TE AWAROA: RESTORING 1000 RIVERS

RESEARCH REPORT 1: WAIMATA RIVER

CAROLA CULLUM, GARY BRIERLEY, MIKE MARDEN

LANDSCAPES & RIVERS OF THE WAIMATA AND TARUHERU, 2017

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

Landscapes and Rivers of the Waimatā and Taruheru

Carola Cullum, Gary Brierley, Mike Marden: Te Awaroa Report No. 1

Waimatā: Obsidian coloured waters, darkish in nature and colour
(Rongowhakaata Deed of settlement)

EXECUTIVE SUMMARY

Report Aims
This report describes the geomorphic template for the Waimatā and Taruheru catchments, near Gisborne, New Zealand. Prospectively, this provides a critical basis for policies aiming to ensure that the rivers, hillslopes and people can continue to support each other in a healthy and sustainable fashion (a state of 'ora'). The report does not discuss water quality or land use issues. Rather, river reaches and landscape types are classified in a way that distinguishes between areas subject to different sets of land forming processes, such that members of a class are likely to respond in similar ways to environmental change or human interventions.

Given that this template constrains the character and behaviour of the entire system, a description of the template provides a context for integration of understandings across disciplines and a platform to link discourses from social and natural sciences with policy and management concerns. An appreciation of the biophysical template and the constraints it imposes on the wider socio-ecological system also supports efforts to assess the physical integrity of a system and the potential for adjustment towards a desired system state.

Approach
We use the River Styles Framework to assess the Waimatā and Taruheru catchments and to recommend priorities for intervention (Brierley and Fryirs, 2005). We describe the character, likely behaviour and capacity for adjustment of each river style, considering the range of variability for each style and management interventions that might promote improvements to its current condition.

Landscape units and river styles are defined on the basis of observations and analysis of remotely sensed data, in particular the 2012 suite of aerial photographs and the LINZ 8m DEM. Maps and guidance provided by Dr. Mike Marden of Landcare Research, who has spent many years studying the geomorphology of this region and mapping the relict terraces within the Waimatā and Waipaoa catchments provided an invaluable resource. Interpretations of the behaviour of each river style are based on observations of valley and channel geometry, bed and bank materials and the nature of geomorphic units in each reach. Together, these observations provide evidence for the contemporary regimes of sediment erosion and deposition and the capacity for adjustment for each river style. This enables an assessment of the current condition of each style in relation to its range of potential variability. It also provides a simple measure of sensitivity to change, whether in response to natural events or human interventions.

Any classification (and, indeed, any map) is highly subjective (see Cullum et al., 2016). Numerous decisions are involved in attempts to represent multifaceted landscapes that contain continuous gradients of numerous attributes at many scales. Selecting the attributes and scales of analysis, constructing classes and drawing boundaries is not an exact science and no two locations are identical. Therefore our aim in constructing the maps and classifications presented in this report is not to delineate precise class or positional boundaries, but to represent broad similarities and differences in forms and processes that are likely to provide useful contexts for management decisions.

Regional Setting
The regional context of any catchment exercises significant control over the character and behaviour of rivers and landscapes. For example, climate patterns control hydrological flows (e.g. the frequency and intensity of floods), whilst geology and the relative permeability of rocks controls water infiltration and hence influence soil development, susceptibility to landslides and sediment inputs to rivers. Together, climate and geology are key controls on vegetation types, which in turn influence patterns and rates of hillslope and fluvial erosion and deposition. All these factors influence human decisions about land use. However, although the regional context

constrains the character and behaviour of landscapes, and their use by humans, the context does not determine landscape history, such that wide variability is usually found at local scales.

The combination of weak lithology, steep slopes resulting from tectonic uplift and incision, high rainfall, frequent storms, and recent forest removal make this landscape exceptionally prone to erosion, generating and delivering huge quantities of sediment to river systems.

The regional climate has warm moist summers and cool wet winters (Marden, 2011). Rainfall is high all year round, with mean annual rainfall around 1,000 mm/year at the coast, rising to 1,300 mm/year in the headwaters (Hicks et al., 1996; Liébault et al., 2005). The area is subject to tropical cyclones from March to May, when intense rainstorms and frequent floods cause extensive landsliding and substantial damage to infrastructure such as roads, bridges and buildings.

The Waimatā catchment lies adjacent to a major tectonic boundary, so faults and earthquakes are common and uplift rates are high. Indeed, the combination of tectonic activity and soft rock makes the East Cape region have some of the highest sediment yields per unit area in the world (Hicks et al., 1996).

Against the backdrop of ongoing tectonic subduction, the Waimatā catchment bears the imprint of changes in sea level associated with long term climate changes in the Pleistocene era. At the Last Glacial Maximum (a glacial period 14,700 years ago), sea level was some 120m lower than present. Since then, periods of relatively high fluvial incision have alternated with periods of relatively low incision during which floodplains formed. With each new incision event, floodplains were abandoned and remain today as remnant terraces. During erosion periods, hillslopes were steepened and valleys filled with sediment. Subsequent sea level rise drowned lowland valleys. The landscape now bears the imprint of multiple cycles of erosion and deposition associated with climate changes over millennia. Flights of terraces border banks along almost the entire river. These terraces resist erosion, effectively pinning the course of the river to a fixed position, within narrow valleys that have little space to store sediment (Fryirs et al., 2016; Fryirs and Brierley, 2010).

Like much of New Zealand, deforestation in the East Cape region occurred in two waves. Maori settlers arrived in the 14th century and burned much of the lowland forest. More extensive and rapid land clearance came with European settlement. From 1880 to 1920, the hill country was extensively deforested, through logging and burning, to establish pasture for sheep and beef (Jones and Preston, 2012). During this period, native beech and podocarp-broadleaf forest cover in the East Cape region was reduced from an estimated 68% cover to some 23% (Ewers et al., 2006). Further clearance was encouraged by government-led incentives in the 1960s and 1970s that provided subsidies for land development, fertiliser grants, reduced loans, and guaranteed minimum livestock prices (Rhodes, 2001). The native podocarp-hardwood forest now accounts for only about 2.5% of cover in the East Cape region, and is limited to high or steep parts of the Raukumara Range. Much of the region is now pasture or regenerating manukā and kanukā scrub (Gomez and Trustrum, 2005; Jones and Preston, 2012; Liébault et al., 2005).

Each period of deforestation was followed by extensive hillslope erosion across the region as soils were no longer stabilised by tree roots and run-off increased as less water was intercepted and transpired by trees (Marden et al., 2012; SCION, 2012). Across the region, responses to deforestation were widespread and included floodplain sedimentation, widening of downstream channels due to sediment scouring, and aggradation (vertical increase in elevation) of channel beds (Allsop, 1973; Marden, 2011; SCION, 2012).

Following concerns over increased hillslope erosion and gullying, reforestation efforts using exotic species (mostly *Pinus radiata*) occurred from 1960 (Marden et al., 2012). Reid and Page (2003) modelled the probability of landslide occurrence in the Waipaoa catchment, to ascertain how afforestation may have altered landsliding during Cyclone Bola. They suggested that targeted reforestation of steep slopes (>20°) in landslide prone areas could have reduced landslide sediment delivery by 40%. Afforestation of the entire landslide-prone region (50% of the catchment) could have reduced it by up to 80%.

Planting in the Waimatā occurred a little later, mostly during the 1990s. Although many pine plantations were established as government-subsidised soil conservation initiatives, most plantations are now commercial forestry businesses, and many have been sold to overseas owners (including much of the forests in the headwaters of the Waimatā catchment). These plantations are now being harvested, prompting new concerns for soil erosion and increased sediment loads in the rivers. However, findings from this study indicate that post-disturbance geomorphic responses across much of the Waimatā catchment are far less dramatic than those documented elsewhere in the region. For example, erosion rates in the Waiapu and Waipāoa catchments are the highest in New Zealand and feature amongst the most eroded catchments in the world (Dymond and de Rose, 2011, Hicks et al., 1996). In these catchments, huge landslips are common – indeed the Tarndale slip in the Waipāoa catchment is reputedly the largest in the Southern hemisphere.

Landscape types

Landscape types in the Waimatā and Taruheru catchments are defined in terms of geology and valley morphology, as observed in the 8 m DEM (Figure 1.1). Each of these landscape types has its own history (ethnography) of physical, biotic and cultural interactions, seen today in the patterns of land use that are loosely associated with each landscape type.

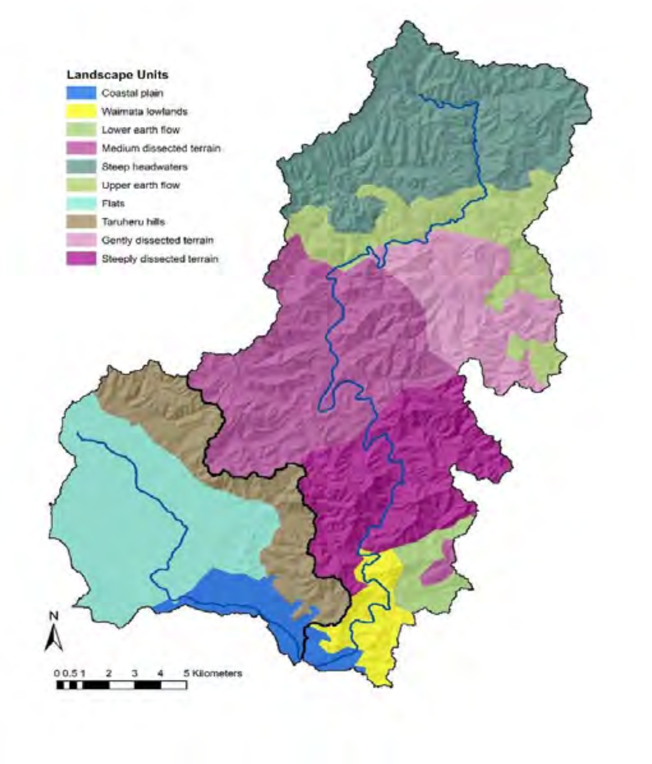


Figure 1.1: Landscape types in the Waimat and Taruheru catchments

Steep headwaters are characterised by narrow, V-shaped valleys with high, steep sides. They are covered by manukā/kanukā scrub, native and exotic forest.

The geology of **earth flow regions**, with frequent subsurface earth movements, generates hummocky, rolling hills, low relief and gentle slopes. These areas are predominantly covered by pasture. The lower earth flow region has more subdued relief than the upper earth flow area, and is covered by manukā/kanukā scrub and native forest.

Mid-catchment areas of the Waimatā contain **finely dissected terrain**, with narrow valleys and steep sides. Flights of relict flood terraces are common. To the south, the terrain becomes steeper, with many bedrock outcrops. There is an area with comparatively gentle slopes to the north-east. Manukā/kanukā scrub, exotic and native forests cover these areas.

The **Waimatā lowlands** and the **Taruheru hills** have low relief and very gentle slopes. They are mainly covered by exotic forests and high-producing grasslands. The Taruheru hills are draped in legacy sediments from the rise and fall of base levels in the Waipaoa floodplains.

The **Flats** and **Coastal plains** are extremely flat, with slopes under 20^{0} (there is some undulating ground with gentler slopes in the south east of the flats). While flats are occupied by horticultural croplands, the coastal plains contain urban settlements.

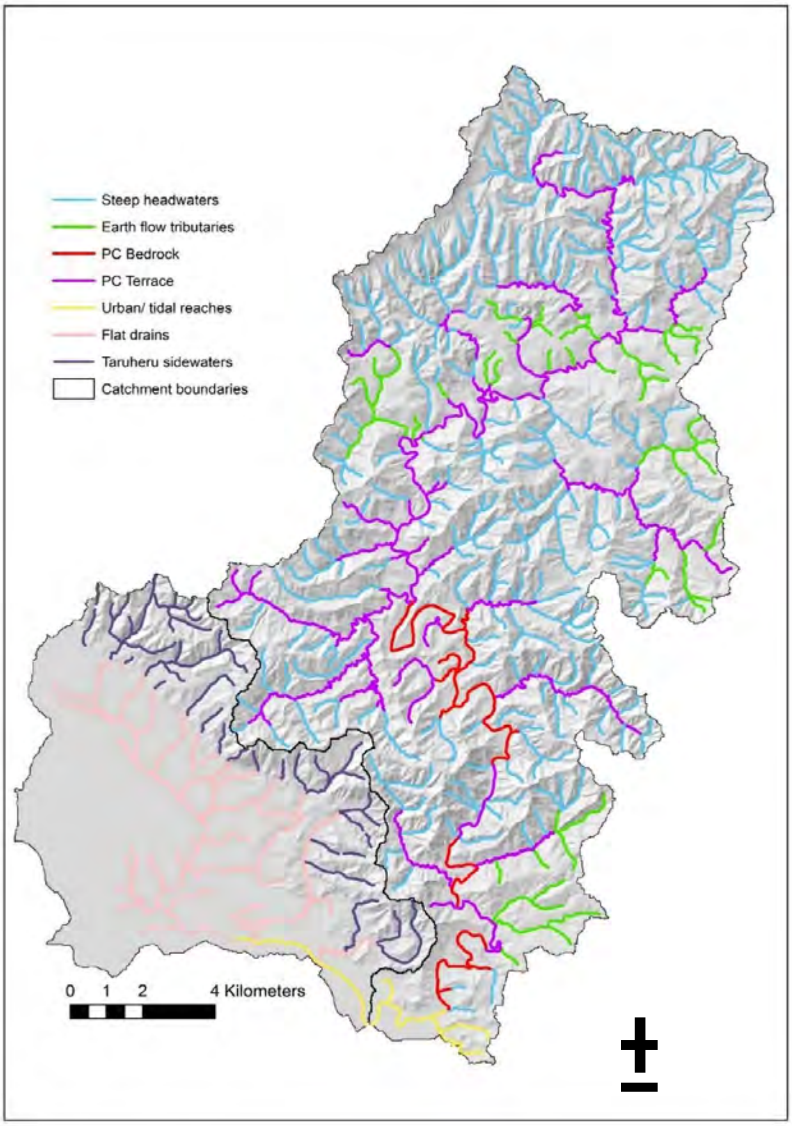
River styles

The character and behaviour of the Waimatā River and its tributaries are largely determined by geology, landscape history and position within the catchment. The various *geologies* found in the catchment produce very different landscapes and rivers. For example, the fragile smectites of the earth flow areas are associated with low relief, hummocky landscapes that offer space for sediment storage and lateral movement of streams. In contrast, the resistant lithology of the steep headwaters and the finely dissected steep terrain of the mid catchment produce narrow valleys that concentrate flow and limit the space available to store sediment. The *history* of rising and falling sea levels has left many old terraces that confine the contemporary floodplain to narrow pockets adjacent to the river. *Position within the catchment* largely determines stream power, which in turn determines the capacity of the river to transport sediment downstream. Stream power generally decreases downstream as channel slope decreases and valley width increases, dissipating flow energy. The more easily transported fine-grained sediments are generally transported further downstream than are coarse-grained sediments, which tend to be stored further upstream. In areas with relatively high stream power (e.g. steep headwaters), fine-grained sediment is easily flushed downstream. By contrast, in areas of relatively low stream power (e.g. low-relief earth flow areas), sediment is generally stored locally before being washed downstream in flood events. However, if the sediment load exceeds the transport capacity of the stream, even fine-grained sediment may be deposited high in the catchment, leading to degraded, muddy streams with little geomorphic or biological diversity.

