstream Catchment Area	240 km^2 (upstream of confluence), 315 km^2 (downstream of confluence)

B.29. Partly Confined, Planform-Controlled, Low Sinuosity, Discontinuous Floodplain, Fine-Grained Bed (PC_PC_LSin_DcFp_Fbed)

Location(s): Mangarapa Stream and Mangapiko River

Distinguishing attributes: The channel abuts the valley margin <50% of the time. The channel is entrenched with a low width to depth ratio. Discontinuous floodplains are present, as the low sinuosity channel regularly switches from one side of the valley to the other. The channel position is very stable as stream power is low, and the fine-grained material which makes up the bed and banks is relatively cohesive. Banks are prone to slumping due to high level of bed incision.

Figure B.54. Photograph showing a representative reach of the PC_PC_LSin_DcFp_Fbed River Style along the Mangarapa Stream.

Figure B.55. Google Earth image showing a representative reach of the PC_PC_LSin_DcFp_Fbed River Style along the Mangarapa Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°16'18.11"S, 175°11'45.83"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Channel abuts the valley margins <50% of the time and alternates between the two valley sides, with relatively low sinuosity, causing discontinuous floodplains to form. The channel position is relatively stable due to being entrenched, the low stream power, and the cohesive fine-grained bed and bank material. Paleochannels and meander cut-offs are evident on the floodplain, as a result of man-made channel straightening processes.

Bed material texture	Fine-grained
Channel geometry	Symmetrical
Geomorphic Units	Within-channel • Incised single thread channel, deprived of in-channel geomorphic units • Low channel width to depth ratio prevents the formation of in-stream geomorphic units • Bank slumps are common due to high level of bed incision destabilising bank faces Floodplain • Floodplains are flat and wide • Paleochannels and meander cut-offs are present as a result of channel straightening processes • Some meander cut-offs develop into bogs/backswamps during wetter seasons
Vegetation associations	Floodplains and bedrock valley margins comprise mainly of pasture, with some small patches of vegetation.

RIVER BEHAVIOUR	
Low Flow Behaviour Undisrupted flow with fine-grained suspended sediments being transported through this reach. **Bankfull Behaviour** Cohesive bed and banks can be scoured, inducing bank slumps. Low sinuosity and deep channel indicate that bed incision is the dominating process. High channel capacity allows for sediment to be easily flushed through this reach, causing the lack of in-stream geomorphic diversity. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension in blankets over the flat floodplains. This sediment deposition causes the floodplains to vertically accrete over time. Flow is highly concentrated within the contemporary channel. Backswamps/bogs are rejuvenated, and floodplains can become saturated.	
CONTROLS	
Landscape Setting and within-catchment position	Found in the mid catchment areas
Valley Morphology	Regular
Process Zone	Sediment transfer/accumulation zone
Channel Slope	0.001 - 0.004 m/m
Upstream Catchment Area	46 km^2 (Mangarapa), 125 km^2 (Mangapiko)

B.30. Partly Confined, Planform-Controlled, Low Sinuosity, Road Constrained, Discontinuous Floodplain, Gravel Bed (PC_PC_LSin_RdCS_DcFp_Gbed)

Location(s): Mangaokewa Stream

Distinguishing attributes: The channel abuts the anthropogenic valley margins (predominantly roads) <50% of the time. Large, discontinuous floodplains are present, as the low-moderate sinuosity channel regularly switches from one side of the valley to the other. The channel has a low-medium sensitivity to geomorphic adjustment, as stream power can be reasonably high during storm events and there is accommodation space available for lateral migration. However, cohesive fine-grained banks and imposed anthropogenic controls restrict excessive erosion. Bank instability is focused along the outside of meander bends, where the fine-grained cohesive banks are scoured and undercut during high flow events.

Figure B.56. Google Earth image showing a representative reach of a PC_PC_LSin_RdCS_DcFp_Gbed River Style along the Mangaokewa Stream.

Figure B.57. Photographs showing representative reaches of a PC_PC_LSin_RdCS_DcFp_Gbed River Style along the Mangaokewa Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth - 38°18'43.38"S, 175° 8'56.41"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Channel abuts the valley margins <50% of the time and alternates between the two valley sides, with relatively low sinuosity, causing discontinuous floodplains to form. The channel position can be sensitive to localised geomorphic adjustment.
Bed material texture	Gravel with interbedded fine-grained material
Channel geometry	Symmetrical along straight sections, asymmetrical around meander bends
Geomorphic Units	Within-channel • Ledges and benches along the outside and inside of meander bends respectively (indicative of lateral migration processes) • Bank slumps

	• Large woody debris and associated forced pool features • Small bank-attached bars in places Floodplain • Floodplains are generally flat and up to 150 m wide • Primarily occupied by farmland
Vegetation associations	Floodplains comprise mainly of pasture. Riverbanks dotted with non-native trees but are primarily covered in grass or weeds.

RIVER BEHAVIOUR
Low Flow Behaviour Undisrupted flow with fine-grained suspended sediments being transported through this reach. **Bankfull Behaviour** Cohesive bed and banks can be scoured. Low sinuosity and reasonably deep channel indicate that bed incision is the dominating process. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension in blankets over the flat floodplains. This sediment deposition causes the floodplains to vertically accrete over time. Flow is highly concentrated within the contemporary channel.

CONTROLS	
Landscape Setting and within-catchment position	Found in the mid catchment areas
Valley Morphology	Regular
Process Zone	Sediment transfer/accumulation zone
Channel Slope	<0.001 m/m
Upstream Catchment Area	185 km^2

B.31. Partly Confined, Planform-Controlled, Low Sinuosity, Road Constrained, Discontinuous Floodplain, Fine-Grained Bed (PC_PC_LSin_RdCS_DcFp_Fbed)

Location(s): Mangapiko River

Distinguishing attributes: This River Style flows through the township of Te Awamutu and the channel abuts road constraints <50% of the time. Some of the channel banks have been cemented in place to protect the town from lateral migration. The channel is entrenched with a low width to depth ratio. Discontinuous floodplains are present, as the low sinuosity channel regularly switches from one side of the valley to the other – this can be described as a passive meandering river. The channel position is very stable as stream power is low, and the fine-grained material which makes up the bed and banks is relatively cohesive.

Figure B.58. Google Earth image showing a reach representing the PC_PC_LSin_RdCS_DcFp_Fbed River Style along the Mangapiko River.

