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River Styles Assessment of the Hamilton Gullies

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RIVER STYLES ASSESSMENT OF THE HAMILTON GULLIES

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WAIKATO REGIONAL COUNCIL, WAIKATO NZ

B24021

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EXECUTIVE SUMMARY

Waikato Regional Council (WRC) commissioned a Stage One River Styles Assessment of the Hamilton Gully Catchments which feed into the Waikato River within Hamilton City. The aim of the assessment was to provide geomorphic baseline information for five main gully systems and to inform high level river management decisions / strategies within the catchments.

The gully systems investigated in this study included (Figure 1-1):

- ***Te Awa O Katapaki***
- ***Kirikiriroa***
- ***Waitawhiriwhiri***
- ***Mangakotukutuku***
- ***Mangaonua / Mangaone***

The River Styles Framework, used to provide a baseline assessment of the aforementioned gully systems, provides a coherent set of procedures throughout 4 distinct stages which integrate catchment-scale geomorphic understandings of river forms, processes, and linkages. 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. Application of Stage One of the River Styles Framework provides a catchment-wide understanding of geomorphic diversity, as well as the controls on river character and behaviour providing insights into the physical template of the waterway, and underpinning interrelationships with ecosystem health.

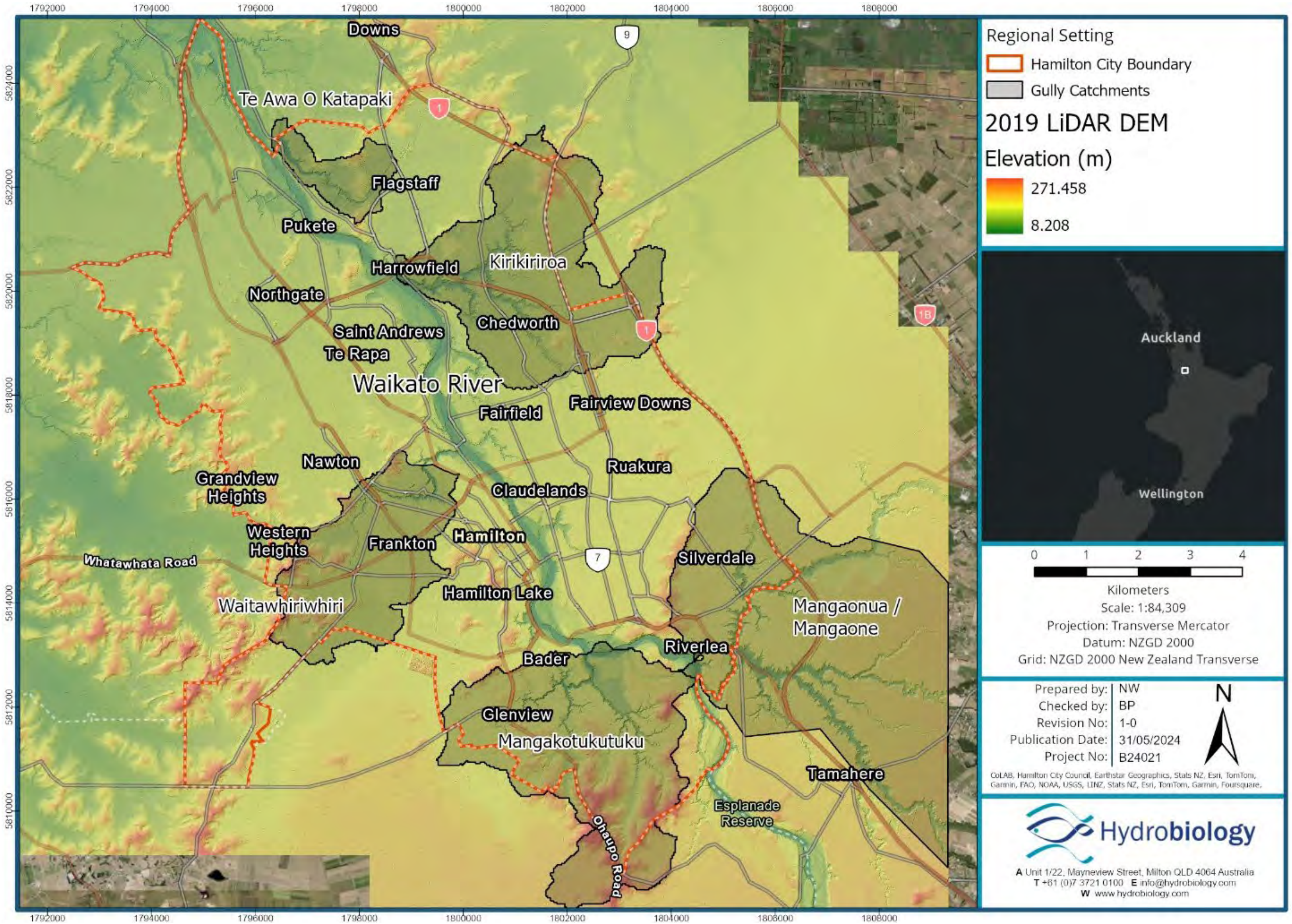

Figure 1-1: Hamilton Gully Catchments assessed as part of the Stage One River Styles Assessment

Across the assessed gully systems, a total of 14 River Styles were identified uncovering a unique pattern of mostly confined and partly confined River Styles gully types, reflecting the strong imprint of landscape history within the region. Historic stages of degradation to the base level of the Waikato River and anthropogenic impacts have provided strong imposed and flux boundary controls on the contemporary character and behaviour of all gullies, directly influencing their sensitivity to geomorphic adjustment.

Findings from this study can be used to support high level, cost-effective, targeted, proactive management and rehabilitation of sensitive reaches in ways that work with the river or gully, prospectively informing targeted applications of riparian initiatives that support diverse habitat creation and ecological rehabilitation, whilst reducing suspended sediment yields to the Waikato River.

Therefore, management investigations and efforts should focus on reaches with Medium to Medium-High sensitivity identified in this study. These waterways were mainly:

- Lower most reaches closest to the Waikato River. Further downcutting of these reaches will likely result in degradation of upstream reaches currently in good condition or worsen those already degraded. These medium and medium-high sensitivity reaches in the lower catchment areas included:
  - Te Awa o Katapaki Reach 4
  - Kirikiriroa Reach 13A and B
  - Waitawhiriwhiri Reach 3A
  - Mangakotukutuku Reach 20A
  - Mangaone Reach 8
- Upper/Middle reaches still undergoing degradation. Provided upstream propagation of the degradation of the lower reaches does not occur, improvement in the condition of these reaches will have a high success rate. These medium and medium-high sensitivity reaches in the upper/middle catchment areas included:
  - Kirikiriroa Reach 3, 10, and 9
  - Mangakotukutuku Reach 5, 14, 19, and 20B
  - Mangaonua Reach 3, 6, and 7 (and streams located upstream outside of the study area)
- Laterally unconfined upper reaches draining peat land, susceptible to future degradation. These are the most sensitive due to the high potential for upstream propagation to initiate degradation and should be managed through protection and concomitant management of downstream reaches. These reaches were:
  - Kirikiriroa Reach 4
  - Waitawhiriwhiri Reach 1B
  - Mangakotukutuku Reach 1 and 3

If not managed, these reaches will continue to incise and widen, resulting in degraded channel condition attributes as well as increased suspended sediment yield to the Waikato River misaligning with key environmental goals. Such inherently sensitive reaches are likely to become increasingly prone to adjustment with the prediction of more frequent extreme events associated with climate change. Concomitantly, continued urban sprawl expanding into alluvial Hinuera and peat bog deposits is increasing the risk to adjacent lands associated with this adjustment and highlighting the need for immediate human intervention.

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1. INTRODUCTION

1.1 BACKGROUND AND AIMS

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.

Waikato Regional Council (WRC) contracted Hydrobiology to undertake a River Styles Stage One Assessment of the Hamilton Gully Catchments within Hamilton City that feed into the Waikato River. The aim of the assessment was to provide geomorphic baseline information of five of the main gully systems and to inform larger river management decisions within the catchment.

1.2 STUDY AREA

The study area incorporated the following five main gully catchment systems in the Hamilton Region (Figure 1-1):

- ***Te Awa O Katapaki***
- ***Kirikiriroa***
- ***Waitawhiriwhiri***

- ***Mangakotukutuku***
- ***Mangaonua / Mangaone***

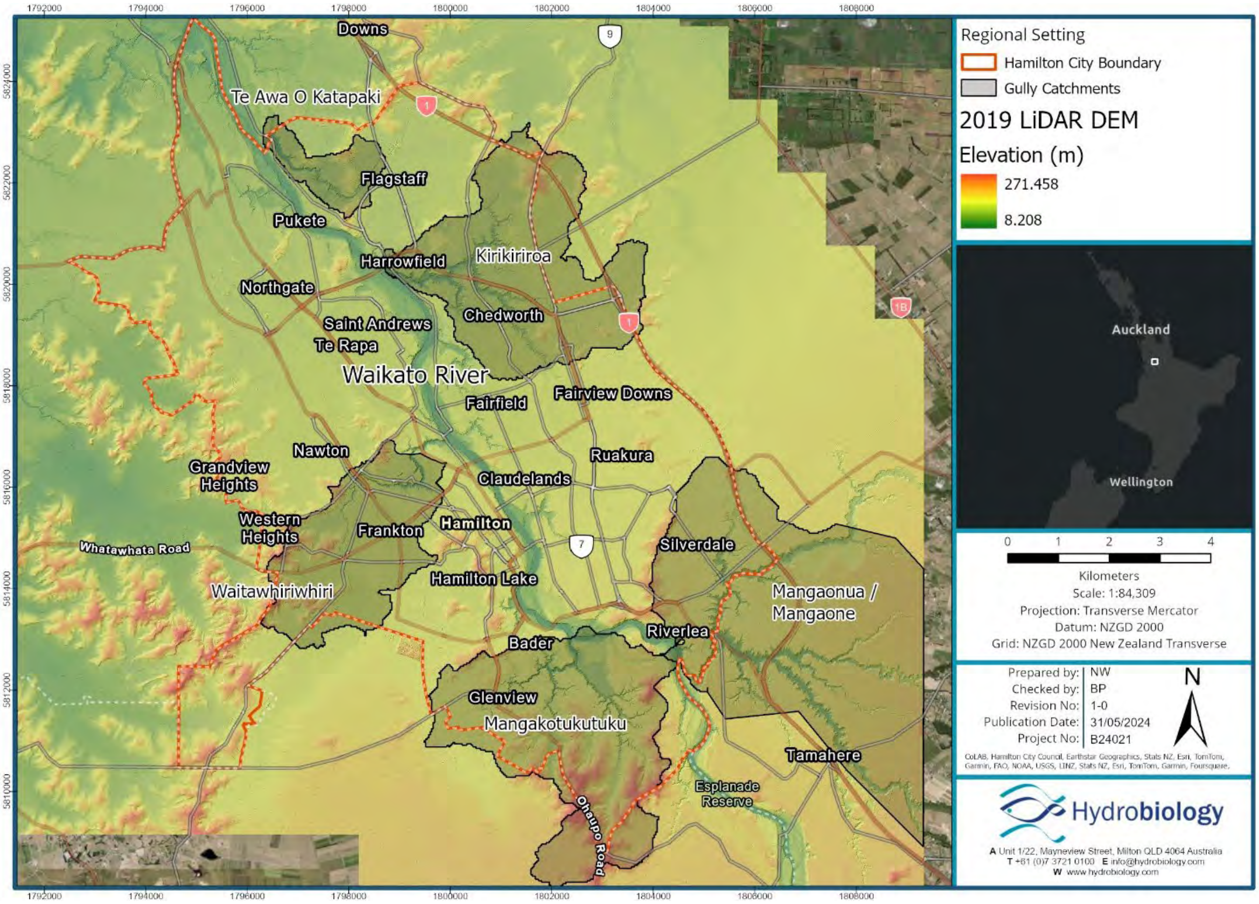

Figure 1-1 Project study area

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.
- 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 – Management Implications and Conclusions.
- Appendix A – Summary of the identified River Styles in a table format.
- Appendix B – Proformas of each River Style.
- Appendix C – River Styles Tree
- Appendix D – Site Photographs

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 km of waterways (Hill, 2011) (Figure 2-1). The Waikato River is the longest river in *Aotearoa* New Zealand and is a *tupuna* (ancestor) and a *taonga* (treasure), and the *mauri* (life force) of *Waikato-Tainui*, *Raukawa*, *Ngāti Tūwharetoa* and the *Te Arawa iwi*. The river starts its journey to the sea from high in the central North Island volcanic zone, 2797 m above sea level. From there it flows into Lake Taupō. Leaving the lake, the river flows northward and cuts through the volcanic plateau, passing through hydro-electric dams and onto the lowlands from Cambridge, through Hamilton City to Mercer. The river finally flows into the Tasman Sea at Port Waikato.

Within Hamilton City, an extensive network of gullies drains into the Waikato River. These extend from the Waikato River through many suburbs and urban developments in the city boundaries, occupying around 750 ha or 8% of the city area (Downs et al., 2000) and are considered a unique feature of the Hamilton area (McCraw, 2000). As described earlier, five major gully systems (analysed in this study) and numerous minor systems exist.

Geomorphic and geological history of the Waikato River and greater Waikato region has been a strong control on the formation of the gully systems. As McCraw (1967; 2011) has shown, the gullies were a result of the undermining of a geological formation of sand, silt, peat and gravel known as the Hinuera Formation or Waikato Fan surface. Around 15,000 years ago, the Waikato River started to cut down through this fan surface, creating its present channel. As it deepened, terraces were formed, and springs were expose along riverbanks. As water drained from the surrounding region, these springs undermined the banks and terrace features, a process known as spring sapping. As this process was repeated, this gave rise to erosion and formation of steep-sided and dendritic network of gullies that adjoin the river today.

Although being poorly treated in the past, gullies have been recognised in recent decades as the central focus of a city-wide restoration of indigenous ecosystems and as the main wildlands in an otherwise urban environment (Clarkson and Downs 2000; Clarkson and McQueen, 2004).

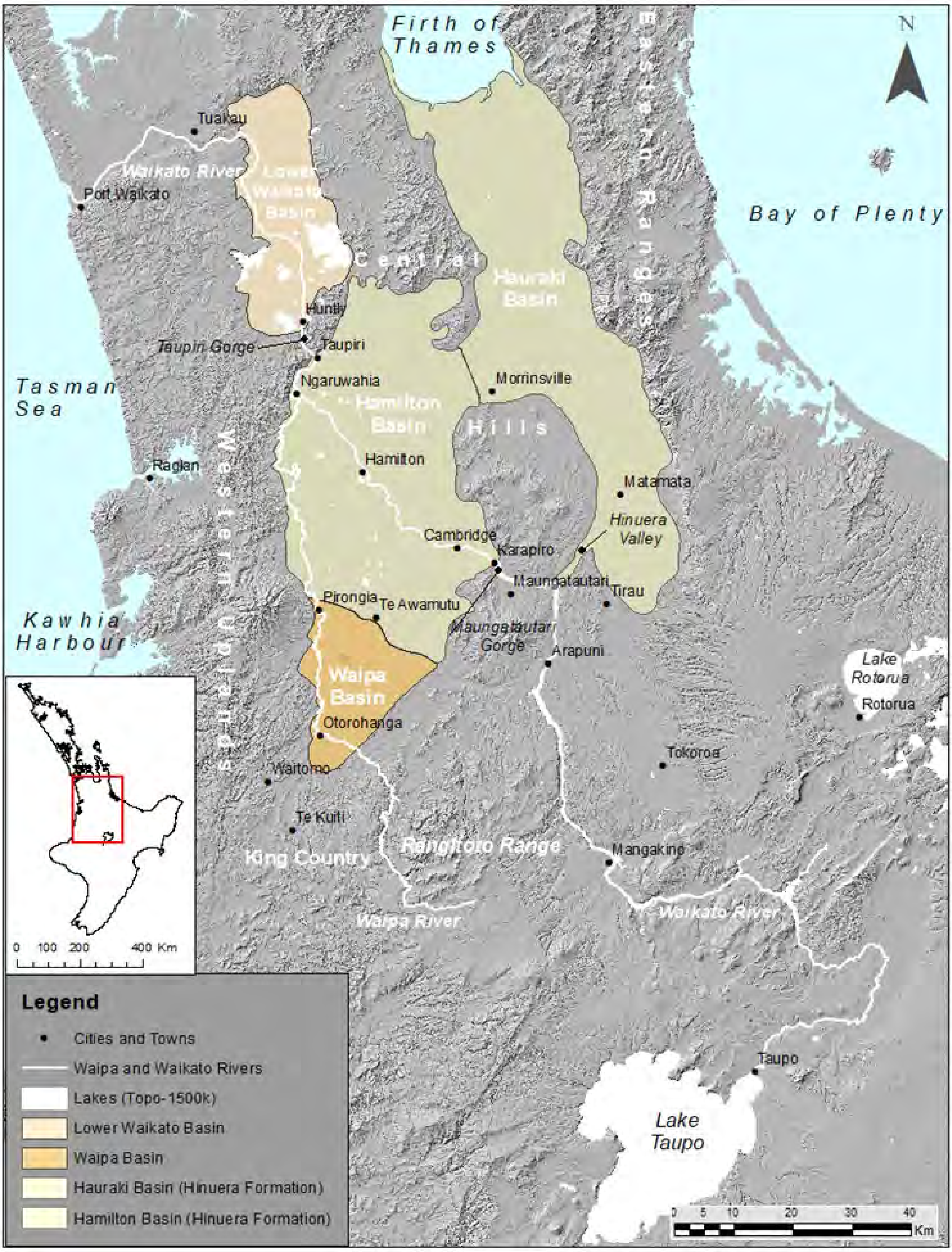

Figure 2-1 Map of the Waikato Region showing the extent of Waikato and Waipā Rivers in the Central North Island of New Zealand and their corresponding Basin formations, (Wheeler, 2019 adapted from Edbrooke, 2005; Manville & Wilson, 2004; McCraw, 2011).

2.2 CLIMATE AND FLOOD HISTORY

2.2.1 REGIONAL

The climate of the Waikato region varies across a range of landscape settings (Chappell, 2014). The climate is humid temperate, with warm humid summers, mild winters and moderate rainfall skewed towards a winter maximum (Collier et al., 2010). Mean annual air temperature is approximately 12.5°C, with daily means of 10°C in winter and 19°C in summer (Collier et al., 2010). Closely related to elevation and exposure to predominant air flows, areas with high annual rainfall over 2000 mm include the Coromandel Ranges, Central Plateau south of Lake Taupō and hill country west of Te Kūiti, which contrast with other areas which receive around 1,100 mm annually, such as areas east of Hamilton and the Hauraki Plains (Chappell, 2014).

Storms are frequent and tend to be low intensity but long duration; however, short-duration, intense rainfalls related to ex-tropical cyclones are common during February - May (Chappell, 2014). High-intensity prolonged rainfall commonly induces localised flooding in low-lying areas and depressions (gullies). The Lower Waikato and Waipā River valleys, including the gully systems, have long been susceptible to flooding, but the combined effects of hydro-electric dams on the Waikato River and flood protection structures on both the Waipā and Waikato rivers (stop banks, channel straightening, flood gates, pumping stations) have significantly reduced this hazard (Edbrooke, 2005; Hurst, 1998a, 1998b), despite impacting channel condition and erosion hazards.

2.2.2 GULLY SYSTEMS

Locally, intensive development and modification of the Hamilton Basin (including channelisation of peatlands) has resulted in more frequent floods, changing hydrographs, and higher peak flows rapidly altering the flood regimes of Hamilton city's extensive gully networks. While flood waters are primarily confined to these gullies due to their incised nature (during the 1% AEP), flood breakouts frequently occur due to back up of flows around anthropogenic constrictions (including undersized stormwater infrastructure) as well as broad lateral engagement of peatlands in the upper catchment.

Hamilton's gully catchments have been subject to stormwater management modifications, with detention, retention, and attenuation devices located through more recently developed catchments (Te Awa o Katapaki) to mitigate flood risk. Other historic developments are subject to the legacy effects of poor stormwater management frameworks and incorporate little flood resilience with large areas of residential and industrial lots experiencing inundation.

2.3 GEOLOGY, LITHOLOGY AND GEOMORPHIC HISTORY

2.3.1 WAIKATO REGIONAL GEOLOGY

As summarized in Wheeler (2019) and Marson et al., (2021), the Waikato region is situated 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). On the mainland, 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 sequence of Cretaceous to Holocene aged sedimentary and volcanic rocks cover these basement rocks. 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 cover much of the region (Edbrooke, 2005).

2.3.2 HAMILTON GULLIES GEOLOGY

Geology of the Hamilton region and gully systems is shown in Figure 2-2. The topography is low lying, consisting of the Waikato Fan system, surrounded by low rolling 'Hamilton Hills' and poorly draining peat bog systems on the outskirts of the city. The gully systems are entrenched into the Waikato Fan surface, draining into the Waikato River. Geology groupings can be described from the GNS 250K mapping (GNS Science, 2020) as follows:

- OIS1 Holocene river deposits - Alluvial and colluvial sand, silt, mud and clay with local gravel and peat beds.
- OIS1 River Deposits (Taupo Pumice Alluvium) - Predominantly pumice, sand, silt and gravel alluvium with charcoal fragments.
- OIS1 Holocene swamp deposits (Peat bogs) – Soft, dark brown to black, organic mud, muddy peat and woody peat. Lithology consisting of mudstone and peat.
- OIS14 + OIS12 Early Pleistocene to Middle Pleistocene river deposits and ignimbrite (Hamilton Hills) – Alluvium dominated by primary and reworked, non-welded ignimbrite. Lithology consisting of pyroclastic material, sand, gravel, tephra and pumice.
- OIS2 Late Pleistocene River Deposits - Locally derived lacustrine mud, silt, gravel and peat.
- OIS3-OIS2 Late Pleistocene river deposits (Hinuera Formation – Waikato Fan) – Cross-bedded pumice sand, silt and gravel with interbedded peat. Lithology consisting of silt, sand, gravel, peat.
- Undifferentiated Walton Subgroup Alluvium - Pumiceous mud, silt, sand and gravel with muddy peat beds; rhyolite pumice, including non-welded ignimbrite, tephra and alluvial pumice deposits.

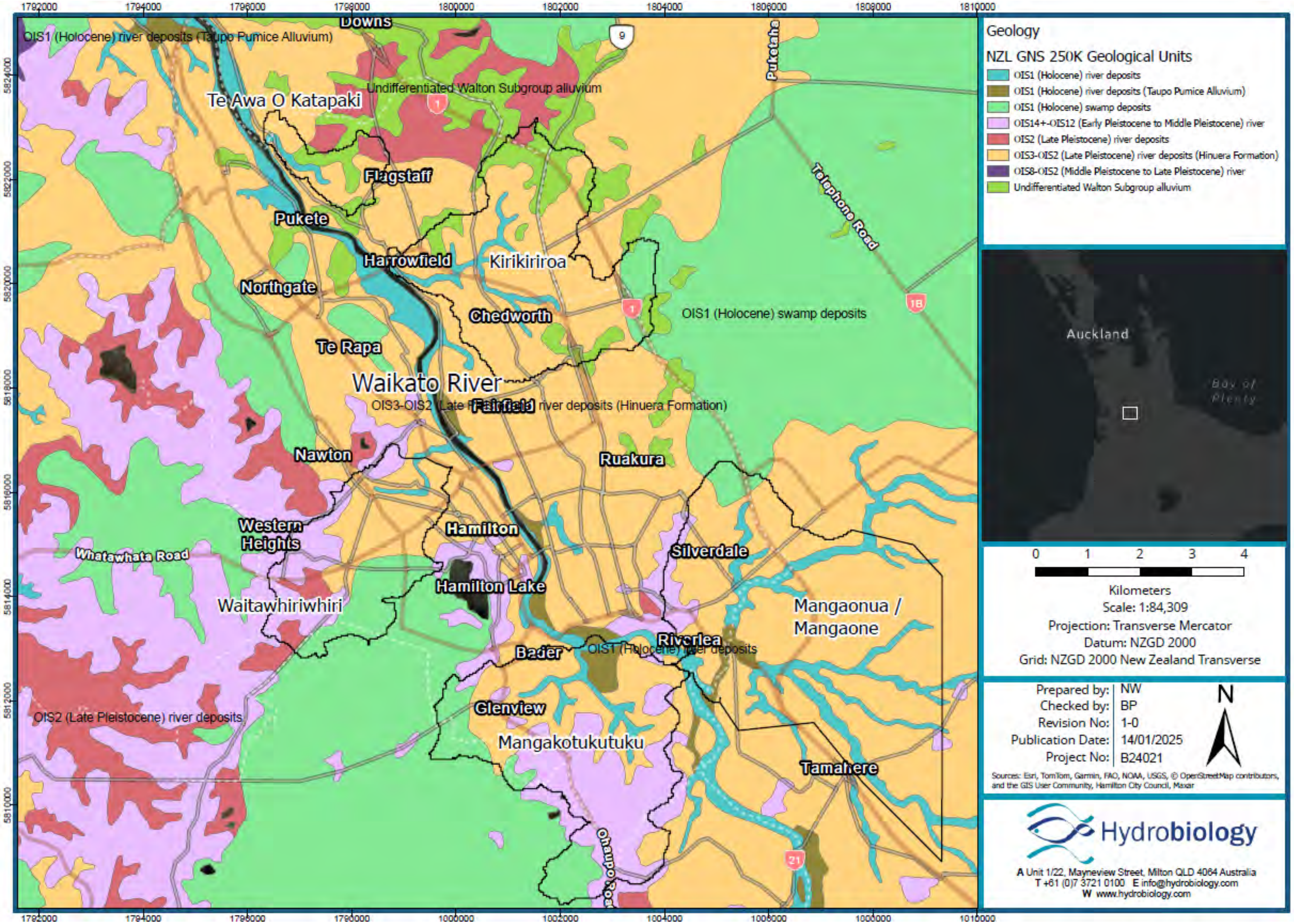

Figure 2-2 250K scale GNS Geology mapping of the Hamilton study area (GNS Science, 2020).

2.3.3 GEOMORPHIC HISTORY

As summarized in Wheeler (2019) and Marson et al., (2021), many river systems in the Waikato Region are influenced by past Quaternary and Holocene changes. This geological history governs much of the contemporary river character and behaviour within the catchment, as well as gully formation. The Waikato River has switched its course (avulsion) between the Hauraki Plains and the Hamilton Basin several times in the last 100,000 years (Manville, 2002; Manville & Wilson, 2004). Avulsions occurred 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 about 19,000 years ago 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 and gully systems now flow (McCraw, 1967, 2011). Following the 181 A.D Taupō Eruption, a large breakout flood caused the Waikato River to quickly incise and become 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).

2.3.4 GULLY FORMATION

In the Hamilton region, the gullies have formed in two different ways as described by McCraw (2011):

1. GULLIES IN PALEOCHANNELS

Several lower reaches of most of the paleochannels of the Waikato River have formed into gullies. These paleochannels have acted as local drainage systems so contain substantial streams and gullies. When the Waikato River began to become entrenched, these tributary streams in old channels also degraded to the new base level of the Waikato River. As their courses deepened, they also widened. These gullies can be separated from the next group only because they gradually become shallower and wider upstream until they become the flat-floored channels characteristic of the old channels of the Waikato River.

The Mangaone and Mangaonua gully channels are examples of this type. McCraw (2011) identified and described these two channels as outflow channels from a late stage in the forming of the Waikato fan:

- The Mangaone channel begins northeast of Cambridge and runs northwest down the Waikato fan as a typical flat-bottomed outflow channel 200-300 metres wide, to the boundary of Hamilton City at Hinton’s Gully where it is joined by the Mangaonua Stream. The combined streams then join the Waikato River. From a point several kilometres upstream from Tamahere, the Mangaone Stream has degraded and modified the paleochannel, forming a gully. The Mangaone channel likely went all the way to the Taupiri Gorge and was an early version of the present course of the Waikato River.
- The Mangaonua Channel runs down the Waikato fan as a typical flat-floored paleo channel until just below the crossing of Woodside Road, its stream begins to degrade. It flows into an ever-deepening gully to join the Mangaone channel at Hinton’s Gully.

2. HAMILTON GULLIES

Formation of these gully types is shown in Figure 2-3. The prominent and numerous gullies that run back from the Waikato River in the Hamilton Basin form dendritic systems that lie between the river and peat bogs (Figure 2-3). Peat bogs began on areas of poorly drained pumiceous silt but as they grew, the peat spread beyond the silt onto the porous gravels and sands that allowed water, stored in the peat, to percolate down into the fan. The water was then intercepted by layers of impervious silt resulting in it flowing above these layers within the fan and emerging at the riverbank as a spring. This undermined the sediments above, which collapsed and were washed away by the spring water, resulting in the initiation of a gully.

These gullies formed as the river deepened its course. As it degraded, it cut through these buried layers, and water that was running through them emerged as springs. Repeated undermining and collapse quickly formed gullies. This process is referred to as 'spring sapping'. As each gully lengthened, springs emerged from the gully walls and soon developed into tributary gullies. The heads of gullies often end fairly abruptly in a small amphitheatre with springs at the foot of the headwall.

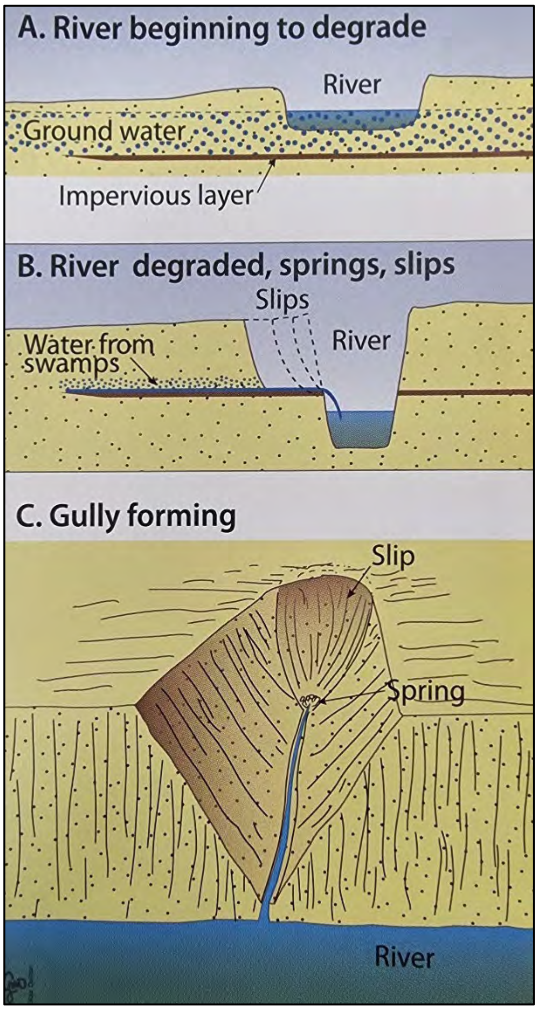

Figure 2-3 . Gully Formation (Figure by McCraw 2011).

2.4 LAND USE AND ANTHROPOGENIC DISTURBANCE HISTORY

Superimposed on the geologic landscapes are the different land uses across the Hamilton region, where much of the land has been highly modified since human settlement. In New Zealand, there is a compressed history of anthropogenic impacts upon landscapes, as it was first settled 750 years ago (Pawson & Brooking, 2002). Since then, the land has been exposed to substantial human disturbance in the period since European settlement (~1800 AD). By the early 1900s, widespread forest clearance from the coast 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).

Since that time, agricultural development, urbanisation with associated infrastructure and other land uses have modified the landscape to such an extent that little remains of the natural character of the area (Hamilton City Council, 2007). Contemporary land use in the Waikato region 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)

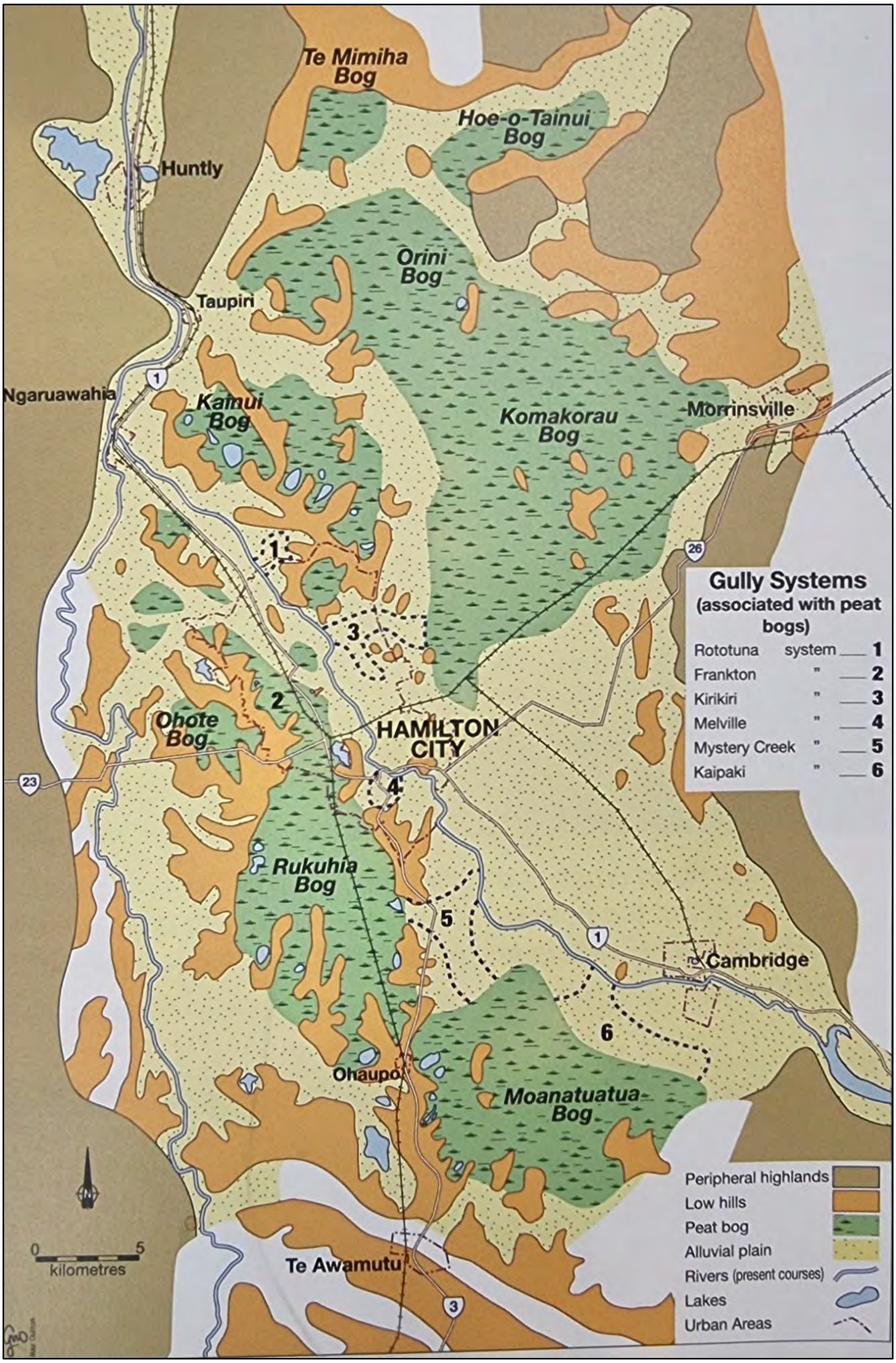

Figure 2-4 Principle areas of peat in the Hamilton Basin (Figure by McCraw, 2011).

The gullies themselves in Hamilton were also largely cleared for timber, horticulture and farmland by the late 19th century (Clarkson and McQueen, 2004). As the city grew and developed as an urban area in the 20th century, the gullies were neglected and often used as dumping grounds for rubbish, and became filled with weeds (Clarkson and McQueen, 2004).

Therefore, the region is one of the most modified in New Zealand, with only 1.6% of the indigenous vegetation remaining (Clarkson and McQueen, 2004). At least 20% of its indigenous flora is threatened or extinct and more than one half of its indigenous bird species have disappeared (Clarkson and McQueen, 2004). In addition, the gully streams are an essential part of Hamilton's drainage network. This land drainage function is a natural feature of the gullies. However, catchment modification through urbanisation has changed the flow regime and the quality of water entering the gullies (Hamilton City Council, 2007).

2.5 MANAGEMENT INTERVENTIONS / REHABILIATION

Despite being poorly treated in the past, the significance of gullies has been recognised in recent decades. Their importance with regard to landscape enhancement was highlighted as early as 1972 by McLeary (1972). Although a Gully Protection Zone had been in force since 1989, this related more to building requirements rather than the protection of gullies themselves and was ineffective at protecting ecological features or preventing infilling of gullies with subdivision development (Clarkson and McQueen, 2004).

Introduction of the Resource Management Act (1991), and obligations of other international agreements, meant that Hamilton City Council undertook a substantial information gathering exercise to improve knowledge of natural values within the City. In addition, the Gully Management Plan (Hamilton City Council; 2001; 2007) had been developed, providing a comprehensive plan for restoration of publicly owned gullies but recognised the need to involve the owners of adjoining privately owned gullies. Since then, many restoration efforts have begun with a number of private restoration groups. The new Waikato Expressway passes near some of these gullies, and they are being restored as part of the expressway construction. In addition, the Nature in the City Strategy 2020 - 2050 sets the goal of increasing native vegetation cover in Hamilton from 2% to 10% by 2050.