The character and behaviour of the Taruheru River is quite different to that of the Waimatā. These very domesticated landscapes are dominated by fertile alluvial flats that have long been used for horticulture. The river has been manipulated to control floods and provide an irrigation system. The main stem lies on the edge of the flat plains of the Waipaoa, where the low relief generates little stream power, inhibiting the capacity of the river to move sediment, such that sediment accumulation occurs.

Eight river styles in the Waimatā and Taruheru catchments are defined firstly in terms of the degree to which streams are confined by valley walls, further subdivided to reflect differences in river character and behaviour, focussing on differences in sediment supply and the ways sediment is transported and/or stored within the channel and its floodplain (Figures 1.2 -1.4).

Figure 1.2: River styles of the Waimat and Taruheru



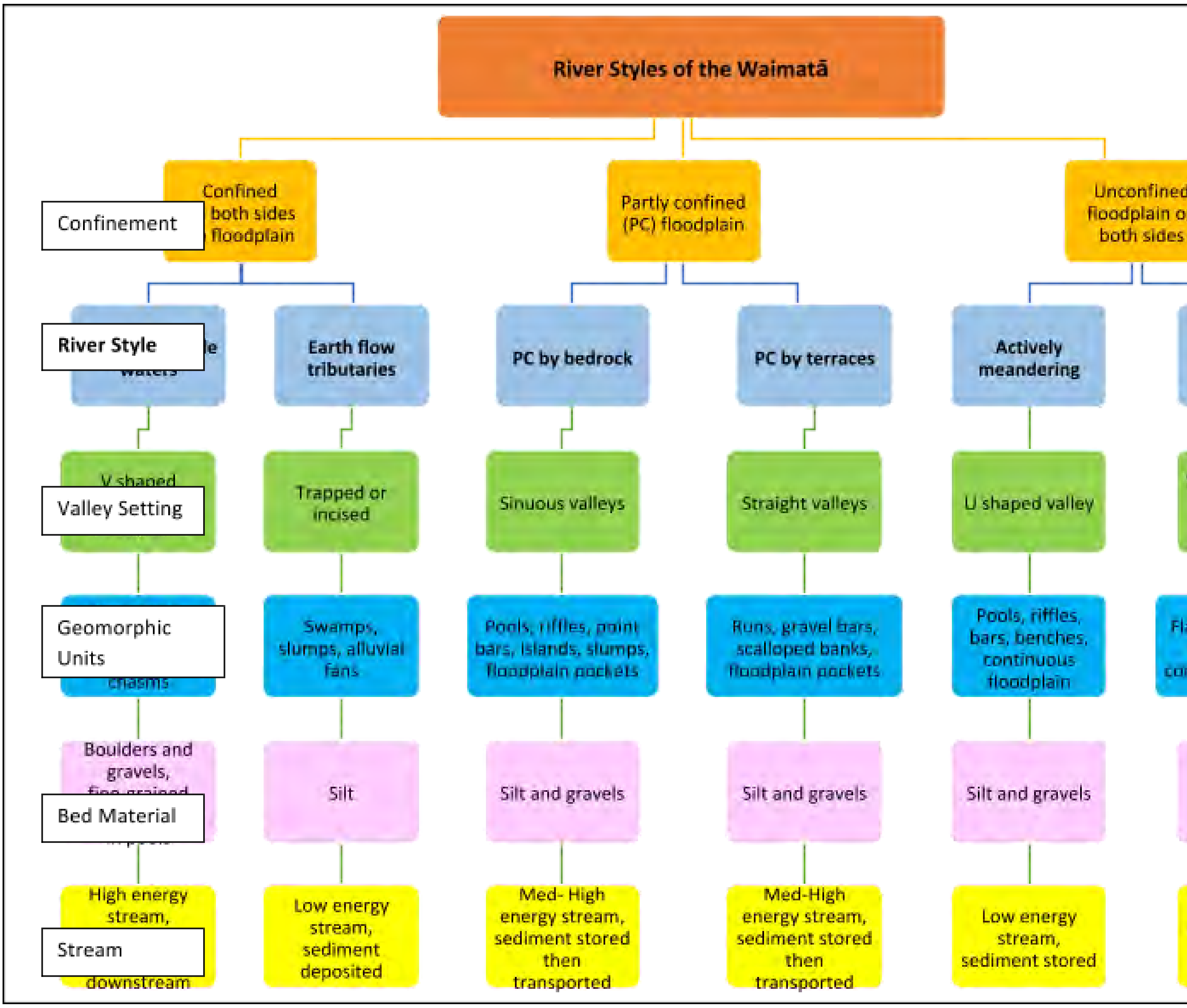


Figure 1.3: River Styles tree for the Waimat   catchment

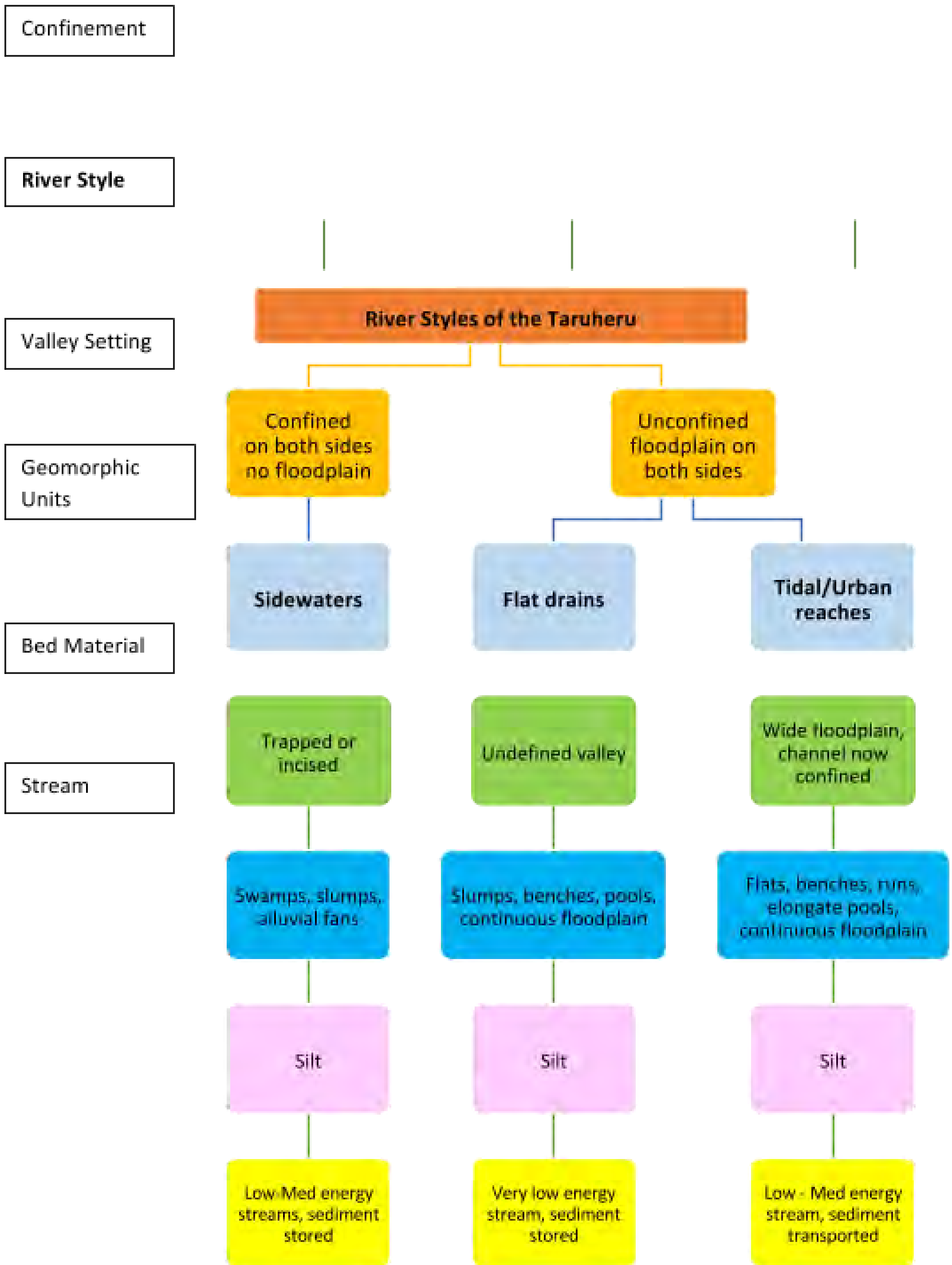


Figure 1.4: River Styles tree for the Taruheru catchment

Defining attributes and capacity for adjustment

Although river condition may change, for example in response to changes in sediment inputs consequent on vegetation changes, these changes are constrained by the valley setting. Thus the different settings of each river style mean that each style has a different capacity for adjustment (Table 1.1). The vast majority of the streams in the Waimatā and Taruheru catchments have extremely low capacities for adjustment. Indeed, only 1% of stream length in the two catchments has a high capacity for adjustment, and only 18% have medium capacity.

Table 1.1: Defining attributes and capacity for adjustment of river styles in the Waimat and Taruheru catchments

River Style	*Defining attributes*	*Capacity for adjustment*	*Comments*	*% Total stream length*
Steep headwaters	Slope map shows stream confined between steep valley walls. No floodplain	Low	Little/no capacity for adjustment, since the channel and bed is confined by bedrock, both laterally and vertically.	44%
Actively meandering streams	Sinuous streams that have a floodplain on both sides.	High	The channel is free to move across the floodplain, able to incise through relatively mobile sediments both laterally and vertically. There is space for sediment to be stored locally on the floodplains.	1%
Earth flow tributaries	In low relief areas within or adjacent to earth flow regions. Main stems are very sinuous, while tributaries lie in valleys with gentler side slopes than those associated with headwater streams.	Medium	Some space to store sediment locally in valley bottoms. Lateral sediment inputs (e.g. from slumps or landslides) are likely to accumulate at the base of slopes. Streams may later incise through these deposits. There is some capacity for lateral and vertical adjustment via cut and fill activity in response to earth movements.	10%
Partly confined by terraces or bedrock	Slope map shows stream confined on one side, with alternating floodplain pockets. Stream lies within a sinuous valley (terraces) or sinuous valley (bedrock).	Low-Medium	Instream units, such as islands can adjust locally where space permits. However, banks can only adjust on the side that is not constrained by relict terraces. Thus channel width can adjust only where floodplain pockets occur. The bed is generally bedrock, with alluvial pockets.	24%
Taruheru sidewaters	Reaches that fall within landscape unit of the rolling Taruheru hills.	Medium	Some capacity for adjustment. Channel may vary between being continuous and being blocked by swampy infills. Some space to store sediment locally in valley bottoms and on floodplains.	8%
Tidal /Urban reaches Flat drains	Reaches within the urban area or on the alluvial flats.	Very Low	These reaches are artificially constrained to prevent adjustments. Under natural conditions these reaches would adjust freely, wandering across their floodplains through swamps and marshes.	13%

Patterns of river types and their connectivity in the Waimat Valley

Downstream changes in valley width are normally expected in a river system, with comparatively narrow streams and valleys in the source zone that widen through the transfer and deposition zones as the river gains water and sediment. However, confinement in the Waimatā system means that little systematic change is seen through most of the system. Valley widths vary markedly in all sections of the river. Although most streams occupy narrow valleys in the headwaters, wider valleys are seen above choke points, where bedrock constricts flow. Valleys widen in the upper earth flow area, where channels are far less constrained by bedrock. Channels narrow intermittently downstream, particularly in bedrock constrained reaches in high relief areas in the lower - mid catchment. It is only on reaching the lowlands and coastal plains that the river and its valleys are able to widen significantly.