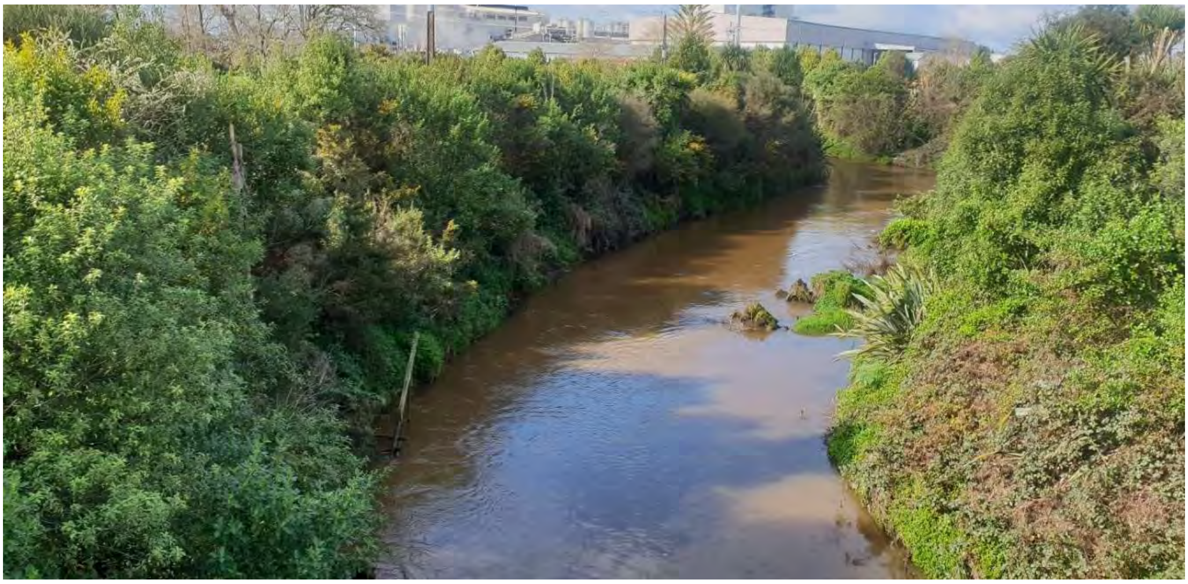

Figure B.59. Photograph showing a representative reach of the PC_PC_LSin_RdCS_DcFp_Fbed River Style along the Mangapiko River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Mangapiko: 38° 0'6.75"S, 175°19'0.74"E

RIVER CHARACTER	
Valley-setting	Partly Confined
Channel Planform	Channel abuts anthropogenic margins (mainly roads) <50% of the time and alternates between the two valley sides, with relatively low sinuosity, causing discontinuous floodplains to form (passive meandering river). Confinement increases through the township of Te Kūiti, as some banks are concreted in place. The channel position is relatively stable due to being entrenched, the low stream power, the cohesive fine-grained bed material and the anthropogenic constraints.
Bed material texture	Fine-grained
Channel geometry	Symmetrical
Geomorphic Units	Within-channel • Incised single thread channel, deprived of in-channel geomorphic units • Low channel width to depth ratio prevents the formation of in-stream geomorphic units

	Floodplain • Some localised shallow levees, however anthropogenic occupation of floodplains restricts geomorphic diversity • Floodplains are very flat and wide
Vegetation associations	Channel is lined by non-native trees in short sections through the township. Floodplains that are not built upon comprise of pasture.

RIVER BEHAVIOUR
Low Flow Behaviour Undisrupted flow with fine-grained suspended sediments being transported through this reach. **Bankfull Behaviour** Cohesive bed and banks can be scoured. Low sinuosity and deep channel indicate that bed incision is the dominating process. High channel capacity allows for sediment to be easily flushed through this reach, causing the lack of in-stream geomorphic diversity. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension in blankets over the flat floodplains. This sediment deposition causes the floodplains to vertically accrete over time. Flow is highly concentrated within the contemporary channel.

CONTROLS	
Landscape Setting and within-catchment position	Found in the lower-mid catchment areas through townships built upon flat alluvial plains.
Valley Morphology	Regular
Process Zone	Sediment transfer/accumulation
Channel Slope	0.007 m/m
Upstream Catchment Area	267 km^2

B.32. Partly Confined, Planform-Controlled, Low Sinuosity, Terrace Constrained, Discontinuous Floodplain, Gravel Bed (PC_PC_LSin_TrCS_DcFp_Gbed)

Location(s): Upper Waipā River and Waimahora Stream

Distinguishing attributes: The channel abuts bedrock margins and additional pumice terrace constraints <50% of the time. The channel has a moderately low width to depth ratio. Discontinuous floodplains are present, as the low sinuosity channel regularly switches from one side of the valley to the other. The channel position is very stable as stream power is low, and the fine-grained material which makes up the banks is relatively cohesive.

Figure B.60. Photographs showing a representative reach (left) and features (pumice terraces, right) of the PC_PC_LSin_TrCS_DcFp_Gbed River Style along the Waipā River.

Figure B.61. Google Earth image showing a representative reach of the PC_PC_LSin_TrCS_DcFp_Gbed River Style along the Waipā River.

DETAILS OF ANALYSIS	
Map(s) used: Google Earth 38°25'49.42"S, 175°22'44.07"E	
RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	The channel has a moderately low width to depth ratio. Discontinuous floodplains are present, as the low sinuosity channel regularly switches from one side of the valley to the other. The channel position is very stable as stream power is low, and the fine-grained material which makes up the banks is relatively cohesive.
Bed material texture	Gravel bed, occasionally interbedded with fine-grained sediments
Channel geometry	Symmetrical
Geomorphic Units	Within-channel • Low channel width to depth ratio prevents the formation of in-stream geomorphic units as sediments are easily flushed through the reach • Occasional forced pools form around obstructing trees or woody debris Floodplain • Occasional ephemeral stream channels • Low elevation levees • Occasional backswamps and flood channels • Older pumice terraces in places
Vegetation associations	Primarily pasture with occasional trees and weeds along channel banks
RIVER BEHAVIOUR	
Low Flow Behaviour Undisrupted flow easily flushes fine-grained material though this reach **Bankfull Behaviour** Gravel bedload begins to mobilise. Scouring of banks can occur, particularly along the outside of meander bends. Ephemeral streams may start to activate during high rainfall events. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension in blankets over the flat floodplains. This sediment deposition causes the floodplains to vertically accrete over time. Flow is generally concentrated within the contemporary channel, but flow can also accumulate along flood channels across the floodplains. Backswamps and ephemeral tributary channels are rejuvenated.	

CONTROLS	
Landscape Setting and within-catchment position	Found in upland tabletop areas within the catchment
Valley Morphology	Generally regular, but can be irregular in places, promoting the formation of localised ephemeral streams
Process Zone	Sediment source/transfer zone. Sediment can accumulate on floodplains during overbank flows.
Channel Slope	0.015 m/m
Upstream Catchment Area	27 km^2 (Waimahora), 89 km^2 (Waipā)

B.33. Partly Confined, Planform-Controlled, Low Sinuosity, Terrace Constrained, Discontinuous Floodplain, Fine-Grained bed (PC_PC_LSin_TrCS_DcFp_Fbed)

Location(s): Waipā River

Distinguishing attributes: The channel abuts bedrock margins and additional terrace constraints <50% of the time. The channel has a moderately low width to depth ratio. Discontinuous floodplains are present, as the low sinuosity channel regularly switches from one side of the valley to the other. The channel position is very stable as stream power is low, and the fine-grained material which makes up the banks is relatively cohesive. Channel straightening practises also characterise this River Style.