3. METHODS

3.1 RIVER STYLES 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).

3.2 RIVER STYLES FRAMEWORK STAGE ONE

3.2.1 GENERAL

The main gully streams and their tributaries mapped by HCC were analysed throughout the aforementioned five gully catchment systems. 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.

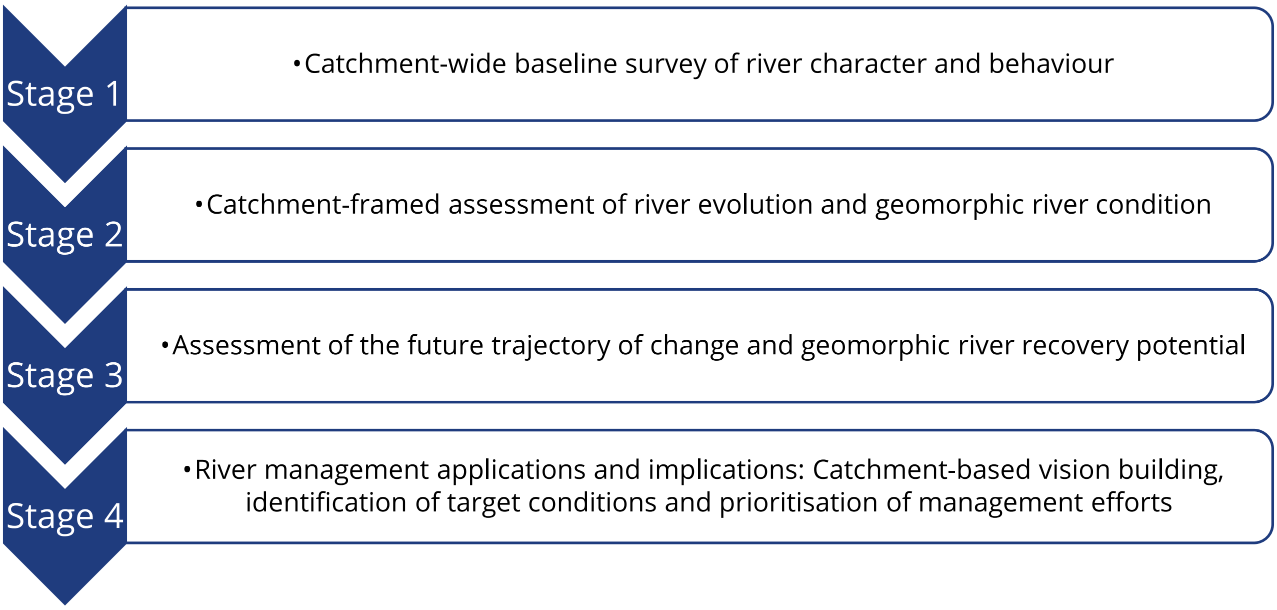

Figure 3-1 Stages and procedures for performing a River Styles Framework assessment of a river catchment (Brierley & Fryirs, 2005).

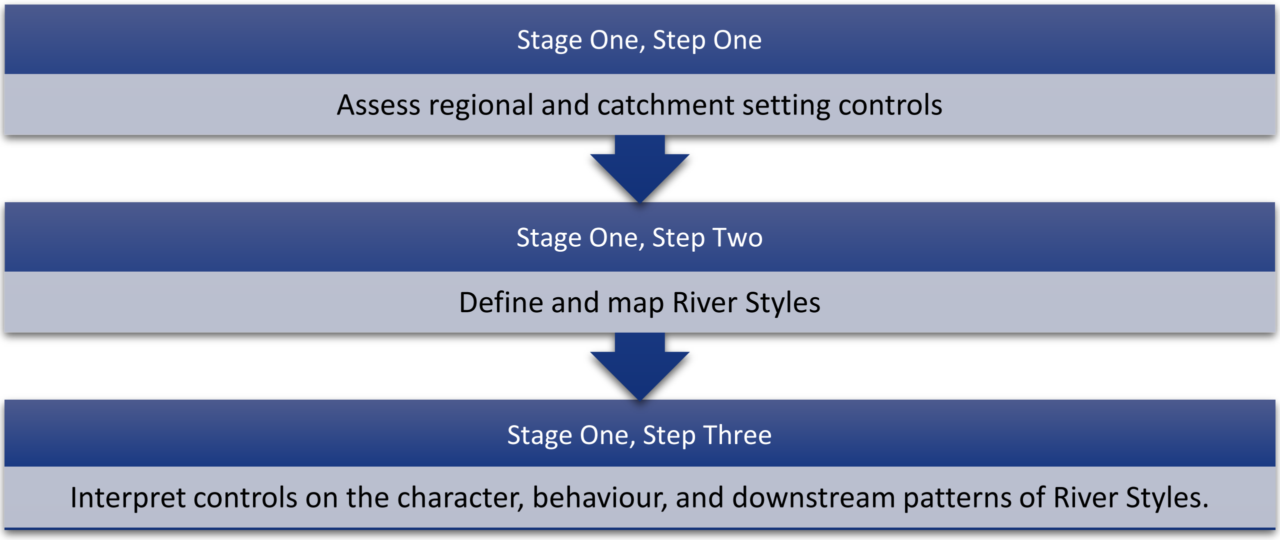

Figure 3-2 The three core steps of Stage One of the River Styles Framework.

3.2.2 STEP ONE

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

- Key geology units were identified from a combination of geology datasets (GNS 250K mapping) and previous landmark surveys (McCraw, 1967, 2011; Schofield, 1965).

- Longitudinal profiles derived using estimated valley slopes along stream polylines extracted from the 1 m regional digital elevation model (DEM) using TopoToolbox in MatLab (Schwanghart & Scherler, 2014).

3.2.3 STEP TWO

Step Two involved identifying, characterising, and interpreting the behaviour of the types of gullies, 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, 1 m 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). Field verification of preliminary mapped River Styles was carried out through a field visit from 18 – 21 March 2024.
- 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).

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 were occasionally employed (mainly for confinement and sinuosity) as necessary when certain reaches bordered between two identifiers (Figure 3-5, Figure 3-6).

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 using advanced GIS tools.

3.2.4 STEP THREE

Step Three involved the analysis of downstream patterns and controls on rivers. This used the longitudinal profiles derived in Step One as a key tool for analysis and visualisation (Brierley & Fryirs, 2005). The step included:

- The differentiation of river courses that had similar patterns from those that were 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). Imposed controls refer to boundary conditions that define the potential range of variability of a River Style including geological imprint (structure and lithology), long-term landscape history and anthropogenic controls. Flux boundary conditions refer to climate controls, stream power and riparian patterns that influence flow and sediment fluxes.

This information can form a baseline which can be used to forecast geomorphic sensitivity of different river reaches to disturbance.

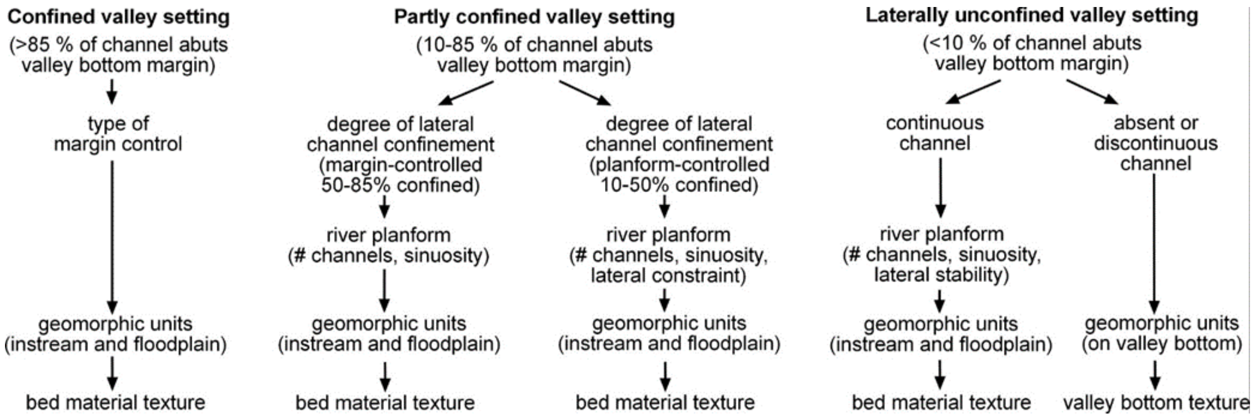

Figure 3-3 : River Styles procedural tree. Hierarchical approach used to identify and differentiate River Styles(Brierley & Fryirs, 2018).

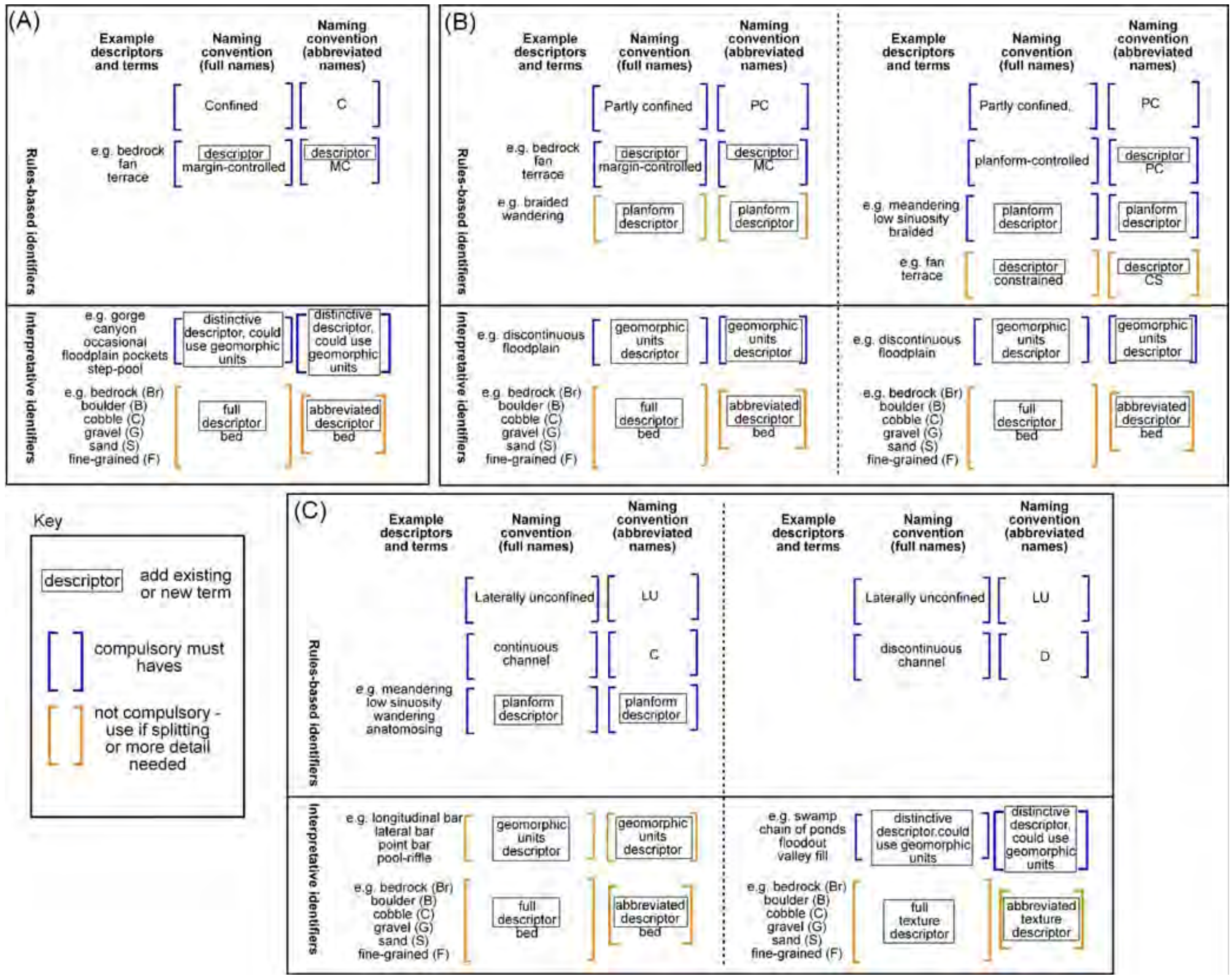

Figure 3-4 The naming convention used for river types (Fryirs & Brierley, 2018). The approach is matched to the River Styles procedural tree (Figure 3.3) and produces full and abbreviated names; A) for confined valley setting, B) for partly confined valley setting and C) for laterally unconfined valley setting.

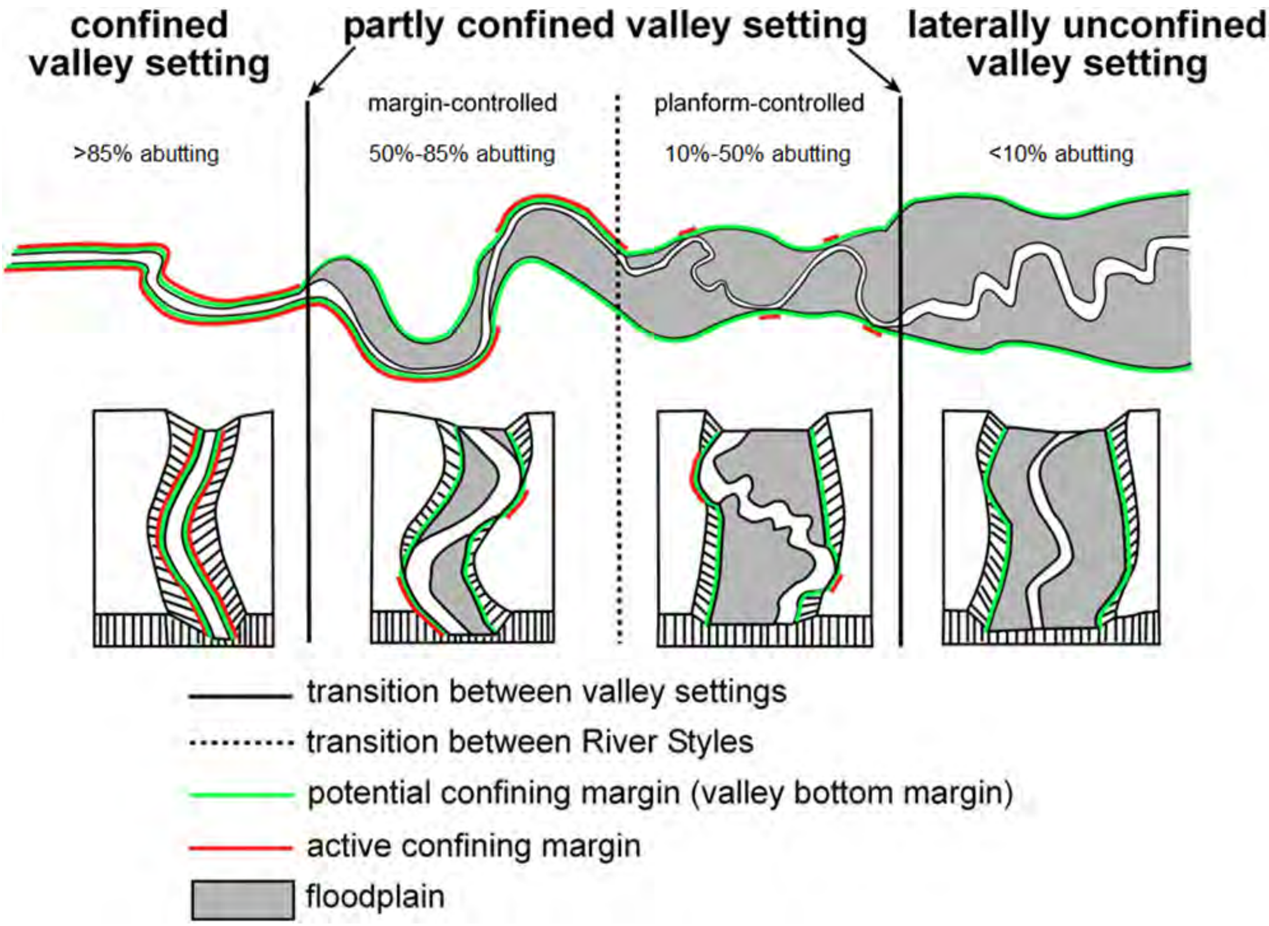

Figure 3-5 Illustration depicting the four categories of valley confinement. Confinement decreases as the length of active channel abutting the valley bottom margin (green) decreases from left to right, resulting in progressively less active confining margin (red). The abutting percentages refer to the 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).

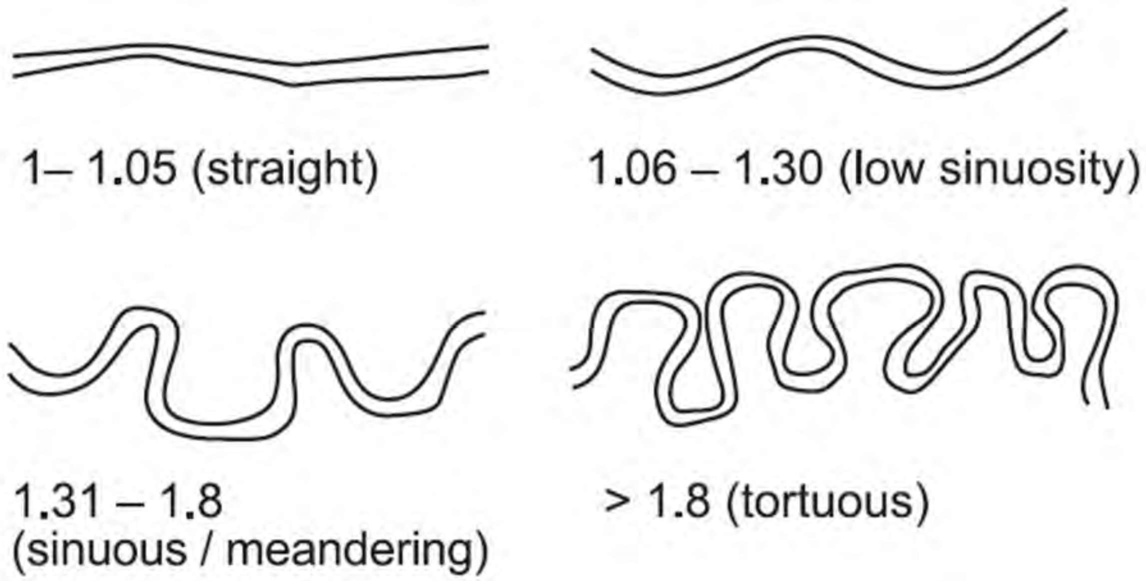

Figure 3-6 Classification of the degree of sinuosity used in analysis of channel planform (Modified from Fryirs & Brierley, 2013).

3.3 POTENTIAL GEOMORPHIC SENSITIVITY RANKING

Reid and Brierley (2015) developed an approach for assessing the potential sensitivity of different River Styles. Wheeler (2019) and Wheeler et al. (2022) 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 uses methods developed by Wheeler et al. (2022) to present potential geomorphic sensitivity rankings based on capacity for adjustment for the gully catchments in the Hamilton region.

As outlined by Brierley and Fryirs (2005), if a channel responds readily and frequently it is considered sensitive and likely to have high rates of adjustment. If channel responses are negligible and uncommon, the river is considered resilient to change due to its ability to absorb excess energy and minimise 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. Each River Style was qualitatively assessed based on its potential range of geomorphic adjustment relative to other types of rivers. Geomorphic sensitivity of each River Style was ranked as High, Medium-High, Medium, Low-Medium, or Low using procedures outlined in Figure 3.7.

1. Classify River Type (River Style)

Classifying based on valley confinement, channel planform, geomorphic units & bed material characteristics

2. Assess Potential Range of Adjustment

Assess for each River Style based on its capacity to rework riparian margins; given the nature, types and rates of adjustment inherent to its character and behaviour

3. Assign a 'Sensitivity Value'

High, Med-high, Medium, Low-Med, Low – depending on the capacity to adjust and rework the floodplain.

Low

- River Styles with no to minimal potential to adjust
- Confined or partly confined with other limiting factors (e.g. low stream power)
- Sediment characteristics limit adjustment by being mor resistant (e.g. boulder/cobble beds, or cohesive fine-grained beds)

Low-Medium

- River Styles with minimal adjustment potential
- Generally ranges between confined to partly confined, with some constraints
- Sediment characteristics limit adjustment (e.g. boulder/cobble beds, or cohesive fine-grained beds)

Medium

- River Styles with some adjustment potential, but have limiting factors such as margin controls, constraints, or resilient bed material
- Responsive to changes and large events, but minimally reworks floodplain areas
- Generally partly confined or laterally unconfined, fine-grained types

Medium-High

- River Styles with more adjustment potential than 'medium', but not extreme levels
- Slope, energy and easily mobilised bed material allow for reworking of floodplains
- Generally laterally unconfined or partly confined, planform-controlled types with minimal constraints.

High

- Highly active River Style - able to rework and flood large areas of land
- High potential for major planform changes (e.g. lateral adjustment, avulsions)
- Typically high energy, laterally unconfined types with no margin controls or constraints, and easily mobilised bed material (generally gravel or sand)

Figure 3-7 An approach to analysis of potential geomorphic river sensitivity. This procedure assesses the manner and capacity (ease) of adjustment (the ability of that River Style to rework large areas of land) to assign a potential sensitivity ranking (adapted from Reid & Brierley, 2015; Wheeler, 2019, Wheeler, 2022)

4. RESULTS – DOWNSTREAM PATTERNS OF RIVER STYLES

4.1 GENERAL

Different patterns of river character and behaviour reflect variability in landscape setting, gradient and energy conditions. In turn, these attributes influence a river or gully's capacity for geomorphic adjustment and the rate at which impacts are conveyed through a catchment. In this section, the downstream patterns of River Styles are presented for each of the assessed gully catchments. The diversity of River Styles displayed in each catchment reflected the geological history of the area, with a legacy of incision into the Hinuera Formation (Waikato Fan).

Overall, it was found that much of the studied gully networks of Hamilton were highly confined by terrace margins, which limited the networks capacity to adjust laterally, with most adjustment being degradational. River Style abbreviations are shown in Table A1 Appendix A. Information on each River Style type including their full names and their distinctive characteristics, are displayed in associated proformas in Appendix B and photographs from the site visit are shown in Appendix C.

4.2 TE AWA O KATAPAKI CATCHMENT

The Te Awa O Katapaki gully catchment is located in the north-east of Hamilton City. The main catchment drains the Late Pleistocene river deposits of the Hinuera surface, with the upper catchments draining Holocene swamp and peat bog deposits (Kainui bog). Downstream variation of four different River Styles found in the Te Awa O Katapaki gully catchment is shown in Figure 4-1, with longitudinal profiles presented in Figure 4-2. A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is reported in Figure 4-3, Figure 4-4 and Figure 4-5. The catchment is dominated by gravel to fine-grained gully types, most of which are either fully or partly confined by terrace margins.

The Te Awa O Katapaki gully system originates as farm drains which drain peat land to the north-east, outside of the mapped area. Once the network reaches the urban development, this quickly transitions to Reach 1, a confined, terrace margin controlled, modified urban channel with gravel and sand bed (C_TrMC_UMC_ModifiedUrban_Gbed). This reach is a highly modified urban channel, with bioretention/detention ponds installed. Moving downstream, the gully becomes further incised into the Hinuera surface and transitions to Reach 2, a confined, terrace margin-controlled, urban gully with gravel bed sediments (C_TrMC_Gully_Gbed). This reach displays alluvium exposures showing incision into the Hinuera surface, but is very straight and notably modified, with areas containing stagnant water.

Mid-way down Reach 2, Reach 3 flows into the main Reach 2 channel. This reach is confined, with urban margin-controls and is a modified urban waterway stormwater outlet with gravel to sand bed material (C_TrMC_UMC_ModifiedUrban_Gbed). There was localised widening and deposition observed at the confluence. Further downstream of this confluence, the gully transitioned to a wider valley setting with inset occasional floodplain pockets, becoming Reach 4. A riffle/grade control structure had been installed, preventing degradation from propagating upstream which marked a transition point. Reach 4 is mapped as a confined, terrace margin-controlled gully, with occasional floodplain pockets and gravel bed material (C_TrMC_OccFp_Gully_Fbed). This reach had become degraded due to changed hydrology as a result of urbanisation upstream, however geomorphic diversity is still apparent with pools, riffles, runs, bars, bench (depositional) and ledge (erosional) geomorphic units. At the golf course, the reach had been rehabilitated with battering of banks and grade control structures to prevent erosion and further incision. There were steep vertical terrace banks, as Reach 4 joins the Waikato River. This incision and confinement had likely occurred in response to lowering of base level set by the Waikato River.

4.3 KIRIKIRIROA CATCHMENT

The Kirikiriroa gully catchment is located to the south-east of Te Awa O Katapaki, in the north-eastern suburbs of Hamilton, with its upper catchment draining surrounding peat bogs to the north-east (Komakorau Bog). Downstream variation of six different River Style types across 13 reaches found in the Kirikiriroa system is shown in Figure 4-6, with longitudinal profiles shown in Figure 4-7. A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is displayed in Figure 4-8, Figure 4-9 and Figure 4-10. The catchment is dominated by dendritic gullies incised into the Hinuera surface, either fully or partly confined by terrace margin controls.

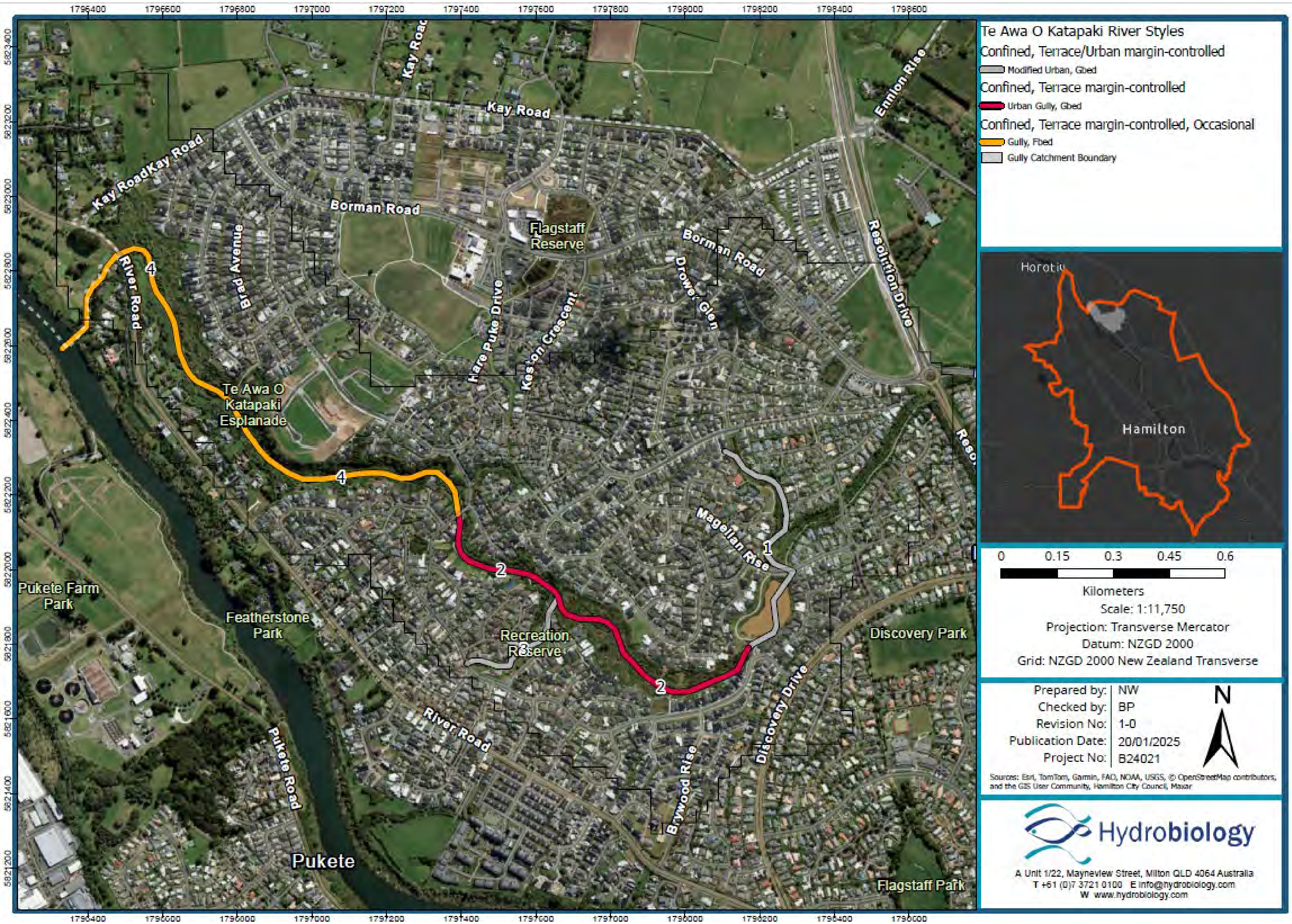

Figure 4-1 Te Awa O Katapaki gully catchment River Styles map.

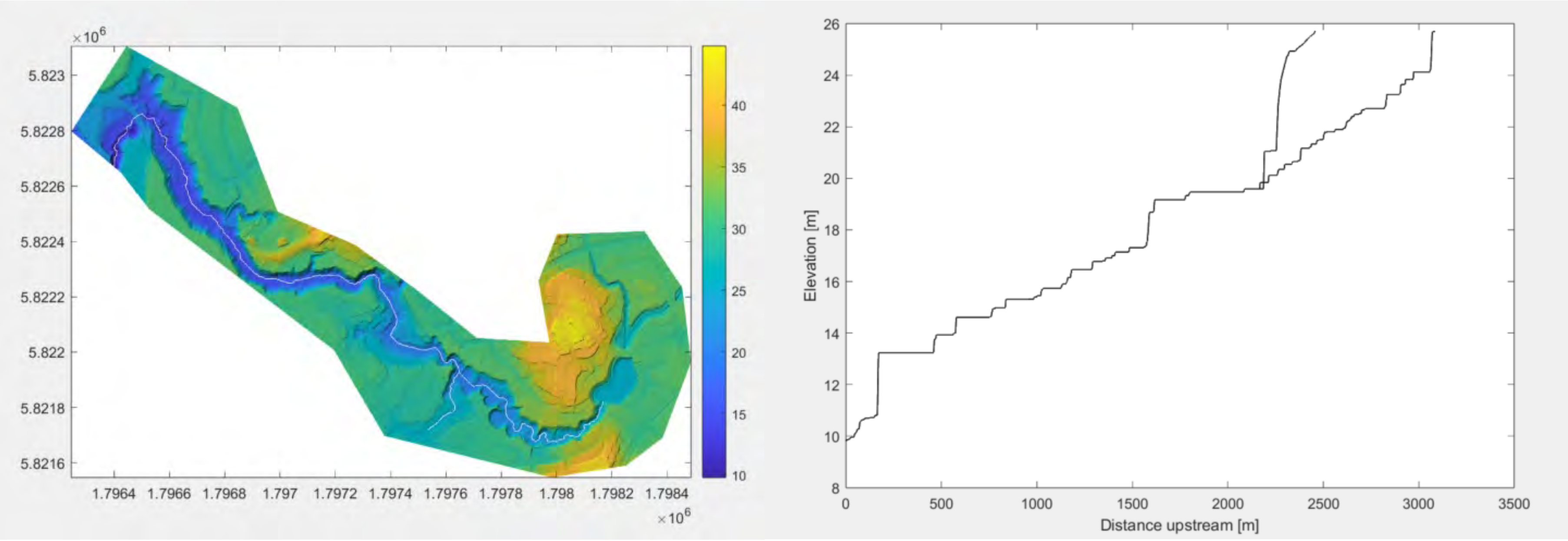

Figure 4-2 Te Awa O Katapaki gully catchment topography and long profiles.

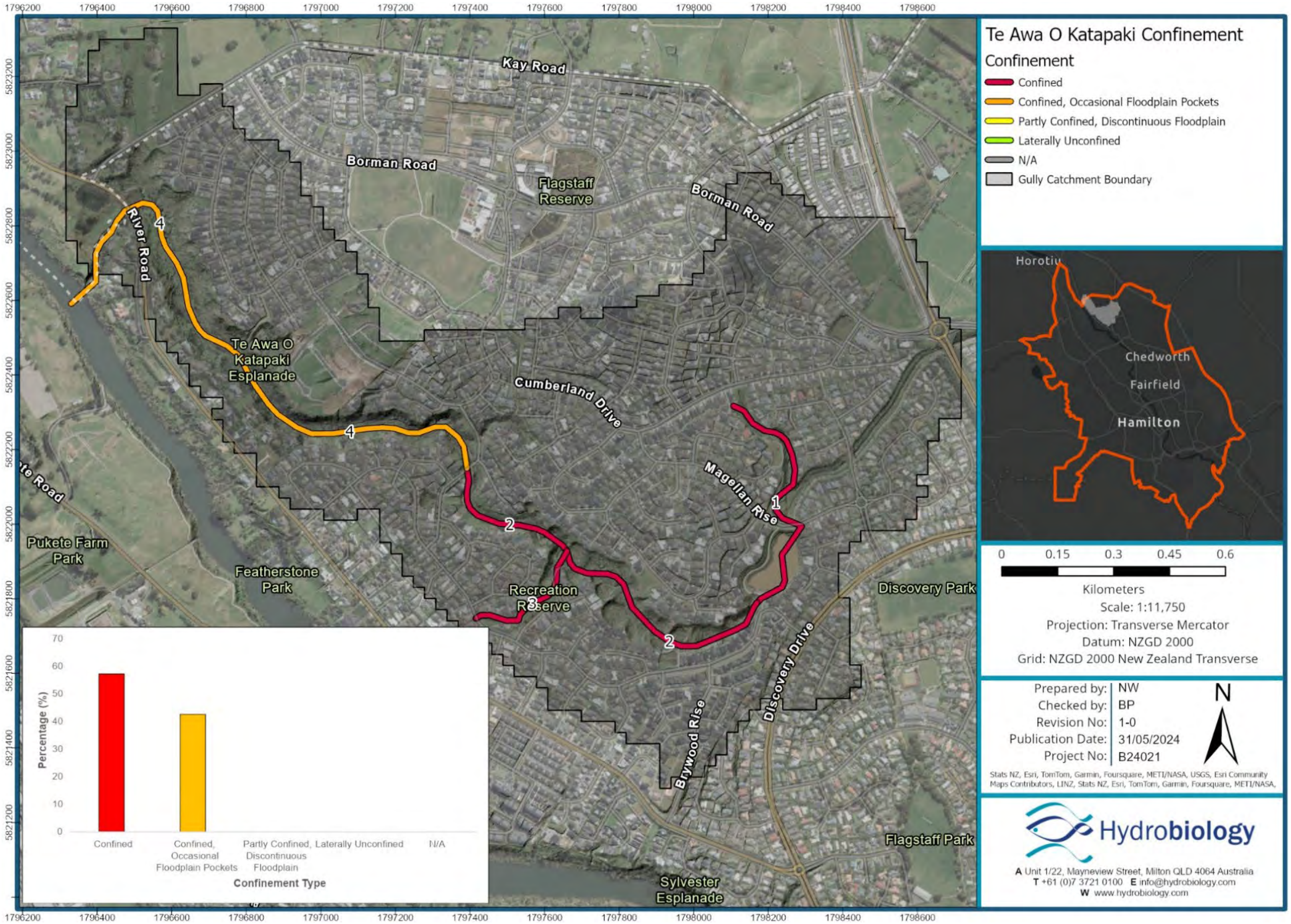

Figure 4-3 Te Awa O Katapaki gully catchment degree of confinement.