Connectivity between hillslopes and the valley floor can also be interrupted by floodplains and/or relict terraces. In the comparatively low relief earth flow regions and the Taruheru hills, tributaries that fall onto the floodplain of the main stem no longer have the energy required to move the sediment they carry across the floodplain to the main river. Under such circumstances, sediment from upslope areas is stored locally, forming alluvial fans that trap tributaries and prevent them from connecting with the main stem of the river.

River condition
Assessment of geomorphic river condition is based on measures of functionality relative to a reference reach of the same type of river (Fryirs et al., 2016). In making these assessments, appraisals are made of 'what is expected' in terms of process-form linkages for that types of river. Some river types have an inherently simple structure and function; others are inherently much more complex (see Fryirs and Brierley, 2009). In general terms, reaches that are in "good" condition have heterogeneous geomorphic features and flow characteristics, offering a diverse range of habitats for flora and fauna. In turn, these biota reinforce the geophysical diversity present. In contrast, reaches that are in "poor" condition tend to be homogeneous, with little diversity of physical features, capable of supporting only a narrow range of biota.

Many *steep headwater* reaches of the Waimatā are currently in poor condition, being prone to overloading by fine-grained sediments resulting from forest harvesting. Enhanced sediment loads also reduce local biodiversity and create a burden for downstream reaches. Sediment inputs from upstream reaches have infilled some valleys, creating streams that are now *actively meandering* across contemporary floodplains. Because of the lack of vegetation, these floodplains are frequently reworked and are therefore considered as being in poor condition. However, most other reaches can be considered as being in good condition from a geomorphic point of view. Many *earth flow* and *Taruheru sidewater tributaries* are trapped, and are separated from the main river stem by local swampy areas that store sediment at source and provide habitat diversity. Channels in *partly confined reaches* are relatively narrow, showing little signs of the widening associated with such reaches in poor condition. Although there is much local bank erosion, slumps are re-draped with alluvial deposits, forming oblique accretion depositional features that build the banks up again. *Urban reaches* and *flat drains* are highly modified and are artificially maintained in a condition that is desired by local communities and businesses.

Given limited capacity for geomorphic adjustment across the Waimatā catchment, where contemporary river activity is constrained by imposed valley confinement (by bedrock and low terraces), disturbance responses associated with deforestation and land use change have been relatively limited in this system. There is no indication that inputs of sediment from hillslopes has altered process relationships on valley floors. In contrast to other parts of the East Cape (such as the Waiapu and Waipāoa catchments), there are remarkably few landslides and gully networks, so inputs of bedload calibre materials and associated bed aggradation are limited. However, forest management practices in headwater reaches, and earthflow activities in numerous tributaries have resulted in pulsed inputs of fine-grained material (wash and suspended load). These materials overload the system on a temporary basis, but given the relative confinement of the river, materials are flushed downstream relatively easily. As a result, the recovery potential of the rivers is high.

Table 1.2 Condition and recovery potential for river styles in the Waimat   and Taruheru catchments

River Style	*Recovery Potential*
Steep headwaters	Low: Condition depends largely on land use. Tree coverage reduces lateral fine-grained sediment. However, after harvesting, fine-grained sediment inputs increase rapidly. After replanting, 8-10 years are needed before sediment production is significantly reduced (Marden, Pers. Commn.) Short term initiatives to improve condition could include limiting forestry harvesting along riparian stream edges.

Actively meandering streams	Low: This river style can adjust easily - but their condition depends largely on upstream condition and a reduction in the amount of sediment delivered to these reaches.
Earth flow tributaries	Tributaries that are already trapped/ or starting to be trapped have good recovery potential. The development of wetlands can be encouraged by appropriate planting and existing wetlands can be given a high priority for conservation. However, incised tributaries have low recovery potential.
Partly confined by terraces or bedrock	These reaches are in good condition, having changed little, despite high throughputs of fine-grained sediment. There is little or no room for lateral movement of the channel, except in the low relief, wider valleys of the earth flow zone. Bank erosion is local and tends to self-repair, with no overall widening of the channel. Judicious planting on floodplain pockets that are well defended from slumping would improve local condition and enhance downstream prospects.
Taruheru sidewaters	The deep legacy sediments in these valleys mean that many tributaries are trapped and that few are incising. Trapping can be encouraged through careful planting of incipient wetlands.
Tidal /Urban reaches	These reaches are highly modified, so the only recovery interventions possible are the use of 'softer' engineering options that give the river more freedom to move and the introduction of artificial niches that provide habitat heterogeneity.
Flat drains	These highly modified reaches provide a valuable service to horticulture. Local patches of wetland would enhance biodiversity in this area.

Conclusion

In many other parts of the East Cape deforestation and landslides have generated large 'slugs' of sediment stored in river floodplains and channels, degrading rivers to a poor condition. However, the Waimatā is quite different, retaining a remarkably good condition from a geomorphic point of view. This is largely because the river is fixed in position by bedrock and terraces, such that there is no accommodation space for large volumes of sediment down much of its length. The river acts as a chute, efficiently flushing sediment through the system to the sea, with little effect on channel morphology, but contributing to sediment accumulations at the river mouth. Thus efforts to improve the condition of the river should focus on reducing the sediment load at source, increasing the capacity to trap sediments at source, in the headwater regions and in the sluggish tributaries of the earth flow zones and the Taruheru hills. Moreover, we recommend further research to examine trends in the accumulation of sediments at the river mouth (e.g. analysis of any dredging records or sediment cores).

Acknowledgements

This project was funded by a PBRF (Performance Based Research Grant) awarded to Professor Gary Brierley by the School of Environment at the University of Auckland. It also contributes to a cross-faculty SRIF (Strategic Research Initiatives Fund) project lead by Professor Dame Anne Salmond, Maori Studies. Dr. Mike Marden of Landcare Research is gratefully acknowledged for his valuable contributions. We have benefitted enormously from the insights he has gained from a lifetime's study of the geomorphology of this area.

Table of Contents

1 INTRODUCTION

2 Aim of this report

It is increasingly recognised that the most effective and sustainable approaches to environmental management 'work with nature', striving to protect and enhance natural mechanisms that generate and sustain desired states, addressing the causes rather than the symptoms of environmental degradation (Folke, 2006; Fryirs, 2015; Holling and Meffe, 1996; Poff et al., 1997). Such strategies require insights into how systems work and the drivers and controls upon this functionality. To gain this understanding, we need to meaningfully describe a system, assessing system components, interactions, interdependencies and evolutionary traits. This information can then be used to analyse the trajectory of change of the system and predict likely system futures under various scenarios (see Brierley and Fryirs, 2016).

Both our lack of understanding and the uncertainties inherent in complex systems such as ecosystems prevent the construction of detailed process models that generate precise predictions. Nevertheless, many insights can be gained through describing the biophysical template that constrains the character and behaviour of a river system, including process relationships on both hillslopes and valley floors. This template consists of repeating patterns of river morphologies, landforms, drainage networks, soils, and vegetation that constrain a wide range of ecological processes within a particular location, providing a fundamental spatial context for both the study and management of ecological systems.

However, both humans and animals manipulate the spaces they live in, creating new relationships, interdependencies and dynamics in what is often described as a 'socio-ecological' system (Berkes et al., 1998). In New Zealand, humans dramatically altered pre-settlement ecosystems through deforestation, agriculture and introduced mammals and plants. Like much of New Zealand, the landscapes of Waimatā are still adjusting to these changes. However, both the patterns of human interventions and the dynamics of the ever-changing socio-ecological system are constrained by the biophysical template, which itself evolves and adapts, bearing the imprint of history. By relating the history of human activities to the remnant traces of past events that are still visible in the landscape, we are able to piece together the 'ethnography' of a landscape. Reconstructing the history of the landscape itself is a key part of this process. This history offers lessons for the future, informing our foresights as to how the landscape may respond to possible future scenarios.

This report describes the geomorphic template for the Waimatā and Taruheru catchments, near Gisborne, New Zealand. Prospectively, this provides a critical basis for policies aiming to ensure that the rivers, hillslopes and people can continue to support each other in a healthy and sustainable fashion (a state of 'ora'). The report focuses on geomorphic aspects of the biophysical template, rather than on water quality or land use issues. River reaches and landscape types are classified in a way that distinguishes between places subject to different sets of land forming processes, such that members of a class are likely to respond in similar ways in response to environmental change or human interventions.

Given that this template constrains the character and behaviour of the entire system, a description of the template provides a context for integration of understandings across disciplines and a platform to link discourses from social and natural sciences with policy and management concerns. An appreciation of the biophysical template and the constraints it imposes on the wider socio-ecological system also supports efforts to assess the physical integrity of a system and the potential for adjustment towards a desired system state.

Deciding on a preferred state for landscapes and rivers is always a delicate balance between using the ecosystem services the system provides, whilst ensuring that the ecosystems themselves are not threatened by such use and that biodiversity is conserved or enhanced. Thus the preferred condition for each river style (within its boundary conditions) is a matter for community and stakeholder debate, and cannot be prescribed by this report. However, this report can inform such debate by considering the key issues and available options. We can also suggest what it might be useful to measure, tracking changes along the current trajectory as well as movements towards desired states and threats to their realisation.

3 Approach

The biophysical template can be described at many spatial and temporal scales (Table 1.1). Here, we focus on repeated patterns of forms and processes:

- at *regional* scales, where both contemporary and historical climate and geology control topography, drainage patterns and the types of soils and vegetation.
- at *catchment* scales, where the character and behaviour of hillslopes and channels are influenced by their position in the river network and the degree and frequency of connections that fashion water and sediment fluxes.
- at *reach* scales, where particular soils and vegetation associated with different hillslope positions, drain into sections of river that have a typical, near uniform, morphology. Both hillslopes and channels are shaped by factors such as the prevailing water and sediment fluxes, the history of disturbance events, the nature and extent of vegetation cover and ecosystem 'engineering' by both animals and humans.

We use the River Styles Framework to classify river reaches and landscape types in the Waimatā and Taruheru catchments and to recommend priorities for intervention (Table 1.2). We focus on Step 1 of the framework, defining the various river styles found in the Waimatā and Taruheru catchments, describing the character, likely behaviour and capacity for adjustment. Steps 2-4 are limited to a consideration of the range of variability for each style and interventions that might promote improvements to its current condition.

This report pays particular attention to the ability of the channel to:

- erode, transport or store/deposit sediment
- adjust its bed and bank morphology
- move across the floodplain and
- contain floodwater.

Although each individual stream has its own history, streams of a certain style are subject to the same behavioural drivers and controls, such that they are likely to share similarities. For example, streams of a particular style are likely to have responded to artificial confinement, catchment deforestation or sediment inputs from landslips in similar ways. Streams of the same style are also likely to respond to future changes in similar ways (Brierley and Fryirs, 2016).

Table 1.2: Description of scales observed in fluvial geomorphology (adapted from Brierley and Fryirs, 2005).

Spatial Scale	Timeframe of Evolutionary Adjustment	Frequency of Disturbance Events	Description
Ecoregion	10^5-10^6 Years	10^5-10^6 Years	Climate, tectonic, and lithological characteristics act as controls on vegetation cover, substrate, flow and other factors that determine the boundary conditions within which catchments function.
Catchment	10^5-10^6 Years	10^3 months	Catchment boundaries define distinct topographic and hydraulic entities. The catchment environment frames the boundary conditions within which rivers operate, constraining the range of behaviour and morphological attributes. Catchment geology, shape, drainage density, tributary-trunk interactions, etc. influence the nature, rate and pattern of forms and processes.
Landscape Unit	10^3-10^4 Years	10^2 months	Catchments can be differentiated into landscape units. These areas of distinct topography (elevation, slope and degree of dissection) are a function of slope, valley confinement, and lithology. They not only determine the calibre and volume of sediment made available to a reach, but also impose major constraints on the distribution of flow energy that mobilises sediments and shapes river morphology. Valley setting differentiates the erosional (confined valley), transport (partly-confined valley) and depositional (unconfined valley) zones of a catchment. The channel, riparian zone, floodplain, aquifer and hillslopes influence sediment and flow connectivity.
Reach	10^1-10^2 Years	10^1 months	Topographic constraints imposed by landscape units result in differing structural and functional attributes along the channel. Geomorphic character and behaviour vary for reaches within different valley settings. Reaches are defined as 'sections of river along which boundary conditions are sufficiently uniform such that the river maintains a near consistent structure' (Kellerhals et al., 1976). Reach structure consists of arrays of erosional and depositional landforms (geomorphic units).
Geomorphic Unit	10^0-10^1 Years	10^0 months	The availability of material and the potential for it to be reworked in any given reach determine the distribution of geomorphic units, and therefore river structure. Some geomorphic units comprise forms that are sculpted into bedrock, e.g. cascades, pools and waterfalls; while others are depositional units, e.g. gravel riffles, bank-attached and mid-channel bars. Geomorphic units are also differentiated on floodplain surfaces – e.g. levees, back-swamps.
Hydraulic Unit	10^{-1}-10^0 Years	10^{-1} months	Flow-sediment interactions vary with flow stage and range from fast flowing variants over a range of coarse substrates to standing water environments on fine substrates. Hydraulic units are spatially distinct patches of relatively homogeneous surface flow and substrate character. These distinct patches provide specific habitat conditions. While large sediments provide greater surface area for insects to cling to as well as protection from hydraulic forces, slow-deep pools and shallow flow on riffles offer various breeding, feeding and cover conditions.
Microhabitat	10^{-1}-100 Years	10^{-1} months	Features at this scale include individual elements such as logs, rocks and gravel patches. The types of species assemblages that develop are controlled by the conditions created at this local scale via the variability in surface roughness, flow hydraulics, and sediment availability and movement.