Figure B.62. Photographs showing a representative reach of the PC_PC_LSin_TrCS_DcFp_Fbed River Style along the Waipā River.

Figure B.63. Google Earth image showing a representative reach of the PC_PC_LSin_TrCS_DcFp_Fbed River Style along the Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38° 6'8.76"S, 175°12'5.92"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Discontinuous floodplains are present, as the low sinuosity channel switches from one side of the valley to the other. The channel position is very stable as stream power is low, and the fine-grained material which makes up the bed and banks is very cohesive.
Bed material texture	Fine-grained sediment
Channel geometry	Generally symmetrical, with localised asymmetricity around meander bends
Geomorphic Units	Within-channel • Incised channel with high carrying capacity prevents the formation of in-stream geomorphic units as sediments are easily flushed through the reach • Occasional scoured pools form around obstructing trees/woody debris, as well as around the outside of meander bends where the thalweg is concentrated Floodplain • Occasional ephemeral stream channels draining terrace risers • Occasional backswamps and flood channels • Lacking geomorphic diversity due to the presence of farming practices
Vegetation associations	Primarily pasture with occasional trees, shrubs, and weeds along channel banks

RIVER BEHAVIOUR
Low Flow Behaviour Undisrupted flow easily flushes fine-grained material though this reach **Bankfull Behaviour** Scouring of bed and banks can occur, particularly along the outside of meander bends. Ephemeral streams may start to activate during high rainfall events. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension in blankets over the flat floodplains. This sediment deposition causes the floodplains to vertically accrete over time. Flow is generally concentrated within the contemporary channel, but flow can also accumulate along flood channels across the floodplains. Backswamps and ephemeral tributary channels are rejuvenated.

CONTROLS	
Landscape Setting and within-catchment position	Found in lowland alluvial plains
Valley Morphology	Generally regular between bedrock margins, but can be irregular where terraces are present, promoting the formation of localised ephemeral streams
Process Zone	Sediment transfer/accumulation zone
Channel Slope	<0.001 m/m
Upstream Catchment Area	1215 km² (mid-Waipā), 3045 km² (lower Waipā)

B.34. Partly Confined, Planform-Controlled, Low Sinuosity, Valley Fill, Fined-Grained Bed (PC_PC_LSin_VFi_Fbed)

Location(s): Upper Waipā River and Mangarapa Stream

Distinguishing attributes: This River Style is set within a partly confined valley setting. The channel abuts bedrock <50% of the time. These reaches are close to the source of low discharge tributaries in flat, upland tabletop areas, where bedrock valleys have become filled with fine-grained material. This has created a fine-grained valley-fill which forms the valley floor, which has a relatively low slope given its upland catchment position. Poor drainage, due to the low gradient, can cause the valley-fill floodplains to become saturated during rainfall events, turning them into swamp-like areas and promoting the formation of backswamps. The channel is generally continuous but can be discontinuous in places as fine-grain sediments are redistributed during high flow events.

Figure B.64. Google Earth image a showing representative reach of the PC_PC_LSin_VFi_Fbed River Style along the Waipā River.

Figure B.65. Google Earth image showing a representative reach of the PC_PC_LSin_VFi_Fbed River Style along the Mangarapa Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth – Waipā: 38°26'28.97"S, 175°31'39.87"E; Mangarapa: 38°20'30.83"S, 175°15'6.55"E

RIVER CHARACTER	
Valley-setting	Partly confined, mostly continuous channel.
Channel Planform	Mostly single thread, low sinuosity channel. Can be discontinuous in places, leading to multiple potential channel pathways. The valley-fill acts as the floodplain in this River Style, however the

	low drainage area and discharge of these streams, along with the lack of upstream fine-grained sediment source, prevents them from supplying fine-grained material to the floodplains from upstream. The channel abuts bedrock <50% of the time. The channel configuration is primarily dictated by valley alignment, as well as being imposed by the valley-fill which pins the channel to on one side of the valley floor or the other as the channel switches sides.
Bed material texture	Fine-grained material
Channel geometry	Regular, low width to depth ratio results in a slot channel. Only 1 – 2 m wide, sometimes <1 m wide.
Geomorphic Units	Within-channel • Sculpted runs • Localised, narrow ledges and bank slumps along valley-fill banks Floodplain • Valley-fill acts as a floodplain, but it was not deposited by the contemporary stream • Becomes saturated during rainfall events, leading to the formation of backswamps • Paleochannels left behind from previous main channel pathways.
Vegetation associations	Pasture dominates along the Mangarapa Stream reach. A combination of planted forest and bush dominates along the Waipā River reach.

RIVER BEHAVIOUR
Low Flow Behaviour Generally, undisrupted flow where suspended sediments are flushed through the reach. Where the channel becomes discontinuous, flow can pool, and deposit suspended sediments. **Bankfull Behaviour** Channel banks can be scoured and cause slumping and the formation of ledges. These slumps can also cause blockages and cause the flow to become discontinuous. Over time, this process can cause lateral migration of the channel. Although, this is a slow, localised process along this River Style given the low discharge and cohesive nature of the floodplain/valley-fill material. **Overbank Behaviour** Valley-fill and floodplains can become waterlogged which can take a long time to drain, promoting the formation/reactivation of backswamps. The preferential flow is retained within the contemporary channel rather than forming flood channels. Paleochannels can become reactivated.

B.35. Partly Confined, Planform-Controlled, Meandering, Backswamp Constrained, Discontinuous Floodplain, Sand Bed (PC_PC_Meand_BSwCS_DcFp_Sbed)

Location(s): Owairaka Stream

Distinguishing attributes: The channel abuts bedrock margins and backswamp constraints <50% of the time. The large amount of accommodation space on the valley floor, combined with many paleochannels and meander cut-offs, has led to the formation of several significant backswamps throughout the contemporary floodplain. The channel has a moderately low width to depth ratio. Discontinuous floodplains are present, as the meandering channel switches from one side of the valley to the other. The channel is sensitive to geomorphic change and lateral migration due to the high potential stream power during flood events and the easily erodible sand bed material.

Figure B.66. Google Earth image showing a representative reach of the PC_PC_Meand_BSwCS_DcFp_Sbed River Style along the Owairaka Stream.