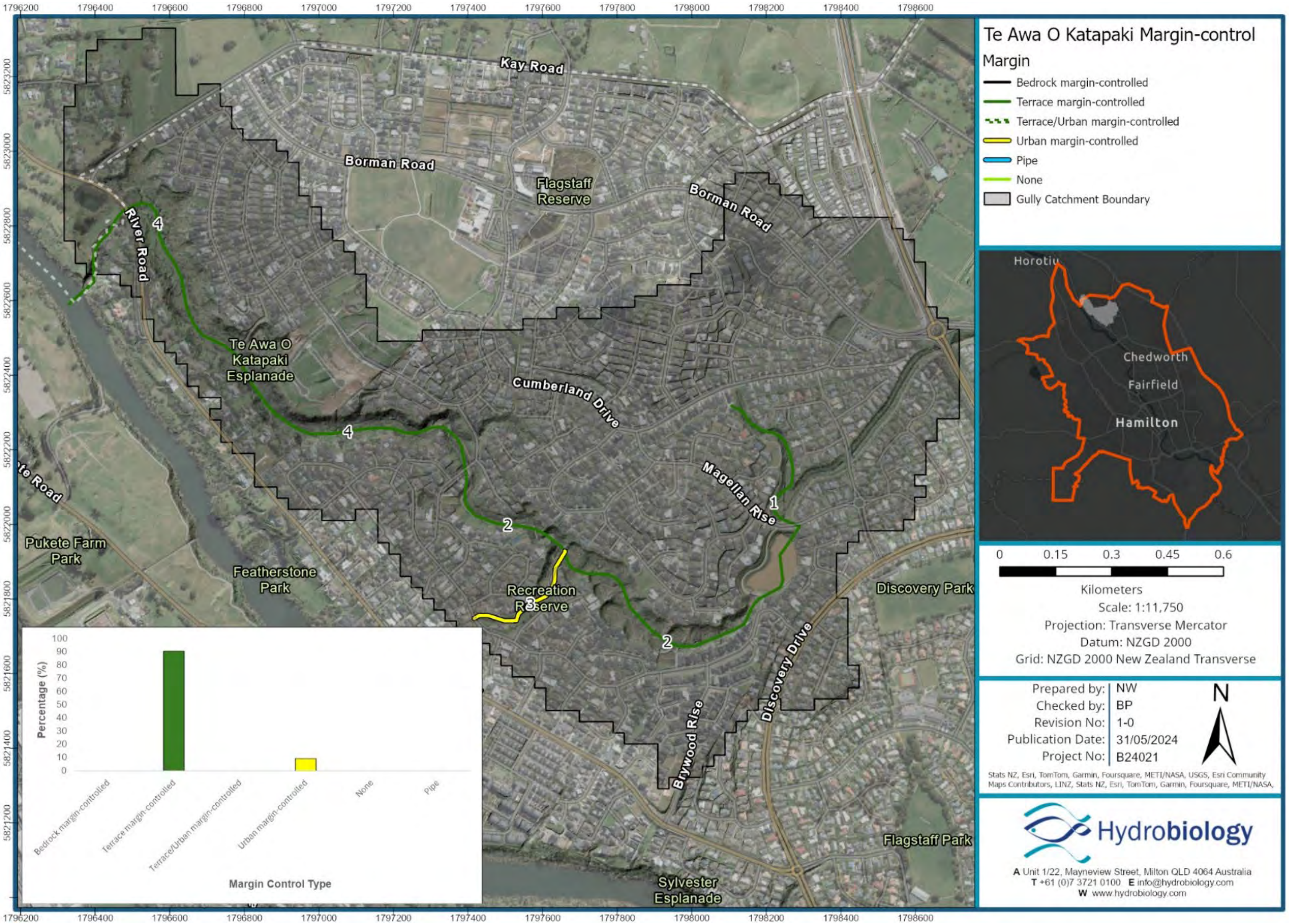

Figure 4-4 Te Awa O Katapaki gully catchment margin control types.

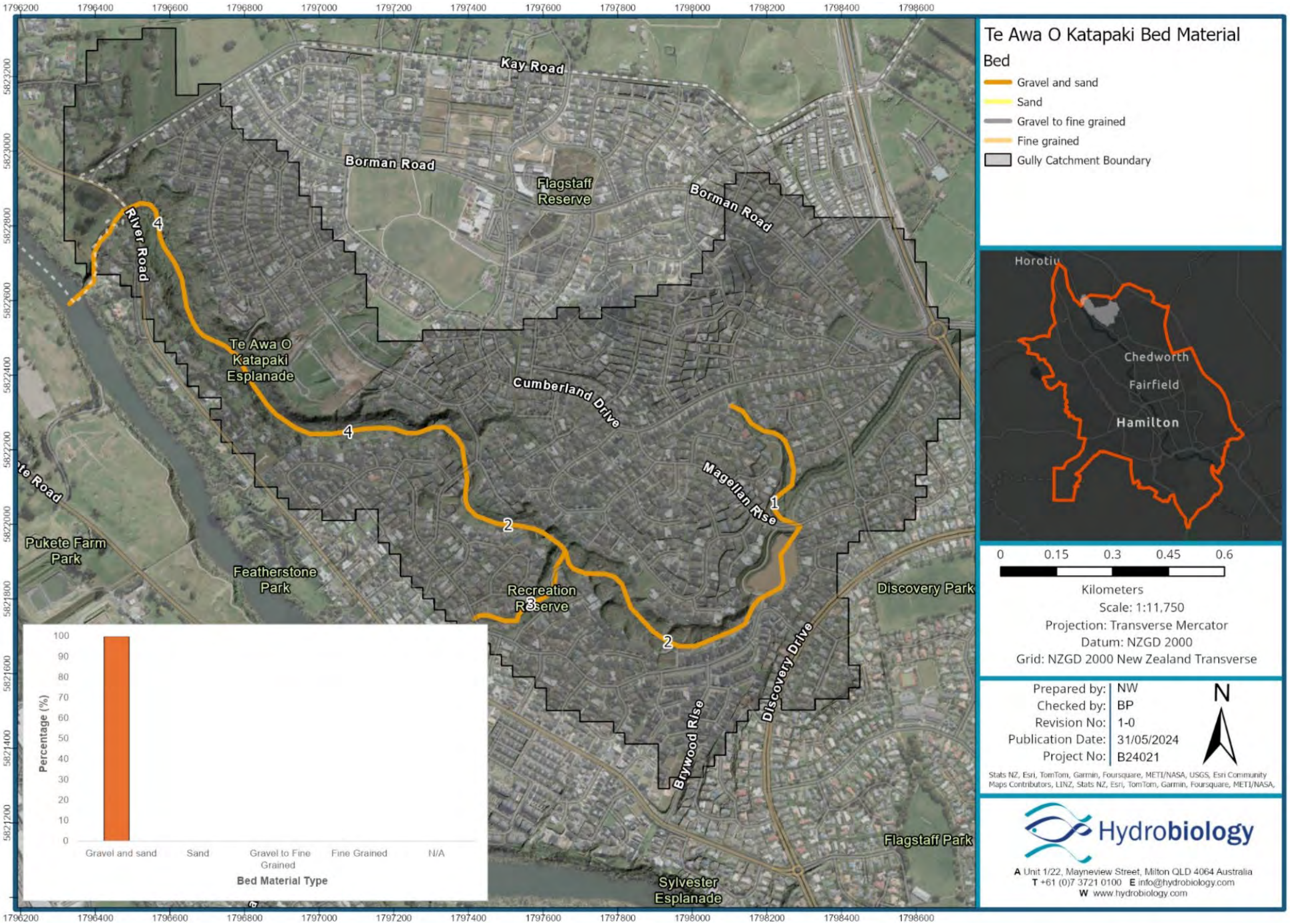

Figure 4-5 Te Awa O Katapaki gully catchment bed material type

Several dendritic gully tributaries drain the upper catchment. Reach 1 and 2 drain an urban development, confined by terrace margins. Reach 1 was mapped as a confined, terrace margin-controlled, modified urban channel with gravel bed material (C_TrMC_UMC_ModifiedUrban_Gbed). Reach 2 was also mapped as the same River Style type. Both reaches were highly modified, with storm water bioretention ponds. Downstream of the confluence of Reach 1 and 2, the River Style remains the same for approximately 300 m until downstream of Thomas Road, where the gully incises and widens further, transitioning to Reach 3. Reach 3 was mapped as a confined gully with terrace margin-controls, occasional floodplain pockets, and fine grained material (C_TrMC_OccFp_Gully_Fbed). Reach 3 extended for some distance downstream, to Wairere Drive (State Highway 5). Along this reach, several gully tributaries join the main channel (Reaches 4/5, Reaches 6A/6B and Reaches 7-10).

Reach 4/5 drains surrounding farmland and peat bogs to the north-east and flows into Reach 3 about 1 km downstream of the Reach 2/3 transition. Reach 4 was mapped as a laterally unconfined, continuous, low sinuosity, farm drain channel, with fine-grained bed material (LU_C_LSin_FarmDrain_Fbed). This reach was starting to incise and is sensitive to the upstream propagation of degradation occurring in the downstream reaches, as well as future urban development. Downstream, the gully became more incised and transitioned to Reach 5. Reach 5 was mapped as a confined, terrace margin-controlled urban gully with fine-grained bed material (C_TrMC_Gully_Fbed). Reach 6A/6B flows into Reach 3 several hundred meters downstream of the Reach3/5 confluence, and begins as a confined, urban margin-controlled, modified urban channel with bioretention (C_UMC_ModifiedUrban_DetentionPonds_Fbed) which transitions to the same River Style as Reach 5 (C_TrMC_Gully_Gbed). The Reach 7-10 tributary network then merges with Reach 3 a further 80 m downstream. Reach 7 was mapped as a confined, terrace margin-controlled, modified urban channel with gravel bed material (C_TrMC_UMC_ModifiedUrban_Gbed). Moving downstream, the gully became more incised and widens, with downstream reaches, Reach 8 and 10, becoming confined, terrace margin-controlled gullies with occasional floodplain pockets and fine-grained bed material (C_TrMC_OccFp_Gully_Fbed). Reach 10 had also undergone gully restoration, with well vegetated wetland and floodplain surfaces. Reach 9 was mapped as the same River Style as Reach 8 and 10 and was fed by a series of smaller, unmapped lateral and upstream gullies and urban runoff.

Reach 12 flows into Reach 3 from the north directly upstream of Wairere Drive, the main highway and 400 m upstream of the Reach 10 confluence. Reach 12 is different from the other gully tributaries, with a non-distinct channel and wetland swamp environment. Reach 12 was characterised as a confined, terrace margin-controlled, swamp wetland with valley fill, with occasional floodplain pockets and fine-grained sediment material (C_TrMC_OccFp_Swamp/Wetland_Fbed). Reach 11 flows into the main channel at the transition between Reach 3 and Reach 13B, about 60 m downstream of Waiwere Drive, with the inflows of Reach 11 resulting in local valley widening and floodplain wetland deposits associated with the confluence zone. Similar to other tributaries, Reach 11 was characterised as a confined, terrace margin-controlled urban gully, with gravel bed material (C_TrMC_Gully_Gbed).

Moving downstream, Reach 13B was wider, partly confined by terrace margins, and had a staged terraced incisional history, suggesting longer term degradation. Reach 13B was therefore characterised as a partly confined terrace margin-controlled gully, with a discontinuous inset floodplain and fine grained material (PC_TrMC_Gully_DcFp_Fbed). Grade control structures and rock revetments have been installed along this reach in an attempt to prevent further upstream propagation of this degradation. With the land under a horse-riding lease from Hamilton City Council, this reach has future management potential. Backwatering effects from Waikato River flooding have also affected incision and widening processes in this reach.

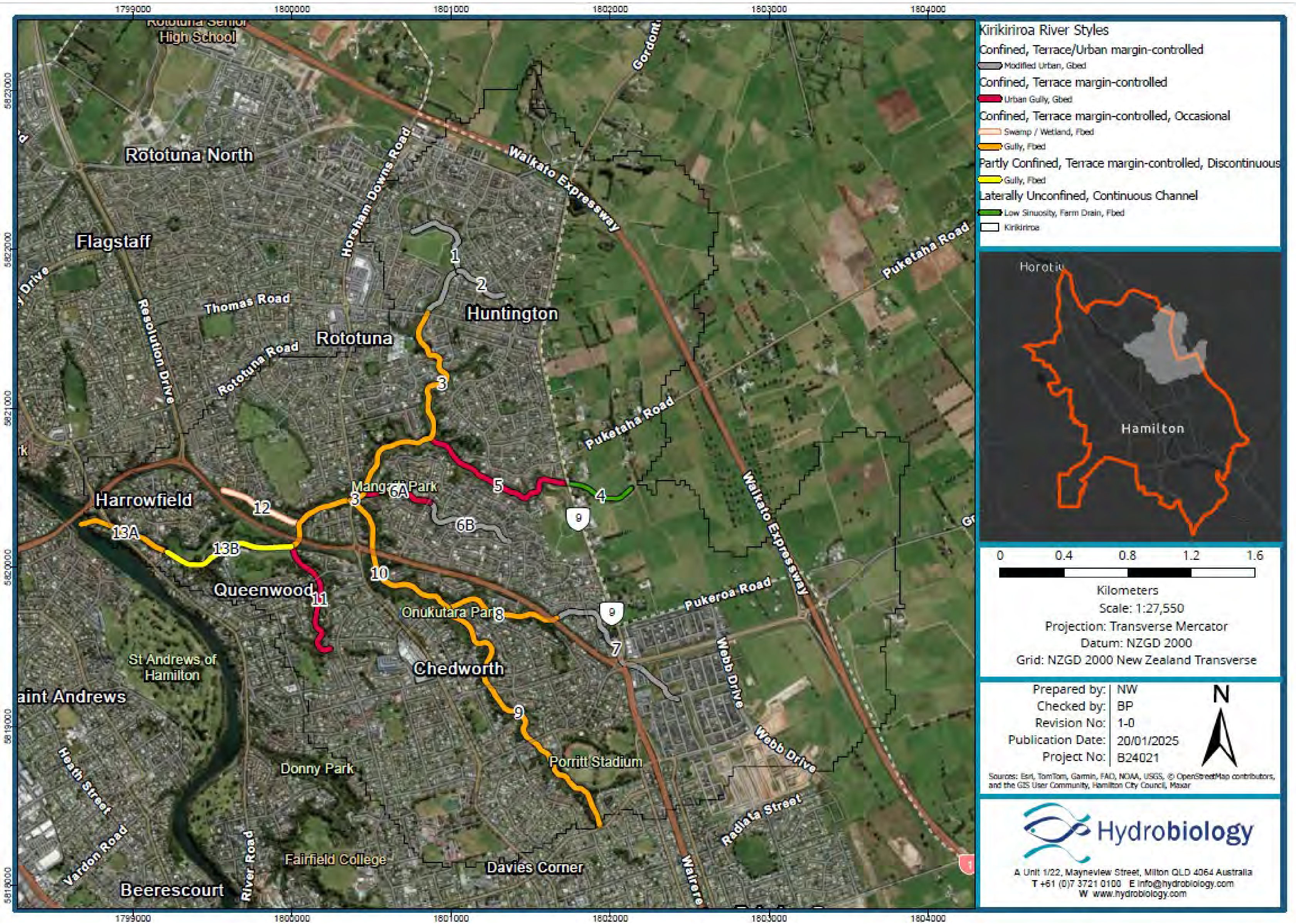

Figure 4-6 Kirikiriroa gully catchment River Styles.

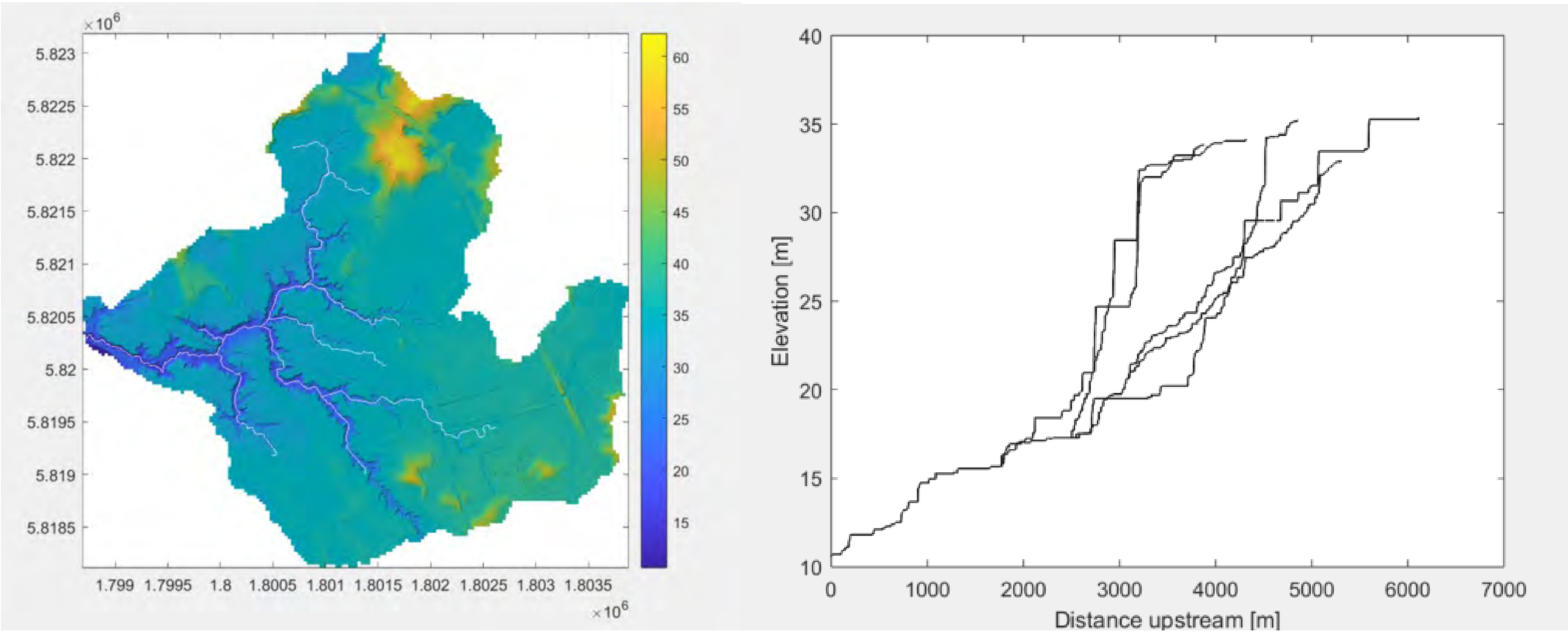

Figure 4-7 Kirikiriroa gully catchment topography and long profiles.

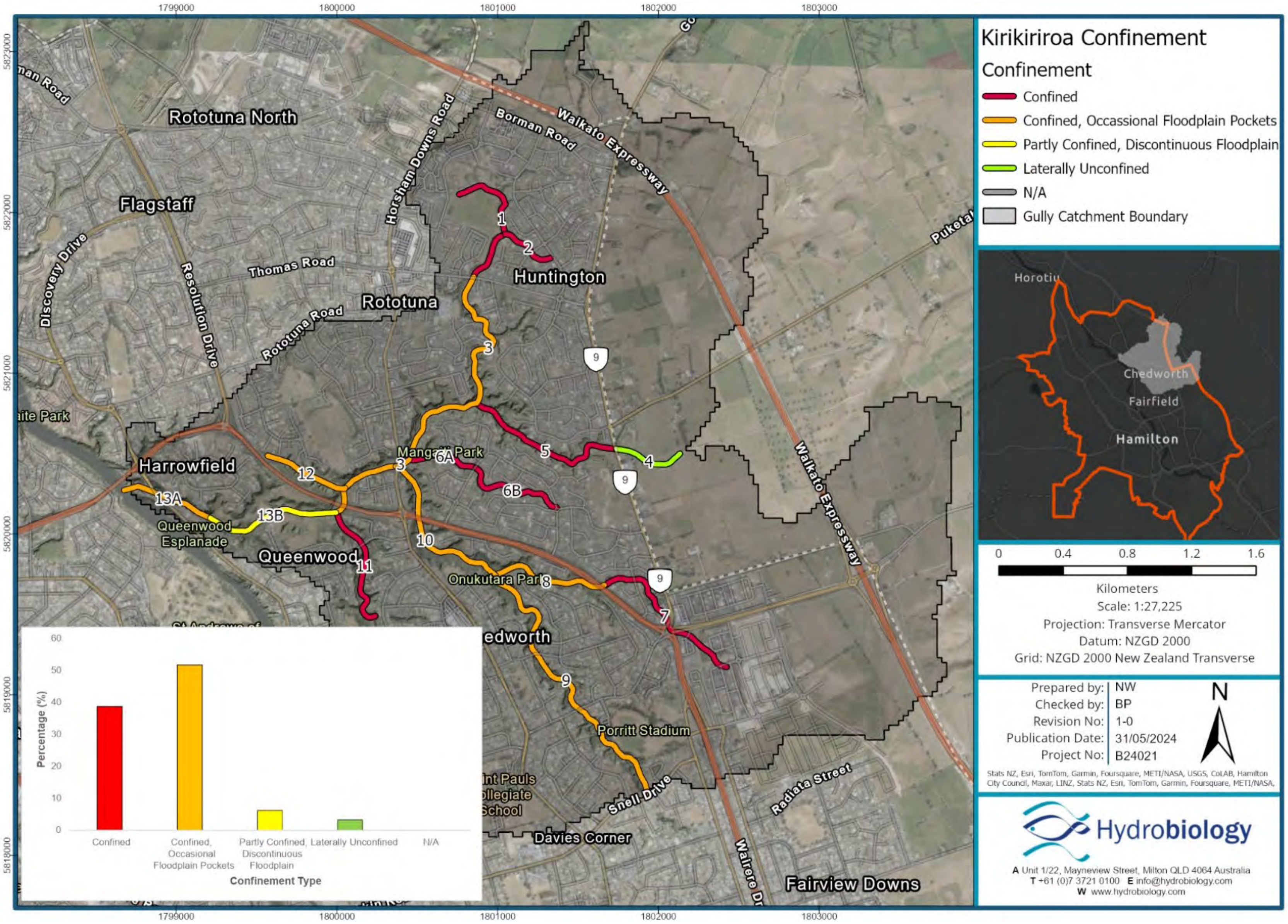

Figure 4-8 Kirikiriroa gully catchment degree of confinement.

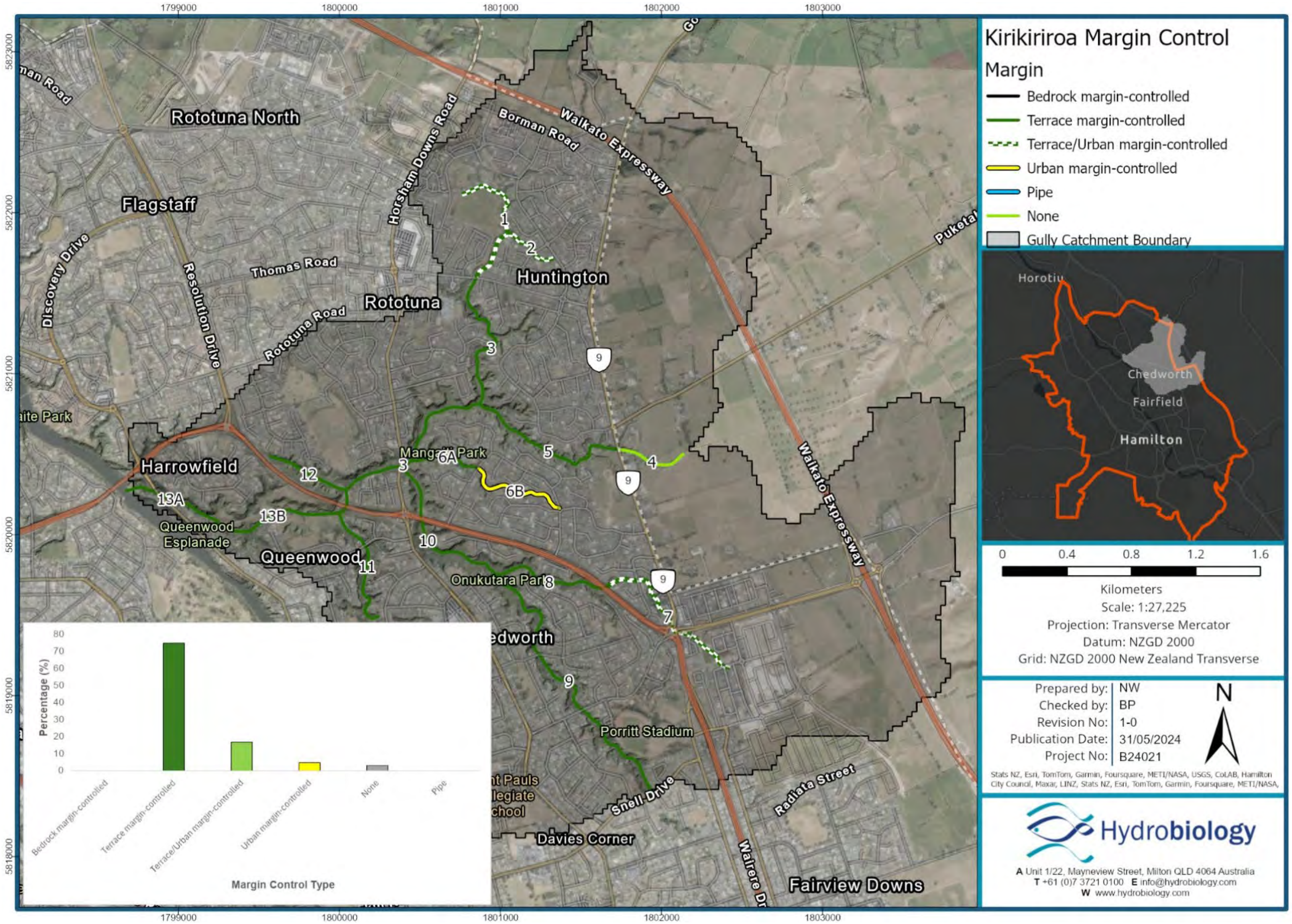

Figure 4-9 Kirikiriroa gully catchment margin control type.

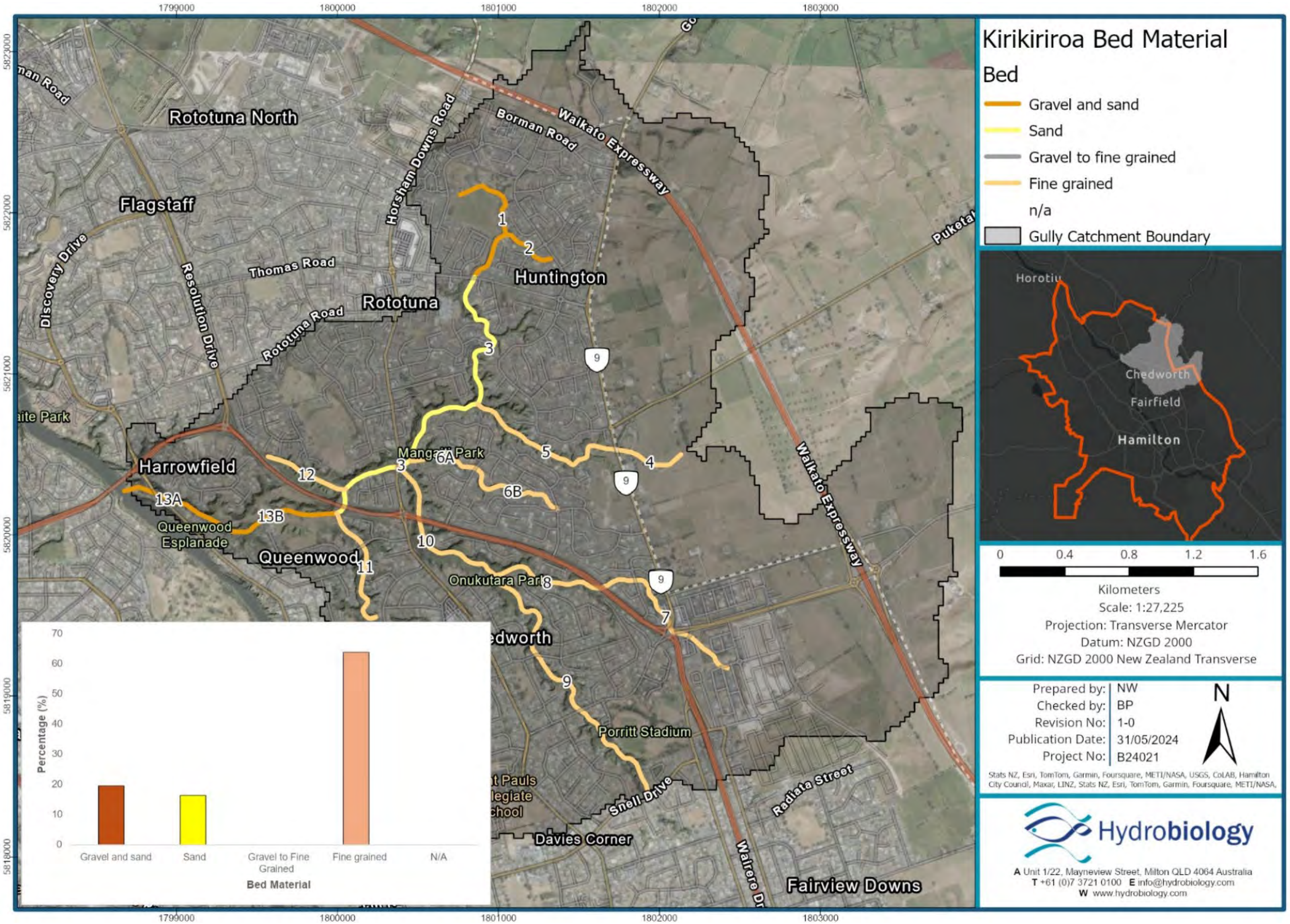

Figure 4-10 Kirikiriroa gully catchment bed material.

This was observed in the field with a footbridge at Tauhara Drive along the esplanade bridge abutments being outflanked by both incision and widening. The last reach before the confluence of the Waikato River is locally constricted, forming Reach 13A. This was characterised as a confined, terrace margin controlled gully with occasional floodplain pockets and fine grained material (C_TrMC_OccFp_Gully_Fbed). This reach had a number of grade control structures installed, in an attempt to prevent incision, with gabion baskets at the River Road bridge crossing protecting both the bed and banks.

4.4 WAITAWHIRIWHIRI CATCHMENT

The Waitawhiriwhiri Catchment gully system is located in Central Hamilton, draining into the Waikato River from the south-western side of the river. The gully systems' upper catchment drains Holocene swamp and peat deposits to the south-west (Rukuhia Bog), and Late Pleistocene Hinuera surface river deposits closer to the Waikato River. Downstream variation of four different River Styles found in the Waitawhiriwhiri gully catchment is shown in Figure 4-11, with longitudinal profiles shown in Figure 4-12. A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is displayed in Figure 4-13, Figure 4-14 and Figure 4-15. The catchment is dominated by urban gully systems which have been heavily modified, most of which are fully confined by terrace or urban margins.

The Waitawhiriwhiri gully system originates as farm drains that drain peat land to the south-west that was once former kahikatea forest, outside of the mapped area. As such, as per other peat draining reaches described above, Reach 1B was characterised as a laterally unconfined, continuous, low sinuosity farm drain, with fine-grained bed material (LU_C_LSin_FarmDrain_Fbed). This area is sensitive to upstream propagation of degradation in downstream reaches. During the site visit, however, Hamilton City Council noted that it has intentions of protecting this area from urban development and rehabilitating the peat wetland.

Reach 1B extends about 800 m before transitioning to Reach 1A, a confined, urban margin-controlled, urban drain channel with gravel and fine-grained bed material (C_UMC_UrbanDrain_Gbed). This reach has been modified, with concrete lining along sections of the channel. Downstream of the Dinsdale roundabout, the gully becomes more incised into the Hinuera surface, confined by both terrace and urban margin control, forming Reach 2. Reach 2 is therefore characterised as a confined, terrace and urban margin controlled, concrete canal channel with gravel and fine-grained bed material (C_UMC_ConcreteCanal_Fbed). This channelised reach is exposed to high velocities. Channel modifications, such as concreting, gabion baskets and rock control, were being used to protect the channel but are being undermined and undercut in places. This reach is also close to infrastructure and such degradation and widening presents a risk to surrounding private property.

Reach 2 extends to downstream of State Highway 1C, where it transitions to Reach 3B, which is further incised into the Hinuera Formation. Reach 3B was characterised as a confined, terrace margin-controlled, urban gully with gravel to fine-grained bed material (C_TrMC_Gully_Gbed). Localised landslips on terrace slopes were observed, with replanting and groyne toe stabilisation. Reach 3B extends to Ulster Street, before transitioning to Reach 3A. Culvert and grade control structures associated with the Ulster Street crossing causes a break in River Style type, by preventing propagation of incision and widening upstream.

Reach 3A was characterised as a wider valley setting, as confined, terrace margin-controlled with occasional floodplain pockets gully with gravel to fine-grained bed material (C_TrMC_OccFp_Gully_Fbed). The reach also consisted of inset benches with sandy and coarse gravel deposits and had been stabilised through the installation of grade control structures and bank rock beaching.

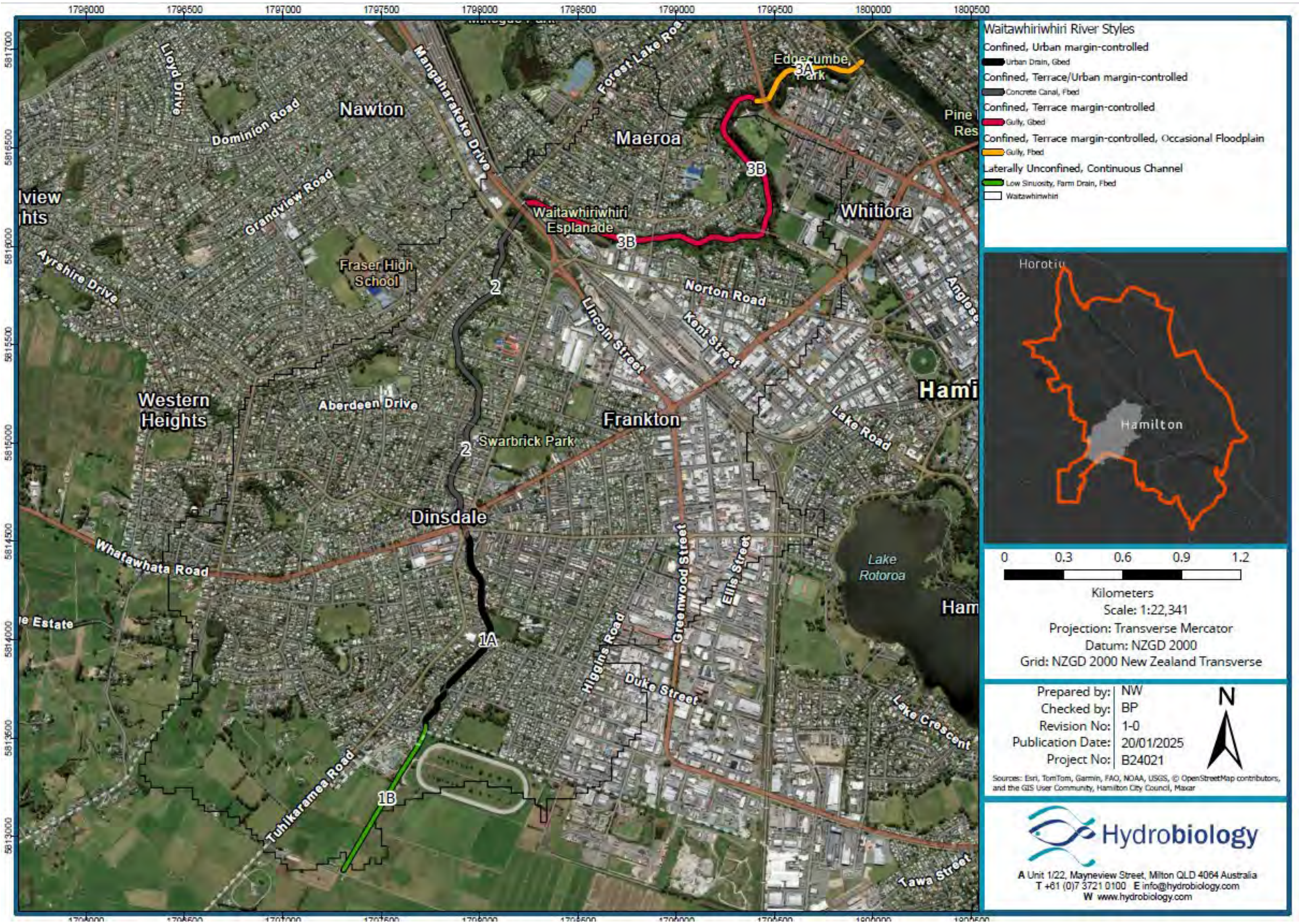

Figure 4-11 Waitawhiriwhiri gully catchment River Styles.