Table 1.2: Stages of analysis in the River Styles framework (Brierley and Fryirs, 2005).

Step 1: Assess river character and behaviour, defining river styles found in the catchment	*Character:* Valley setting, channel profile and planform, geomorphic units and bed texture

	Behaviour: Process-form associations of river character and geomorphic units. *At catchment scale*: Pattern and connectivity of different river styles, including slope, relationship to hillslopes and valley morphology, sediment and water fluxes, discharge and stream power.
Step 2: Assess current condition in the context of the natural range of variability	'Expected' range of variability for each river style. Drivers and controls on the current condition.
Step 3: River histories and futures	Assessment of river evolution to scope possible future scenarios, given reach and catchment-scale sensitivities to human interventions and environmental change. Identification of pressures and processes that may compromise future river condition.
Step 4: Catchment based visioning, identification of target conditions and management priorities	Based on the identification of condition and recovery potential for each reach and the whole catchment, given system connectivities and the range of variability within natural boundary conditions.

3.1 *Methods*

The report is based largely on a 3 day field visit in September 2014, when the rivers were in high flow, following a large flood event the previous month. It is neither comprehensive nor inclusive of the vast amount of knowledge that is undoubtedly held locally. Indeed, the report will never be totally finished - it is a living database - a starting point for ongoing research and initiatives that deepen our understanding of the system.

We focus on Step One of the River Styles framework (Brierley and Fryirs, 2005), which involves

- Assessing the regional setting, considering the drivers and controls that influence catchment processes (Section 2)
- Defining and mapping landscape units (Section 3)
- Defining and mapping river styles, interpreting controls on the character and behaviour of each river style and determining its capacity for adjustment (Section 4)
- Considering the downstream patterns of river styles and connectivity within the entire catchment (Section 5)

Assessment of the regional setting draws on a literature search supplemented by maps and guidance provided by Dr. Mike Marden of Landcare Research, who has spent many years studying the geomorphology of this region and mapping the relict terraces within the Waimatā and Waipaoa catchments.

The definition of both landscape units and river styles are based on observations and analysis of remotely sensed data, in particular the 2012 suite of aerial photographs and the LINZ 8m DEM. Interpretations of the behaviour of each river style are based on observations of valley and channel geometry, bed and bank materials and the nature of geomorphic units in each reach. Together, these observations provide evidence for the contemporary regimes of sediment erosion and deposition and the capacity for adjustment for each river style. This analysis enables an assessment of the current condition of each style in relation to the range of potential variability. It also provides a simple measure of sensitivity to change, whether in response to natural events or human interventions.

3.2 *Limitations of this study*

This broad assessment of the study area is based largely on field observations along the main stem of the river, extrapolating the classification across the entire study area using GIS analysis and a map of historic terraces kindly provided by Dr. Mike Marden. As time and resources permit, we recommend that the classifications are validated by inspecting a large sample of locations throughout the catchments.

Indeed, any classification (and, indeed, any map) is highly subjective (see Cullum et al., 2016). Numerous decisions are involved in attempts to represent multifaceted landscapes that contain continuous gradients of numerous attributes at many scales. Selecting the attributes and scales of analysis, constructing classes and drawing boundaries is not an exact science and no two locations are identical. Therefore our aim in constructing the maps and classifications presented in this report is not to delineate precise class or positional boundaries, but to represent broad similarities and differences in forms and processes that are likely to provide useful contexts for management decisions.

REGIONAL CONTEXT

4 Introduction

The regional context of any catchment exercises significant control over the character and behaviour of rivers and landscapes. For example, climate patterns control hydrological flows (e.g. the frequency and intensity of floods), whilst geology and the relative permeability of rocks controls water infiltration and hence influences soil development, susceptibility to landslides and sediment inputs to rivers. Together, climate and geology are key controls on vegetation types, which in turn influence patterns and rates of hillslope and fluvial erosion and deposition. All these factors influence human decisions about land use. However, although the regional context constrains the character and behaviour of landscapes, and their use by humans, the context does not determine landscape history, such that wide variability is usually found at local scales.

The Waimatā catchment is located within and to the north of Gisborne City. The river flows almost due south, joining with the Taruheru River in the centre of Gisborne, and flowing into Poverty Bay via the very short (<1 km long) Tūranganui River (Figure 2.1). Whilst the Waimatā travels for most of its length across finely dissected, steep terrain, the Taruheru flows south-east across the Poverty Bay flats.

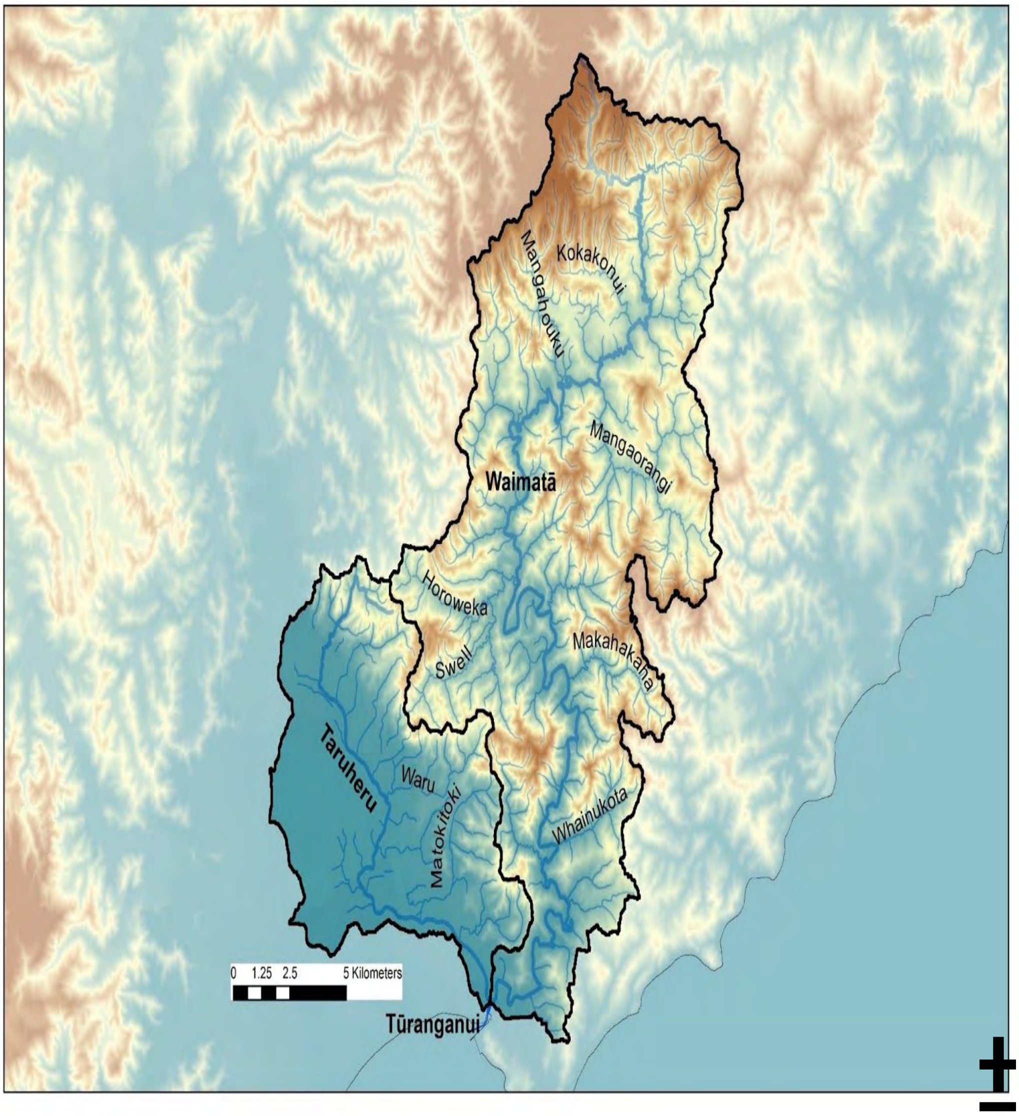


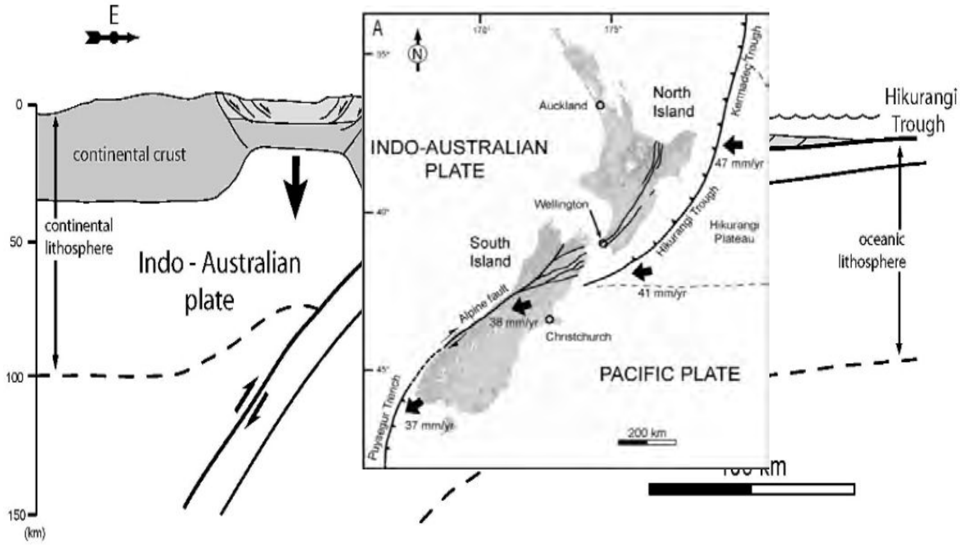
Figure 2.1: Location of the Waimat and Taruheru Rivers

5 *Climate*

The regional climate is warm temperate maritime, with warm moist summers and cool wet winters (Marden, 2011). Mean annual rainfall is around 1,000 mm/year at the coast, rising to 1,300 mm/year in the headwaters (Hicks et al., 1996; Liébault et al., 2005). Rainfall is high all year round, such that intra-annual variability is low compared to many other places (coefficient of variability = 9%, compared to 17.5% in Australia) (Finlayson and McMahon, 1988). The area is subject to frequent intense rainstorms from March to May when tropical cyclones arrive from the north (Marden et al., 2011; Page et al., 1999). During the large *ex*-tropical Cyclone Bola in March 1988, 300-900 mm of rainfall fell over three days (Page et al., 1999). Furthermore, the climate is strongly influenced by the El Nino Southern Oscillation with an increase in significant rainfall events during La Nina conditions and considerable and extended droughts during El Nino phases (Marden et al., 2011; Plummer et al., 1999). Frequent floods and intense rainstorms contribute to high rates of hillslope erosion and cause substantial damage to infrastructure such as roads, bridges and buildings.

6 *Geology*

The Waimatā catchment lies adjacent to a major tectonic boundary. Offshore, the Pacific Plate is moving under the Indo-Australian Plate at the Hikurangi subduction margin at a rate of up to 6 cm a year (Wallace et al., 2009), so that faults and earthquakes are common and uplift rates are high (Figure 2.2).



Taupo volcanic region

Waimat

B

Figure 2.2: a) The tectonic setting of New Zealand. b) The location of the Waimat catchment in relation to the Hikurangi subduction zone (modified from Bailleul et al., 2007).