Figure B.67. Photographs showing representative reaches of the PC_PC_Meand_BSwCS_DcFp_Sbed River Style along the Owairaka Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38° 6'13.32"S, 175°29'35.74"E

RIVER CHARACTER	
Valley-setting	Partly confined
Channel Planform	Single thread, continuous channel with high sinuosity. Discontinuous floodplains with numerous backswamps that fill much of the accommodation space on the valley floor.
Bed material texture	Sand bed, floodplains generally comprised of fine-grained material.
Channel geometry	Generally irregular and relatively narrow compared to the valley width.
Geomorphic Units	Within-channel • Occasional mid-channel islands • Bank slumps where the channel is slightly more incised

	• Woody debris and other in-channel vegetation can trap sediments, creating localised bars and islands Floodplain • Meander cut-offs • Levees • Backswamps • Flood channels
Vegetation associations	Pasture dominates the floodplains with freshwater plants associated with wetlands found along channel banks and within backswamps.

RIVER BEHAVIOUR
Low Flow Behaviour Generally, undisrupted flow flushes fine-grained material through this reach. Hydraulic diversity can occur where islands and slumps have occurred, and where in-stream vegetation traps suspended sediments. **Bankfull Behaviour** Previously trapped sediments are remobilised. Bed and bank erosion can be prolific. In-channel vegetation can be stripped, but it can also act to increase flow resistance where the vegetation is particularly well established. **Overbank Behaviour** Fine-grained and sandy sediments are deposited on the floodplains. Flood channels and meander cut-offs are reactivated. Avulsions can occur, creating more abandoned meander loops. Backswamps are rejuvenated.

CONTROLS	
Landscape Setting and within-catchment position	Found in the transition zone between confined, upland areas and unconfined, lowland plains, where accommodation space increases and alluvial deposits can begin to form.
Valley Morphology	Regular, ~400 m wide
Process Zone	Sediment transfer zone
Channel Slope	0.004 m/m
Upstream Catchment Area	69 km^2

B.36. Partly Confined, Planform-Controlled, Meandering, Discontinuous Floodplain, Gravel Bed (PC_PC_Meand_DcFp_Gbed)

Location(s): Ōamaru Stream & Mid Moakurarua Stream

Distinguishing attributes: This River Style occupies pockets of increased accommodation space within partly confined planform-controlled bedrock margin landscape setting, where the channel abuts bedrock <50% of the time within the Moakurarua sub-catchment. These pockets are the result of wider valley settings within the sub-catchment which have been filled with alluvial deposits, through which the river channel can laterally adjust. Backswamps and the occasional oxbow cut-offs are distinguishing features of this River Style. High stream power combined with space to adjust and easily mobilized gravel sediments results in a River Style that is more sensitive to geomorphic adjustment than other styles within this sub-catchment and the greater Waipā Catchment.

Figure B.68. Drone images looking upstream (left) and downstream (right) along the Ōamaru Stream representative reach.

Figure B.69. Google Earth image showing the section along the Ōamaru Stream used for presenting the PC_PC_Meand_DcFp_Gbed River Style.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38° 8'44"S, 175° 4'50"E

RIVER CHARACTER	
Valley-setting	Partly Confined
Channel Planform	Channel abuts bedrock <50% of the time and alternates between the two valley sides, with relatively high sinuosity, causing discontinuous floodplains. Oxbow cut-offs and backswamps occur frequently. Channel position is unstable and sensitive to adjustment.
Bed material texture	Gravel
Channel geometry	Symmetrical channel along straight sections, with occasional mid-channel islands. Asymmetrical on bends.
Geomorphic Units	Within-channel • Mid-channel bars (3 m wide, 10 m long) • Point bars (5 – 10 m wide, up to 30 m long) • Point benches on the inside of bends • Ledges throughout • Bank slumps (7 m wide, 10 m long) • Man-made riffles (4-5 m long) • Rock groynes on the outside of meander bends Floodplain • Frequent oxbow cut-offs & paleochannels • Frequent backswamps
Vegetation associations	Floodplains are occupied by pasture and occasional non-native trees. Young vegetation has been planted and fenced off along most of the channel banks, however, this is currently still relatively sparse and is yet to fill out. Point and lateral bars contain small pockets of grass. Mid-channel islands are also vegetated with grass. Majority of valley margin hillslopes are occupied by forestry practices.

RIVER BEHAVIOUR
Low Flow Behaviour Largely undisrupted flow, apart from where management structures, such as rock groynes and man-made riffles have been constructed. Finer-grained sediments are flushed through this reach. **Bankfull Behaviour** The gravel sediment is mobilised. Channel banks can be scoured and/or undercut inducing bank collapse (i.e. slump formations), channel widening and lateral migration. This develops the ledges and point benches. Mid-channel and point bars are reworked.

Focused bank erosion can occur in-between rock groynes on the outside of meander bends, which allows the formation of eddies and forced pools. **Overbank Behaviour** Reactivation of backswamps and oxbows/paleochannels occurs. Floodplain can become waterlogged which can take a long time to drain. The preferential flow tends to be retained within the contemporary channel and paleochannels/oxbows rather than forming distinct flood channels across the floodplain. Oxbow cut-offs are formed during high flow events, as the preferential flow acts to short-circuit meander bends.

CONTROLS	
Landscape Setting and within-catchment position	Found in the mid-upper catchment areas
Valley Morphology	Regular, typically 250 m wide
Process Zone	Sediment transfer/accumulation
Channel Slope	0.009 m/m
Upstream Catchment Area	94 km² from the Moakurarua section, 31 km² from the lowest Ōamaru section

B.37. Partly Confined, Planform-Controlled, Meandering, Discontinuous Floodplain, Sand Bed (PC_PC_Meand_DcFp_Sbed)

Location(s): Mangarapa Stream

Distinguishing attributes: The channel abuts bedrock margins <50% of the time. Discontinuous floodplains are present, as the meandering channel switches from one side of the valley to the other. The channel is sensitive to geomorphic change and lateral migration due to the high potential stream power during flood events and the easily erodible sand bed material. Large backswamps are found on some of the floodplains, as well as some meander cut-offs.

Figure B.70. Google Earth images showing a representative reach of the PC_PC_Meand_DcFp_Sbed River Style along the Mangarapa Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°18'54.97"S, 175°12'43.40"E

RIVER CHARACTER	
Valley-setting	Partly Confined
Channel Planform	Channel abuts bedrock <50% of the time and alternates between the two valley sides, with relatively high sinuosity, causing discontinuous floodplains. Oxbow cut-offs and backswamps occur frequently. Channel position is unstable and sensitive to adjustment.
Bed material texture	Sand
Channel geometry	Symmetrical channel along straight sections. Asymmetrical around meander bends.
Geomorphic Units	Within-channel • Mid-channel bars • Point bars • Point benches on the inside of bends • Ledges throughout • Bank slumps Floodplain • Frequent oxbow cut-offs & paleochannels • Frequent backswamps
Vegetation associations	Floodplains are occupied by pasture and occasional non-native trees. Wetland-type vegetation occupies backswamp areas.