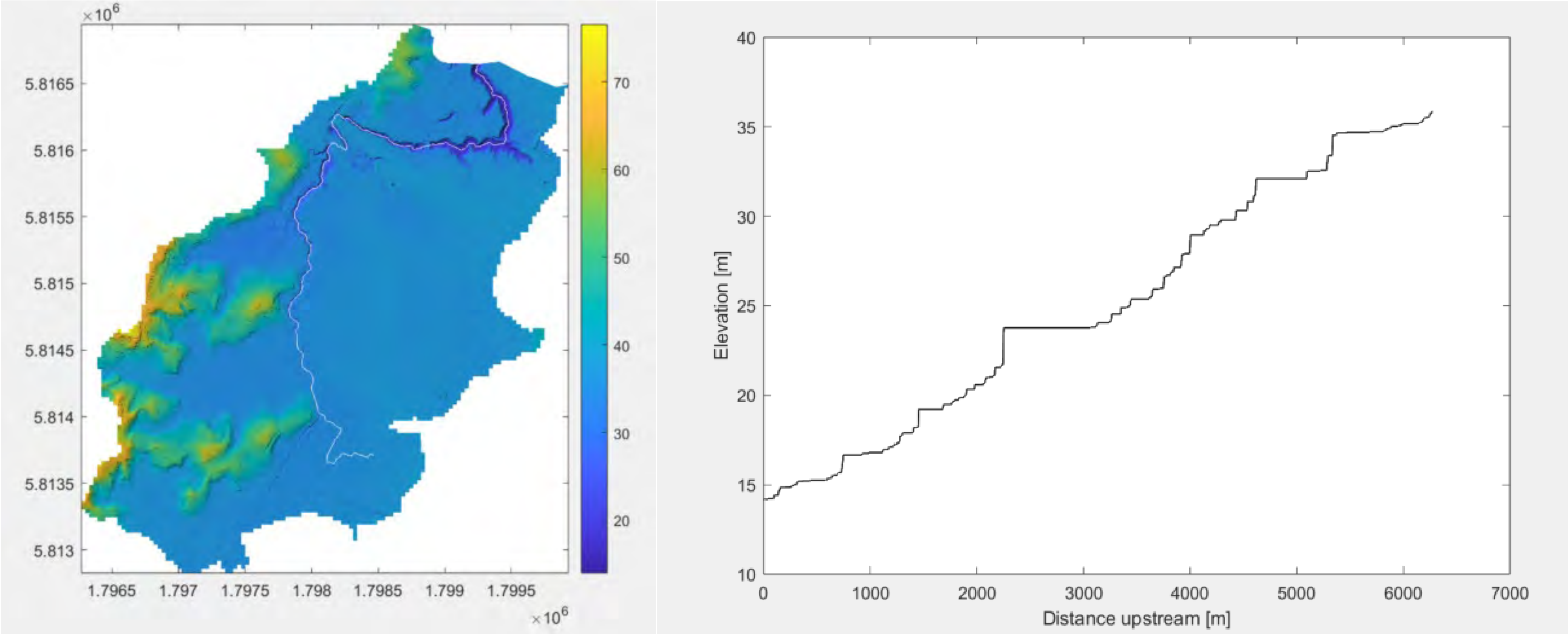

Figure 4-12 Waitawhiriwhiri gully catchment topography and long profiles.

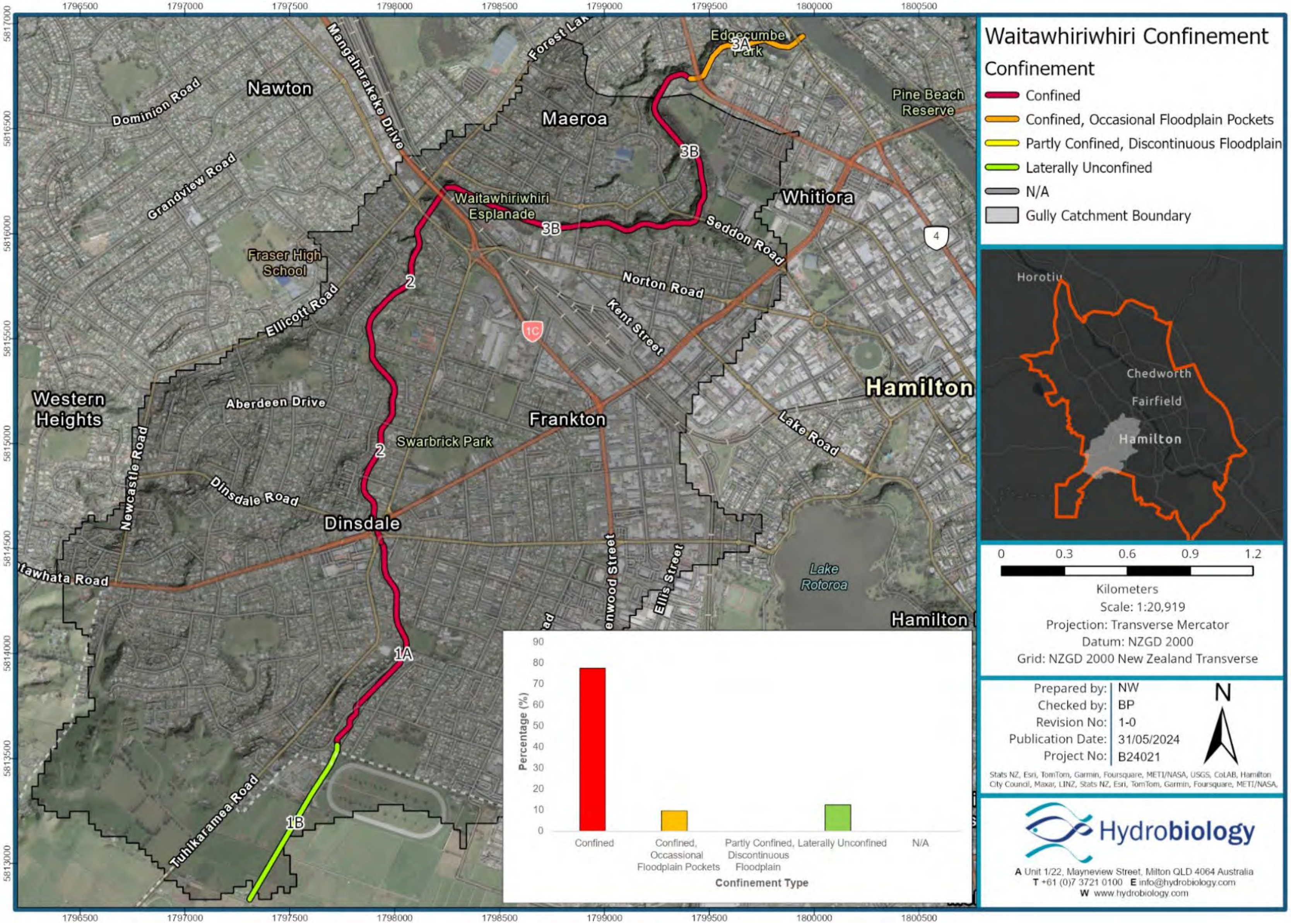

Figure 4-13 Waitawhiriwhiri gully catchment degree of confinement.

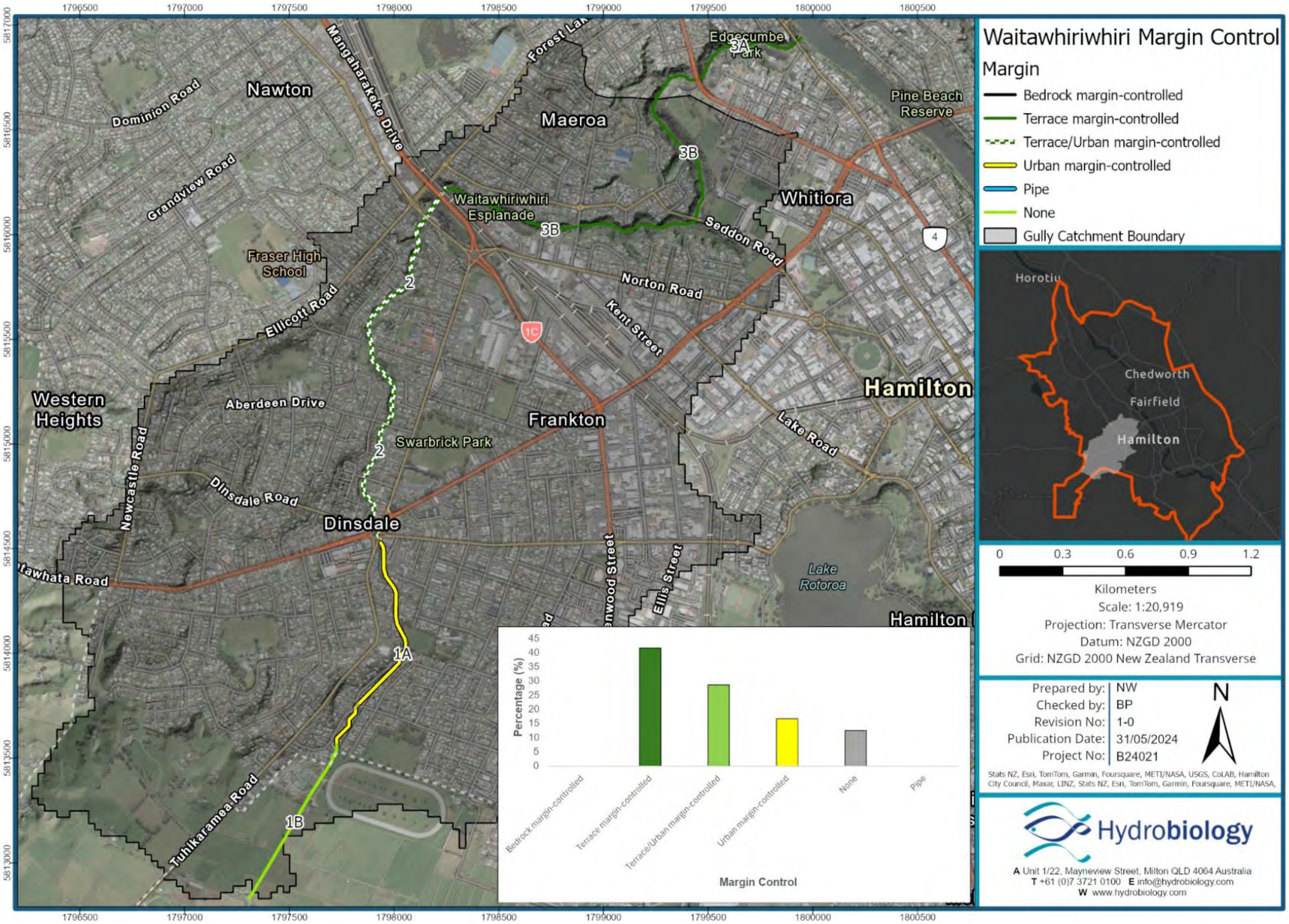

Figure 4-14 Waitawhiriwhiri gully catchment margin control type.

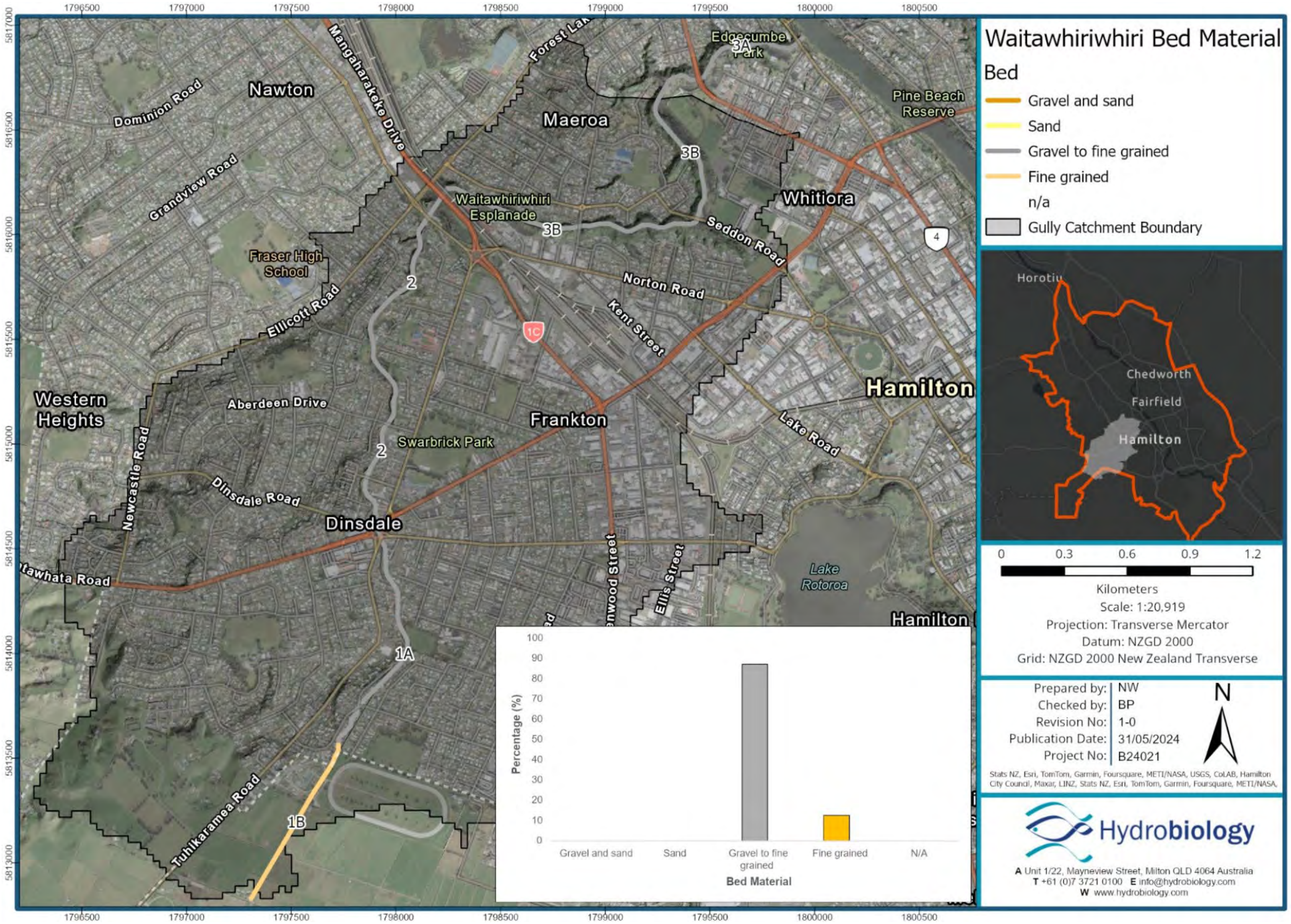

Figure 4-15 Waitawhiriwhiri gully catchment bed material type.

Along the reach there were a high presence of stormwater outflows, pumice seeps, and groundwater movement from recent rainfall events, resulting in storm drainage erosion. Near the confluence with the Waikato River, banks were protected with sheet mats. This reach is a high priority management reach for Hamilton City Council, with tree removal and root structure maintenance occurring. At the confluence, there has been realignment since the 1970's and at the Victoria Street bridge crossing near Edgcumbe Park and before the Waikato confluence there is a concrete box culvert acting as a bed level control to Waikato River, with flow discharging onto exposed bedrock.

4.5 MANGAKOTUKUTUKU CATCHMENT

The Mangakotukutuku Catchment gully system is located to the south-west of Hamilton City, on the southern side of the Waikato River. The systems' upper catchment drains Holocene swamp and peat deposits to the south-west (Rukuhia Bog), Hamilton Hills (river deposits and volcanic ignimbrite deposits), and Late Pleistocene Hinuera surface river deposits closer to the Waikato River. Downstream variation of 12 different River Style types across 20 reaches found in the catchment is shown in Figure 4-16, with the longitudinal profiles shown in Figure 4-17A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is displayed in Figure 4-18, Figure 4-19 and Figure 4-20. This catchment is mainly dominated by confined, terrace margin controlled urban gullies, some of which have undergone restoration.

The upper catchment of the gully system comprises farm drains that flow across the larger Rukuhia Peat bog system to the south-west. Reach 1 and 3 originate in this bog system so were characterised as laterally unconfined, continuous low sinuosity farm drains with fine-grained bed material (LU_C_LowSin_FarmDrain_Fbed). Both Reach 2 and 4 drain downstream of here as highly modified channels, that are piped in places. Therefore, both were characterised as confined, terrace and urban margin controlled, modified urban channels with gravel to fine-grained bed (C_TrMC_UMC_ModifiedUrban_Gbed).

Moving downstream, the gully becomes more incised into the Hinuera surface, and widens, transitioning to Reach 5. Reach 5 was therefore characterised as a confined, terrace margin-controlled gully with occasional floodplain pockets and gravel to fine-grained material (C_TrMC_OccFp_Gully_Fbed). Reach 6 flows into Reach 5 about 350 m downstream of Splitt Avenue and was characterised as a confined, terrace margin-controlled urban gully with gravel and sand bed material (C_TrMC_Gully_Gbed). Reach 6 is fed from Reach 7 as piped stormwater.

Reaches 8/9/10/11 flow into Reach 5 from the northwest about 350 m downstream of the Reach 6 confluence, draining the Glenview urban development. Reach 8 originates as a confined, urban margin-controlled swale with a fine-grained bed (C_UMC_UrbanSwale_Fbed). This then transitions into Reaches 9 and 10, both characterised as confined, terrace and urban margin-controlled, modified urban channels with gravel to fine-grained bed material (C_TrMC_UMC_ModifiedUrban_Gbed). Downstream of Ohaupo Road (State Highway 3), Reach 10 transitions to Reach 11, a confined, terrace margin-controlled urban gully with gravel and sand bed material (C_TrMC_Gully_Gbed).

At the Reach 11/5 confluence the channel transitions to Reach 20B and was characterised as confined with terrace margin-control and occasional floodplain pockets, gully with gravel and fine grained bed material (C_TrMC_OccFp_Gully_Fbed). The channel was more incised than its upstream reaches with a wider valley setting.

About 500 m downstream of the Reach 11 confluence, Reach 19 flows into Reach 20B from the south, draining Reaches 12 – 19. This part of the catchment drains slightly differing geology, with the upper catchment draining rolling hill morphology of the Hamilton Hills (river and ignimbrite tephras), as well as the Hinuera Surface.

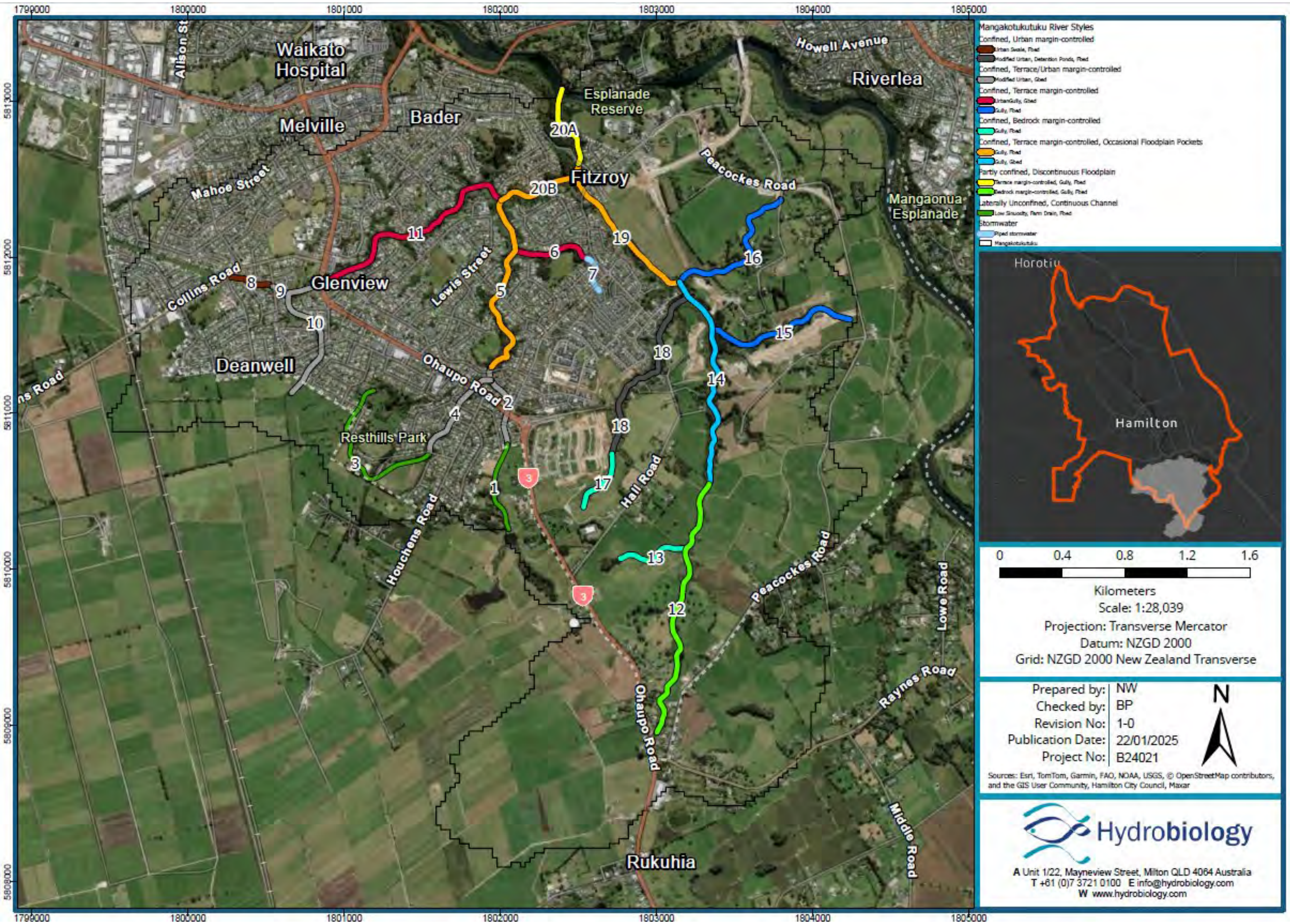

Figure 4-16 Mangakotukutuku gully catchment River Styles.

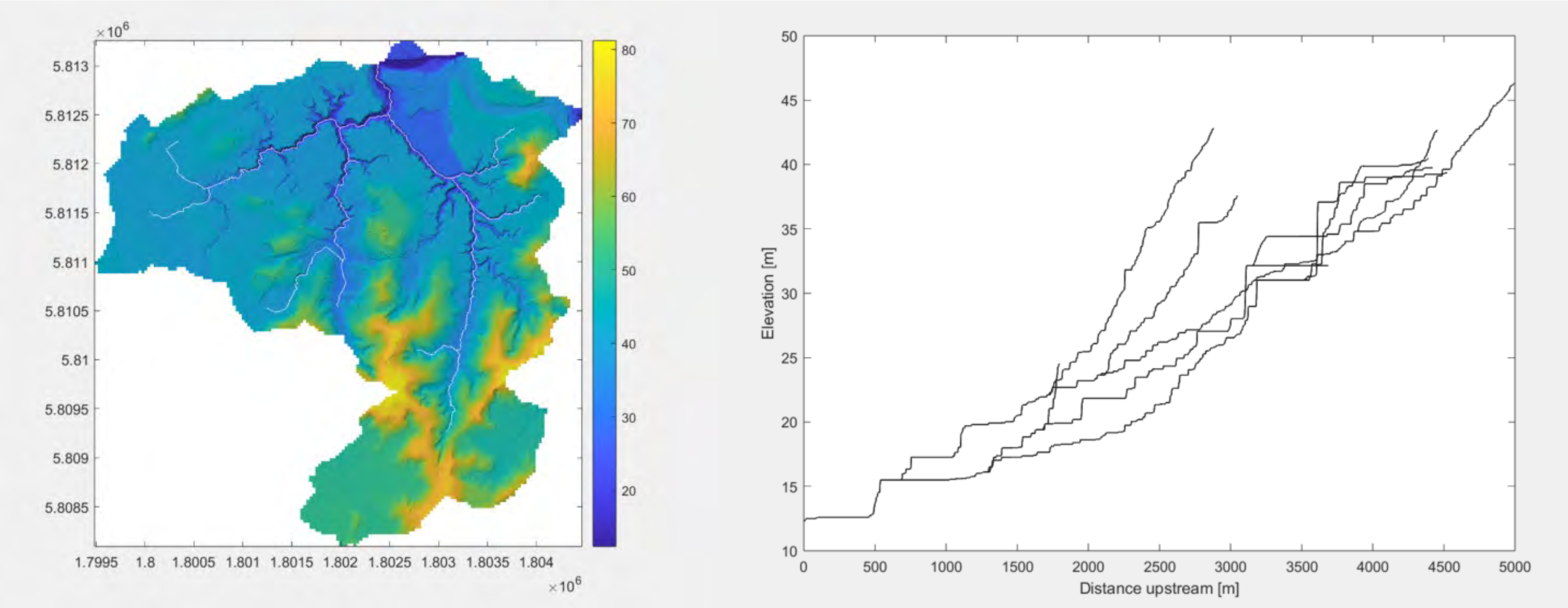

Figure 4-17 Mangakotukutuku gully catchment topography and long profiles.

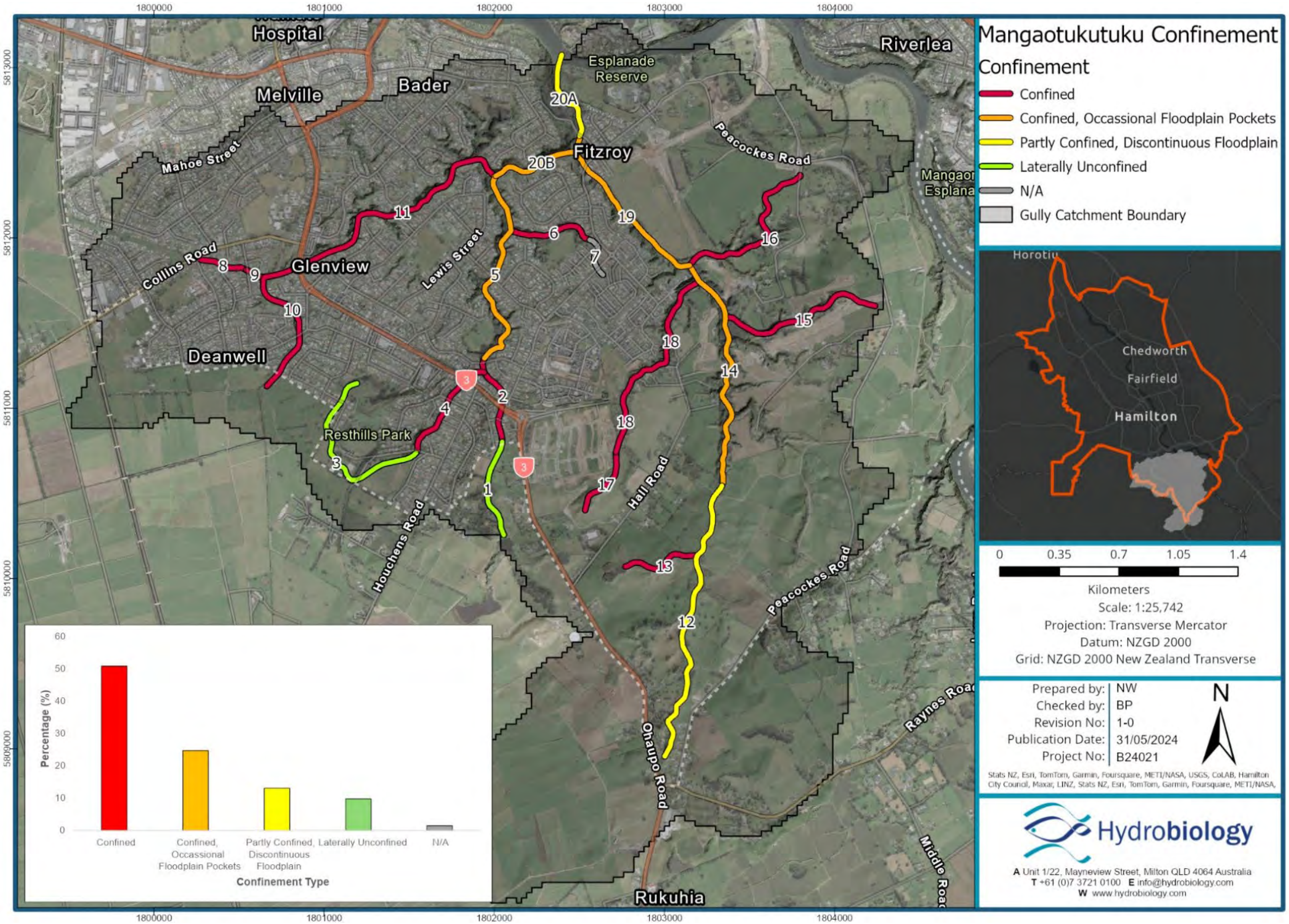

Figure 4-18 Mangakotukutuku gully catchment degree of confinement.

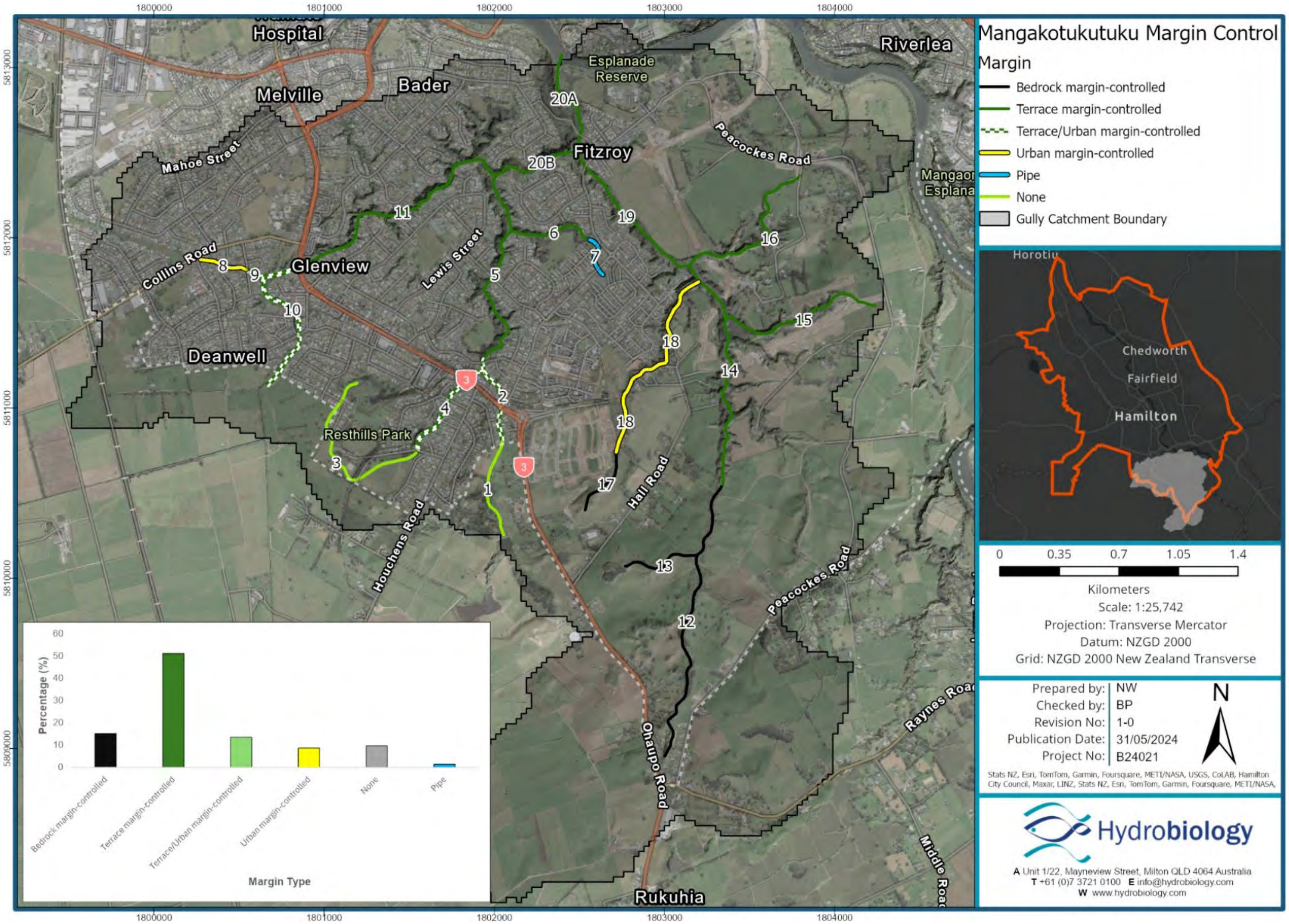

Figure 4-19 Mangakotukutuku gully catchment margin control type.

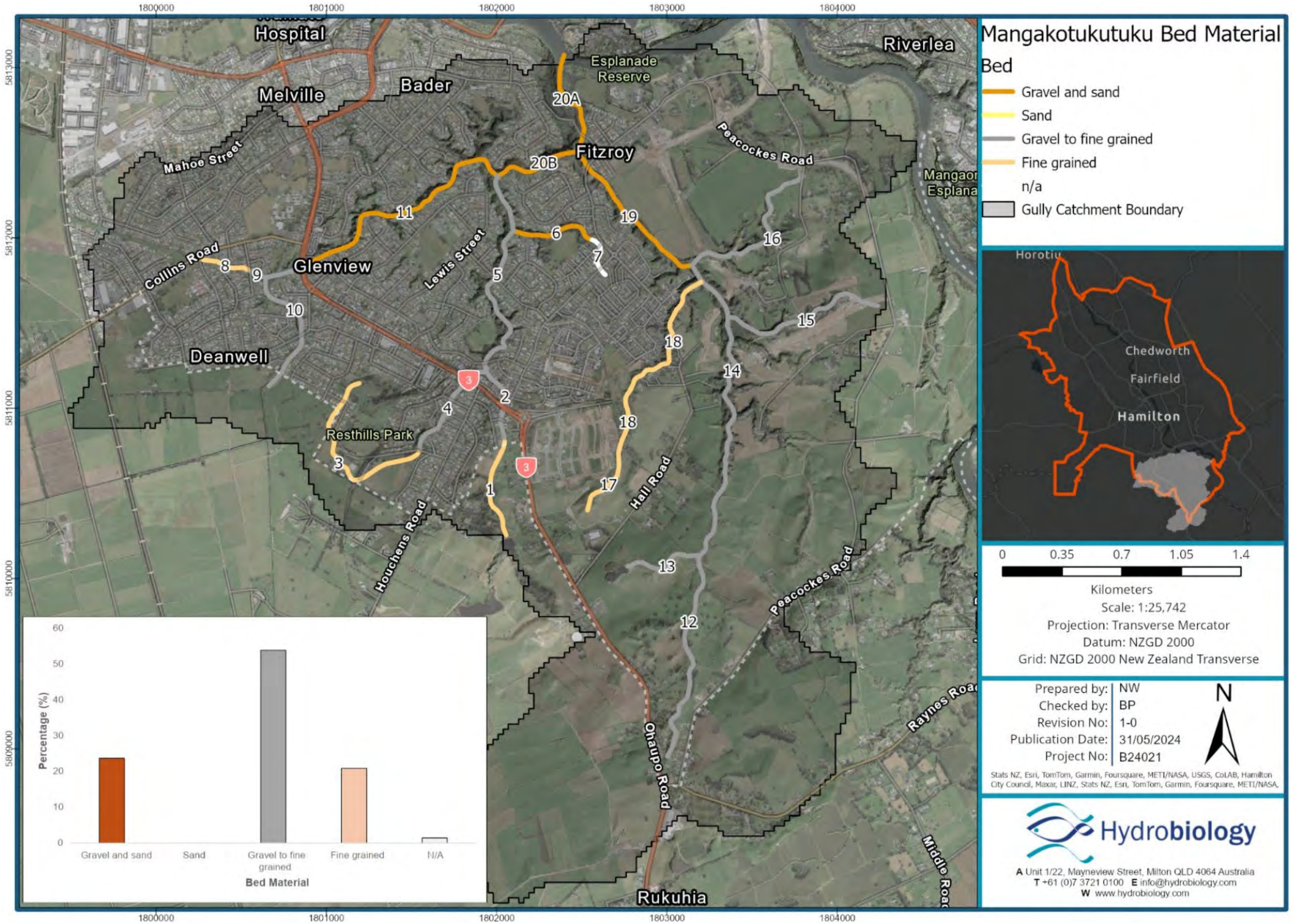

Figure 4-20 Mangakotukutuku gully catchment bed material.

Reach 12 was characterised as a partly confined, bedrock margin-controlled farm gully with discontinuous floodplain surfaces, with gravel to fine-grained bed material (PC_BrMC_Gully_DcFp_Fbed). Reach 13 is a small tributary of Reach 12 and was characterised as a confined, bedrock margin-controlled farm gully with gravel to fine-grained bed material (C_BrMC_Gully_Fbed). Moving downstream, Reach 12 becomes entrenched and incised into the Hinuera Surface, transitioning to Reach 14, which was characterised as a confined, terrace margin-controlled farm gully with occasional floodplain pockets and gravel to fine-grained bed material (C_TrMC_OccFp_Gully_Gbed). On the true right, several dendritic gully systems join, including Reaches 15 and 16, which were mapped as confined, terrace margin-controlled farm gullies with gravel and sand bed material (C_TrMC_Gully_Fbed. Between the confluences of Reaches 15 and 16 with Reach 14, the highly modified Reach 17/18 flows into Reach 14. It was characterised as a confined bedrock margin-controlled farm gully with fine-grained bed material that was starting to become modified as part of the surrounding urban development (C_BrMC_Gully_Fbed). Reach 18 was characterised as a confined, urban margin-controlled modified urban channel with detention ponds and fine-grained bed material (C_UMC_ModifiedUrban_DetentionPonds_Fbed).

Moving downstream at the Reach 14/16 confluence, the channel transitioned into the wider Reach 19. This was also characterised as a confined, terrace margin-controlled gully with occasional floodplain pockets and gravel and sand bed material. There was localised widening and sediment accumulation associated with the confluence of gullies upstream. This reach had issues with sap springs and land sliding, with alluvium exposures. The reach had been restored with planting initiatives.

Downstream of the Reach 19/20B confluence and Peacockes Road, the channel transitions to the wider Reach 20A. This reach was characterised as a partly confined, with terrace margin-control gully with discontinuous inset floodplain surfaces and bed material ranging from gravels to fine-grained (PC_TrMC_Gully_DcFp_Fbed). This reach has undergone incision and widening, with rehabilitation planting works aiding accumulation and stabilisation recovery processes. At the confluence with the Waikato River, the reach is highly incised with an inset floodplain, and with back water effects resulting in island and bench features. At the confluence, there is heavy rock armouring to protect a water mains pipe, stabilising the confluence.