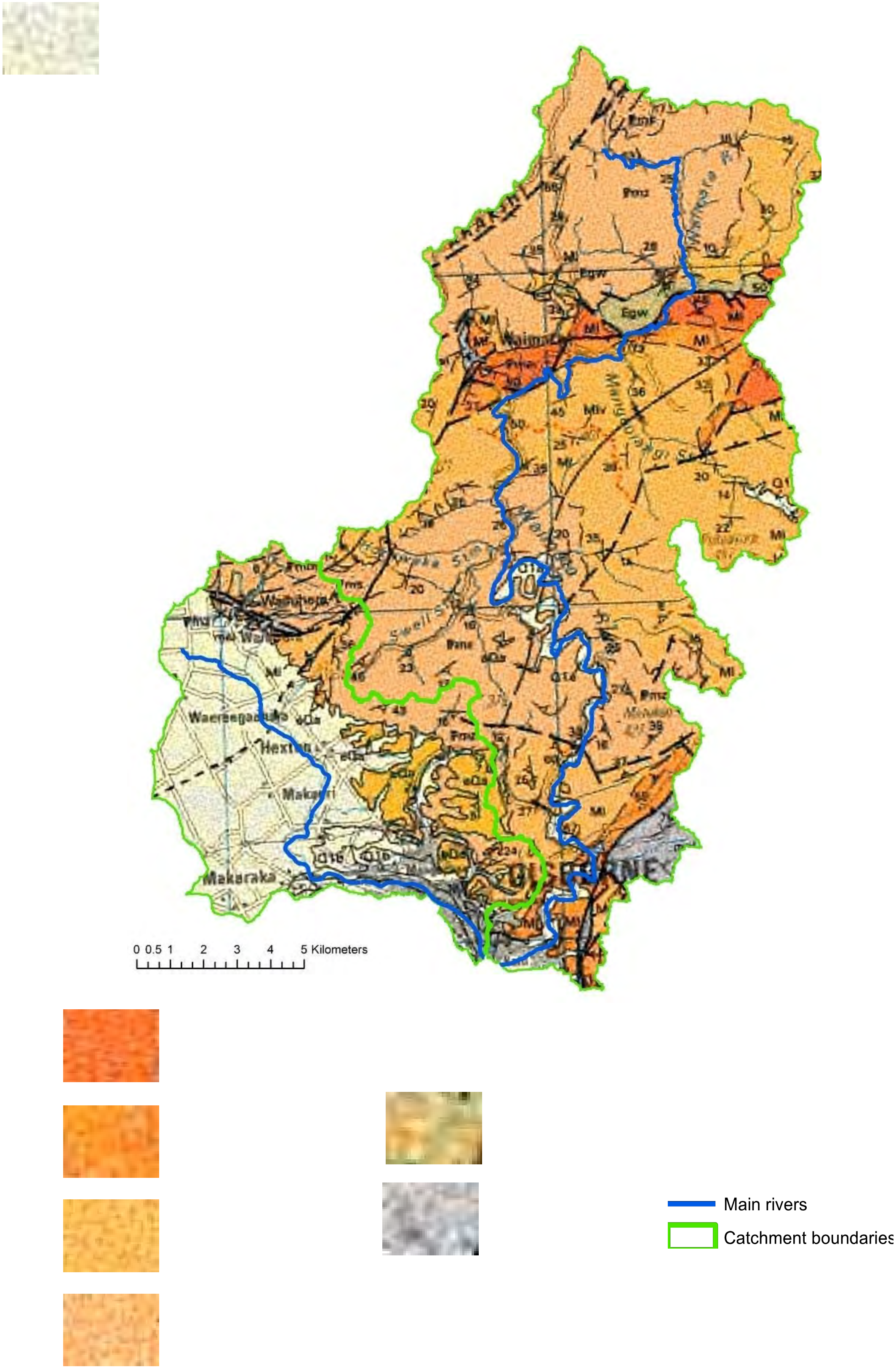
The headwaters of the catchment lie in the foothills of the Raukumara Ranges, which are formed from sedimentary rocks originating in marine environments (Figure 2.3). These rocks continue to be uplifted over the continental crust at a rate of about 3 mm a year (Wilson et al., 2006). The sedimentary sequences are primarily mudstones, with rare sandstones, conglomerates, limestones and intercalated tephra (volcanic ash). Similar lithology is found throughout the Waimatā catchment, with mudstones of different ages being thrust over each other through geological time (Mazengarb and Speden, 2000). These rocks are easily weathered, yielding considerable amounts of sediment as they are uplifted and then eroded. The more recent mudstones, found in the headwater and lower-mid catchment areas are associated with higher relief landscapes compared to areas with older geologies.

Some 200 kms inland, eruptions in the Taupo volcanic zone release the underground pressures and molten magma generated by subduction. Tephra (ash) from many eruptions has periodically draped the landscape. Although tephra is easily eroded, if not blown away, much remains. Since the tephra from each eruption has a distinctive colour and chemistry, these layers are extremely useful in dating the various exposed features and landforms found within the catchment.

Also easily weathered are the older mudstones that contain smectitic clays. A band of such material stretches across the upper catchment, continuing eastward to the coast. Smectites are also found in the melange rocks in the lower catchment. Smectite clays allow water to be absorbed between the weakly bonded sheets of molecules, such that layered rocks shear easily when water is present. This process facilitates the formation of earthflows which typically fail along a basal shear plane at depths between 0.5-0.6 m, with the displaced material forming a highly erodible, low relief landscape (Marden, 2011). When soils are persistently wet, large and sudden earthflows can occur on slopes between 5° and 25°, when the normally very slow movement speeds up, moving metres to tens of metres per day. In dry periods, earthflows can remain stable for periods as long as decades to centuries (Marden, 2011).

The geology of the Taruheru catchment is quite different. Along the eastern border, the mudstone hills have been eroded and fragmented by the encroaching floodplains of the Taruheru and Waipaoa rivers. Most of the catchment consists of alluvial flats, built up through numerous flood events.

The combination of tectonic activity and soft rock makes the East Cape region have some of the highest sediment yields per unit area in the world (Hicks et al., 1996). The total sediment yield from the Waimatā catchment since the Last Glacial Maximum (LGM) has been estimated at 2.6 km^3, most of which has been transported by the rivers to the ocean (Marden et al., 2014).


Makaraka
Hexton
0 0.5 1 2 3 4 5 Kilometers
Main rivers
Catchment boundaries

MI
16 mya
13 mya
4 mya
40mya
10 mya
<1.mya
Folds

Faults
Mudstone: slightly calcareous with beds of sandstone, tuff and conglomerates
DATES ARE APPROXIMATE – FOR COMPARISONS ONLY
Smectitic mudstone and greensands with beds of sandstone, tuff and conglomerates
Mixed
Recent alluvial deposits
Melange: Mixed rocks East Coast Allochthon
Figure 2.3: Extract from the 1:250,000 geological map of the Raukumara area (Mazengarb and Speden, 2000).

7 Relict terraces

Against the backdrop of ongoing subduction, the Waimatā catchment bears the imprint of changes in sea levels associated with long term climate changes in the Pleistocene era. At the Last Glacial Maximum (around 14,700 years ago), sea level was some 120m lower than present. Since then, periods of relatively high fluvial incision have alternated with periods of relatively low incision during which floodplains formed. With each new incision event, floodplains were abandoned and remain today as remnant terraces. During erosion periods, hillslopes were steepened and valleys filled with sediment. Subsequent sea level rise drowned lowland valleys, leaving terraces at valley margins. The landscape now bears the imprint of multiple cycles of erosion and deposition associated with climate changes over millennia. Flights of terraces border banks along almost the entire river. These terraces resist erosion, effectively pinning the course of the river to a fixed position, within narrow valleys that have little space to store sediment (Fryirs et al., 2016; Fryirs and Brierley, 2010)., with flights of terraces now bordering banks along almost the entire river (Figure 2.4). Each cycle has left its own series of terraces along the river, such that seven separate surfaces can now be identified in the Waipaoa catchment (Berryman et al., 2000; Marden et al., 2014). Contemporary hillslopes are still adjusting to these changes. Numerous landslides reflect adjustments where hillslopes steepen themselves to bring them into equilibrium with contemporary base levels (Marden et al., 2014).

Contemporary floodplain

4 Levels of relict terraces

Figure 2.4: Relict terraces along the course of the Waimat .
These terraces are associated with falling sea levels and the incision of the river through previous floodplains. Each terrace was once a floodplain.

8 Landslides

Sediment also enters the system from landslides. Many landslides have been recorded in the last hundred years or so. For example, in 1955 a large slump near Darwin road created a new lake on the hillside, and in 1958 a large landslip near Waimiro station blocked the river until a channel was cleared (Figure 2.5). During an 1892 flood, engineer Napier Bell estimated 2.47 million m^3 of silt was transported along the Waimatā River in just 24 hours (Reeve, 2015).

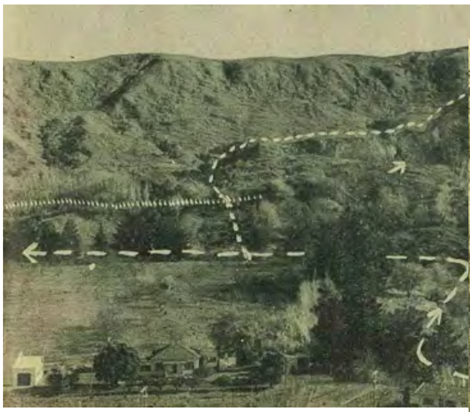


Figure 2.5: Historical evidence of landslides in the Waimat valley a) 1955: A view from above Darwin Road on the opposite side of river shows the extent of the slip, enclosed by a dotted line. The fine dotted

line shows road entering and leaving the slip area and the course of the Waimat River is shown by the heavier line in foreground. The arrow on hillside indicates the position of a lake formed by the slip. b) Close up of the slip. c) 1958: Landslip into the Waimat River. d) After a few hours, the river had already backed up to some 20 m above normal level, while the lower river bed was virtually dry. (PHOTOS: Gisborne Herald)

9 Land Use

Like much of New Zealand, deforestation in the East Cape region occurred in two phases. Maori settlers arrived in the 14th century and burned most of the lowland forest. More extensive and rapid land clearance came with European settlement between 1880 and 1920 (Glade, 2003; Wilmshurst et al., 1999). Further clearance was encouraged by government-led incentives in the 1960s and 1970s. Thus native podocarp-hardwood forest now accounts for only about 2.5% of land cover in the East Cape region. Each period of deforestation was followed by extensive hillslope erosion, floodplain sedimentation, widening of downstream channels due to sediment scouring, and aggradation of channel beds.

From the 1960s, many pine plantations were established in the Waipaoa as government-subsidised soil conservation initiatives (Marden et al., 2012). Reid and Page (2003) modelled the probability of landslide occurrence in the Waipaoa catchment, to ascertain how afforestation may have altered landsliding during Cyclone Bola in 1988. They suggested that targeted reforestation of steep slopes (>20°) in landslide prone areas could have reduced landslide sediment delivery by 40%. Afforestation of the entire landslide-prone region (50% of the catchment) could have reduced it by up to 80%.

Pine plantations in the Waimatā came somewhat later, mostly in the 1990s, seeking to conserve soil and repair damage caused by Cyclone Bola. However, most plantations are now commercial forestry businesses, and many have been sold to overseas owners (including much of the forests in the headwaters of the Waimatā catchment).

These plantations are now being harvested, prompting new concerns for soil erosion and increased sediment loads in the rivers.

The combination of weak lithology, steep slopes resulting from uplift and incision, high rainfall, frequent storms, and forest removal make this landscape exceptionally prone to landsliding and slumping. Eroding East Cape hill country and the huge sediment yields of the East Cape rivers have been documented for decades (e.g. Gibbs, 1959; Marden et al., 2012; Phillips, 1988). Indeed, the East Cape region generates some 33% (69 megatonnes/year) of the North Island yield, despite occupying only 2.5% of land area (NIWA, 2014; Page et al., 2007).

An extensive flood control scheme, completed in 1969, created high value horticultural land on the Taruheru and Waipaoa floodplains. The floodplain was drained and the streams of the Taruheru are now intensively managed as part of an irrigation network for the crop lands. An ambitious $16m upgrade to the scheme was agreed in February 2016, aiming to protect the area in the face of predicted climate change and sea level rise. Starting in 2017/8, the works will take about 15 years to complete (Gisborne Herald, February 3, 2016). In the urban area of Gisborne, rivers are contained within timber and concrete revetment walls that are designed to contain and control flood flows.

LANDSCAPE TYPES IN WAIMAT AND TARUHERU CATCHMENTS

10 Systematic patterns of landscape morphology, hydrology, soils and vegetation

Landscape types describe topographic areas that differ from each other in terms of landscape-forming processes, in particular those processes that result in different water and sediment inputs to the channels, such as:

- Rate of sediment production / susceptibility to hillslope erosion
  - related to geology/ soils/ tectonics/ land use/ rainfall
- Energy available to move materials through the landscape
  - related to relief, slope, discharge area
- Resistance to erosion
  - related to vegetation, land use, soils

The degree to which hillslope and channel flow paths are connected within a particular landscape type determines the ease with which sediment and water can flow across and through the landscape. Relationships between hillslopes and the valley floor also change through the stream network: further downstream, as more water is discharged into channels, streams have wider and deeper channels, flowing within wider valleys where sediment accumulates and is stored on floodplains (Schumm, 1977). Floodplains may disconnect channels from lateral inputs of sediment from hillslopes. Tributary/ trunk connections may also be interrupted by the accumulation of sediment within tributary valleys (Fryirs, 2013). Such 'choke points' slow the flow of water and sediment across and through the landscape. They can, over time, lead to an upstream build-up of sediment and debris, changing patterns of flow and sediment transfer.

These processes interact to shape topography over multiple scales in time and space. Over geological time scales, patterns of landscape dissection emerge within the constraints of the overall regional context that characterise local areas, each with distinctive valley spacing, hillslope gradients and local relief. At hillslope scales, soil, vegetation and topography co-evolve to form 'catenas' – toposequences of soil and vegetation that control hillslope hydrology.

Landscapes are not only shaped by interactions between biota and physical factors, but also by the way humans use the land. However, land use is often constrained by biophysical conditions, such that geographical areas with similar physical and biological characteristics and processes also have distinct land uses. For example, the potential for different types of agriculture is related to gradient, soils, fertility, microclimate etc. – the same factors that control the distribution of natural vegetation. Thus interactions between physical, biotic and cultural factors shape areas in distinctive ways, leaving a lasting imprint of the intertwined histories of rocks, landforms, vegetation and humans in a particular area.

At a finer scale, each landscape type would, under natural conditions, show characteristic patterns of soil and vegetation along each hillslope. These catenas are formed by co-evolved associations between hydrology, soils, vegetation and morphology that tend to differ systematically down slopes within a certain geological and climatic setting. Although, these relationships are altered by human interventions (e.g. deforestation), some patterns can still be observed. For example, in the headwater areas of the Waimatā, relatively pervious ash (tephra) sits atop relatively impervious mudstone (Figure 3.1). Although the ash layer is easily eroded (it blows away once topsoil is removed), intact layers are often seen on relatively flat crests. Here, darker, greener grass is seen on the relatively fertile soils. Further downslope, gradients steepen and deforestation has induced soil erosion and landslides, so that soils are thin and fragile, unsuitable for farming and are now reforested with pine. The steep V shaped valleys have no floodplains. Further downstream, in the steep terrain of the mid catchment, the upper slopes have similar soil-vegetation associations, but flat, relatively fertile land is found on alluvial plains at the foot of the slope, usually restricted to one side of the stream.