RIVER BEHAVIOUR
Low Flow Behaviour Largely undisrupted flow, apart from where mid-channel bars are present. Finer-grained sediments are flushed through this reach. **Bankfull Behaviour** Channel banks can be scoured and/or undercut inducing bank collapse (i.e. slump formations), channel widening and lateral migration. This develops the ledges and point benches. Mid-channel and point bars are reworked. **Overbank Behaviour** Reactivation of backswamps and oxbows/paleochannels occurs. Floodplain can become waterlogged which can take a long time to drain. The preferential flow tends to be retained within the contemporary channel and paleochannels/oxbows rather than forming distinct flood channels across the floodplain. However, it can also short circuit certain meander loops, which over time can create meander cut-offs.

CONTROLS	
Landscape Setting and within-catchment position	Found in the mid-upper catchment areas
Valley Morphology	Regular, typically 150 m wide
Process Zone	Sediment transfer/accumulation
Channel Slope	0.004 m/m
Upstream Catchment Area	26 km^2

B.38. Partly Confined, Planform-Controlled, Meandering, Discontinuous Floodplain, Fine-Grained Bed (PC_PC_Meand_DcFp_Fbed)

Location(s): Mangapū River

Distinguishing attributes: This River Style is found along the Mangapū River in between laterally unconfined reaches, where the channel is abutting the valley margin >10% of the time. The channel is relatively sinuous, although, its incised nature combined with cohesive fine-grained bed material and low stream power causes the channel to be very stable, thus allowing it to be described as a "passive meandering" River Style. Large woody debris can be found along the banks of this river, remnants of large ancient forests which once dominated this area before they were buried during past volcanic events.

Figure B.71. Google Earth image showing a representative reach of the PC_PC_Meand_DcFp_Fbed River Style along the Mangapū River .

Figure B.72. Photograph showing a representative reach of the PC_PC_Meand_DcFp_Fbed River Style along the Mangapū River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°19'2.00"S, 175° 7'13.00"E

RIVER CHARACTER	
Valley-setting	Partly Confined

Channel Planform	Channel abuts bedrock between 10% and 50% of the time, alternating between the two valley sides with relatively high sinuosity, causing discontinuous floodplains. This style is stable to adjustment, due to low stream power and cohesive fine-grained bed & bank material, thus making it a passive meandering River Style
Bed material texture	Fine-grained material
Channel geometry	Symmetrical channel, typically 2 – 4 m wide with a low wide-depth ratio due to being entrenched.
Geomorphic Units	Within-channel • Ledges found periodically on the outside of bends • Forced pools have the potential to form where isolated trees and woody debris are found on the channel bank • Small occasional bank-attached bars Floodplain • Occasional paleochannels because of localised anthropogenic channel straightening • Occasional backswamps
Vegetation associations	Floodplains are occupied by pasture and occasional non-native trees. Channel is mostly fenced along the top of the banks, presumably for farm-stock safety. Channel banks are vegetated with grass and non-native weeds, with the occasional trees.

RIVER BEHAVIOUR	
Low Flow Behaviour Undisrupted flow. Suspended sediments are flushed through this reach. **Bankfull Behaviour** Channel banks can be scoured and/or undercut inducing bank collapse (i.e. slump formations) and the formation of ledges. Over time, this can cause channel widening and lateral migration, although this is a slow process along this River Style. Large woody debris and trees along the banks can produce localised forced pools. **Overbank Behaviour** Reactivation of backswamps and paleochannels occurs. Floodplain can become waterlogged which can take a long time to drain. The preferential flow tends to be retained within the contemporary channel rather than forming flood channels across the floodplain. Suspended sediments are deposited on the floodplain surface, causing it to vertically accrete over time.	
CONTROLS	
Landscape Setting and within-catchment position	Found in the mid-catchment areas
Valley Morphology	Regular, typically 200 – 400 m wide
Process Zone	Sediment transfer/accumulation
Channel Slope	0.0034 m/m (average over each reach)
Upstream Catchment Area	111 km^2 (upper Mangapū reach), 145 km^2 (lower Mangapū reach)

B.39. Partly Confined, Planform-Controlled, Meandering, Railroad Constrained, Discontinuous Floodplain, Gravel Bed (PC_PC_Meand_RaRdCS_DcFp_Gbed)

Location(s): Mangapū River, continuing up lower Mangaokewa Stream

Distinguishing attributes: The channel abuts valley margins between 10% and 50% of the time, as well as occasionally meeting railroad and road constraints on the floodplain surface. Periodically switching from one side of the valley bottom to the other, the meandering channel has created discontinuous floodplains on the valley floor. With the base level of this river being set by the Waipā River, it has become incised over time. This, combined with cohesive fine-grained banks and low stream power, causes the channel to be very stable to adjustment, thus forming a passive meandering River Style.

Figure B.73. Google Earth image showing a representative reach of the PC_PC_Meand_RaRdCS_DcFp_Gbed River Style along the Mangapū River.

Figure B.74. Photograph showing a representative reach of the PC_PC_Meand_RaRdCS_DcFp_Gbed River Style along the lower Mangaokewa Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°12'53.00"S, 175°12'17.00"E

RIVER CHARACTER	
Valley-setting	Partly Confined
Channel Planform	The planform-controlled channel abuts bedrock valley margins <50% of the time, as well as being occasionally abutting railroad and road constraints on the floodplain surface. The passive meandering channel alternates between the two valley sides, creating discontinuous floodplains. The channel is incised because of its base level being set by the Waipā River. The cohesive fine-grained bank material, combined with a low stream power, results in the channel being very stable to adjustment.
Bed material texture	Gravel with interbedded fine-grained sediments
Channel geometry	Symmetrical, typically 5 – 10 m wide, getting wider as you go downstream
Geomorphic Units	Within-channel • Incised single thread channel, deprived of in-channel geomorphic units • Low channel width to depth ratio prevents the formation of in-stream geomorphic units • Ledges found periodically on the outside of bends • Forced pools have the potential to form where isolated trees are found on the channel bank • Small occasional bank-attached bars Floodplain • Anthropogenic occupation of floodplains restricts geomorphic diversity • Floodplains are very flat and wide • Occasional oxbows & paleochannels due to anthropogenic channel straightening • Occasional backswamps
Vegetation associations	Floodplains are occupied by pasture and occasional non-native trees. Channel banks are mostly vegetated with grass and non-native weeds, with the occasional trees. Banks are occasionally bare where they are too steep for vegetation to take hold.

RIVER BEHAVIOUR
Low Flow Behaviour Undisrupted flow with fine-grained suspended sediments being transported through this reach. **Bankfull Behaviour** Cohesive bed and banks can be scoured, producing slumps and ledges over time. Mobilised gravel bedload can enhance scouring processes through abrasion. Low width to depth ratio indicates that bed incision is the dominating process. High channel capacity allows for sediment to be easily flushed through this reach, causing the lack of in-stream geomorphic diversity. Smaller bar surfaces are reworked during these flows. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension and deposited on floodplain surfaces, vertically accreting them over time. Flow is concentrated within the contemporary channel, although secondary flows can occur in paleochannels and oxbows. Backswamps become reactivated.