4.6 MANGAONUA / MANGAONE CATCHMENT

The Mangaonua / Mangaone gully catchment is located to the far south-east of Hamilton, on the north side of the Waikato River. These gully systems, unlike the other catchments, are former paleochannels of the Waikato River, forming outflow channels from a late stage in the development of the Waikato Fan that drain Hinuera Formation river deposits. Downstream variation of 5 different River Styles across 8 reaches is shown in Figure 4-21, with the longitudinal profiles shown in Figure 4-22. A summary of attributes of these River Styles (degree of confinement, margin type and bed material type) is displayed in Figure 4-23, Figure 4-24 and Figure 4-25.

The Mangaonua Stream drains from the north-east, outside of the mapped area near Newstead, draining the Hinuera Surface. This was mapped as Reach 3 and was characterised as a confined, terrace margin-controlled gully with occasional floodplain pockets and gravel to fine-grained bed material (C_TrMC_OccFp_Gully_Fbed). Reaches 1/2 are northern tributaries of Reach 3. Reach 1 represents a confined, terrace margin-controlled urban gully with gravel to fine-grained bed material (C_TrMC_Gully_Gbed) and flows into Reach 2 about 300 m upstream of the Reach 3 confluence. Reach 1 had several headcuts propagating upstream as an incised slot channel, with several grade control structures placed to mitigate degradation. Reach 2 was mapped as a confined farm gully (C_TrMC_Gully_Fbed). The main channel (Reach 3) transitions into Reach 8 at the confluence of Reach 1. Reach 8 is described further below.

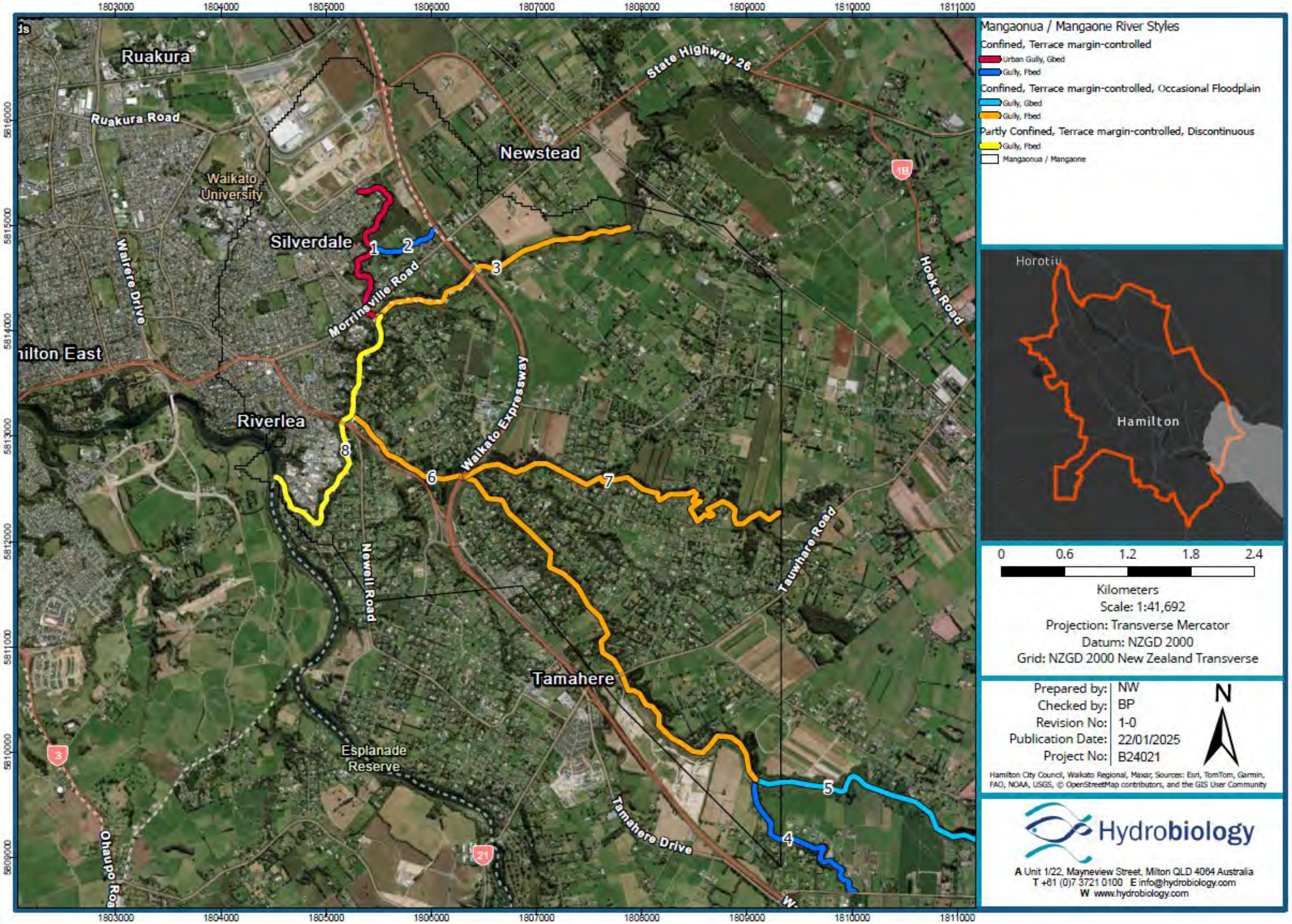

Figure 4-21 Mangaonua / Mangaone gully catchment River Styles.

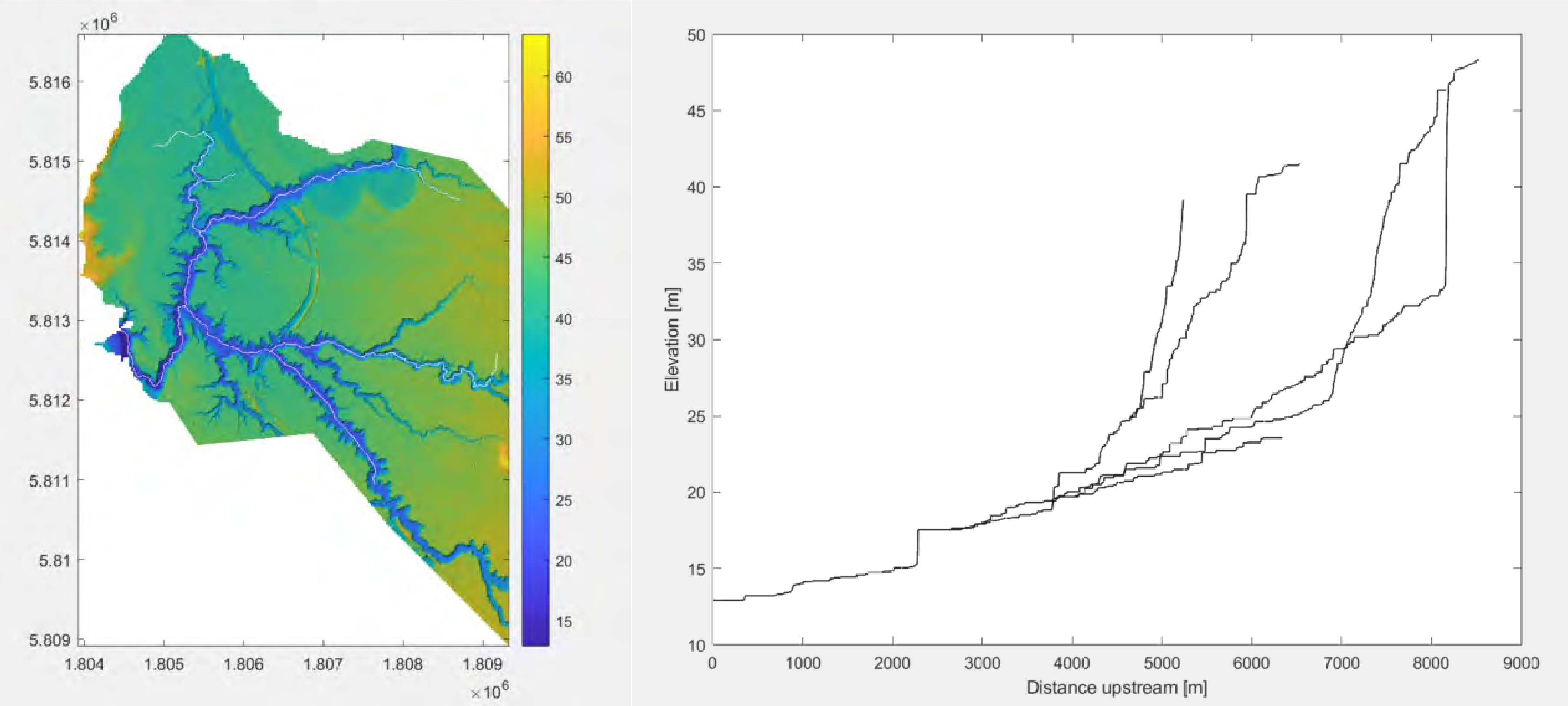

Figure 4-22 Mangaonua / Mangaone gully catchment topography and long profiles.

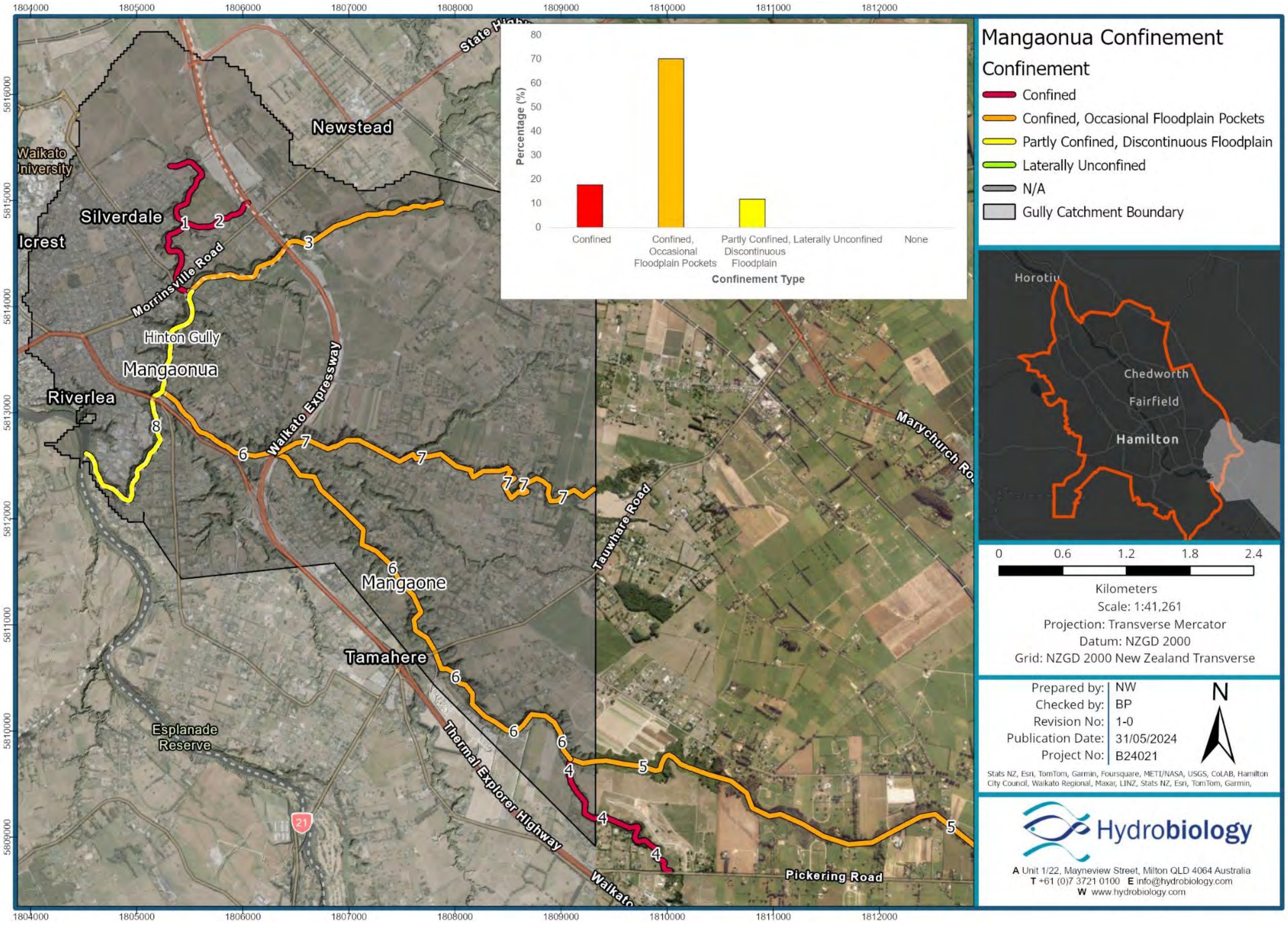

Figure 4-23 Mangaonua / Mangaone gully catchment degree of confinement.

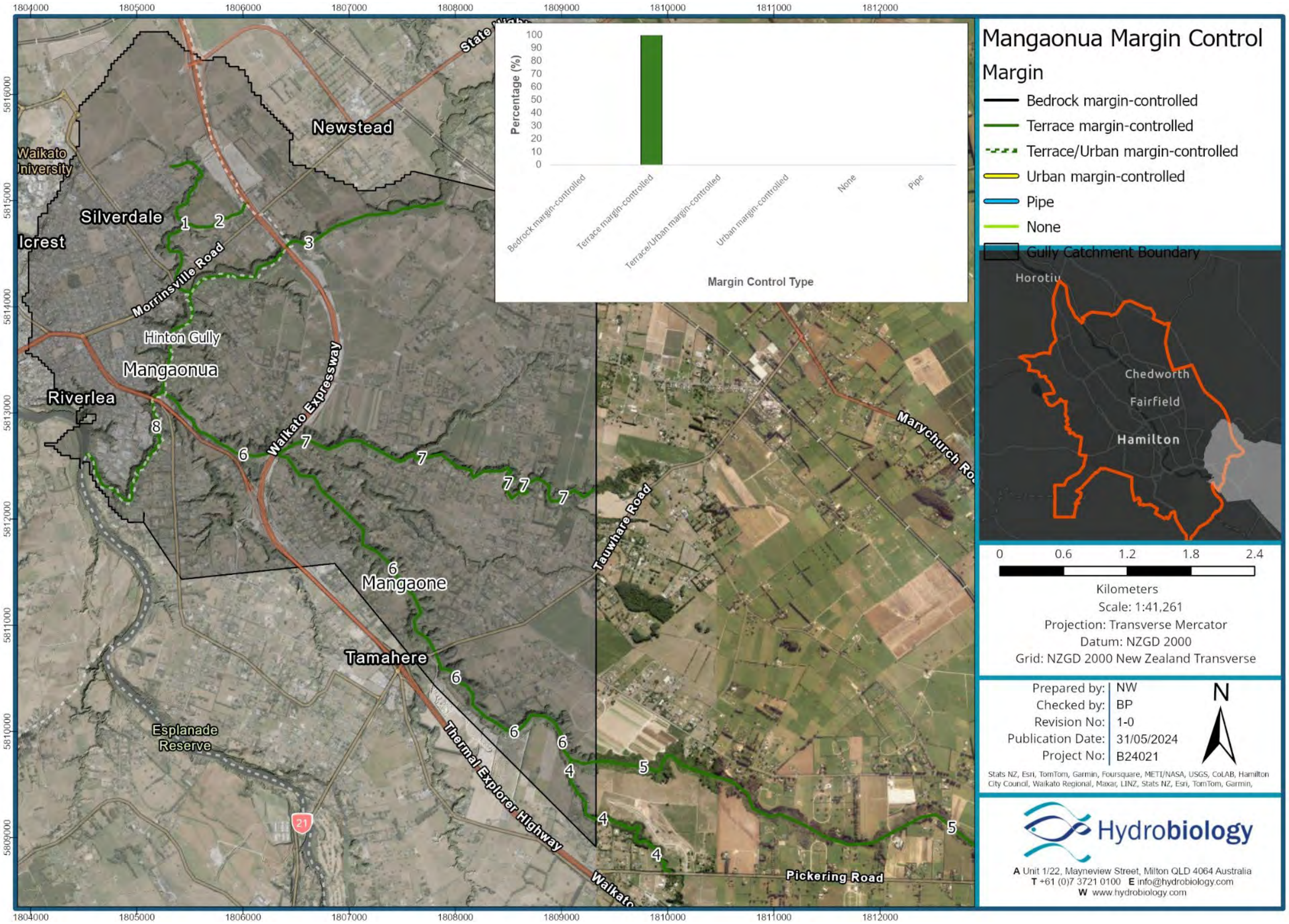

Figure 4-24 Mangaonua / Mangaone gully catchment margin control type.

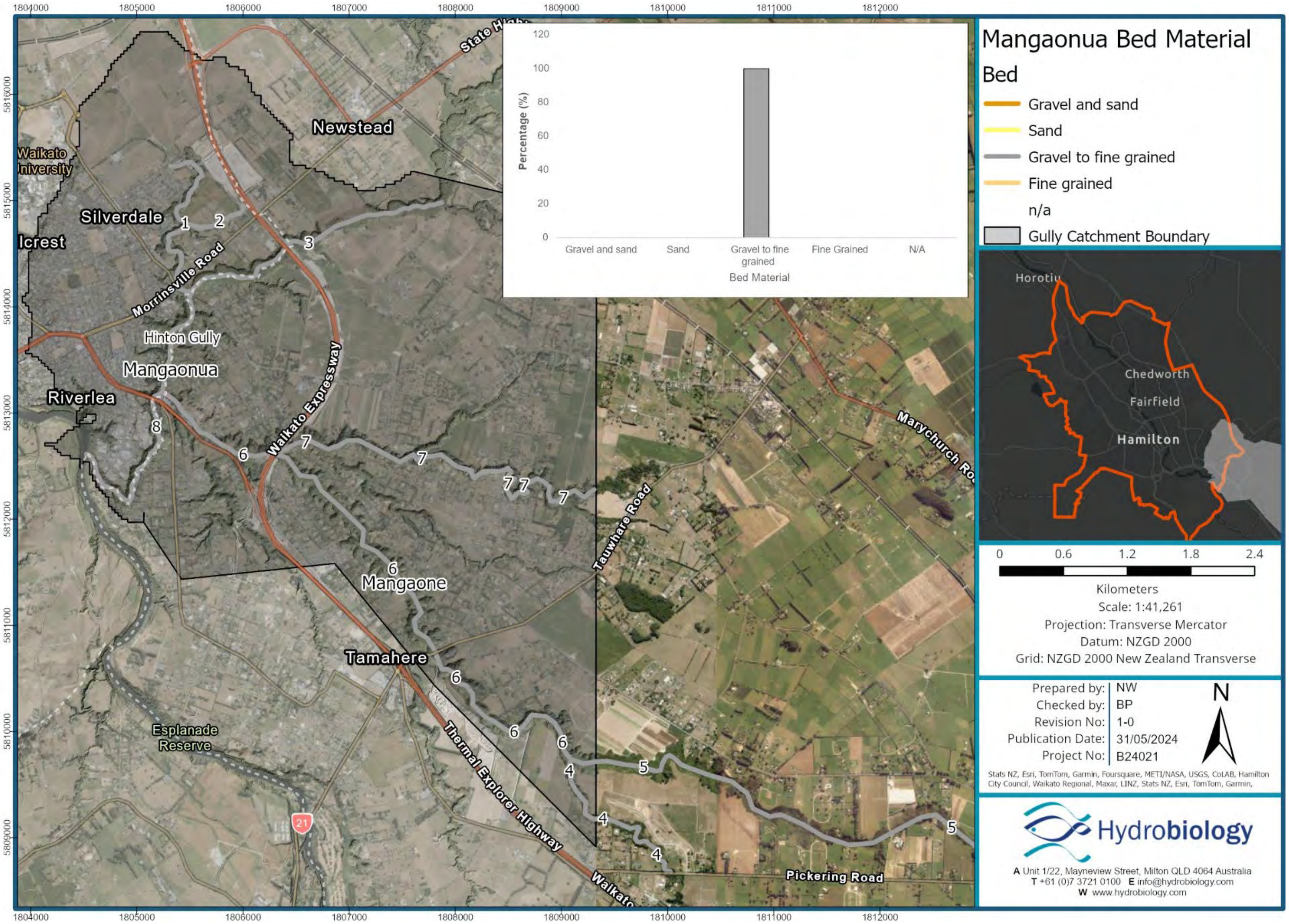

Figure 4-25 Mangaonua / Mangaone gully catchment bed material type.

The Mangaone Stream drains the south-eastern side of the catchment (Reaches 4 – 7), flowing into Reach 8 just upstream of State Highway 1, about 1 km downstream of the Reach 1 confluence, and about 1.75 km upstream from the Reach 9-Waikato River confluence. Reaches 4-7 originate as farm gullies (Reaches 4 and 5), of varying confinement before incising into the main gully stream with occasional floodplain pockets (Reaches 6 and 7). Reach 4 was characterised as a confined, terrace margin-controlled farm gully with gravel and fine-grained bed material (C_TrMC_Gully_Fbed). Reach 5 was wider, characterised as a confined, terrace margin-controlled farm gully with occasional floodplain pockets and gravel and fine grained bed material (C_TrMC_OccFp_Gully_Gbed). Reach 4 and 5 merge to form Reach 6 downstream. Reach 6 has been rehabilitated by the Tamahere Reserve Restoration Group, with rehabilitated wetland and inset floodplain surfaces. Reach 6 and 7 are wider and more incised, characterised as confined, terrace margin-controlled with occasional floodplain pockets gully with gravel to fine-grained bed material (C_TrMC_OccFp_Gully_Fbed). Reach 7 has also undergone restoration at Wally Pollock Reserve.

Reach 8 is much wider than the upstream supply reaches (1-7), reflective of its position in the catchment. It was characterised as a partly confined, terrace margin-controlled gully with discontinuous inset floodplain surfaces and gravel to fine-grained bed material (PC_TrMC_Gully_DcFp_Fbed). Multiple terraces through this reach show stages of incision, with alluvium exposures on vertical banks. Bedrock outcrops were observed suggesting the channel has incised to bedrock and the base level set by the Waikato River.

5. RESULTS – CONTROLS ON RIVER STYLES

5.1 BACKGROUND

In the five gully catchments analysed in the Hamilton region, the extent of River Styles reflects a distribution of inherited/legacy 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 the River Styles of the gully systems in the Hamilton region.

5.2 GEOLOGICAL AND GEOMORPHIC HISTORY (IMPOSED)

5.2.1 TOPOGRAPHY AND VALLEY SETTING

Geologic and geomorphic history has left a strong landscape imprint (memory) on the Hamilton Gullies, 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 Hamilton region, Late Pleistocene and Holocene geomorphic history have been the factors forming the gully systems and controlling their present-day confinement by terraces and paleochannels, restricting lateral adjustment but controlling degradation to the base level of the Waikato River. Many systems are still incising, draining peat bogs on the outskirts of the city. Many of the urban gullies and farm drains are at risk to future degradation.

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), as well as its ability to be weathered. Within the gullies, Holocene River Deposits of alluvial and colluvial sands, silts, muds, clays and local gravels are available to be reworked. Gullies that are already well formed (lower gully catchment zones), despite their steepness, appear to comprise remarkably stable gully margins. This stability has apparently been present for a long period (McCraw, 2011). The horizontal bedding of the Hinuera Formation, reinforced by horizontal layers of silt, and possibly a slight cementation by iron oxides are important factors in gully-wall stability (McCraw, 2011). When slopes are modified the likelihood of erosion increases significantly.

The exception to this is in the middle and upper catchments (observed in all catchments except for Te Awa O Katapaki), where sap springs are still emerging, and headwall erosion is still occurring back through the Late Pleistocene river deposits (Hinuera Formation), where cross bedded pumice, sand, silt and gravel are eroded easily once disturbed. In the upper catchments (particularly Kirikiriroa, Mangakotukutuku, and Mangaonua catchments), farm channels drain peat bog systems (Holocene swamp deposits consisting of soft dark brown to black organic muds, muddy and woody peat). These areas are at high risk of future gully formation if the peat becomes undermined.

5.3 CLIMATE – MAGNITUDE FREQUENCY RELATIONSHIPS, GEOMORPHICALLY EFFECTIVE FLOODS (FLUX)

Large magnitude decadal flood events exert a strong control on geomorphic adjustment of localised reaches that are inherently sensitive to change within the Hamilton region. 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.

Gullies in the Hamilton region can be influenced by flooding by two main processes. Firstly, large magnitude events such as recent events (e.g., Cyclone Gabrielle) can lead to the build-up of water in poorly drained peat bog systems surrounding the outskirts of the city. The drainage of these systems into gullies can exacerbate the 'sap springing' process, accelerating headwall failure and resulting in land sliding of terrace features. Secondly, large floods on the Waikato River result in backwater effects on many of the gully systems, inducing reworking of inset floodplain surfaces. However, it is more often the draw down effects of these floods that can further promote gully wall failure, as well as headcut propagation.

5.4 HIGHLY MODIFIED SYSTEMS – (IMPOSED) ANTHROPOGENIC CONTROLS

Geomorphic adjustment and sensitivity in the Hamilton gully systems have been strongly affected by anthropogenic factors, as many reaches have been impacted or highly modified (especially Te Awa O Katapaki and Waitawhiriwhiri catchments). Indirect response to vegetation changes and drainage of surrounding peat and swamp lands laid the foundations for disturbance responses to human impacts, prompting significant human actions and interventions in recent decades.

It is mainly interference and other engineering interactions associated with urban development that impact the systems. For example, removing the toe of slopes for infrastructure causes the upper slopes to become unstable. Tipping spoil into the gully from excavations for houses or for other reasons has also led to erosion. Urban margins have meant that hard engineering in the form of rock groynes or other slope stabilisation to protect houses have also modified gully systems and caused subsequent adjustment. In addition, stormwater or other urban drainage of water moving along the surface of a buried layer of impermeable silt (Section 2.3) can lead to geotechnically induced/mass failure events. Altered urban hydrology has also increased runoff and lag times of flows to these systems, likely to significantly affect adjustment and degradation.

Along many of the gullies, culverts, concrete structures, concrete lining, grade control structures or rock gabions associated with road crossings have stopped upstream propagation of degradation, resulting in clear breaks in River Style types. Such hard engineering imposes a significant control on the gully adjustment and sensitivity. However, once previously used as rubbish dumps, Gully Protection Zones and Restoration Plans have meant that many are being restored with native forest, likely to aid recovery into the future.

5.5 RIPARIAN VEGETATION (FLUX)

Riparian vegetation exerts a strong control on the stabilisation of banks and terrace margins of the gully systems. Not only do root systems increase slope stability, but they also reduce water content of side slopes. All gullies were observed to have experienced vegetation clearance along inset floodplain surfaces or terrace features which are susceptible to geomorphic adjustment. Many locations within all assessed catchments were subject to poor vegetative coverage including weed infestation issues. The Hamilton gully systems have active restoration groups, part of larger management plans that have resulted in significant ecological restoration within the city and have aided recovery and stabilisation of these systems. It is those cleared pastures and peat lands on the outskirts of catchments that are of greatest risk, where future riparian initiatives should then be focussed. These locations are covered in the ensuing management implication section.

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 Hamilton gully systems. A strong landscape memory means that geomorphic adjustment of gullies is strongly controlled by base level of the Waikato River and degradation of gully tributaries, as well as responses to contemporary disturbance events.

6. MANAGEMENT IMPLICATIONS AND CONCLUSIONS

6.1 RIVER STYLES DIVERSITY AND SENSITIVITY

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, gully catchment systems of the Hamilton region were found to have a unique pattern of mostly confined to partly confined River Styles gully types, reflecting the strong imprint of landscape history within the region. Stages of degradation to the base level of the Waikato River and anthropogenic impacts influences the character and behaviour of different gullies and their sensitivity to geomorphic adjustment.

Figure 6-1 to Figure 6-5 summarise the potential geomorphic sensitivity (potential capacity for adjustment) of the different gully catchment systems. The main results are summarised in the following sections for each gully catchment system.

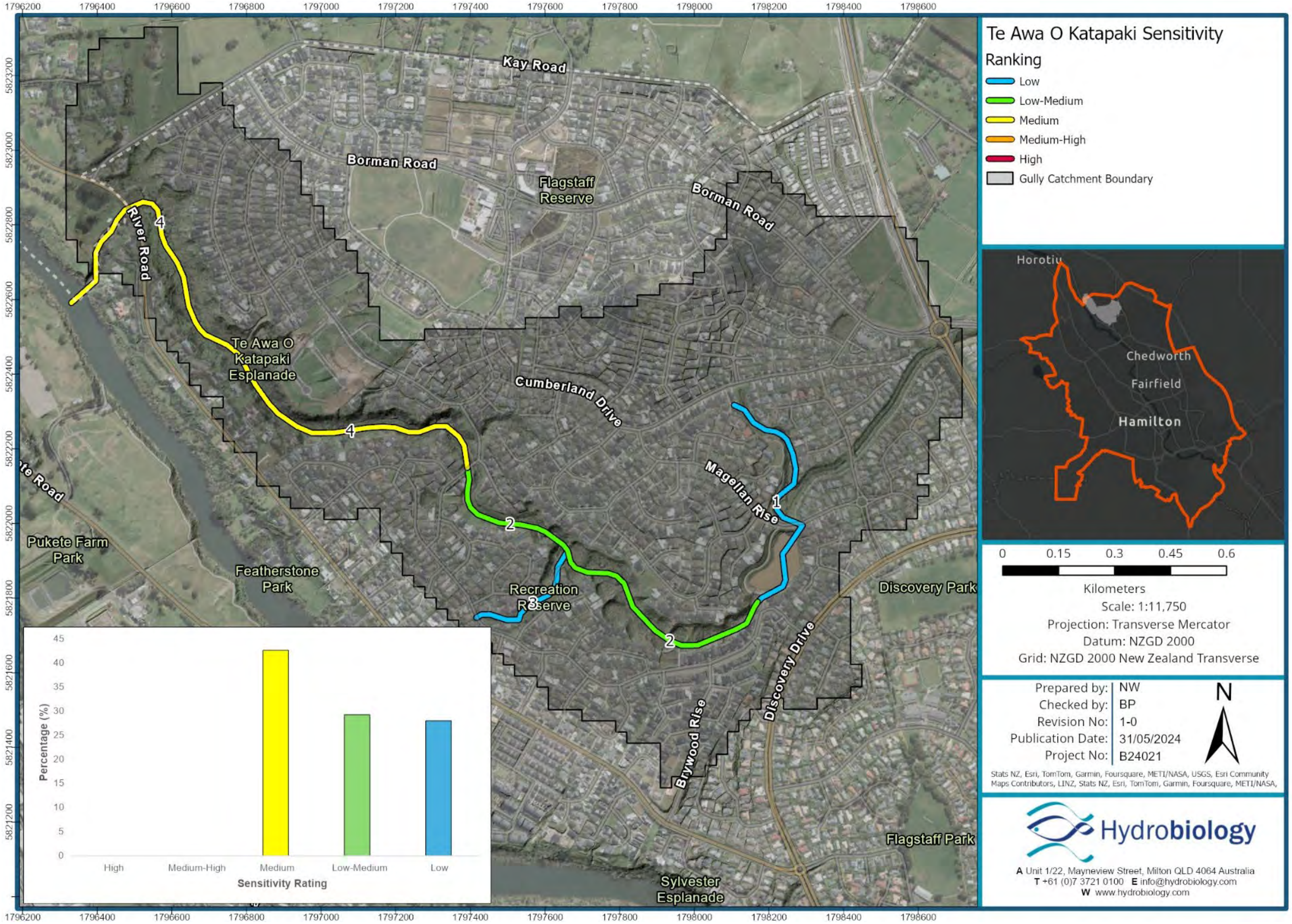

Figure 6-1 Te Awa O Katapaki gully catchment geomorphic sensitivity ranking.

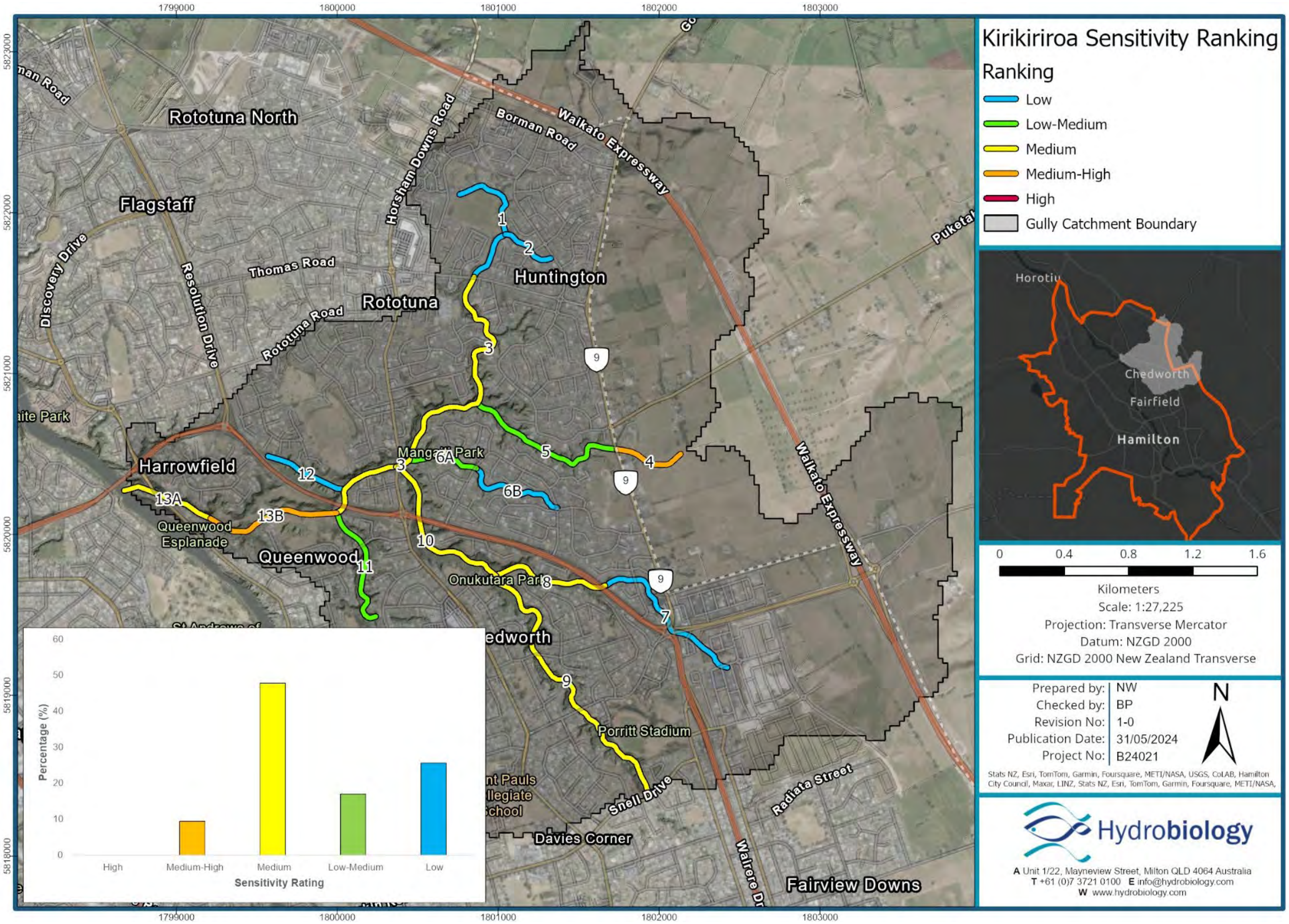

Figure 6-2 Kirikiriroa gully catchment geomorphic sensitivity ranking.