Figure 3.1: An exposure in the headwater area of the Waimat , where relatively pervious ash (tephra – the orange layer) sits atop relatively impervious mudstone (the grey layer)

11 Landscape types in the Waimat and Taruheru catchments

Landscape types in the Waimatā and Taruheru catchments are defined in terms of valley morphology, hillslope gradient and geology (Figures 3.2 and Table 3.1). Each of these landscape types has its own history (ethnography) of physical, biotic and cultural interactions, seen today in the patterns of land use that are loosely associated with each landscape type (Figure 3.3 and Table 3.2).

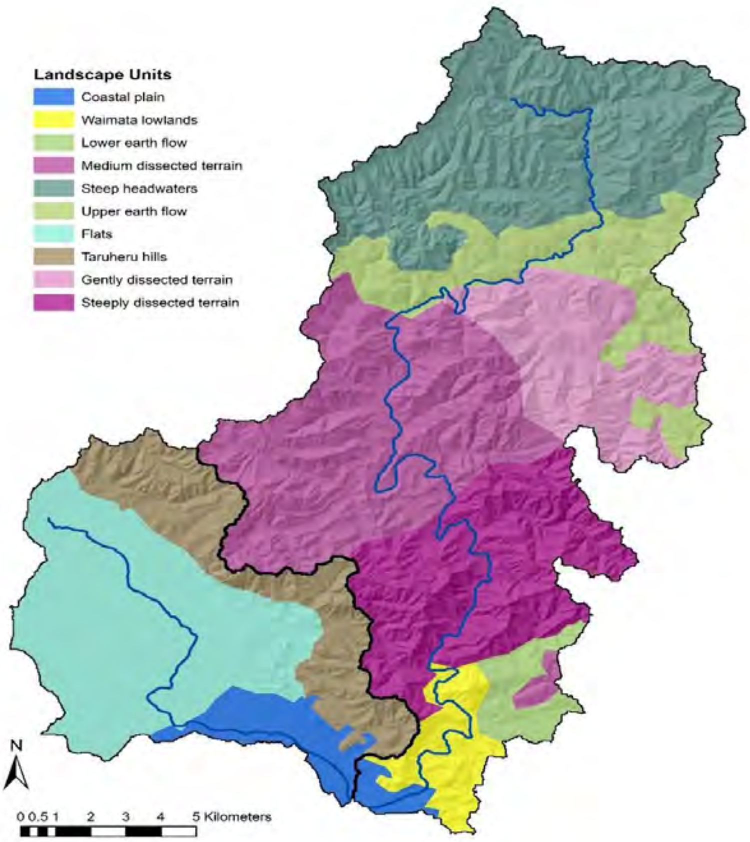


Figure 3.2: Landscape types in the Waimat and Taruheru catchments

Table 3.1: Landscape types of the Waimat and Taruheru catchments

	Physiographic character (Gradient/ Dissection/ Relief)		Dominant contemporary land uses	Landslip susceptibility	Connectivity (Relationshi Trunk/ Tribu
Steep headwaters	Narrow, V-shaped valleys with high, steep sides	Headwaters, source streams throughout Waimatā catchment	Manukā/kanukā scrub, native and exotic forest	High, due to steep slopes	High. Free fl sediment
Earth flow region - Upper	Hummocky, rolling hills, low local relief, gentle slopes	High in Waimatā catchment, though below headwaters	Low- and high producing grasslands	High risk of subsurface earth flows, due to geology	Low: Freque disconnecte infilled by slu downward s movements
Earth flow region - Lower	As above, but less relief	Lower-mid Waimatā catchment	Manukā/kanukā scrub, native forest	Lower risk of earth flows as gentler slopes	
Finely dissected steep terrain	Narrow valleys with high, steep sides. U - shaped, often with	Mid Waimatā catchment	Manukā/kanukā scrub, exotic and native forest	High, due to steep slopes	High. Free fl sediment

	flights of relict flood terraces				
Medium relief dissected terrain	As above, but wider valleys with less steep slopes	Low/High Waimatā catchment	Manukā/kanukā scrub, exotic and native forest	Medium, as slopes are less steep than elsewhere	
Low relief dissected terrain	As above, but still wider valleys and relatively gentle slopes	Low Waimatā catchment	Manukā/kanukā scrub and native forest	Low, as slopes are relatively gentle	As above
Waimatā lowlands	Low relief and very gentle slopes	Low Waimatā catchment	Exotic forest and high producing grasslands	Low	High. Free, c
Taruheru hills	Similar to low relief terrain	Headwaters of catchment	Exotic forest and high producing grasslands	Low, as slopes are relatively gentle	Low: Freque disconnecte infilled
Flats	Extremely flat	Mid/Lower Taruherucatchment (bordering on lower Waipaoa)	Cropland	Very low/none	Low: Channe adjustment a floodplain, w to cut-offs
Coastal plain	Extremely flat	Lower parts of all catchments and Tūranganui river	Urban	Very low/none	Low: Channe adjustment a floodplain, w to cut-offs

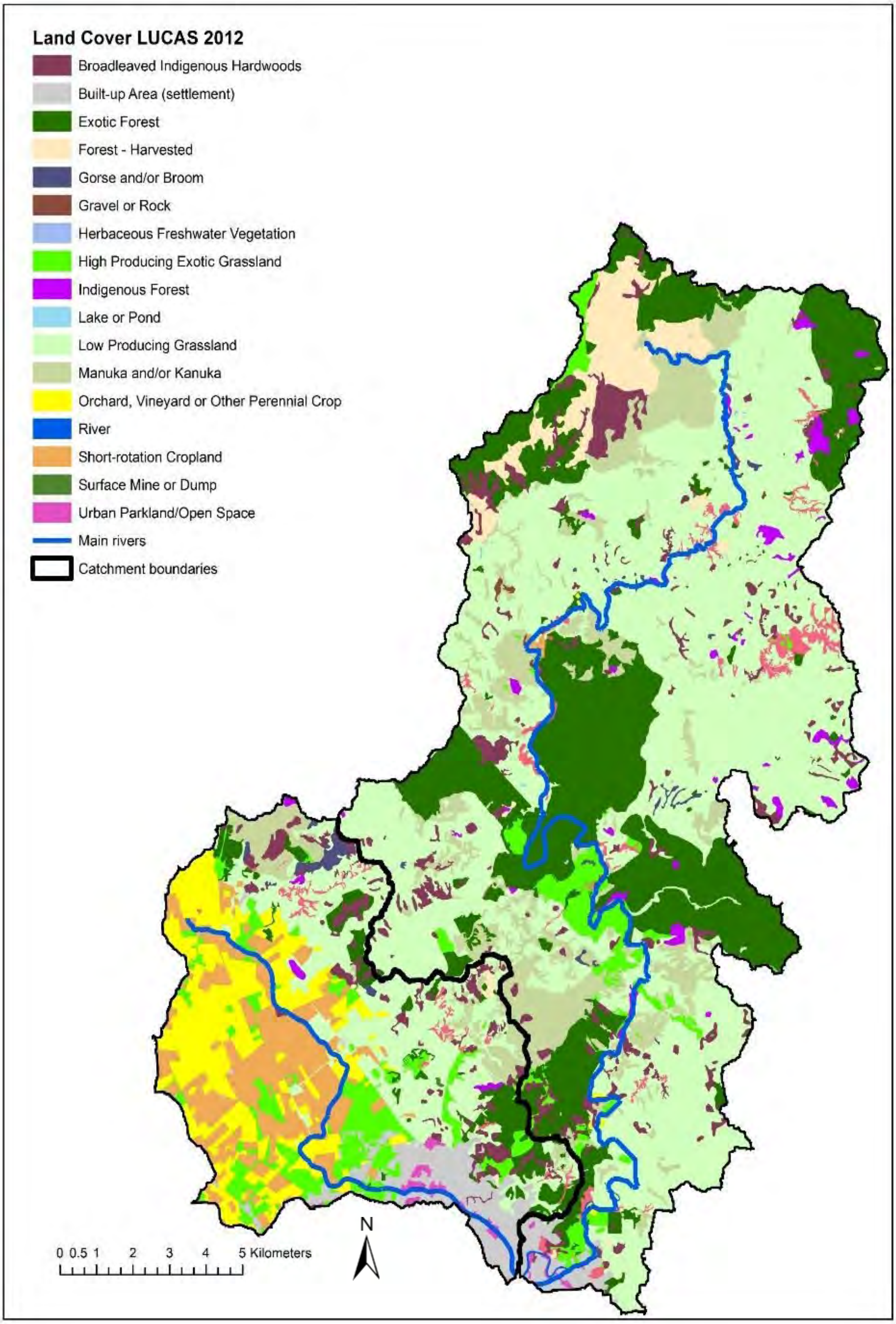


Figure 3.3 Land use (LUCAS) in the Waimat and Taruheru catchments (Ministry for the Environment, 2012)

12 Steep headwaters

Located in the steep headwater region of the Waimatā, these landscapes contain narrow, V-shaped valleys, with occasional chasms. As the area lies atop a tectonic boundary, it is subject to constant uplift and movement that breaks up rocks, destabilises slopes and delivers large quantities of sediment to the streams. Relatively pervious ash (tephra) lies atop relatively impervious mudstone bedrock (Figure 3.4), both of which are easily weathered.

Trees were cleared throughout most of this area by the 1920s, but the thin, fragile soils and increased susceptibility to landslides prompted subsidised planting of pine plantations, at a time when sheep farming was, in any case, falling in profitability. Harvesting of these trees now presents an environmental challenge, since unvegetated hillslopes pose a threat to their stability and prospectively increase sediment inputs to streams. Furthermore, it is likely that soils become thinner and more fragile after each planting and harvesting cycle, casting doubt on the long-term sustainability of profitable forestry in this area. Farming has long been unprofitable – indeed a swathe of land between the steep headwaters and the upper earth flow region was retired from farming and donated to DoC about 10 years ago. It now has a cover of regenerating kanukā and manukā forest.



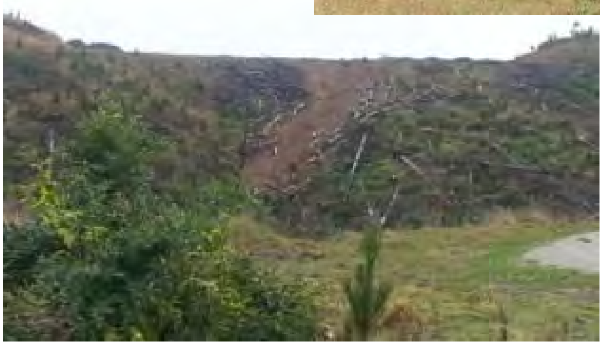




Figure 3.4: Steep headwaters in the Waimat catchment

13 Earth flow regions

Earth flow regions contain distinctive geology (e.g. smectic clays) that is associated with seismic activity and subsurface movement of soil and weathered materials (earth flows). In contrast to the episodic, rapid, surface landslides typical of the steep headwaters, earth flows move slowly, failing along a shear face that is typically 1-2 m below ground. These shallow movements and subsequent erosion generate hummocky, low-relief terrain, with poorly defined stream channels (Figure 3.5). In one area, 'mud volcanoes' bring Cretaceous-age materials to the surface, together with methane and salt.

Earth flow movements also damage infrastructure, such as buildings, roads and fences. Trees often stand on a slant, with contorted trunks. However, despite these drawbacks to settlement and farming, the area has long been settled, boasting a village hall and a school (closed in 2009). Compared to other parts of the catchment, land is relatively flat and fertile. Slopes have more soil and therefore hold more moisture than elsewhere in the catchment, supporting green foliage longer into the summer months than elsewhere.

Trees tend to dampen the effect of earthflows by taking up some of the groundwater that otherwise deflocculates the clays and promotes earth movements. In the 1960s government subsidies encouraged the planting of poplars and willows to mitigate the effects of earth flows. However, these trees are now senescent. As they fall, earth is disturbed and becomes prone to erosion. These days a different species of poplar is used, with stronger, deeper root systems that are not so prone to uprooting on senescence.

The lower earth flow region is in an area of lower relief compared to that bordering the headwaters. It therefore has a lower propensity for earth flow, with reduced risk to infrastructure. However, the hummocky landscape typical of earth flow areas is still seen.

a)

e)

d)

c)

b)

Figure 3.5: Earth flow landscapes in the Waimat catchment

a)

Note the low-relief, hummocky terrain of the lower earth flow region, contrasting with the hills in the background. b) Poplars and willow have been extensively planted to mitigate earth movements and strengthen river banks c) Mud volcanoes in the upper earth flow region. d) Slanted and distorted tree trunks. e) Buried fence.

14 Finely dissected terrain

The middle areas of the Waimatā catchment are characterised by finely dissected terrain. Geological controls (uplift and incision of relatively resistant rocks) have resulted in a pattern that is contrary to that normally found – here the hills surrounding the lower reaches of the river are considerably steeper than those in upstream areas (Figure 3.6).