CONTROLS	
Landscape Setting and within-catchment position	Found in the lower catchment areas through flat alluvial plains.
Valley Morphology	Regular, typically >1 km wide.
Process Zone	Sediment transfer/accumulation
Channel Slope	0.001 – 0.002 m/m
Upstream Catchment Area	193 - 460 km^2

B.40. Partly Confined, Planform-Controlled, Meandering, Terrace Constrained, Discontinuous Floodplain, Fine-Grained Bed (PC_PC_Meand_TrCS_DcFp_Fbed)

Location(s): Waipā River, Pūniu River and Mangapiko River

Distinguishing attributes: The channel abuts valley margins between 10% and 50% of the time, as well as occasionally meeting terrace constraints. Periodically switching from one side of the valley bottom to the other, the meandering channel has created discontinuous floodplains on the valley floor. With the base level of this river being set by the lower Waipā River, it has become incised over time. This, combined with cohesive fine-grained banks and low stream power, causes the channel to be very stable to adjustment, thus forming a passive meandering River Style. Past channel straightening practices have left behind several large meander cut-off lakes/swamps.

Figure B.75. Google Earth image showing a reach representing the PC_PC_Meand_TrCS_DcFp_Fbed River Style along the Waipā River.

Figure B.76. Google Earth Street View image showing a representative reach of the PC_PC_Meand_TrCS_DcFp_Fbed River Style along the Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38° 9’45.92"S, 175°12'19.31"E

RIVER CHARACTER	
Valley-setting	Partly Confined
Channel Planform	The planform-controlled channel abuts bedrock valley margins <50% of the time, as well as occasionally abutting terrace constraints. The passive meandering channel alternates between the two valley sides, creating discontinuous floodplains. The channel is incised because of its base level being set by the lower Waipā River and Waikato River. The cohesive fine-grained bank material, combined with a low stream power, results in the channel being very stable to adjustment.
Bed material texture	Fine-grained sediments, with occasional fine gravel/sand deposits
Channel geometry	Symmetrical, typically 5 – 10 m wide, getting wider as you go downstream. Asymmetrical around tight meander bends
Geomorphic Units	Within-channel • Incised single thread channel, generally deprived of in-channel geomorphic units • Low channel width to depth ratio prevents the formation of in-stream geomorphic units • Ledges found periodically on the outside of bends • Forced pools have the potential to form where isolated trees are found on the channel bank • Occasional point bars can be found around tight meander bends Floodplain • Floodplains are very flat and wide • Occasional oxbows & paleochannels due to anthropogenic channel straightening • Occasional backswamps
Vegetation associations	Floodplains are occupied by pasture and occasional non-native trees. Channel banks are mostly vegetated with grass and non-native weeds, with the occasional tree. Banks are occasionally bare where they are too steep for vegetation to take hold.

RIVER BEHAVIOUR
Low Flow Behaviour Undisrupted flow with fine-grained suspended sediments being transported through this reach. **Bankfull Behaviour** Cohesive bed and banks can be scoured, producing slumps and ledges over time. Low width to depth ratio indicates that bed incision is the dominating process. High channel capacity allows for sediment to be easily flushed through this reach, causing a lack of in-stream geomorphic diversity. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension and deposited on floodplain surfaces, vertically accreting them over time. Flow is concentrated within the contemporary channel, although secondary flows can occur in paleochannels and oxbows. Backswamps become reactivated.

CONTROLS	
Landscape Setting and within-catchment position	Found in the lower catchment areas through flat alluvial plains.
Valley Morphology	Regular, typically >1 km wide.
Process Zone	Sediment transfer/accumulation
Channel Slope	Generally, <0.001 m/m
Upstream Catchment Area	Varies between 270 - 3000 km^2 depending on reach position within the catchment

B.41. Laterally Unconfined, Continuous Channel, Low Sinuosity, Gravel Bed (LU_C_LSin_Gbed)

Location(s): Waipā River

Distinguishing attributes: Continuous floodplains are found along both sides of the channel. The channel abuts the valley margin <10% of the time. The channel is of low sinuosity, primarily due to extensive man-made channel straightening practices. This River Style has a high sensitivity ranking due to its high stream power and unconfined nature. It is prone to aggressive lateral migration, which is evident by frequent ledge features along the channel banks. Gravel bars are also a common occurrence.

Figure B.77. Google Earth image showing a representative reach of the LU_C_LSin_Gbed River Style along the Waipā River.

Figure B.78. Photographs showing a representative reach of the LU_C_LSin_Gbed River Style along the Waipā River.

Figure B.79. Photographs showing a representative reach of the LU_C_LSin_Gbed River Style along the Waipā River.

DETALS OF ANALYSIS
Map(s) used: Google Earth 38°12'31.76"S, 175°16'21.72"E

RIVER CHARACTER	
Valley-setting	Laterally Unconfined with continuous channel
Channel Planform	The laterally unconfined channel abuts valley margins <10% of the time. Continuous floodplains exist on either side of the channel. It has a low sinuosity due to past channel-straightening practices.
Bed material texture	Gravel
Channel geometry	Irregular with frequent gravel bars. Typically, 5 – 10 m wide, getting wider as you go downstream.
Geomorphic Units	Within-channel • Ledges found frequently throughout • Mid channel bars • Point bars • Forced pools around trees planted along the channel bank Floodplain • Floodplains are very flat and wide • Occasional oxbows & paleochannels due to past anthropogenic channel straightening practices
Vegetation associations	Floodplains are occupied by pasture and occasional non-native trees. Channel banks are mostly vegetated with grass and non-native weeds, with the occasional tree. Banks are occasionally bare where they are too steep for vegetation to take hold.

RIVER BEHAVIOUR
Low Flow Behaviour Fast, energetic flow. Mid channel bars generate localised hydraulic diversity. Fine-grained sediments are flushed through this reach. **Bankfull Behaviour** Gravel bed becomes mobilised and can aid in bed and bank erosion via abrasion. This develops ledges and forced pools over time. Gravel bars and geomorphic unit assemblages are reworked at this flow stage, whilst banks on the outside of bends are scoured. This can result in lateral migration in the form of downstream bend translation over time. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension and deposited on floodplain surfaces, vertically accreting them over time. Flow is concentrated within the contemporary channel. Backswamps and meander cut-offs become reactivated.