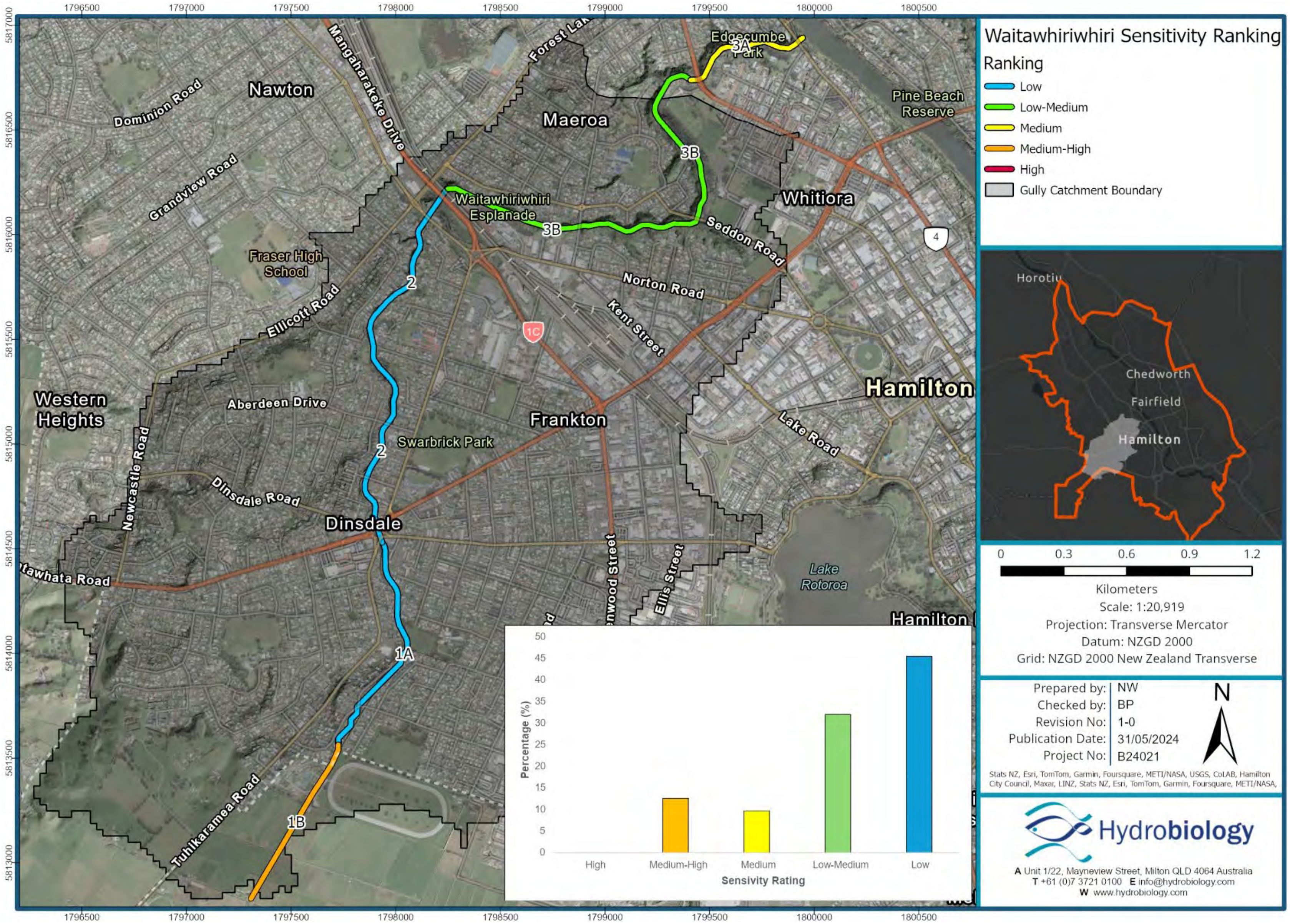

Figure 6-3 Waitawhiriwhiri gully catchment geomorphic sensitivity ranking.

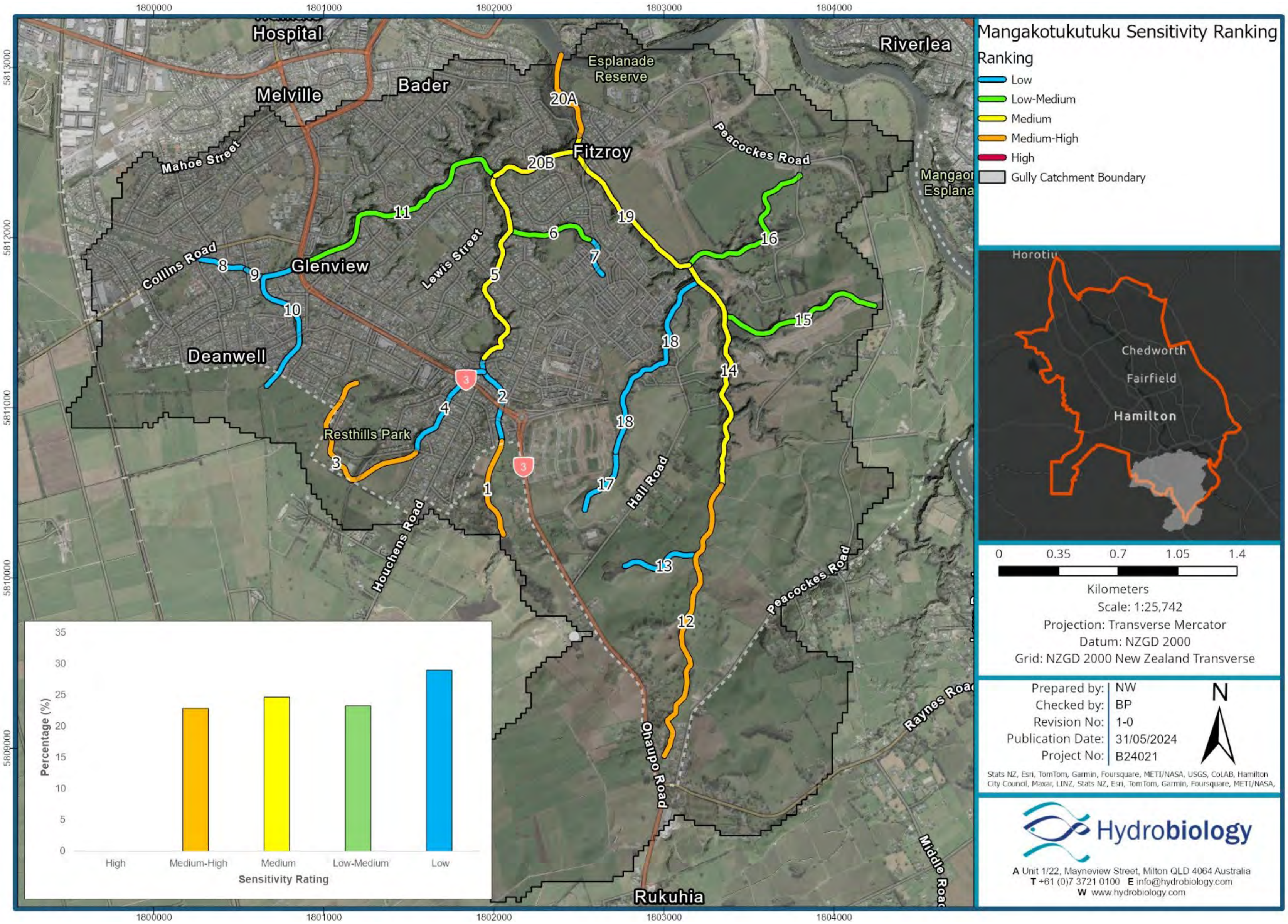

Figure 6-4 Mangakotukutuku gully catchment geomorphic sensitivity ranking.

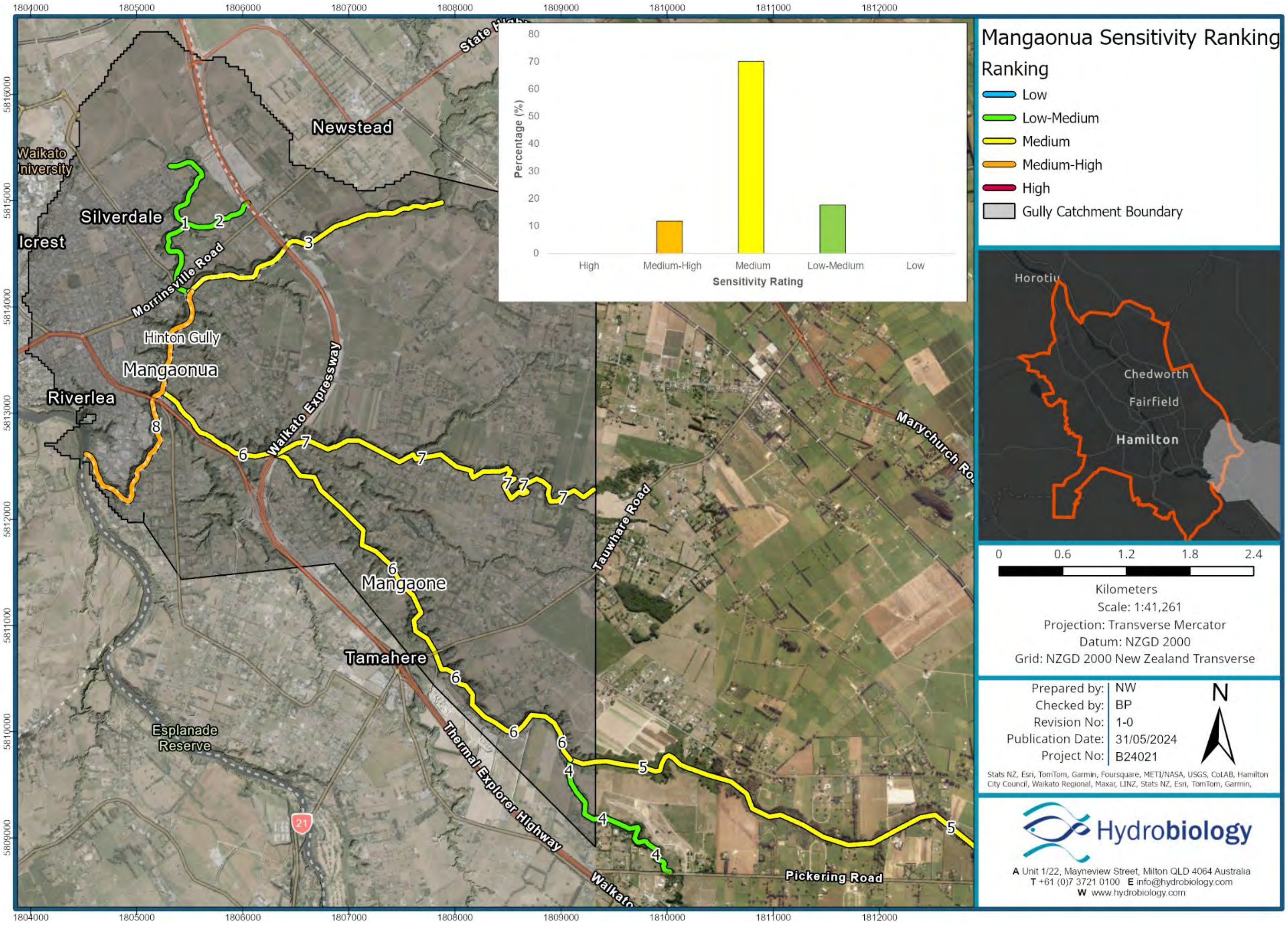

Figure 6-5 Mangaonua / Mangaone gully catchment geomorphic sensitivity ranking.

TE AWA O KATAPAKI

This gully catchment had relatively Low to Medium sensitivity to geomorphic adjustment (28% ranked Low, 43% ranked Medium). This was largely due to the high degree of confinement, with mapped gullies either being fully confined or confined with occasional floodplain pockets, with either terrace or urban margin control. Reach 4 is therefore the most sensitive, with mobile sediments and occasional floodplain surfaces that can be worked. Other reaches are mostly protected by urban infrastructure and are highly modified, preventing upstream degradation.

KIRIKIRIROA

This gully catchment had mostly Medium sensitivity to geomorphic adjustment (48% ranked as Medium, 10% ranked as Medium-High). This was due to greater accommodation and adjustment space offered by the gullies in the catchment (confined gully types with occasional floodplain pockets/partly confined channels with discontinuous floodplain). Despite this, a high degree of the catchment is confined by terrace or urban margin control. The middle reaches were ranked with Medium sensitivity, due to potential for further degradation to propagate upstream. Reach 13B was ranked as Medium-High sensitivity, with large inset floodplain surfaces able to be reworked and were sensitive to further widening due to a lack of riparian vegetation. Reach 4 was representative of other unmapped farm drains which are at risk from future incision from upstream propagation of the degraded reaches downstream and was ranked as Medium-High potential sensitivity to adjustment.

WAITAWHIRIWHIRI

This gully catchment had mostly Low sensitivity to geomorphic adjustment with localised Medium to Medium-High sensitive reaches (46% ranked as Low, 10% ranked as Medium, 12% ranked as medium-high). This was due to the high degree of confinement, as well as anthropogenic management limiting adjustment. Most of the reaches were either terrace or urban margin controlled, with a high degree of reaches being concrete lined or modified (e.g., Reach 2). Reach 3A and Reach 1B were identified as the most sensitive reaches to geomorphic adjustment. Reach 3A has occasional floodplain pockets which are able to be reworked, particularly due to the high hydraulic forces that are likely present during high flows as a result of modified channels upstream. Reach 1B was incising and susceptible to future degradation from headward erosion from downstream.

MANGAKOTUKUTUKU

This gully catchment had a mix between Low and Low-Medium to Medium and Medium-High sensitivity rankings (29% ranked as low, 23% ranked as low-medium, 25% ranked as Medium and 23% ranked as Medium-High), representative of the diversity of River Styles and varying controls within the gully system. Middle/Upper reaches were mostly ranked as Low due to the high degree of urban margin control and anthropogenic modification (Reaches 2, 4, 8, 9, 10, 18). Middle reaches with occasional floodplain pockets still undergoing degradational processes were ranked with Medium sensitivity (e.g., Reaches 5, 19 and 20B). The most sensitive reaches, which were ranked as Medium-High, were upstream Reaches 1 and 3, and the downstream Reach 20A. Reach 20A is susceptible to adjustment within terrace margins, downstream of the confluence of several large upstream gullies. While upstream Reach 1 to 3 are relatively stable, they are at risk from future degradation.

MANGAONUA / MANGAONE

This gully catchment is the most sensitive out of all the gully catchments analysed. This is mainly due to draining a larger catchment area, as well as being a different gully type, formed within larger paleochannels of the Waikato River. Most of the analysed mapped gullies are ranked as Medium or

Medium-High sensitivity (70% ranked as Medium, 12% ranked as Medium-High). This is due to the lower confinement relative to the other gullies, where most are either confined with larger occasional floodplain pockets or partly confined, discontinuous floodplain pockets, therefore having larger inset accommodation space for adjustment. Most of the bed sediments comprise gravel to fine-grained alluvium of the Hinuera Formation, that are easily mobilised and reworked. Reaches 3, 5, 6 and 7 were ranked as Medium sensitivity to adjustment. The most sensitive reach to adjustment was identified as Reach 8, ranked as Medium-High, due to being partly confined and still undergoing active degradation. It should be noted that the most sensitive reaches are likely to be those extending upstream outside the mapped area, HCC boundary and scope of this study. Many of these are susceptible to future degradation from downstream, particularly those in farmland that lack native stabilising vegetation.

6.2 MANAGEMENT IMPLICATIONS

Stage One of the River Styles Framework provides a catchment-wide baseline survey of river or gully character and behaviour. Although Stages 2 to 4 can provide more understanding of river condition, evolutionary trajectories and detailed management implications to prioritize proactive rehabilitation efforts, this initial Stage One study along with potential sensitivity analysis can give some preliminary management advice.

Findings from this study can be used to support cost-effective targeted proactive management and rehabilitation of sensitive reaches in ways that work with the river or gully, prospectively informing targeted applications of riparian initiatives that support diverse habitat creation and ecological rehabilitation, whilst reducing suspended sediment yields to the Waikato River.

Therefore, management investigations and efforts should focus on reaches with Medium to Medium-High sensitivity identified in this study. These were mainly:

- Lower most reaches closest to the Waikato River. Further downcutting of these reaches will likely result in degradation of upstream reaches currently in good condition or worsen those already degraded. These medium and medium-high sensitivity reaches in the lower catchment areas included:
  - Te Awa o Katapaki Reach 4
  - Kirikiriroa Reach 13A and B
  - Waitawhiriwhiri Reach 3A
  - Mangakotukutuku Reach 20A
  - Mangaone Reach 8
- Upper/Middle reaches still undergoing degradation. Provided upstream propagation of the degradation of the lower reaches does not occur, improvement in the condition of these reaches will have a high success rate. These medium and medium-high sensitivity reaches in the upper/middle catchment areas included:
  - Kirikiriroa Reach 3, 10, and 9
  - Mangakotukutuku Reach 5, 14, 19, and 20B
  - Mangaonua Reach 3, 6, and 7 (and streams located upstream outside of the study area)
- Laterally unconfined upper reaches draining peat land, susceptible to future degradation. These are the most sensitive due to the high potential for upstream propagation to initiate degradation and should be managed through protection and concomitant management of downstream reaches. These reaches were:
  - Kirikiriroa Reach 4

- Waitawhiriwhiri Reach 1B
- Mangakotukutuku Reach 1 and 3

If not managed, these reaches will continue to incise and widen, resulting in degraded channel condition attributes as well as increased suspended sediment yield to the Waikato River misaligning with key environmental goals. Such inherently sensitive reaches are likely to become increasingly prone to adjustment with the prediction of more frequent extreme events associated with climate change. Concomitantly, continued urban sprawl expanding into alluvial Hinuera and peat bog deposits is increasing the risk to adjacent lands associated with this adjustment and highlighting the need for immediate human intervention.

6.3 CONCLUDING COMMENTS AND RECOMMENDATIONS FOR FUTURE WORKS

Adoption of the underlying principles of the River Styles Framework and sensitivity analysis can help clear moves towards strategic and multifaceted approaches to plan geospatial trade-offs and make sure actions occur where and when they are most appropriate and beneficial now and under future scenarios (Wheeler et al., 2022). This study provides a geomorphic baseline survey of the five main gully systems within the Hamilton region. Understanding river character and behaviour gives insight for the capacity for geomorphic adjustment and sensitivity to change. Stages of degradation to the base level of the Waikato River and anthropogenic impacts exert strong controls on the character and behaviour of different gullies and their inherent sensitivity to geomorphic adjustment. Identifying such reaches can be used to prioritise management initiatives.

Concluding comments and recommendations from this study include:

- Sensitive priority reaches (as identified in Section 6.2) should be revegetated with community led native riparian initiatives, with hard engineering avoided. Hard engineering and concrete lined channels promote high velocities that only increase downstream degradation and are likely to be undermined.
- Peat lands should be prioritised for future wetland rehabilitation and set aside for conservation/protection from future urban development. These are at risk from future degradation.
- Future works/ research should be focussed on more detailed geomorphic assessments into predicting degradation rates and headward erosion of the gully systems, to inform hazard mapping geospatial trade-offs and appropriate infrastructure setbacks to protect the community.

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APPENDIX A. RIVER STYLES SUMMARY

Table 7-1 Summary of River Styles identified in the five gully catchments of the Hamilton Region.

River Style (Full Name)	River Style (Abbreviated Name)	Catchment Locations	Potential Geomorphic Sensitivity Ranking
1. Confined, Urban Margin-controlled, Urban Swale, Fine-grained Bed	C_UMC_UrbanSwale_Fbed	Mangakotukutuku Catchment – Reach 8	Low
2. Confined, Urban Margin-controlled, Urban Drain, Gravel Bed	C_UMC_UrbanDrain_Gbed	Waitawhiriwhiri Catchment – Reach 1A	Low
3. Confined, Urban Margin-controlled, Concrete Canal, Fine-grained Bed	C_UMC_ConcreteCanal_Fbed	Waitawhiriwhiri Catchment – Reach 2	Low
4. Confined, Urban Margin-controlled, Modified Urban Channel, Detention ponds, Fine-grained Bed	C_UMC_ModifiedUrban_Detentionponds_Fbed	Mangakotukutuku Catchment – Reach 18 Kirikiriroa Catchment – Reach 6B	Low
5. Confined, Terrace Margin-controlled, Urban Margin Constrained, Modified Urban Channel, Gravel Bed	C_TrMC_UMC_ModfiedUrban_Gbed	Mangakotukutuku Reach 2, 4, 9 ,10. Kirikiriroa Reach 1, 2, 7. Te Awa O Katapaki Reach 1 and 3	Low
6. Confined, Terrace Margin-controlled, Gully, Gravel Bed	C_TrMC_Gully_Gbed	Mangaonua Reach 1, Mangakotukutuku Reach 6 and 11, Waitawhiriwhiri Reach 3B, Kirikiriroa Reach 5, 6A and 11, Te Awa O Katapaki Reach 2.	Low-Medium
7. Confined, Terrace Margin-controlled, Gully, Fine-grained Bed	C_TrMC_Gully_Fbed	Mangakotukutuku Reach 15 and 16, Mangaonua Reach 2 and 4	Low-Medium
8. Confined, Bedrock Margin-controlled, Gully, Fine-grained Bed	C_BrMC_Gully_Fbed	Mangakotukutuku Catchment Reach 13 and 17	Low
9. Confined, Terrace Margin-controlled, Occasional Floodplain Pockets, Gully, Fine-grained Bed	C_TrMC_OccFp_Gully_Fbed	Mangakotukutuku Reach 5, 19 and 20B, Mangaonua Reach 3, 6 and 7, Waitawhiriwhiri Reach 3A, Kirikiriroa Reach 3, 8, 9 and 10, 13A, Te Awa O Katapaki Reach 4	Medium

River Style (Full Name)	River Style (Abbreviated Name)	Catchment Locations	Potential Geomorphic Sensitivity Ranking
10. Confined, Terrace Margin-controlled, Occasional Floodplain Pockets, Gully, Gravel Bed	C_TrMC_OccFp_Gully_Gbed	Mangakotukutuku Reach 14 Mangaonua Reach 5	Medium
11. Confined, Terrace Margin-controlled, Occasional Floodplain Pockets, Swamp / Wetland, Fine-grained Bed	C_TrMC_OccFp_Swamp/Wetland _Fbed	Kirikiriroa Catchment – Reach 12	Low
12. Partly Confined, Terrace Margin-controlled, Gully, Discontinuous Floodplain, Fine-grained Bed	PC_TrMC_Gully_DcFp_ Fbed	Mangakotukutuku Reach 20A, Mangaonua Reach 8, Kirikiriroa Reach 13B	Medium-High
13. Partly Confined, Bedrock Margin-controlled, Farm Gully, Discontinuous Floodplain, Fine-grained Bed	PC_BrMC_Gully_DcFp_Fbed	Mangakotukutuku Catchment – Reach 12	Medium-High
14. Laterally Unconfined, Continuous Channel, Low Sinuosity Farm Drain, Fine-grained Bed	LU_C_LSin_FarmDrain_Fbed	Mangakotukutuku Catchment Reach 1 and 3, Waitawhiriwhiri Reach 1B, Kirikiriroa Reach 4	Medium-High

APPENDIX B. RIVER STYLES PROFORMAS

B.1 CONFINED, URBAN MARGIN-CONTROLLED, URBAN SWALE, FINE-GRAINED BED (C_UMC_URBANSWALE_FBED)

Location(s): Mangakotukutuku Catchment – Reach 8

Figure B.1. Google Earth image showing the Reach 8 of the Mangakotukutuku Catchment, representative of the C_UMC_UrbanSwale_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°49'7.84"S, 175°16'35.54"E**

RIVER CHARACTER	
Valley-setting	Confined by Urban Margins
Channel Planform	Channel abuts anthropogenic margins (predominantly landscaped swales, embankments, and urban development (concrete)) >85% of the time. Permeable fencing located along landscaped margin. These factors result in a highly stable channel position. Low sinuosity Urban Swale.
Bed material texture	Fine-grained
Channel geometry	Uniform depression
Geomorphic Units	Within channel: Uniform, Depressions, preferential flow path Floodplain: Larger external older floodplain surface is highly urbanised and is disconnected from the contemporary channel.
Vegetation associations	None, Grassland. Wider older disconnected floodplain is highly urbanised.

RIVER BEHAVIOUR

Low Flow Behaviour

During low flows, flow pools and moves slowly as preferential flow paths over the swales, with little hydraulic diversity. The non distinct channel remains stable and is mostly depositional.

Bankfull Behaviour

During bankfull flows, fine grained sediments are transported as through the reach. Lateral adjustment is limited by low landscaped surface and housing.

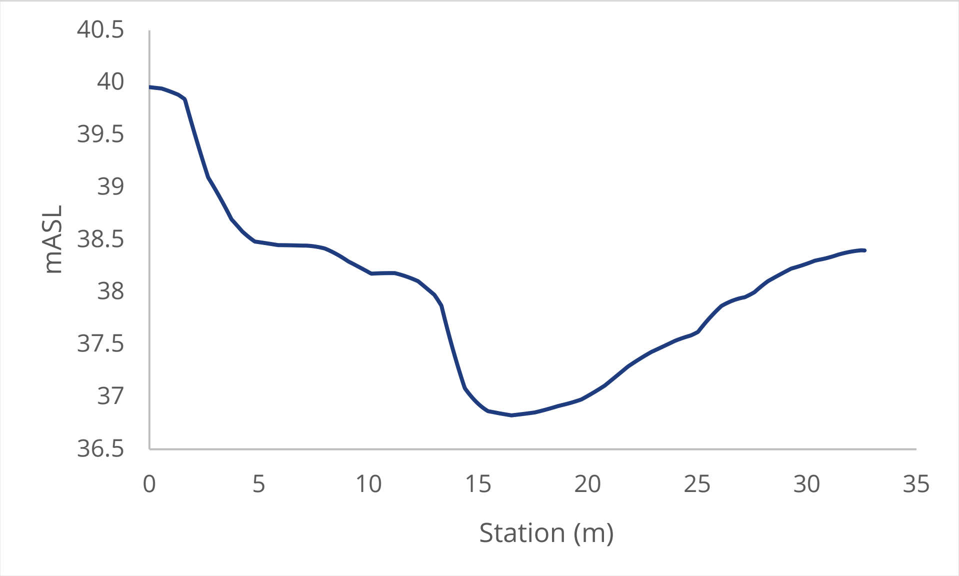
Overbank Behaviour

During rare overbank flows, the wider floodplain may be engaged, resulting in the spread of flow onto urbanised floodplain and the deposition of fines.

CONTROLS

Landscape Setting and within-catchment position	Found in the upper catchment area, in an urban setting.
Valley Morphology	Hinuera Surface
Process Zone	Sediment Source Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 8 Mangakotukutuku Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 8 Mangakotukutuku Catchment

B.2 CONFINED, URBAN MARGIN-CONTROLLED, URBAN DRAIN, GRAVEL BED (C_UMC_URBANDRAIN_GBED)

Location(s): Waitawhiriwhiri Catchment – Reach 1A

Figure B.2. Google Earth image showing Reach 1A of the Waitawhiriwhiri Catchment, representative of the C_UMC_UrbanDrain_Gbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°48'5.27"S, 175°14'52.99"E**

RIVER CHARACTER	
Valley-setting	Confined by urban margins
Channel Planform	Channel abuts anthropogenic margins (predominantly landscaped margins, embankments, as well as roads and concrete) >85% of the time. This results in a highly stable channel position. Low sinuosity, urban drain channel.
Bed material texture	Gravel bed (some fines)
Channel geometry	Symmetrical trapezoid, entrenched
Geomorphic Units	Within channel: Uniform Glide/runs, pools, benches Floodplain: Multi-staged landscaped bench, urbanised
Vegetation associations	Channel is lined by non-native trees in short sections through the township. Banks consist predominantly of mown lawn. The wider older disconnected floodplain is highly urbanised.

RIVER BEHAVIOUR

Low Flow Behaviour

During low flows, flow moves undisrupted through these reaches, with little hydraulic diversity. The channel remains relatively stable, confined by numerous anthropogenic margins and concrete lined channel.

Bankfull Behaviour

During bankfull flows, banks may 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, like a flume, resulting in a lack of instream geomorphic diversity. Occasional bar surfaces are reworked and mobilised during these flows. Lateral adjustment is limited as the channel is fixed in place by infrastructure, housing and landscaped margins.

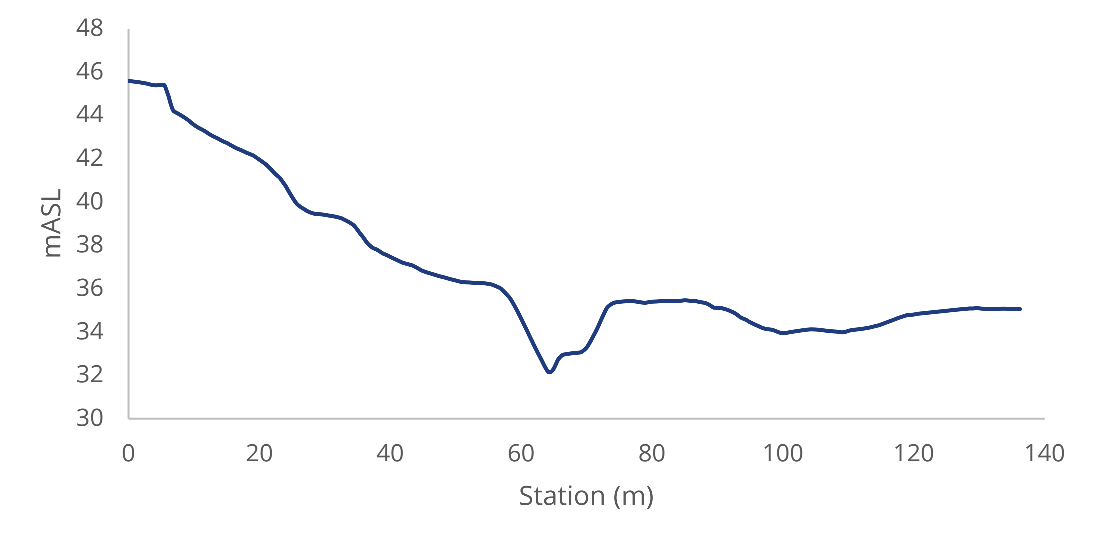
Overbank Behaviour

During overbank flows, benches and any inset floodplain surfaces are likely to be stripped and scoured as the flow is concentrated between banks. Only in extremely large, rare events are banks overtopped, resulting the spread of flow onto the urbanised disconnected floodplain and the deposition of fines.

CONTROLS

Landscape Setting and within-catchment position	Upper/middle catchment, in urban setting
Valley Morphology	Hinuera Surface, with narrow anthropogenic margins
Process Zone	Source/Transfer Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 1A Waitawhiriwhiri Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 1A Waitawhiriwhiri Catchment

B.3 CONFINED, URBAN MARGIN-CONTROLLED, CONCRETE CANAL, FINE-GRAINED BED (C_UMC_CONCRETECANAL_FBED)

Location(s): Waitawhiriwhiri Catchment – Reach 2

Figure B.3. Google Earth Image showing Reach 2 of the Waitawhiriwhiri Catchment, representative of the C_UMC_ConcreteCanal_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°47'4.59"S, 175°14'54.52"E**

RIVER CHARACTER	
Valley-setting	Confined by Urban margins
Channel Planform	Channel abuts anthropogenic margins (predominantly landscaped margins, embankments, as well as roads and concrete) >85% of the time. This results in a highly stable channel position. Low sinuosity concrete canal.
Bed material texture	Fine-grained bed
Channel geometry	Symmetrical Trapezoid, entrenched
Geomorphic Units	Within channel: Uniform Glide/Runs, some pools and riffles but mostly deprived of in-stream geomorphic units, with concrete lining. Floodplain: Occasional inset floodplain and benches between landscaped margins. Larger external older floodplain surface is highly urbanised and is disconnected from the contemporary channel.
Vegetation associations	The channel is lined by mostly mown lawn/grassland surfaces, with some non-native trees. The wider older disconnected floodplain is highly urbanised.

RIVER BEHAVIOUR

Low Flow Behaviour

During low flows, flow moves undisrupted through these reaches over concrete lining, with little hydraulic diversity. The channel remains relatively stable, confined by numerous anthropogenic margins and concrete lined channel.

Bankfull Behaviour

During bankfull flows, banks may 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, like a flume, resulting in a lack of instream geomorphic diversity. Occasional bar surfaces are reworked and mobilised during these flows, with the concrete lined channel becoming outflanked in places. Lateral adjustment is limited as the channel is fixed in place by infrastructure, housing and landscaped margins.

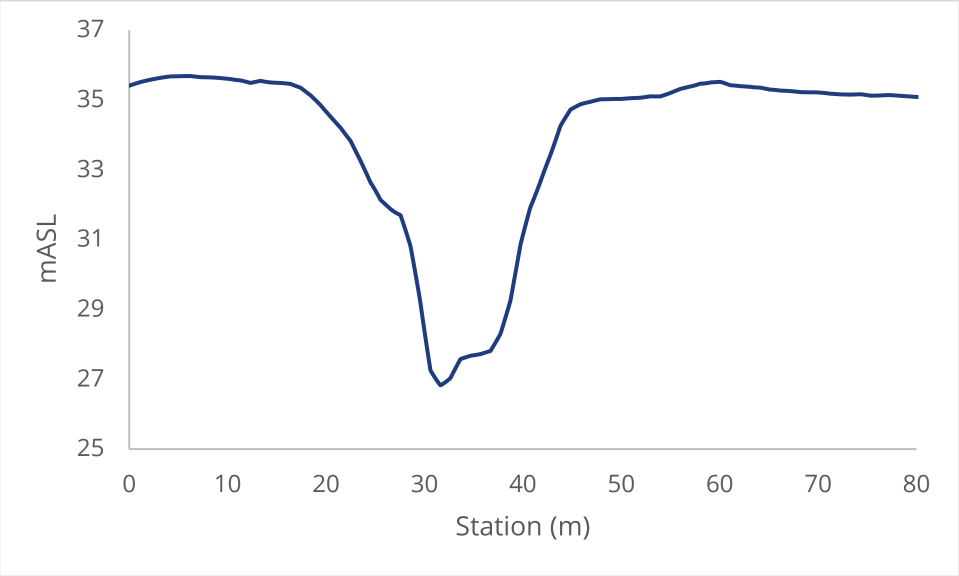
Overbank Behaviour

During overbank flows, benches and any inset floodplain surfaces are likely to be stripped and scoured as the flow is concentrated between landscaped banks. Only in extremely large, rare events are the banks overtopped, resulting the spread of flow onto the urbanised disconnected floodplain and the deposition of fines.

CONTROLS

Landscape Setting and within-catchment position	Middle catchment in urban setting
Valley Morphology	Hinuera Surface
Process Zone	Transfer Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 2 Waitawhiriwhiri Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 2 Waitawhiriwhiri Catchment

B.4 CONFINED, URBAN MARGIN-CONTROLLED, MODIFIED URBAN CHANNEL, DETENTION PONDS, FINE-GRAINED BED (C_UMC_MODIFIEDURBAN_DETENTIONPONDS_FBED)

Location(s): Mangakotukutuku Catchment – Reach 18

Figure B.4. Google Earth image showing Reach 18 of the Mangakotukutuku Catchment, representative of C_UMC_ModifiedUrban_DetentionPonds_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°49'25.49"S, 175°18'19.70"E**

RIVER CHARACTER	
Valley-setting	Confined by urban margins
Channel Planform	Channel abuts anthropogenic margins (predominantly landscaped margins, embankments, as well as constructed footpaths) >85% of the time. This results in a highly stable channel position. Low sinuosity modified channel with detention ponds
Bed material texture	Fine-grained
Channel geometry	Symmetrical constructed pools
Geomorphic Units	Within channel: Modified detention ponds/pools Floodplain: Wider older disconnected floodplain surface is becoming urbanised with new development and disconnected from the contemporary channel.
Vegetation associations	Planted riparian zone on landscaped banks. Wider older disconnected floodplain is becoming urbanised with new development, with floodplains that are not built upon comprising of pasture.

RIVER BEHAVIOUR

Low Flow Behaviour

During low flows, flows are mostly stagnant, moving between detention ponds with the settling out of fine-grained material.

Bankfull Behaviour

During bankfull flows, banks may be engaged but flows are largely controlled by the modified channel, flowing between detention ponds and flushing out of fines.

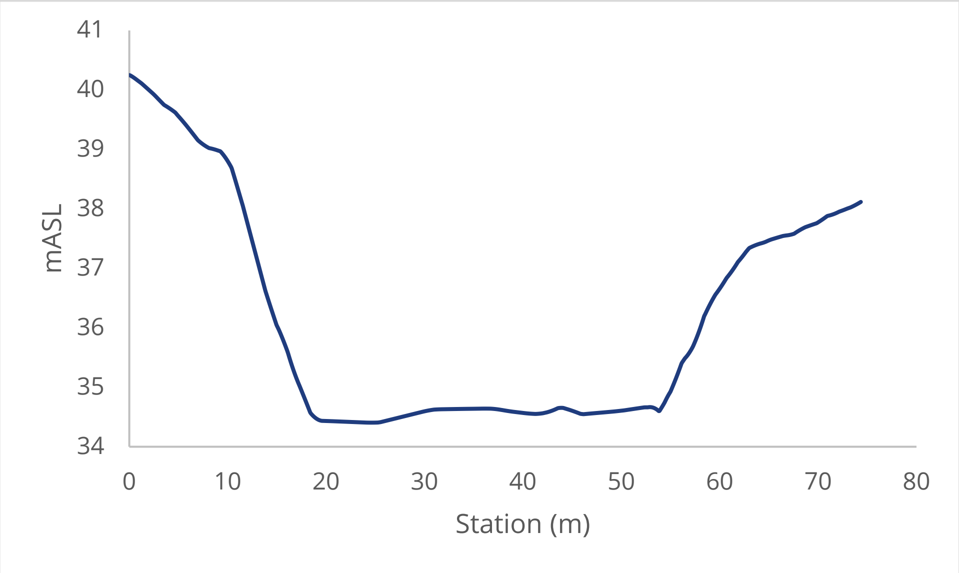
Overbank Behaviour

Only during rare overbank flows are the banks overtopped, resulting in the spread of flow onto urbanised floodplain and the deposition of fines.