Valleys are narrow, with steep sides, but unlike steep headwaters, are U-shaped, with relict floodplains in the valley bottom. Flights of terraces now reflect the history of incision into former floodplains.

This land type can be subdivided into areas with relatively

- High relief and steeper slopes, associated with higher risk of landslides and slumps
- Medium relief
- Low relief, with gentler slopes and reduced landslip risk.

a)

b)

c)

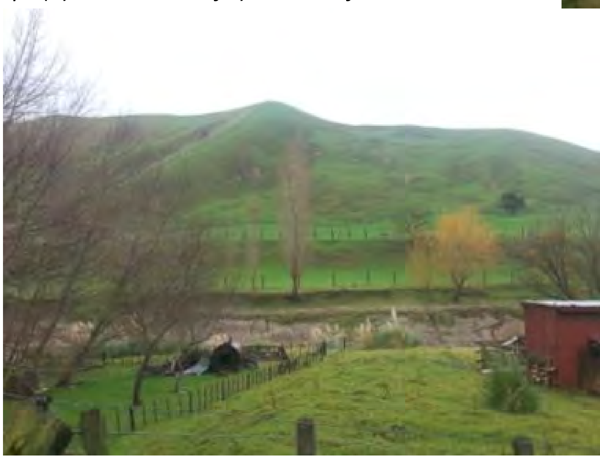


Figure 3.6: Finely dissected steep terrain in the Waimat catchment a) The steep slopes in high relief areas are susceptible to slumps (b) Medium relief c) Low relief dissected landscapes (in background)

15 *Waimat lowlands*

These are areas of comparatively low relief, with wide valleys and relict terraces (Figure 3.7).

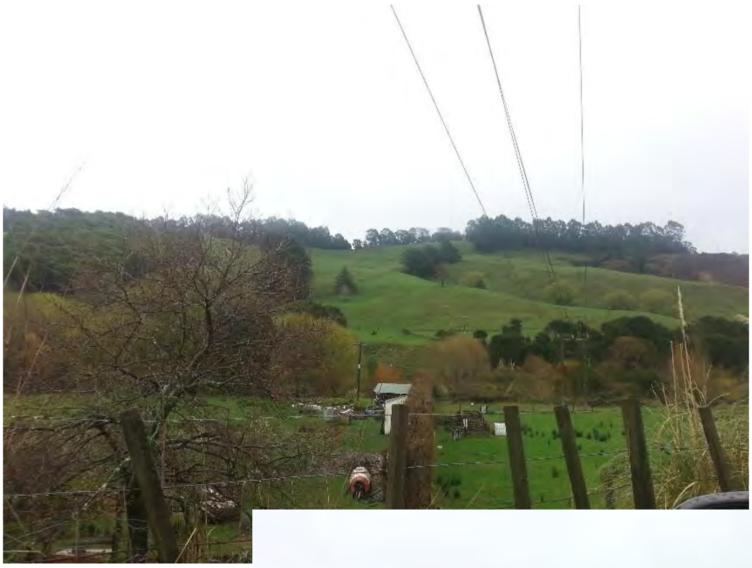


Figure 3.7: Waimat lowlands

16 Taruheru hills

These hillslopes border the wide floodplain of the Taruheru and Waipaoa rivers. The valleys have similar morphology to those found in the low relief, dissected land type, but have been infilled with sediment following deforestation (Figure 3.8). Accumulated sediment in the lower parts of the valleys sometimes prevents tributaries from joining the main trunk of the river, with swamps formed at tributary junctions. These are sometimes referred to as trapped tributary fills. Alluvial fans are common.

Figure 3.8: Taruheru hills
These hills are draped in legacy sediments, deposited from former phases of anthropologically induced sedimentation. In the lower picture, the contemporary stream is incising through a large alluvial fan. A half-buried abandoned channel can be seen to the right.

17 Alluvial flats

The alluvial flats of the Taruheru form part of the Waipaoa floodplain, with gradients less than 20^{0} (although there is some undulating ground with gentler slopes in the south east of this area).

Only a very small remnant (12 ha: Gray's Bush) remains of the native lowland kahikatea forest that once covered this area. Now protected from floods, the fertile alluvial soils provide valuable land for horticulture and vineyards (Figure 3.9). The landscape is highly modified, with the original swamplands drained and streams used as irrigation channels for horticulture.

Figure 3.9: Alluvial flats of the lower Taruheru.

18 Coastal plains

The city and port of Gisborne now straddles the coastal plains. Here the Waimatā and Taruheru join to form the Tūranganui River that carries waters from the Waimatā and Taruheru catchments to the sea (Figure 3.10).

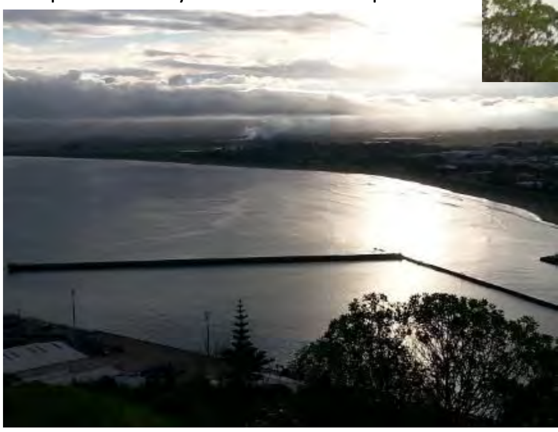
Within the town, many buildings sit on top of relict terraces, whilst the lower elevation, more flood prone areas are used for parks and recreation. This has the effect of connecting the people of the city to the river, which is extensively enjoyed for activities ranging from walking and jogging along the banks to boating and waka ama on the river. Whilst some houses and business premises have clear connections to the river, suggesting that the river is prized/ valued, this is not always the case. The urban area around the mouth of river is changing fast as the old port buildings and warehouses make way for new apartments and hotels.

Boundaries between urban and rural areas are quite sharp, reflecting local land use and planning policies.

Figure 3.10: Coastal plain
The port and city of Gisborne occupy the coastal plains of the Waimat , Taruheru and T ranganui Rivers.

THE CHARACTER AND BEHAVIOUR OF THE WAIMAT AND TARUHERU RIVERS

19 Overview



The character and behaviour of the Waimatā River and its tributaries is largely determined by geology, landscape history and position within the catchment. The various **geologies** found in the catchment produce very different landscapes and rivers. For example, the fragile smectites of the earth flow areas are associated with low relief, hummocky landscapes that offer space for sediment storage and the lateral movement of streams. In contrast, the resistant lithology of the steep headwaters and the finely dissected steep terrain of the mid catchment produce narrow valleys that concentrate flow and limit the space available to store sediment.

The **history** of rising and falling sea levels has left many old terraces that resist erosion and now serve as retaining walls for the contemporary river. These terraces control contemporary patterns of river adjustment and sediment storage throughout much of the length of the river. Between these terraces and bedrock outcrops, the path of the river is severely constrained along most of its length.

Position within the catchment largely determines stream power, the capacity to transport sediment downstream. Stream power generally decreases downstream as gradient decreases and valley width increases, dissipating flow energy. In areas with relatively high stream power (e.g. steep headwaters), sediment is easily flushed downstream. By contrast, in areas of relatively low stream power (e.g. low-relief earth flow areas), sediment is stored locally before being washed downstream in flood events.

The character and behaviour of the Taruheru River is quite different to that of the Waimatā. These very domesticated landscapes are dominated by fertile alluvial flats that have long been used for horticulture. The river has been manipulated to flow around and drain neat fields that produce valuable crops. The dominant control on this river is thus **anthropogenic**. The **position** of the river also influences its character and behaviour. The main stem lies on the edge of the flat plains of the Waipaoa, where the low relief generates little stream power to move sediment.

Different combinations of these fundamental constraints result in several different river styles, each of which has a distinct character and behaviour, responding in different ways to storms and floods. In this section, we define the various river styles and describe their character and behaviour. In later sections we describe the capacity for adjustment of each river style and its likely behaviour under different sediment regimes and vegetative cover.

20 River styles in the Waimat and Taruheru catchments

Eight river styles in the Waimatā and Taruheru catchments are defined firstly in terms of the degree to which streams are confined by valley walls (Figures 4.1 and 4.2):

- **Confined** streams are fixed in position by valley walls. Floodplains do not exist, or are found in very small pockets.
- **Partly confined** streams, with floodplain pockets that alternate from side to side of the stream in a somewhat systematic manner, with one channel bank confined by bedrock or relict terraces composed of materials that are resistant to erosion.
- **Unconfined streams** have floodplains on both sides, so that the stream is free to move, adjusting its position within its contemporary bed, bank deposits and floodplain. In the Waimatā and Taruheru catchments many such streams are currently artificially confined (e.g. by stop banks or by excavation to form irrigation channels).

These broad categories are further subdivided to reflect differences in river character and behaviour, focussing on differences in sediment supply and the ways sediment is transported and/or stored within the channel and its floodplain.

Confined streams are separated into:

- **Steep headwaters**, which are generally fast flowing, relatively steep and straight streams contained within V-shaped valleys in the headwater regions. Only very coarse sediment is stored in these streams, with fine-grained sediment being rapidly transported downstream.
- **Earth flow tributaries**. These streams are found in the earth flow landscape types, where subsurface earth flows have shaped hummocky, low relief hills and valleys. Over thousands of years, large amounts of sediment have been delivered to these streams. Whilst much has been transported downstream, the remainder is stored locally, creating alluvial fans and infilling small valleys. Subsequently, tributaries have incised through these fills, creating steep V-shaped gullies. Sediment often accumulates again in the lower reaches of these streams, blocking the channel and forming a swamp, so that these tributaries may be disconnected from the main trunk of the river.
- **Taruheru sidewaters** flow from the edge of the Taruheru hills down onto the extensive Waipaoa floodplain over which the Taruheru travels. These streams have gentler gradients and less well defined valleys than their counterparts in the steep headwaters of the Waimatā.

Partly confined streams are separated according to their geology and the manner of their confinement (Fryirs et al., 2016; Fryirs and Brierley, 2010):

- Partly confined by **bedrock:** These streams meander within a sinuous valley, with valley sides that have resisted erosion for tens of thousands of years.
- Partly confined by **terraces**: These streams tend to meander within a fairly straight valley that has been eroded by the rivers that formed the terraces. Although terraces are somewhat less resistant to erosion than bedrock, their persistence for thousands of years suggests that they are not readily reworked and that they are likely to confine the river for many years to come In the earth flow regions, the main stems meander through hummocky, low-relief, wide valleys. Although many of terraces are partly buried by the relatively mobile and erodible sediment typical of these areas, these terraces still constrain the position of these meanders.

Unconfined streams are separated into:

- **Actively meandering rivers.** These unconfined, meandering rivers typically change their courses over decadal time scales. Sediment is stored on floodplains, where it is deposited by laterally spreading floodwaters that dissipate flood energy. Such rivers generally dominate the middle and lower reaches of stream networks, but here are confined to a few small areas in the Waimatā valley, often upstream of ‘choke points’. Choke points are areas where the downstream flow of water and sediment is blocked or slowed, either long-term by a narrowing of the valley (e.g. a gorge, where rocks have resisted erosion) or, over shorter timescales, by a block of sediment and/or woody debris.

- **Flat drains** are found in the Taruheru catchment, on the flat alluvial lands that border the lower reaches of the Waipaoa River. These streams would originally have wandered over the floodplain, but are now mostly excavated and confined, forming a network of irrigation channels through an area that is now protected by a flood control scheme.
- The lower **Tidal/urban reaches** of the Waimatā and Taruheru catchments and the entire short Tūranganui River were once unconfined. However, they are now confined, with flood measures in place to minimise damage and inconvenience within Gisborne town centre. The beds and banks of these wide reaches are draped with fine-grained sediment, offering temporary storage before being transported out to sea.