CONTROLS	
Landscape Setting and within-catchment position	Found in the lower catchment areas through flat alluvial plains.
Valley Morphology	Regular, typically >1 km wide.
Process Zone	Sediment transfer/accumulation

Channel Slope	Generally, <0.001 m/m
Upstream Catchment Area	360 km^2

B.42. Laterally Unconfined, Continuous Channel, Low Sinuosity, Fine-Grained Bed (LU_C_LSin_Fbed)

Location(s): Mangapū River, Mangarapa Stream, Mangaohoi Stream, Mangapiko River, Moanatuatua Swamp Drain and Jude Road Swamp Drain

Distinguishing attributes: Continuous floodplains are found along both sides of the channel. The channel abuts the valley margin <10% of the time. The channel is of low sinuosity, and due to its entrenched nature and cohesive banks, it is laterally stable. Past meander cut-offs on the floodplains were created through man-made straightening practices. The channel is generally narrow, set within a fine-grained floodplain. This River Style is particularly prevalent in the Mangapiko sub-catchment.

Figure B.80. Photographs showing a representative reach of the LU_C_LSin_Fbed River Style along the Mangapū River.

Figure B.81. Google Earth image showing a representative reach of the LU_C_LSin_Fbed River Style along the Mangapū River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°14'46.14"S, 175°10'30.54"E

RIVER CHARACTER	
Valley-setting	Laterally unconfined with continuous channel
Channel Planform	Continuous floodplains occur along both valley margins. Channel is single thread, with low sinuosity. Paleochannels have been left behind from man-made channel straightening practices occur on the floodplain.
Bed material texture	Predominately fine-grained sediments, with occasional fine gravels. Occasional lenses of coarser materials and sand and/or gravel in banks. Banks are predominantly fine-grained and cohesive.
Channel geometry	Symmetrical slot channel along straight sections, with some asymmetry on bends. Channel is up to 10 m wide.
Geomorphic Units	Within-channel • Bank slumps along channel edges associated with incision and banks becoming undercut • Channel is generally devoid of geomorphic units Floodplain • Continuous fine-grained floodplains on both sides of the channel • Paleochannels left behind from channel straightening practices
Vegetation associations	Variable, largely exotics to solely pasture. Some riparian scrub in places.

RIVER BEHAVIOUR

Low Flow Behaviour

Low gradients and broad floodplains make for low energy systems. Flow occurs over fine-grained sculpted geomorphic units and fills pools.

Bankfull Behaviour

The channel generally has a low width to depth ratio due to the cohesive, fine-grained floodplain sediments and long-term incision. The cohesive fine-grained floodplains mean that bank erosion occurs at very low rates. The dominant forms of bank erosion processes are slumping and block failure due to undercutting. Riparian vegetation is often highly disturbed due to intensive agricultural practices, which produces accelerated rates of bank erosion. Low slope limits energy conditions, which in conjunction with cohesive banks and low sinuosity, limits lateral migration. Bankfull flow may scour pools along the concave banks of bends.

Overbank Behaviour

The floodplains are dominantly formed via vertical accretion when flood flows spread out across the floodplain. Lateral migration rates are low. Oxbows become reactivated.

CONTROLS	
Landscape Setting and within-catchment position	Located in lowland plain settings.
Valley Morphology	Regular, generally >1 km wide
Process Zone	Sediment accumulation zone
Channel Slope	0.001 – 0.002 m/m
Upstream Catchment Area	75 - 151 km^2 depending on the position of the reach in the catchment

B.43. Laterally Unconfined, Continuous Channel, Meandering, Gravel Bed (LU_C_Meand_Gbed)

Location(s): Mangapū-Mangawhitikau Stream, Waipā River, Mangatutu Stream and Mangaohoi Stream

Distinguishing attributes: Continuous floodplains are found along both sides of the channel. The channel abuts the valley margin <10% of the time and is sinuous. This River Style has a high sensitivity ranking due to its high stream power and unconfined nature. It is prone to aggressive lateral migration, which is evident by frequent ledge features along the channel banks. Gravel bars are also a common occurrence. Along the Waipā River reaches, hard engineering management practices (i.e. channel straightening practises, installation of groynes) have occurred in the past in an effort to improve flow efficiency and reduce the loss of farmland from erosion. This has left behind abandoned meander loops in places, as well as imposed additional constraints on the river, enhancing incisional processes and creating off-site impacts.

Figure B.82. Google Earth image showing a representative reach of the LU_C_Meand_Gbed River Style along the Waipā River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°11'49.58"S, 175°14'6.46"E

RIVER CHARACTER	
Valley-setting	Laterally unconfined, continuous channel
Channel Planform	The laterally unconfined channel abuts valley margins (occasionally, roads) <10% of the time. Continuous floodplains exist on either side of the channel. It has a high sinuosity despite past channel-straightening practices.
Bed material texture	Gravel
Channel geometry	Symmetrical slot channel along straight sections, with asymmetry on bends. Channel is between 5 m (upland reaches) and 20 m wide (Waipā reaches).
Geomorphic Units	Within-channel • Ledges found frequently throughout • Mid channel bars • Point bars • Forced pools around trees planted along the channel bank as well as around lodged large woody debris • Occasional groynes and cemented bars (primarily along the Waipā River reaches) Floodplain • Floodplains are very flat and wide • Occasional oxbows & paleochannels due to anthropogenic channel straightening
Vegetation associations	Primarily pasture. Occasional planted trees along stream banks.

RIVER BEHAVIOUR
Low Flow Behaviour Fast, energetic flow. Gravel bars and frequent meanders generate hydraulic diversity. Fine-grained sediments are flushed through this reach. **Bankfull Behaviour** Gravel bed becomes mobilised and can aid in bed and bank erosion via abrasion, particularly on the outside of meander bends, promoting lateral migration. This develops ledges and forced pools over time. Gravel bars and geomorphic unit assemblages are reworked at this flow stage. **Overbank Behaviour** Fine-grained sediments are dropped out of suspension and deposited on floodplain surfaces, vertically accreting them over time. Flow is concentrated within the contemporary channel. Backswamps and meander cut-offs become reactivated. In some places along the Waipā River reaches, roads have been undercut by the channel and have required maintenance.

CONTROLS	
Landscape Setting and within-catchment position	Found in the mid-catchment area, generally along transition points between confined, upland areas and downstream, alluvial plains.
Valley Morphology	Regular, typically 300 m to 1 km wide or more.
Process Zone	Sediment transfer zone
Channel Slope	0.001 – 0.006 m/m depending on catchment position of reach (steeper gradient with higher elevation)
Upstream Catchment Area	22 - 385 km^2 depending on catchment position of reach

B.44. Laterally Unconfined, Continuous Channel, Meandering, Fine-Grained Bed (LU_C_Meand_Fbed)

Location(s): Mangapū River and Mangarapa Stream

Distinguishing attributes: Continuous floodplains are found along both valley margins. The channel abuts the valley margin <10% of the time. The channel is sinuous, however, due to its entrenched nature and cohesive bed and banks, is relatively laterally stable. It can, therefore, be described as a passive meandering River Style. Past meander cut-offs on the floodplains were created through man-made straightening practices. The channel is generally narrow, set within a fine-grained floodplain. Large woody debris can be found along the banks of this river, remnants of large ancient forests which once dominated this area before they were buried during past volcanic events.