CONTROLS

Landscape Setting and within-catchment position	Middle catchment, in urban modified setting
Valley Morphology	Development on Hinuera Surface
Process Zone	Transfer/Accumulation Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 18 Mangakotukutuku Catchment (photo from Reach 6B Waitawhiriwhiri Catchment)



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 18 Mangakotukutuku Catchment (photo from Reach 6B Waitawhiriwhiri Catchment)

B.5 CONFINED, TERRACE MARGIN-CONTROLLED, URBAN MARGIN CONSTRAINED, MODIFIED URBAN CHANNEL, GRAVEL BED (C_TRMC_UMC_MODIFIEDURBAN_GBED)

Location(s): Mangakotukutuku Reach 2, 4, 9 ,10 and Te Awa O Katapaki Reach 1 and 3

Figure B.5. Google Earth image showing Reach 1 of the Te Awa O Katapaki Catchment, representative of C_TrMC_UMC_ModifiedUrban_Gbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°43'33.39"S, 175°14'57.57"E**

RIVER CHARACTER	
Valley-setting	Confined with terrace and urban margins
Channel Planform	Channel abuts terrace/urban margins >85% of the time. Low sinuosity modified urban channel with rehabilitation planting.
Bed material texture	Gravel bed (some fines)
Channel geometry	Asymmetrical / Symmetrical
Geomorphic Units	Within channel: Pools, riffles, bars, benches Floodplain: Some small inset bench and floodplain surfaces. Larger external disconnected floodplain is highly urbanised.
Vegetation associations	Riparian planting on bench surfaces. Wider disconnected old floodplain is highly urbanised.

RIVER BEHAVIOUR

Low Flow Behaviour

At low flow stages, the thalweg is aligned along concave banks and form point bars. Flow occurs over riffles and fills pools. The channel remains relatively stable, confined by terrace and urban margins.

Bankfull Behaviour

During bankfull flows, banks may be scoured. The deeper slot channel indicates that bed incision is the dominant process. Bar surfaces are reworked and mobilised during these flows and benches/ledges may be stripped. Lateral adjustment is limited to between terrace/urban margins.

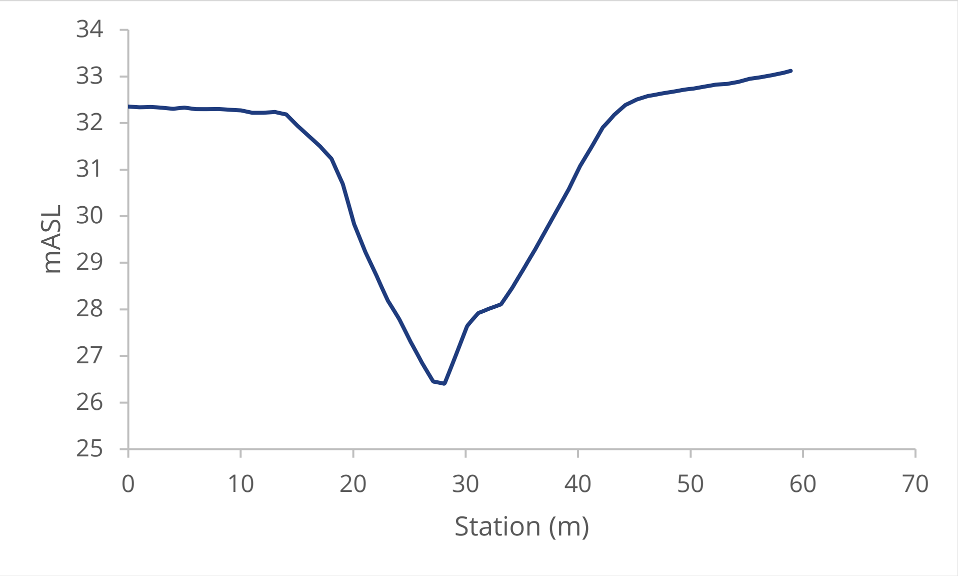
Overbank Behaviour

Only in rare large events, terrace/urban margins are overtopped, resulting in the spread of flow onto the urbanised floodplain and the deposition of fines.

CONTROLS

Landscape Setting and within-catchment position	Upper catchment in an urbanised setting
Valley Morphology	Confined by terraces of the Hinuera Surface
Process Zone	Source / Transfer Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 1 Te Awa o Katapaki Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 1 Te Awa o Katapaki Catchment

B.6 CONFINED, TERRACE MARGIN-CONTROLLED, GULLY, GRAVEL BED (C_TRMC_GULLY_GBED)

Location(s): Mangaonua Reach 1, Mangakotukutuku Reach 6 and 11, Waitawhiriwhiri Reach 3B, Kirikiriroa Reach 5, 6A and 11, Te Awa O Katapaki Reach 2.

Figure B.6. Google Earth Image showing Reach 5 of the Kirikiriroa Catchment, representative of C_TrMC_Gully_Gbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°44'20.49"S, 175°16'54.73"E**

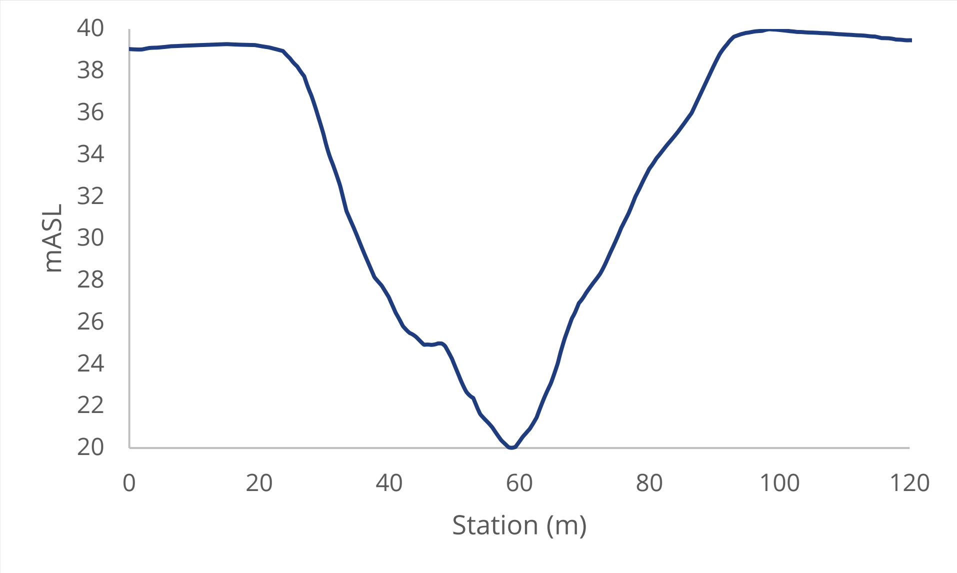
RIVER CHARACTER	
Valley-setting	Confined with terrace margins of the Hinuera Surface
Channel Planform	Channel abuts terrace margins >85% of the time. This results in a relatively stable channel position. Sinuous urban gully
Bed material texture	Gravel Bed (some fines)
Channel geometry	Single thread, low sinuosity slot channel with low width to depth ratio. The channel appears highly sinuous; however, this sinuosity is dictated by terrace planform. The channel has low sinuosity overall. Irregular channel geometry at bends, generally symmetrical along straight sections.
Geomorphic Units	Within channel: Pools, riffles, runs, occasional sculpted bars, localised woody debris. Floodplain: inset contemporary bench pockets between gully and terrace margins (Waikato fan material), occasional backswamps and wetlands on inset bench surfaces, disconnected elevated terrace floodplain (Waikato fan).

RIVER CHARACTER	
Vegetation associations	Native and replanted vegetation on inset floodplain pockets, urbanisation dominates on elevated terrace floodplain.

RIVER BEHAVIOUR
Low Flow Behaviour Largely undisrupted flow, with hydraulic diversity which induces some minor scour. Flow moves over riffles and fills pools. Fine-grained material is carried in suspension and bars are sculpted. **Bankfull Behaviour** Scouring occurs along the bed and banks, particularly on the outside of bends. Bars are sculpted from the surrounding sediment. Accretion of these bars occurs during the waning stage of flow. Slot channel form indicated that bed incision to be the dominating process. **Overbank Behaviour** Inset bench surfaces can be developed through vertical accretion processes but can also be scoured by particularly high flow events. Flood channel as well as preferential channel flow can scour the terrace margins and cause instability along the terrace banks. Draw down of flows or backwater effects at confluences can also enhance this instability. Only during rare large events are terraces likely to be overtopped, and flows spill out onto the older terrace floodplain, depositing fine grained material.

CONTROLS	
Landscape Setting and within-catchment position	Upper / Middle catchment setting in an urban environment
Valley Morphology	Terrace formations of the Hinuera Surface
Process Zone	Source Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 5 Kirikiriroa Catchment



B.7 CONFINED, TERRACE MARGIN-CONTROLLED, GULLY, GRAVEL BED (C_TRMC_GULLY_GBED)

Location(s): Mangakotukutuku Reach 15 and 16, Mangaonua Reach 2 and 4

Figure B.7. Google Earth image showing Reach 4 of the Mangaonua Catchment, representative of C_TrMC_Gully_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°50'24.51"S, 175°22'48.81"E**

RIVER CHARACTER	
Valley-setting	Confined by terrace margins of the Hinuera Surface
Channel Planform	Channel abuts terrace margins >85% of the time. This results in a relatively stable channel position. Sinuous gully
Bed material texture	Gravel Bed (some fines)
Channel geometry	Single thread, low sinuosity slot channel with low width to depth ratio. The channel appears highly sinuous; however, this sinuosity is dictated by terrace planform. The channel has low sinuosity overall. Irregular channel geometry at bends, generally symmetrical along straight sections.
Geomorphic Units	Within channel: Pools, riffles, runs, occasional sculpted bars, localised woody debris. Floodplain: inset bench pockets between gully and terrace margins (Waikato fan material), occasional backswamps and wetlands on inset bench surfaces, disconnected elevated terrace floodplain (Waikato fan).
Vegetation associations	Natives and exotics in gully, pasture atop of the Hinuera Surface

RIVER BEHAVIOUR

Low Flow Behaviour

Largely undisrupted flow, with hydraulic diversity which induces some minor scour. Flow moves over riffles and fills pools. Fine-grained material is carried in suspension and bars are sculpted.

Bankfull Behaviour

Scouring occurs along the bed and banks, particularly on the outside of bends. Bars are sculpted from the surrounding sediment. Accretion of these bars occurs during the waning stage of flow. Slot channel form indicated that bed incision to be the dominating process.

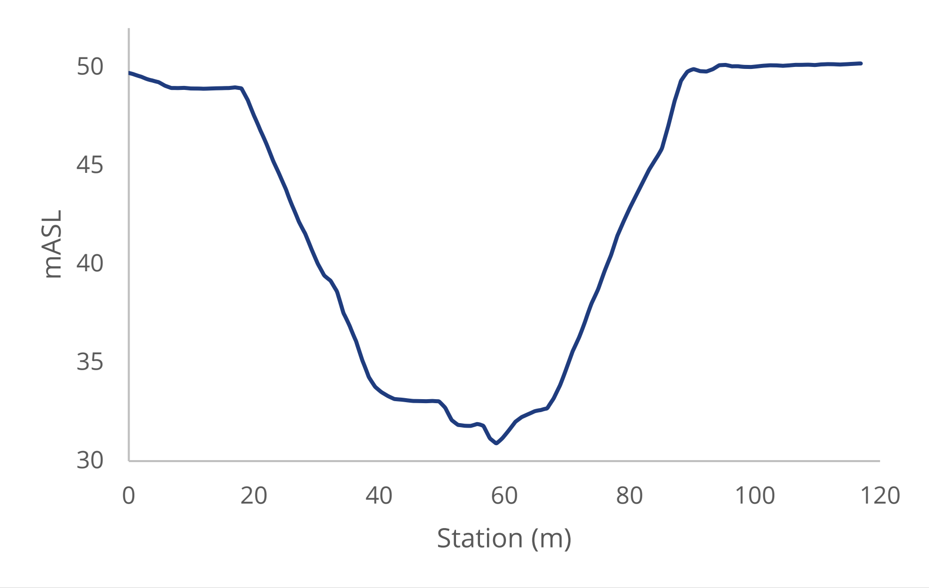
Overbank Behaviour

Inset bench surfaces can be developed through vertical accretion processes but can also be scoured by particularly high flow events. Flood channel as well as preferential channel flow can scour the terrace margins and cause instability along the terrace banks. Draw down of flows or backwater effects at confluences can also enhance this instability. Only during rare large events are terraces likely to be overtopped, and flows spill out onto the older terrace floodplain, depositing fine grained material.

CONTROLS

Landscape Setting and within-catchment position	Upper Catchment, surrounding farmland
Valley Morphology	Within terrace margins of the Hinuera Surface
Process Zone	Source Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 4 - Mangaonua Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 4 - Mangaonua Catchment

B.8 CONFINED, BEDROCK MARGIN-CONTROLLED, GULLY, FINE-GRAINED BED (C_BRMC_GULLY_ FBED)

Location(s): Mangakotukutuku Catchment Reach 13 and 17

Figure B.8. Google Earth image showing Reach 13 of the Mangakotukutuku Catchment, representative of C_BrMC_Gully_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°50'2.64"S, 175°18'20.38"E**

RIVER CHARACTER	
Valley-setting	Confined, valley margins comprise of undulating low rolling Hamilton Hills
Channel Planform	Channel abuts bedrock >85% of the time and takes up most of the available space on the valley floor. Channel configuration is dictated by valley alignment and is a Sinuous Farm Gully.
Bed material texture	Fine-grained
Channel geometry	Irregular, bedrock confined headwater gully
Geomorphic Units	Within channel: Pools, Riffles, Headcut steps, Farm ponds/dams Floodplain: Almost no floodplain, only very small pockets of floodplain exist where the valley is locally wider.
Vegetation associations	Pasture, some trees

RIVER BEHAVIOUR

Low Flow Behaviour

During low flows, flow moves over bedrock steps and around coarse substrate, producing some hydraulic diversity. With a relatively stable channel setting, there is next to no room for lateral movement or floodplain formation, other than small areas of accommodation space. Vertical gully incision is the dominant adjustment process.

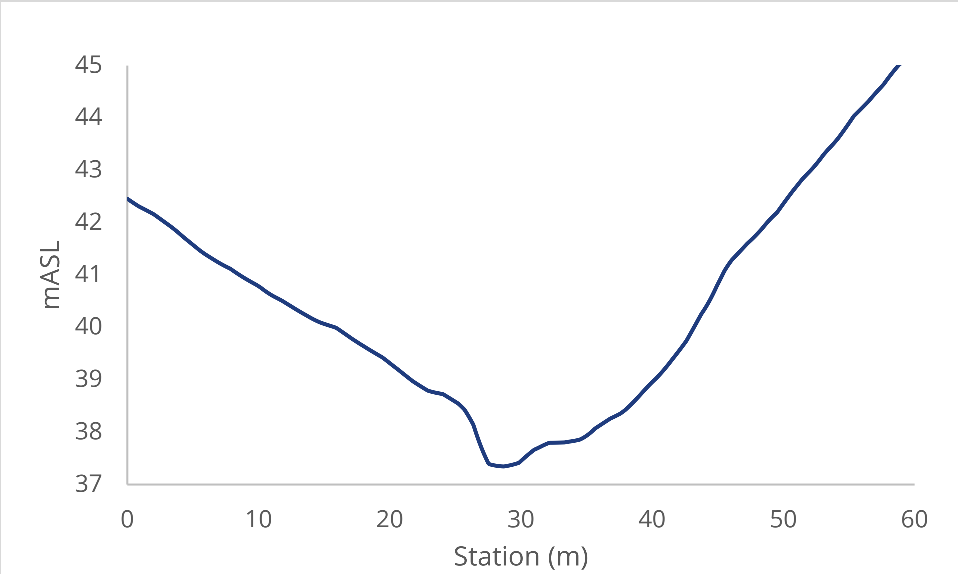
Bankfull/Overbank Behaviour

During bankfull and overbank flows, stream powers can move coarse and fine bedload, re-arranging the geomorphic unit assemblage. This River Style acts as a source zone for sediment. During extremely high flow events, valley sides bay be undercut by gully erosion and the gully may further incise.

CONTROLS

Landscape Setting and within-catchment position	Upper catchment, surrounding farmland
Valley Morphology	Rolling Hamilton Hills
Process Zone	Source Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 13 Mangaokotukutuku Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 13 Mangaokotukutuku Catchment

B.9 CONFINED, TERRACE MARGIN-CONTROLLED, OCCASIONAL FLOODPLAIN POCKETS, GULLY, FINE-GRAINED BED (C_TRMC_OCCFP_GULLY_ FBED)

Location(s): Mangakotukutuku Reach 5, 19 and 20B, Mangaonua Reach 3, 6 and 7, Waitawhiriwhiri Reach 3A, Kirikiriroa Reach 3, 8, 9 and 10, Te Awa O Katapaki Reach 4

Figure B.9. Google Earth image showing Reach 7 of the Mangaonua Catchment, representative of C_TrMC_OccFp_Gully_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°48'42.53"S, 175°22'2.43"E**

RIVER CHARACTER	
Valley-setting	Confined by terrace margins of the Hinuera Surface
Channel Planform	Channel abuts terrace margins >85% of the time. This results in a relatively stable channel position. Sinuous gully
Bed material texture	Fine-grained bed
Channel geometry	Single thread, low sinuosity slot channel with low width to depth ratio. The channel appears highly sinuous; however, this sinuosity is dictated by terrace planform. The channel has low sinuosity overall. Irregular channel geometry at bends, generally symmetrical along straight sections.
Geomorphic Units	Within channel: Pools, riffles, runs, occasional sculpted bars, localized woody debris. Floodplain: inset occasional floodplain pockets between gully and terrace margins (Waikato fan material), occasional backswamps and wetlands on inset floodplain surfaces, disconnected elevated terrace floodplain (Waikato fan).

RIVER CHARACTER	
Vegetation associations	Native and exotics in gully, urban development atop the Hinuera Surface

RIVER BEHAVIOUR

Low Flow Behaviour

Largely undisrupted flow, with hydraulic diversity which induces some minor scour. Flow moves over riffles and fills pools. Fine-grained material is carried in suspension and bars are sculpted.

Bankfull Behaviour

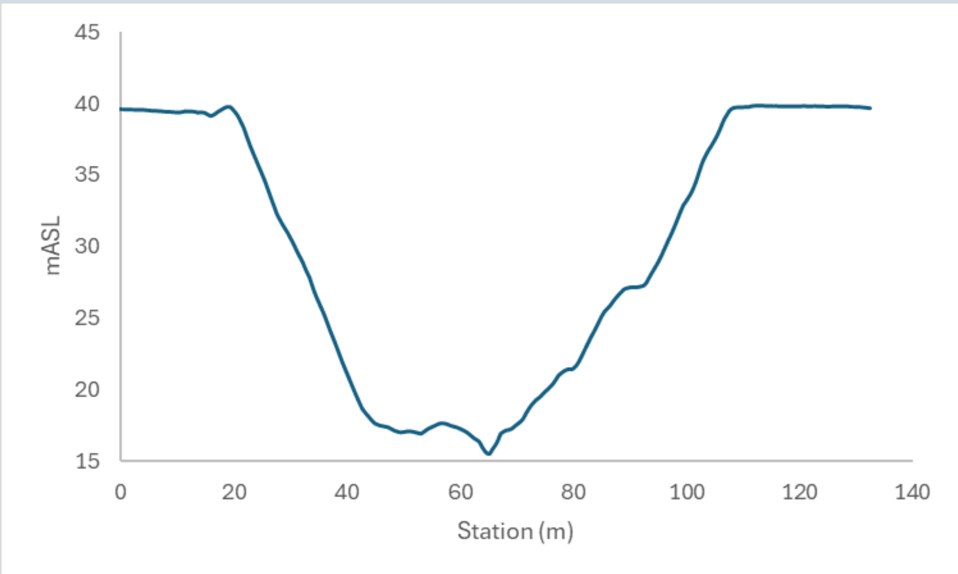
Scouring occurs along the bed and banks, particularly on the outside of bends. Bars are sculpted from the surrounding sediment. Accretion of these bars occurs during the waning stage of flow. Slot channel form indicated that bed incision to be the dominating process.

Overbank Behaviour

Inset occasional floodplain surfaces can be developed through vertical accretion processes but can also be scoured by particularly high flow events. Flood channel as well as preferential channel flow can scour the terrace margins and cause instability along the terrace banks. Draw down of flows or backwater effects at confluences can also enhance this instability. Only during rare large events are terraces likely to be overtopped, and flows spill out onto the older terrace floodplain, depositing fine grained material.

CONTROLS	
Landscape Setting and within-catchment position	Upper / Middle catchment in urban or mixed environment
Valley Morphology	Within terrace margins of the Hinuera Surface
Process Zone	Source / Transfer Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 7 Mangaonua Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 7 Mangaonua Catchment

B.10 CONFINED, TERRACE MARGIN-CONTROLLED, OCCASIONAL FLOODPLAIN POCKETS, GULLY, GRAVEL BED (C_TRMC_OCCFP_GULLY_GBED)

Location(s): Mangakotukutuku Reach 14

Figure B.10. Google Earth image showing Reach 14 of the Mangakotukutuku catchment, representative of the C_TrMC_OccFp_Gully_Gbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°49'16.76"S, 175°18'38.41"E**

RIVER CHARACTER	
Valley-setting	Confined by terrace margins of the Hinuera Surface
Channel Planform	Channel abuts terrace margins >85% of the time. This results in a relatively stable channel position Sinuous gully
Bed material texture	Gravel Bed (some fines)
Channel geometry	Single thread, low sinuosity slot channel with low width to depth ratio. The channel appears highly sinuous; however, this sinuosity is dictated by terrace planform. The channel has low sinuosity overall. Irregular channel geometry at bends, generally symmetrical along straight sections.
Geomorphic Units	Within channel: Pools, riffles, runs, occasional sculpted bars, localized woody debris. Floodplain: inset occasional floodplain pockets between gully and terrace margins (Waikato fan material), occasional backswamps and wetlands on inset floodplain surfaces, disconnected elevated terrace floodplain (Waikato fan).

RIVER CHARACTER	
Vegetation associations	Native and exotics within the gully, pasture atop of surrounding terrace surface

RIVER BEHAVIOUR

Low Flow Behaviour

Largely undisrupted flow, with hydraulic diversity which induces some minor scour. Flow moves over riffles and fills pools. Fine-grained material is carried in suspension and bars are sculpted.

Bankfull Behaviour

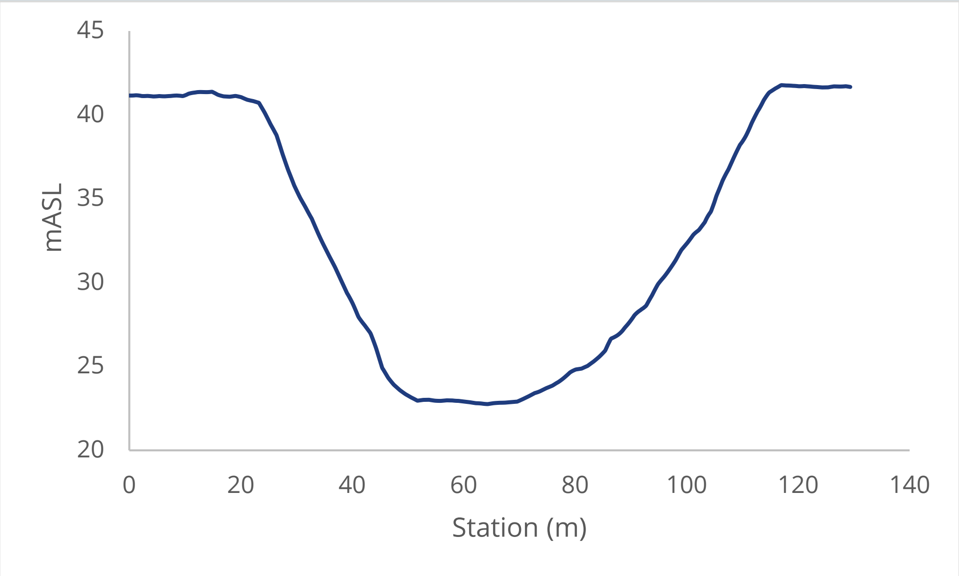
Scouring occurs along the bed and banks, particularly on the outside of bends. Bars are sculpted from the surrounding sediment. Accretion of these bars occurs during the waning stage of flow. Slot channel form indicated that bed incision to be the dominating process.

Overbank Behaviour

Inset occasional floodplain surfaces can be developed through vertical accretion processes but can also be scoured by particularly high flow events. Flood channel as well as preferential channel flow can scour the terrace margins and cause instability along the terrace banks. Draw down of flows or backwater effects at confluences can also enhance this instability. Only during rare large events are terraces likely to be overtopped, and flows spill out onto the older terrace floodplain, depositing fine grained material.

CONTROLS	
Landscape Setting and within-catchment position	Upper/Middle catchment in farmland environment
Valley Morphology	Terraces of the Hinuera Surface and surrounding Hamilton Hills
Process Zone	Source zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 14 Mangakotukutuku Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 14 Mangakotukutuku Catchment

B.11 CONFINED, TERRACE MARGIN-CONTROLLED, OCCASIONAL FLOODPLAIN POCKETS, SWAMP / WETLAND, FINE-GRAINED BED (C_TRMC_OCCFP_SWAMP/WETLAND_FBED)

Location(s): Kirikiriroa Catchment – Reach 12

Figure B.11. Google Earth image showing Reach 12 of the Kirikiriroa Catchment, representative of the C_TrMC_OccFp_Swamp/Wetland_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°44'31.67"S, 175°16'3.38"E**

RIVER CHARACTER	
Valley-setting	Confined by terrace margins of the Hinuera Surface
Channel Planform	Channel abuts terrace margins >85% of the time. Discontinuous preferential flow paths and wetland areas within valley fill
Bed material texture	Fine-grained bed
Channel geometry	Asymmetrical
Geomorphic Units	Within channel: Preferential flow paths, pools, wetland areas, benches Floodplain: Valley fill surfaces. Wider older elevated terrace floodplain is urbanised.
Vegetation associations	Natives and exotics

RIVER BEHAVIOUR

Low Flow Behaviour

Low flow moves via preferential flow paths. Areas of stagnant water in backswamps and wetlands on valley fill surfaces.

Bankfull Behaviour

Channel banks may be scoured and cause widening. Although this is a slow process due to degree of confinement, cohesive sediments and low energy system due to small upstream catchment area. Susceptible to channelisation from downstream degradation.

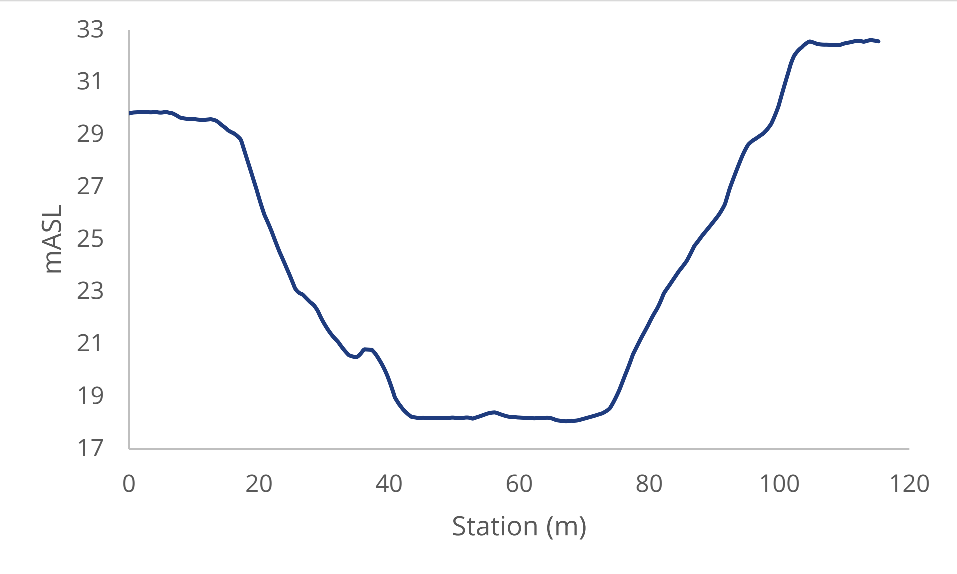
Overbank Behaviour

Valley-fill can become waterlogged which can take a long time to drain, promoting the formation/reactivation of backswamps. Only during rare large events may the terraces be overtopped.

CONTROLS

Landscape Setting and within-catchment position	Upper/Middle catchment in an urban environment
Valley Morphology	Terraces of the Hinuera Surface
Process Zone	Transfer / Accumulation zone

REPRESENTATIVE CROSS SECTION & PHOTO – Reach 12 Kirikiriroa Catchment



No Photo Available

B.12 PARTLY CONFINED, TERRACE MARGIN-CONTROLLED, GULLY, DISCONTINUOUS FLOODPLAIN, FINE-GRAINED BED (PC_TRMC_GULLY_DCFP_ FBED)

Location(s): Mangakotukutuku Reach 20A, Mangaonua Reach 8, Kirikiriroa Reach 13B

Figure B.12. Google Earth image showing Reach 8 of the Mangaonua Catchment, representative of the PC_TrMC_Gully_DcFp_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°48'50.04"S, 175°19'38.37"E**

RIVER CHARACTER	
Valley-setting	Partly confined by terrace margins of the Hinuera Surface
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 terrace margins. Sinuous gully channel, with staged inset floodplain of incisional history.
Bed material texture	Fine-grained bed
Channel geometry	Symmetrical slot entrenched channel in straight sections, and asymmetrical at bends.
Geomorphic Units	Within channel: Pools, riffles, run/glides, benches, ledges, occasional bank attached lateral and point bars. Floodplain: Discontinuous inset floodplain between terrace margins. Backswamp areas in the contemporary floodplain. Elevated terrace floodplains consisting of the Waikato Fan surface.

RIVER CHARACTER	
Vegetation associations	Mix of natives and exotics and cleared terrace surfaces

RIVER BEHAVIOUR

Low Flow Behaviour

During low flows, flow moves undisrupted over riffles and filling pools. The channel remains highly stable, confined by terrace margins. Channel incision via headcut headward erosion is the dominant erosion process.

Bankfull Behaviour

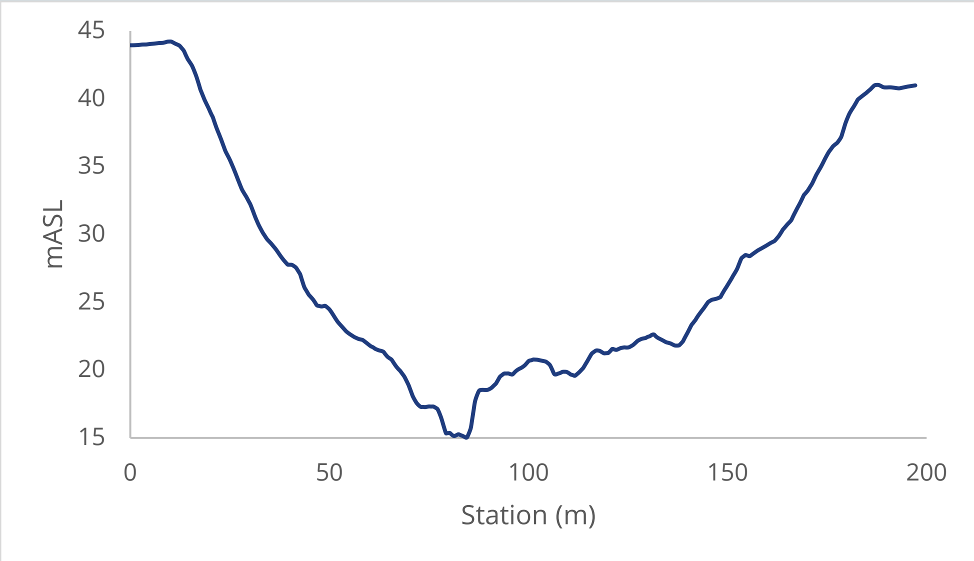
Banks may be scoured by slumping and block failure. During bankfull flow, bank attached bars are reworked, as well as bench/ledge surfaces. Vertical incision is still the dominant process.

Overbank Behaviour

In overbank flow, flow spills out over contemporary floodplains and fills the area between terrace margins. Contemporary floodplains are formed by vertical accretion processes. Only under large flow events (e.g., 1 in 100-year event) are the terrace margins overtopped.

CONTROLS	
Landscape Setting and within-catchment position	Lower catchment in an urban setting, often adjoining the Waikato River
Valley Morphology	Partly confined, wider valley setting, confined by terraces of the Hinuera Surface
Process Zone	Transfer / Accumulation Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 8 Mangaonua Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 8 Mangaonua Catchment

B.13 PARTLY CONFINED, BEDROCK MARGIN-CONTROLLED, GULLY, DISCONTINUOUS FLOODPLAIN, FINE-GRAINED BED (PC_BRMC_GULLY_DCFP_FBED)

Location(s): Mangakotukutuku Catchment – Reach 12

Figure B.13. Google Earth image showing Reach 12 of the Mangakotukutuku Catchment representative of PC_BrMC_FarmGully_DcFp_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°49'56.23"S, 175°18'35.10"E**

RIVER CHARACTER	
Valley-setting	Partly confined by bedrock margins of the Hamilton rolling hills and Hinuera Surfaces
Channel Planform	The channel abuts bedrock margins >50% of the time with low to moderate sinuosity. Alternating irregular pockets of floodplain occur along the valley. The gully is moderately stable, as it is pinned against the valley margin.
Bed material texture	Fine grained bed
Channel geometry	Mostly symmetrical gully.
Geomorphic Units	Within channel: Pools, riffles, step-pools, glide/runs, benches, sand bars. Floodplain: discontinuous floodplain
Vegetation associations	Riparian margin of natives and exotics, surrounded by pasture

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 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. However, the gully is prone to degradation and widening into the Hamilton Hills, susceptible to degradation from downstream incisional processes.

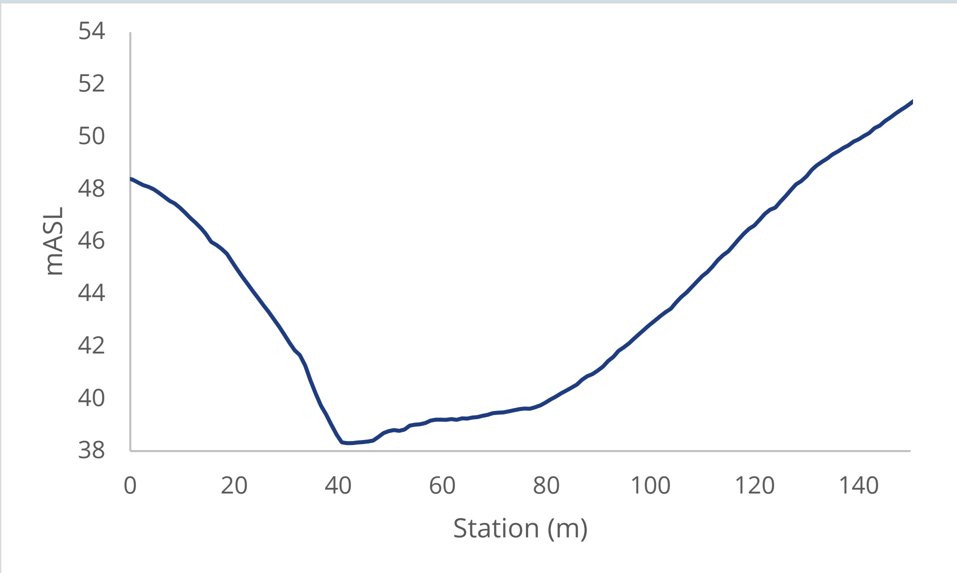
Overbank Behaviour

The channel is relatively stable, with smaller capacity for lateral adjustment and more susceptible to degradation. The floodplain is built up via vertical accretion processes.

CONTROLS

Landscape Setting and within-catchment position	Upper catchment in farmland setting
Valley Morphology	Hamilton rolling hills
Process Zone	Source Zone

REPRESENTATIVE CROSS SECTION & PICTURE – Reach 12 Mangakotukutuku Catchment



REPRESENTATIVE CROSS SECTION & PICTURE – Reach 12 Mangakotukutuku Catchment

B.14 LATERALLY UNCONFINED, CONTINUOUS CHANNEL, LOW SINUOSITY FARM DRAIN, FINE-GRAINED BED (LU_C_LSIN_FARMDRAIN_FBED)

Location(s): Mangakotukutuku Catchment Reach 1 and 3, Waitawhiriwhiri Reach 1B, Kirikiriroa Reach 4

Distinguishing attributes:

Figure B.14. Google Earth image showing Reach 4 of the Kirikiriroa Catchment, representative of a LU_C_LSin_FarmDrain_Fbed River Style.

DETAILS OF ANALYSIS
Map(s) used: **Google Earth 37°44'26.82"S, 175°17'36.72"E**

RIVER CHARACTER	
Valley-setting	Laterally unconfined, draining farmland and peat bogs in the upper catchment with continuous channel
Channel Planform	Continuous floodplains occur along both valley margins. Channel is single thread, with low sinuosity, forming a straightened farm drain that drains the floodplain.
Bed material texture	Fine-grained
Channel geometry	Symmetrical slot channel
Geomorphic Units	Within channel: channel is general devoid of geomorphic units, some small pools and riffles, uniform glides. Bank slumps along channel associated with incision and banks becoming undercut. Floodplain: continuous fine-grained floodplain
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 draining farm and peat land. Flow occurs over fine-grained sculpted geomorphic units and fills pools.