Figure B.83. Google Earth image showing a representative reach of the LU_C_Meand_Fbed River Style along the Mangapū River.

Figure B.84. Photographs showing a representative reach of the LU_C_Meand_Fbed River Style along the Mangapū River.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°18'34.15"S, 175° 7'30.96"E

RIVER CHARACTER	
Valley-setting	Laterally unconfined with a continuous channel.
Channel Planform	Continuous floodplains occur along both valley margins. The incised channel is single thread with moderate to high sinuosity. Paleochannels and cut-offs that were engineered through man-made channel straightening occur on the floodplain.
Bed material texture	Predominately fine-grained sediments with some gravel in the bed. Occasional lenses of coarser materials, sand and or gravel, in banks, but banks are predominantly fine-grained and cohesive.
Channel geometry	Symmetrical slot channel in straight sections, and asymmetrical on bends. Channel is typically 3 – 6 m wide and can be up to 15 m wide on asymmetrical bends.
Geomorphic Units	Within-channel • 1-2 m tall benches & ledges on meander bends, associated with areas of channel migration • Pools up to 15 m long at meander bends • Occasional in-channel islands associated with localised channel widening • Large woody debris protruding from banks and deposited withing the channel can form localised forced pools and hydraulic diversity Floodplain • Continuous fine-grained floodplains on both sides of the channel • Oxbow cut-offs • Backswamps
Vegetation associations	Primarily pasture with some riparian scrub and planted trees in places.

RIVER BEHAVIOUR
Low Flow Behaviour Low gradients and broad floodplains make for low energy systems. Flow occurs over fine-grained sculpted geomorphic units and fills pools. Fine sediments are dropped out of suspension. **Bankfull Behaviour**

The channel generally has a low width to depth ratio due to the cohesive, fine-grained floodplain sediments. The cohesive fine-grained floodplains mean that bank erosion occurs at relatively low rates. However, when lenses of coarser sediments are present, bank erosion rates can be much higher. The dominant forms of bank erosion processes are undercutting, resulting in slumping and block failure. Riparian vegetation is often highly disturbed due to intensive agricultural practices, which produces accelerated rates of bank erosion. However, low slope limits energy conditions, which in conjunction with cohesive banks, limits lateral migration. Bankfull flow may scour pools along the concave banks of bends. Bed incision is the dominant process.

Overbank Behaviour

The floodplains are dominantly formed via vertical accretion. Oxbows and backswamps are reactivated. Flow is concentrated within the main channel; however secondary flows can occur through oxbows.

CONTROLS	
Landscape Setting and within-catchment position	Located in lowland plain settings.
Valley Morphology	Regular, generally >1 km wide
Process Zone	Sediment accumulation zone
Channel Slope	<0.001 m/m
Upstream Catchment Area	128 km^2 (Mangapū River), 54 km^2 (Mangarapa Stream)

B.45. Laterally Unconfined, Continuous Channel, Valley Fill, Fine-Grained Bed (LU_C_VFi_Fbed)

Location(s): Mangarama Stream and Waipari Stream

Distinguishing attributes: This River Style is set within a laterally unconfined valley setting. The channel abuts bedrock <10% of the time. These reaches are close to the source of low discharge tributaries in flat, upland tabletop areas, where bedrock valleys have become filled with fine-grained material. They may have once been upland swamps which have been channelized and drained to make way for agricultural land use. This has created a fine-grained valley-fill which forms the valley floor, which has a relatively low slope given its upland catchment position. Poor drainage, due to the low gradient, can cause the valley-fill floodplains to become saturated during rainfall events, turning them into swamp-like areas and promoting the formation of backswamps.

Figure B.85. Google Earth image showing a representative reach of the LU_C_VFi_Fbed River Style along the Mangarama Stream.

Figure B.86. Photograph showing a representative reach of the LU_C_VFi_Fbed River Style along the Mangarama Stream.

DETAILS OF ANALYSIS
Map(s) used: Google Earth 38°21'10.66"S, 175° 6'50.47"E

RIVER CHARACTER	
Valley-setting	Laterally unconfined, continuous channel.
Channel Planform	Single thread, low sinuosity channel. The valley-fill acts as the floodplain in this River Style. The channel abuts bedrock <10% of the time. The channel generally maintains its position in the middle of the valley bottom.
Bed material texture	Fine-grained material
Channel geometry	Regular, low width to depth ratio results in a slot channel. 1 – 2 m wide, sometimes <1 m wide.
Geomorphic Units	Within-channel • Sculpted runs • Localised, narrow ledges and bank slumps along valley-fill banks • Lacking geomorphic diversity due to low discharge and excess fine-grained sediment blanketing the valley floor. Floodplain • Valley-fill acts as a floodplain, but it was not deposited by the contemporary stream • Becomes saturated during rainfall events, leading to the formation of backswamps • Remains wet most of the time. Would become a wetland/swamp if it were not for farming practices draining the land. • Meander cut-offs left behind from man-made channel straightening (Waipari Stream)
Vegetation associations	Pasture dominates with pockets of wetland-type vegetation.

RIVER BEHAVIOUR
Low Flow Behaviour Generally, undisrupted flow where suspended sediments are flushed through the reach. **Bankfull Behaviour** Channel banks can be scoured and cause slumping and the formation of ledges. These slumps can also cause blockages and cause the flow to become discontinuous. Over time, this process can cause lateral migration of the channel. Although, this is a slow, localised process along this River Style given the low discharge and cohesive nature of the floodplain/valley-fill material.

Overbank Behaviour
Valley-fill and floodplains can become waterlogged which can take a long time to drain, promoting the formation/reactivation of backswamps. The preferential flow is retained within the contemporary channel rather than forming flood channels. Paleochannels can be reactivated (Waipari Stream).

CONTROLS	
Landscape Setting and within-catchment position	Located in lowland plain settings.
Valley Morphology	Regular, generally >1 km wide
Process Zone	Sediment accumulation zone
Channel Slope	0.016 m/m (Waipari Stream), 0.003 (Mangarama Stream)
Upstream Catchment Area	6 km^2 (Waipari Stream), 55 km^2 (Mangarama Stream

Appendix C: GIS Data

The polyline shapefile entitled “Waipā_Catchment_River_Styles.shp” is supplementary to this report. It delineates the identified River Styles within the Waipā River Catchment, and also displays several accompanying characteristics. This data builds on prior field work and desktop analysis performed by Marson (2019) and Wheeler (2019). Included with this shapefile are several formatting layers which can be imported via the “symbology” properties tab within ArcMap to display each attribute in the same manner presented in the figures of this report.

This spatial data is supplied to enable river managers, researchers, and others to further visualise our findings in more detail and interactively create additional products.

For additional technical information relating to this dataset, as well as attribute descriptions, please refer to the documentation provided with the shapefile.