Bankfull Behaviour

The channel generally has a low width to depth ratio, with fine-grained alluvium floodplain sediments. Channel is incising, resulting in bank slumping and block failure, although low slopes limit energy conditions. Susceptible to degradation from downstream incisional processes.

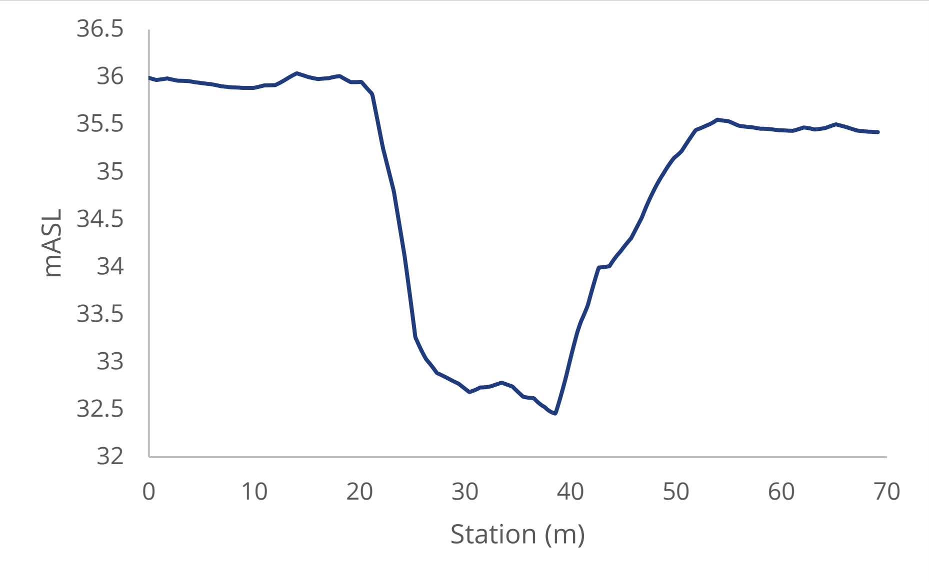
Overbank Behaviour

The floodplains are dominantly formed via vertical accretion when flows spread out across the floodplain. As flows recede, banks are susceptible to erosion from spring sapping, as the peat and floodplain is drained.

CONTROLS

Landscape Setting and within-catchment position	Upper catchment
Valley Morphology	Laterally unconfined
Process Zone	Source Zone

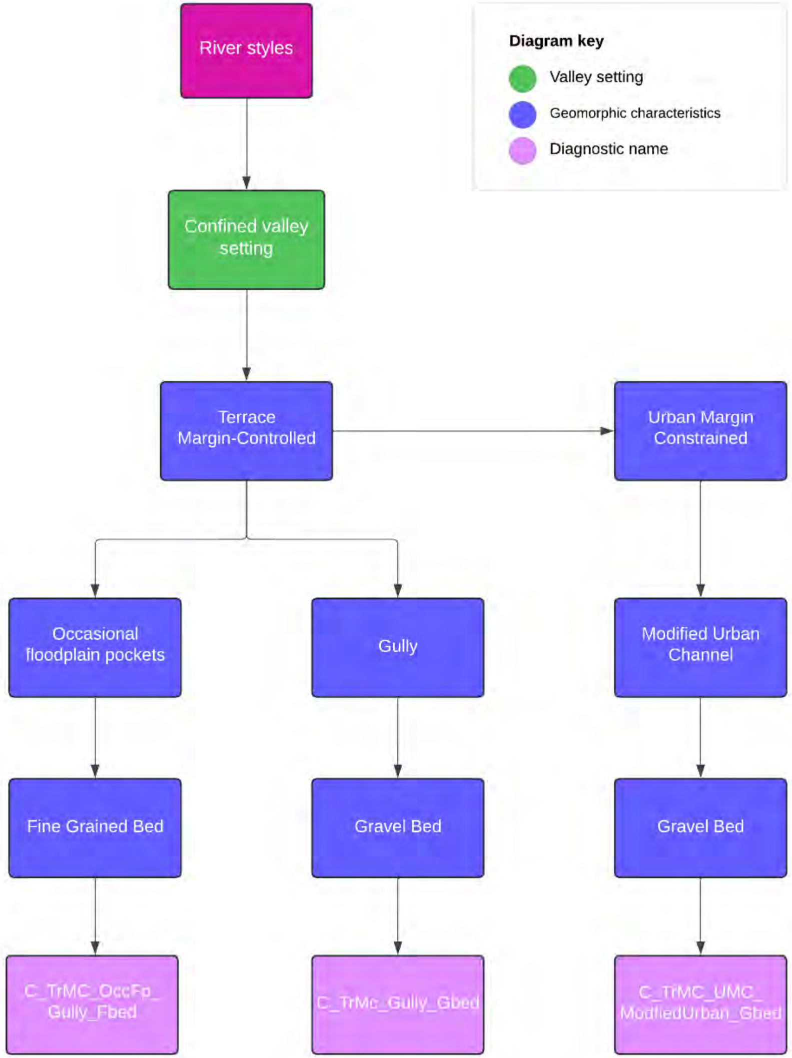
REPRESENTATIVE CROSS SECTION & PICTURE – Reach 4 Kirikiriroa Catchment



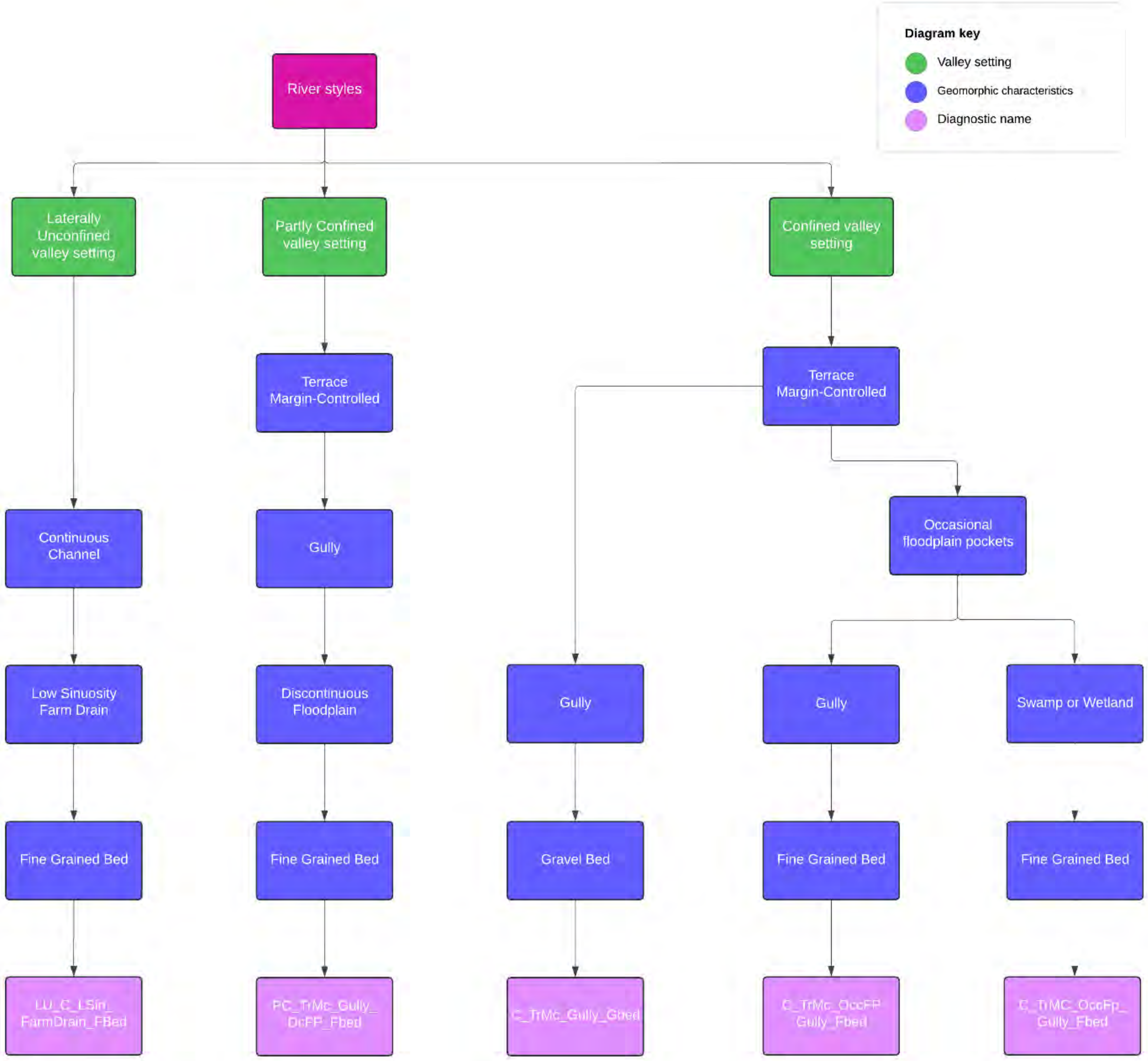
REPRESENTATIVE CROSS SECTION & PICTURE – Reach 4 Kirikiriroa Catchment

APPENDIX C. RIVER STYLES TREE

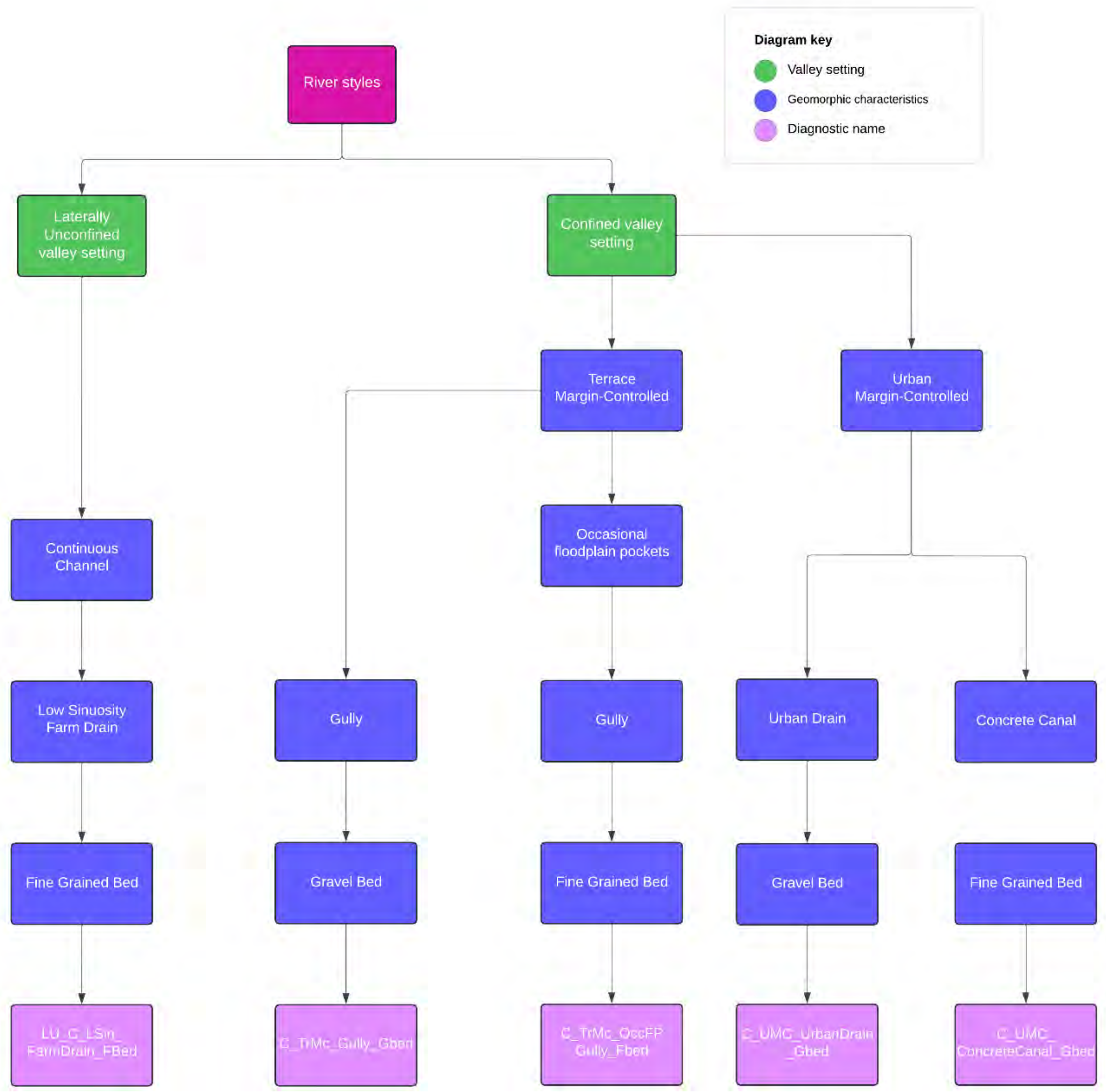
C.1 TE AWA O KATAPAKI



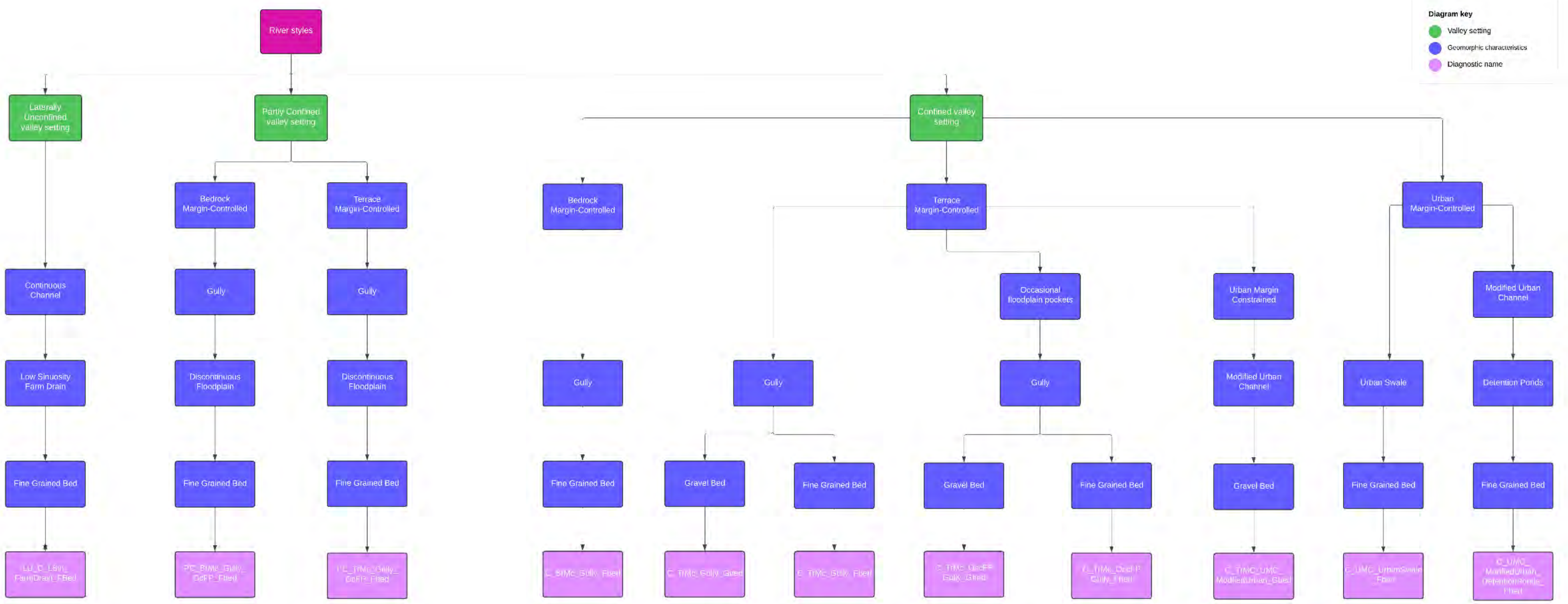
C.2 KIRIKIRIROA



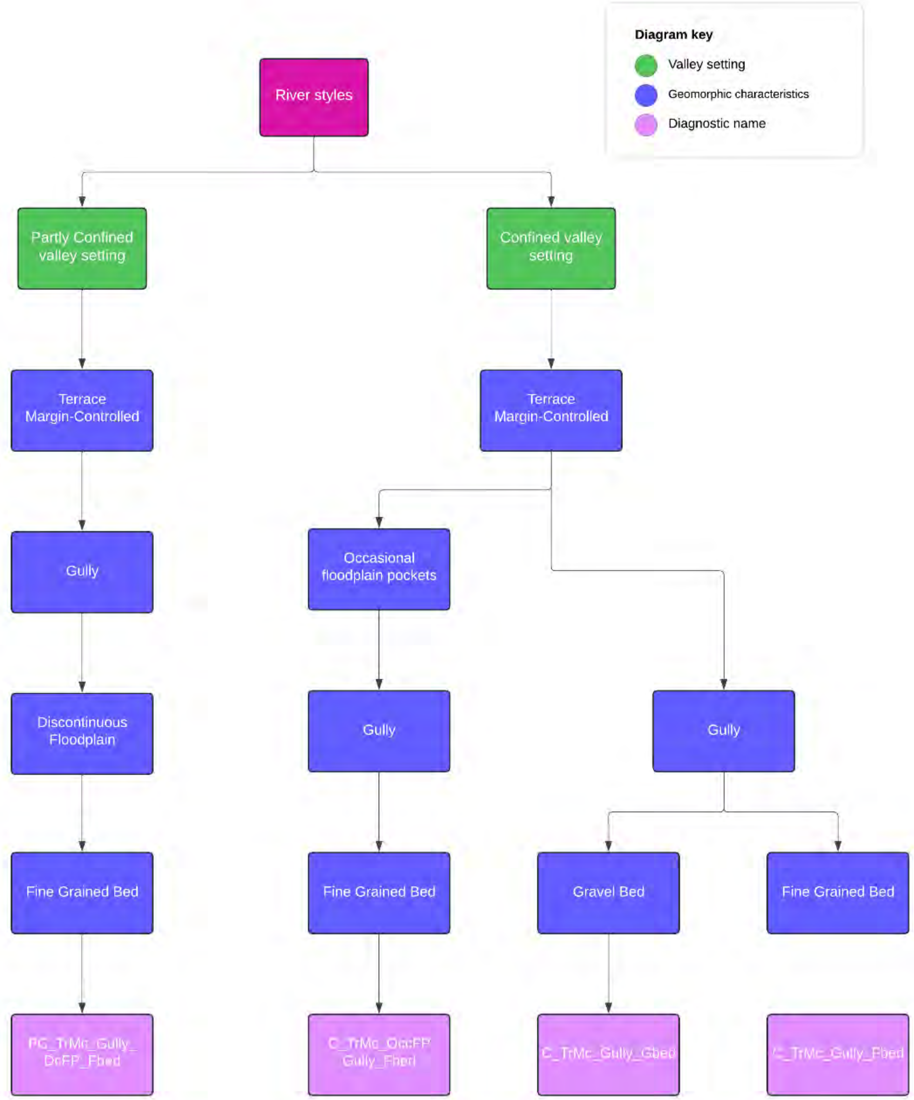
C.3 WAITAWHIRIWHIRI



C.4 MANGAKOTUKUTUKU



C.5 MANGAONUA / MANGAONE



APPENDIX D. PHOTOGRAPHS

D.1 TE AWA O KATAPAKI CATCHMENT

	
Reach 1. Rehabilitated Urban Channel - C_TrMc_UMC_ModifiedUrban_Gbed	Reach 1. Detention pond serving surrounding urban developments - C_TrMc_UMC_ModifiedUrban_Gbed
	
Reach 2. Incised channel flanked by native vegetation- C_TrMc_Gully_Gbed	Reach 2. Incised channel - C_TrMc_Gully_Gbed
	
Reach 2. Floodplain surface - C_TrMc_Gully_Gbed	Reach 2. Vertical alluvium terrace exposure - C_TrMc_Gully_Gbed

	
Reach 3. Modified urban tributary - C_TrMc_UMC_ModifiedUrban_Gbed	Reach 3. Floodplain surface on true left bank with terrace margin confinement on true right bank - C_TrMc_UMC_ModifiedUrban_Gbed
	
Reach 3. Scruffy dome - C_TrMc_UMC_ModifiedUrban_Gbed	Reach 4. Floodplain surface dominated by weeds on true left bank - C_TrMC_OccFp_Gully_Fbed
	
Reach 4. Extensive weed coverage on floodplain surface - C_TrMC_OccFp_Gully_Fbed	Reach 4. View from River Road with extensive gorse coverage - C_TrMC_OccFp_Gully_Fbed

	
Reach 4. Rehab / modification at golf course - C_TrMC_OccFp_Gully_Fbed	Reach 4. Rehab / modification at golf course - C_TrMC_OccFp_Gully_Fbed
	
Reach 4 at golf course transitioning toward Waikato River - C_TrMC_OccFp_Gully_Fbed	Reach 4 - Grade controls at golf course - C_TrMC_OccFp_Gully_Fbed
	
Reach 4 / Confluence with Waikato River - C_TrMC_OccFp_Gully_Fbed	Waikato River Confluence at the downstream extent of Te Awa o Katapaki catchment.

D.2 KIRIKIRIROA CATCHMENT

	
Reach 1 / Reach 2. Landscaped embankments - C_TrMc_UMC_ModifiedUrban_Gbed	Reach 1. Detention pond - C_TrMc_UMC_ModifiedUrban_Gbed
	
Reach 3. Terrace margin control / incised gully with native vegetation and exotic species - C_TrMC_OccFp_Gully_Fbed	Reach 3. Potentially rehabilitated location with extensive native vegetation coverage - C_TrMC_OccFp_Gully_Fbed
	
Reach 3. Extensive riparian vegetation with small primary channel within - C_TrMC_OccFp_Gully_Fbed	Reach 3. Progressively expanding slot channel - C_TrMC_OccFp_Gully_Fbed

Reach 3. Channel with high vertical connection to adjacent surfaces - C_TrMC_OccFp_Gully_Fbed

Reach 3. Occasional floodplain pocket within parkland - C_TrMC_OccFp_Gully_Fbed

Reach 4. Draining farm land with laterally unconfined floodplain surface dominated by weeds - LU_C_LSin_FarmDrain_Fbed

Reach 5. Urban gully set within terraced confinement - C_TrMc_Gully_Gbed

Reach 5. Minor channel - C_TrMc_Gully_Gbed

Reach 5 - C_TrMc_Gully_Gbed

	
Reach 6A - C_TrMc_Gully_Gbed	Reach 6B. Bio-retention ponds – C_UMC_ModifiedUrban_DetentionPonds_Fbed
	
Reach 9. Mature trees leaning toward channel potentially indicating ongoing channel expansion. Reach near Waikato Athletic Centre - C_TrMC_OccFp_Gully_Fbed	Reach 10. Rehabilitated gully with pathway accessible by the public - C_TrMC_OccFp_Gully_Fbed
	
Reach 10 channel - C_TrMC_OccFp_Gully_Fbed	Reach 1. Inset floodplain surface on true right bank where channel abuts terrace on true left bank - C_TrMc_Gully_Gbed

	
Reach 11. Confluence with main gully / Reach 3 / 13B - C_TrMc_Gully_Gbed	Reach 3 / transition to 13B. Grade control structures on main gully - C_TrMC_OccFp_Gully_Fbed / PC_TrMc_Gully_DcFP_Fbed
	
Reach 13B. Partly confined, inset floodplain. Protection applied to bank to reduce channel expansion into floodplain - PC_TrMc_Gully_DcFP_Fbed	Reach 13B. Grade control structure limiting upstream channel expansion – PC_TrMc_Gully_DcFP_Fbed
	
Reach 13B. Rock protection / channel alteration - PC_TrMc_Gully_DcFP_Fbed	Reach 13A. Confined valley setting with occasional floodplain pockets - C_TrMC_OccFp_Gully_Fbed

Reach 13A. Grade control structures - C_TrMC_OccFp_Gully_Fbed

Reach 13A. Bridge being outflanked. Evidence of incision / widening - C_TrMC_OccFp_Gully_Fbed

Reach 13A channel with grade control structure controlling upstream water level / energy slope - C_TrMC_OccFp_Gully_Fbed

Reach 13A. Confined valley setting with occasional floodplain pocket - C_TrMC_OccFp_Gully_Fbed

Reach 13A. Grade control structure and rock toe protection near confluence with Waikato River - C_TrMC_OccFp_Gully_Fbed

Reach 13A. Near confluence with Waikato River. Gabions protecting bridge and bed from incision - C_TrMC_OccFp_Gully_Fbed

D.3 WAITAWHIRIWHIRI CATCHMENT

Reach 1A. Concrete lined channel – C_UMC_UrbanDrain_Gbed

Reach 1A. Concrete lined channel - C_UMC_UrbanDrain_Gbed

Reach 1A transitioning to 1B, draining farm and peat land - C_UMC_UrbanDrain_Gbed / LU_C_LSin_FarmDrain_Fbed

Reach 2. Terrace and urban margin control. Concrete lined canal / channel – C_UMC_ConcreteCanal_Fbed

Reach 2. Gabion baskets protecting banks and constraining flows- C_UMC_ConcreteCanal_Fbed

Reach 2. Concrete lining becoming outflanked - C_UMC_ConcreteCanal_Fbed

	
Reach 2. Infrastructure located close to channel. Some floodplain stripping occuring on right of picture - C_UMC_ConcreteCanal_Fbed	Reach 2. Urban margins - C_UMC_ConcreteCanal_Fbed
	
Reach 3B. Terrace land slip stabilized by groynes at toe and replanting. Sediment accumulation occuring within channel - C_TrMc_Gully_Gbed	Reach 3B. Degraded reach confined by terrace margin controls- C_TrMC_Gully_Gbed
	
Reach 3B. Terrace surface dominated by weeds. Some sediment accumulation occuring in the form of lateral and point bars. Some LWD present - C_TrMC_Gully_Gbed	Reach 3B. Inset floodplain with poorly maintained access track. Reach dominated by exotic weeds/fauna - C_TrMC_Gully_Gbed

	
Reach 3B channel - C_TrMC_Gully_Gbed	Reach 3B - C_TrMC_Gully_Gbed
	
Reach 3A change in River Style. Culvert crossing at Ulster St. - C_TrMC_OccFp_Gully_Fbed	Reach 3A grade control and toe/bank protection to prevent outflanking - C_TrMC_OccFp_Gully_Fbed
	
Reach 3A. Inset floodplain with high native vegetation coverage - C_TrMC_OccFp_Gully_Fbed	Reach 3A channel. Fine elongated gravel bars with grass vegetated a small proportion of the bar- C_TrMC_OccFp_Gully_Fbed

	
Reach 3A channel with bar on inside bend - C_TrMC_OccFp_Gully_Fbed	Reach 3A. Point bar becoming vegetated. Some woody debris within channel providing hydraulic diversity - C_TrMC_OccFp_Gully_Fbed
	
Reach 3A. Incised with inset bench - C_TrMC_OccFp_Gully_Fbed	Reach 3A. Near Waikato River confluence. Inset floodplain. Inset floodplain looks to be modified / implemented. - C_TrMC_OccFp_Gully_Fbed
	
Gully confluence with Waikato River. Rock protection within the channel	Confluence, gabion baskets and grade control structures protecting infrastructure.

D.4 MANGAKOTUKUTUKU CATCHMENT

Reach 1 - Upper catchment channels, farmland draining peat - LU_C_LSin_FarmDrain_Fbed

Incising slot channel, draining upper catchment, upstream of Reach 1–3 - LU_C_LSin_FarmDrain_Fbed

Reach 3 / 4. Inset slot channel LU_C_LSin_FarmDrain_Fbed / C_TrMc_UMC_ModifiedUrban_Gbed

Reach 3 / 4. Broad floodplain which channel can migrate freely within - LU_C_LSin_FarmDrain_Fbed / C_TrMc_UMC_ModifiedUrban_Gbed

Reach 5. Transition to confined channel with connection to occasional floodplains where sediment has been able to accumulate - C_TrMC_OccFp_Gully_Fbed

Reach 5. Incising slot channel with vertical banks - C_TrMC_OccFp_Gully_Fbed

Reach 5. Poorly vegetated (weeds) terrace margins - C_TrMC_OccFp_Gully_Fbed

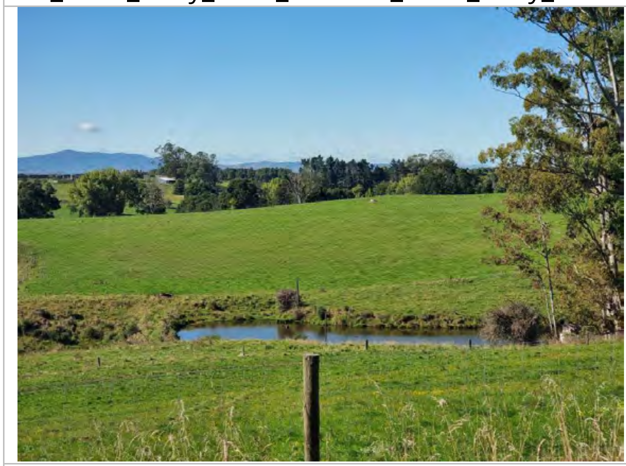
Reach 5. Channel confined by terraces on both banks. Woody debris observed within channel. - C_TrMC_OccFp_Gully_Fbed

Reach 6. Steep terrace margins controlling extent of channel movement - C_TrMc_Gully_Gbed

Reach 6. Bank slumping into channel - C_TrMc_Gully_Gbed

Reach 8. Urban Swale – C_UMC_UrbanSwale_Fbed

Reach 10. Incised channel with urban margin constraints - C_TrMc_UMC_ModifiedUrban_Gbed

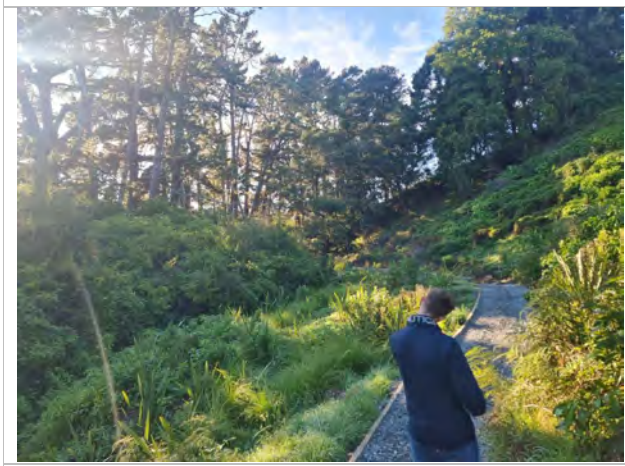
	
Reach 10 - C_TrMc_UMC_ModifiedUrban_Gbed	Looking towards Reach 11 heavily incised gully-C_TrMc_Gully_Gbed
	
Looking towards Reach 12 / 13 – PC_BrMc_Gully_DcFP_Fbed / C_BrMc_Gully_Fbed	Reach 12. Rolling Hamilton hills with gully expansion evident - PC_BrMc_Gully_DcFP_Fbed
	
Reach 13 farm pond (modified)- C_BrMc_Gully_Fbed	Reach 12 transitioning to Reach 14 downstream in the left of the image, gully becoming more incised - PC_BrMc_Gully_DcFP_Fbed

Looking towards Reach 17 and surrounding development occuring - C_BrMc_Gully_Fbed

Reach 17 – retention ponds, modified waterway / gully - C_BrMc_Gully_Fbed

Reach 19. Boardwalk traversing through restored gully - C_TrMC_OccFp_Gully_Fbed

Reach 19. Confined terrace margins limits extent of lateral adjustment - C_TrMC_OccFp_Gully_Fbed



Reach 19 - C_TrMC_OccFp_Gully_Fbed

Reach 19. Incising slot channel - C_TrMC_OccFp_Gully_Fbed

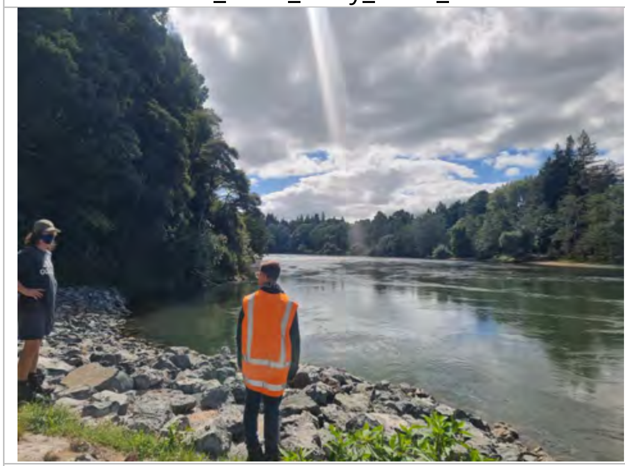
<table>
<tr><td></td><td></td></tr>
<tr><td>Reach 20B. Incised channel with almost vertical banks - C_TrMC_OccFp_Gully_Fbed</td><td>Reach 20B - C_TrMC_OccFp_Gully_Fbed</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Reach 20B. Tension crack showing evidence of incision and widening. LWD observed in channel - C_TrMC_OccFp_Gully_Fbed</td><td>Reach 20B. Inset floodplain pockets. Sediment accumulation on inside bend forming bar. - C_TrMC_OccFp_Gully_Fbed</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Reach 20A. Wider channel with inset floodplain and benches. Chute channel evident behind bar feature. - PC_TrMc_Gully_DcFP_Fbed</td><td>Reach 20A. Channel with coarse sands, some gravel and mud bed material. LWD within channel. - PC_TrMc_Gully_DcFP_Fbed</td></tr>
</table>

Reach 20A. Partly confined with terrace margins, with broad inset floodplain - PC_TrMc_Gully_DcFP_Fbed

Reach 20A. Rehabilitation planting works within inset floodplain - PC_TrMc_Gully_DcFP_Fbed

Reach 20A. Backwater affect with Waikato River Confluence - PC_TrMc_Gully_DcFP_Fbed

Confluence with the Waikato River



Confluence with the Waikato River

Confluence with the Waikato River. Rock bank protection protecting water pipeline.

D.5 MANGAONUA CATCHMENT

Reach 1. Incised channel in poor condition - C_TrMc_Gully_Gbed

Reach 1. Actively incising slot channel - C_TrMC_Gully_Gbed

Reach 1. Grade control structure controlling bed level - C_TrMC_Gully_Gbed

Reach 1. Terrace confinement - C_TrMC_Gully_Gbed

Reach 2 confluence. Riprap protecting infrastructure – C_TrMc_Gully_Fbed

Reach 3. Channel is able to engage floodplain pockets during moderate flows. LWD evident within channel - C_TrMC_OccFp_Gully_Fbed

Reach 4. Terrrace confinement - C_TrMc_Gully_Fbed

Reach 4. Incised gully - C_TrMc_Gully_Fbed

Reach 6. Tamahere Reserve (rehabilitated reach) - C_TrMC_OccFp_Gully_Fbed

Reach 6. Terrace confinement in background of picture - C_TrMC_OccFp_Gully_Fbed

Reach 6. Channel with floodplain surface on left of picture - C_TrMC_OccFp_Gully_Fbed

Reach 6 channel with sedge plants placed during rehabilitation - C_TrMC_OccFp_Gully_Fbed

	
Reach 7. Deeply incised, terrace margins - C_TrMC_OccFp_Gully_Fbed	Reach 7. Gravel bar occuring on true left bank - C_TrMC_OccFp_Gully_Fbed
	
Reach 7. Incised slot channel. Large woody debris across channel indicating channel expansion - C_TrMC_OccFp_Gully_Fbed	Reach 7. Gravel bars - C_TrMC_OccFp_Gully_Fbed
	
Reach 7 at Allan Turner Walkway - C_TrMC_OccFp_Gully_Fbed	Reach 7 channel - C_TrMC_OccFp_Gully_Fbed

Reach 7 looking downstream. Confined terrace margins - C_TrMC_OccFp_Gully_Fbed

Reach 7 looking upstream. Extensive native vegetation within gully - C_TrMC_OccFp_Gully_Fbed

Reach 8. Mangaonua Esplanade - PC_TrMc_Gully_DcFP_Fbed

Reach 8. Large woody debris within channel. Floodplain set at high elevation indicating historic incision - PC_TrMc_Gully_DcFP_Fbed

Reach 8. Partly confined, with inset terraces and floodplain surface. Groynes installed to redirect flow away from vertical bank. - PC_TrMc_Gully_DcFP_Fbed

Reach 8. Alluvium terrace exposure with rock riprap protection at toe - PC_TrMc_Gully_DcFP_Fbed

<table>
<tr><td></td><td></td></tr>
<tr><td>Reach 8. Wide channel - PC_TrMc_Gully_DcFP_Fbed</td><td>Reach 8. Wide channel - PC_TrMc_Gully_DcFP_Fbed</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Reach 8. Bedrock outcropping, showing gully has incised to bedrock - PC_TrMc_Gully_DcFP_Fbed</td><td>Reach 8. Rock protecting infrastructure (boardwalk) - PC_TrMc_Gully_DcFP_Fbed</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Reach 8 confluence with Waikato River - PC_TrMc_Gully_DcFP_Fbed</td><td>Waikato River confluence.</td></tr>
</table>

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