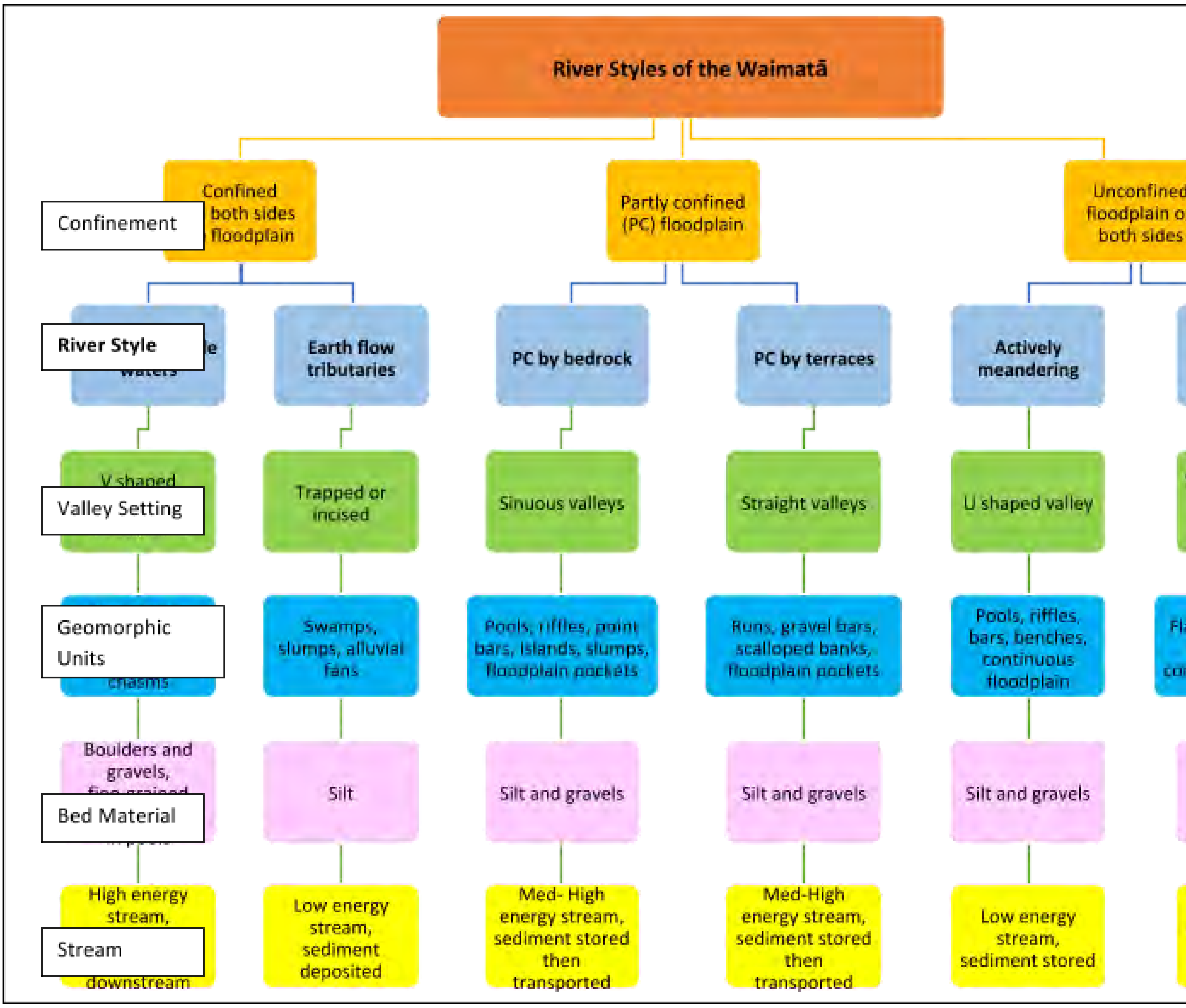


Figure 4.1: River Styles tree for the Waimat catchment

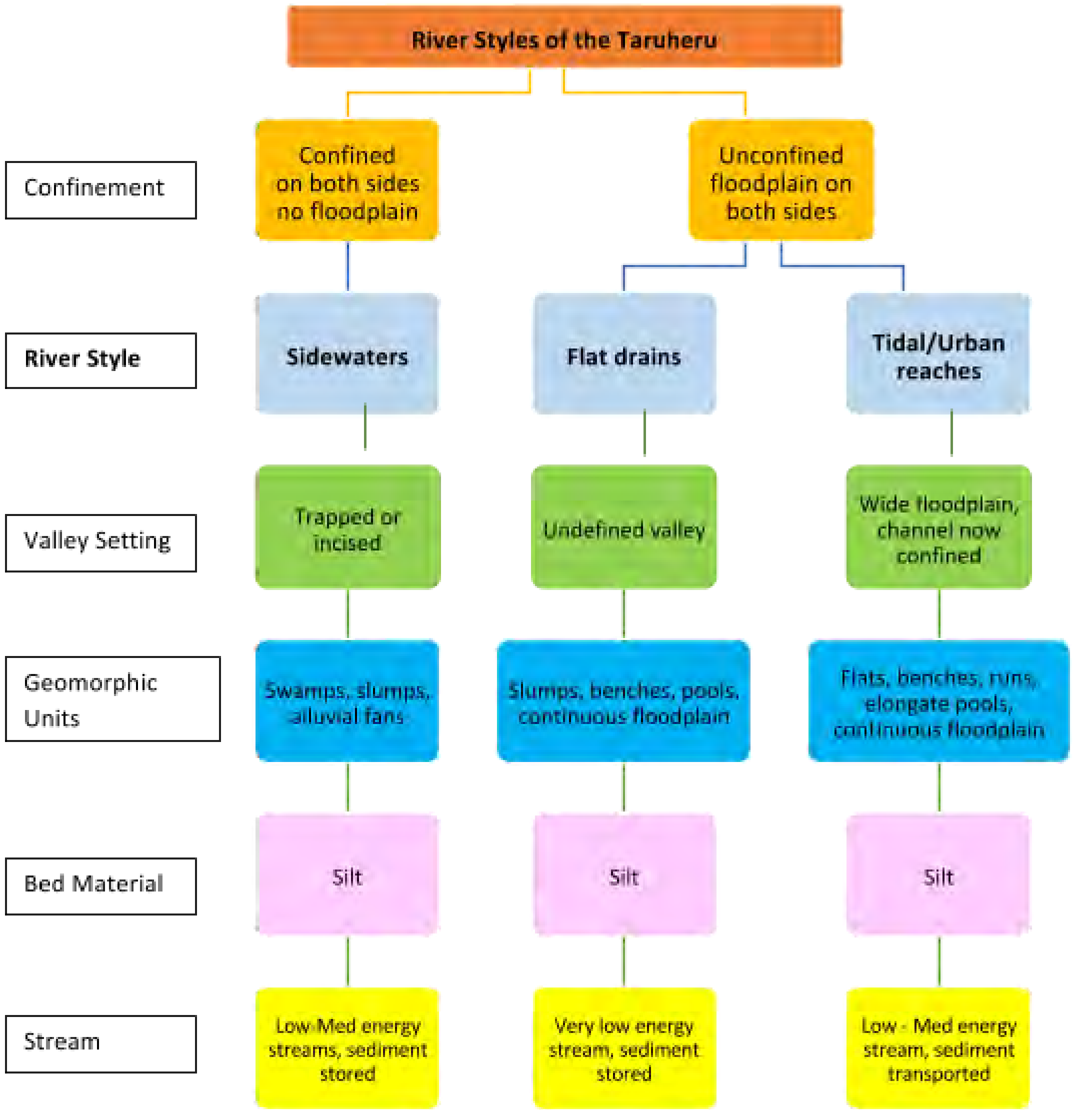


Figure 4.2: River Styles tree for the Taruheru catchment

21 Delineating river styles in the Waimat and Taruherh catchments

Streams were classified into river styles according to the criteria shown in Table 4.1 (Figure 4.3 and 4.4). In the Waimatā catchment, confined stream types (steep headwaters and partly confined streams) account for 64% of stream length and 80% of the area drained. By contrast, the vast majority of the streams in the Taruheru catchment are unconfined. Maps showing gradients and river styles are shown in Appendix 1.

Table 4.1: River styles in the Waimat and Taruheru

	Defining characteristics	% stream length	% catchment drained
Waimat			
Steep headwaters	Slope map shows stream confined between steep valley walls. No floodplain	55%	55%
Active meandering	Sinuous streams that have a floodplain on both sides. Terraces may exist*.	2%	1%
Partly confined by Bedrock	Slope map shows stream confined on one side, with alternating floodplain pockets. Stream lies within a sinuous valley.	6%	4%
Partly Confined by Terraces	Slope map shows stream confined on one side, with alternating floodplain pockets. Stream lies within a relatively straight valley. Terraces present.	24%	26%
Earth flow tributaries	In low relief areas within or adjacent to earth flow regions. Main stems are very sinuous, while tributaries lie in valleys with gentler side slopes than those associated with headwater streams.	12%	12%
Urban/Tidal Reaches	Reaches within the urban area.	2%	2%
Taruheru			
Flat drains	Reaches lying on the alluvial flats.	55%	62%
Taruheru Sidewaters	Reaches that fall within landscape unit of the rolling Taruheru hills.	41%	29%
Urban/Tidal Reaches	Reaches within the urban area.	4%	9%

Figure 4.3: River styles of the Waimat and Taruheru

Figure 4.4: River styles

of the Waimat   and Taruheru, showing roads and points of interest

22 Steep headwaters

Steep headwaters are classified where a slope map shows a ‘slot’ valley between steep valley sides. This river style is found in the head and sidewaters of the Waimatā River and its tributaries.

The morphology of the steep headwaters of the Waimatā is constrained by bedrock. Although these streams incise both headwards and downwards (vertically) over thousands of years, their morphology can be considered fixed for contemporary management purposes. The confined valley setting means that there is little space to store sediment locally. Although sediment or woody debris inputs may form temporary local dams, these blockages move downstream at some stage, as the steep gradient imparts considerable energy to the stream.

The steep terrain means that there is little space for the river to spread out to dissipate energy or deposit sediment. The cobbled beds and geomorphic units of these reaches (Step - pool sequences and riffles and occasional steep sided chasms) bear witness to the bedrock controls on these streams and the way in which sediment inputs are quickly flushed downstream. Some streams have silt beds, associated with sediment inputs following plantation harvesting. Larger boulders and woody debris can cause temporary dams, which may set the position of step-pool sequences (Figure 4.5 and Table 4.2).

Changes to land cover will alter the amount and type of sediment input to the stream. For example, when hillslopes are forested, sediment inputs are comparatively small. If this cover is removed, soil erosion, landslips and the availability of woody debris increase the sediment load in the stream. However, the lack of storage space and the high energy of these streams mean that even very large sediment loads are transported downstream, with little or no effect on local stream morphology.

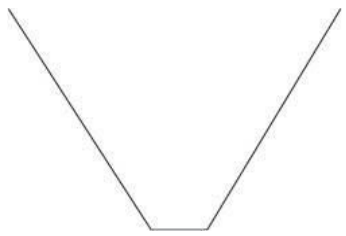
a)

b)

c)

Figure 4.5: Steep headwaters in the Waimat catchment Typical valley settings (a and b) and channel (c). Note the silt present in the channel.

Table 4.2: The character and behaviour of ***steep headwaters***

<table>
<tr><td>Cross section</td><td></td><td>Confined, steeply sloping small streams in narrow, V-shaped ‘slot’ valleys, with occasional chasms.</td></tr>
<tr><td>Planform diagram</td><td></td><td>Relatively straight, confined by bedrock on both sides, with no significant floodplain.</td></tr>
<tr><td>Stream attributes</td><td colspan="2">Fast flowing, shallow, relatively straight streams with steep gradients.</td></tr>
<tr><td>Bed and banks</td><td colspan="2">Cobbles and boulders on bed and banks. May contain temporary stores of fine-grained sediment.</td></tr>
<tr><td>Channel geomorphic units</td><td colspan="2">Step - pool sequences, whose positions may be related to woody debris
Boulder bars
Pool/ riffles
Occasional steep sided chasms
Woody debris can cause temporary damming.</td></tr>
<tr><td>Floodplain geomorphic units</td><td colspan="2">No floodplain.</td></tr>
<tr><td>Behaviour</td><td colspan="2">Relatively high stream power, with high potential energy levels that allow sediment to be flushed through the reaches, limited only locally by woody debris and/or bedrock exposures. The channel is constrained by bedrock, which constrains both vertical and lateral adjustments of the bed and banks.
During low flows, some sediment and woody debris may be stored in the channel, but these are flushed downstream during high flows, when the water level and flow rate are likely to rise rapidly.</td></tr>
<tr><td>Capacity for the bed to adjust its materials and texture</td><td colspan="2">Grain size, sorting and hydraulic diversity are constrained by bedrock, so that only local, temporary reworking is possible.</td></tr>
<tr><td>Capacity for the banks and channel to adjust their morphology</td><td colspan="2">Little/no capacity for adjustment, since the channel and bed is confined by bedrock. Ongoing long-term vertical incision.</td></tr>
<tr><td>Capacity for the channel to adjust its course</td><td colspan="2">Little/no capacity for erosion or adjustment, since the channel is confined by steep valley walls. Ongoing long-term headward incision.</td></tr>
<tr><td>Capacity to transport, store and release sediment</td><td colspan="2">A little space for local storage of sediment. Lateral sediment inputs (e.g. from landslips) are likely to be rapidly flushed downstream.</td></tr>
<tr><td>Overall capacity for adjustment</td><td colspan="2">LOW - RESILIENT</td></tr>
</table>

23

Actively meandering streams

Reaches classified as actively meandering streams have a regular pattern of floodplain pockets on both sides of the stream. Valleys are comparatively wide, with gentle slopes and tend to have a ‘U’ shape.

In the Waimatā catchment, these reaches tend to be found above chokepoints, where the channel is constricted. Above these chokepoints, water tends to pond. Floods can be sudden and deep, depositing much sediment on recession, burying relict terraces and forming a floodplain. The floodplain formed by this contemporary sediment is relatively easy to rework, so the river is free to move laterally, resulting in a sinuous stream (Figure 4.6; Table 4.3).

These reaches are rare in the Waimatā system and are all located in the headwater region. One is near Kowhai station, just above the confining gorge.

This river style has a large capacity for adjustment. Sitting atop of its own contemporary floodplain, the river is free to move sediment around the valley, adjusting channel morphology both vertically and laterally. Sediment can be stored on the floodplain in these reaches. However, these valleys are generally quite narrow, such that the whole floodplain can be stripped and reworked in high floods (Table 4.3).

b)

a)

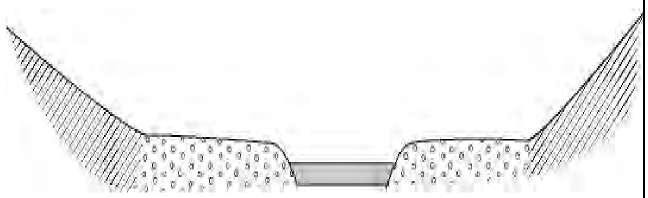
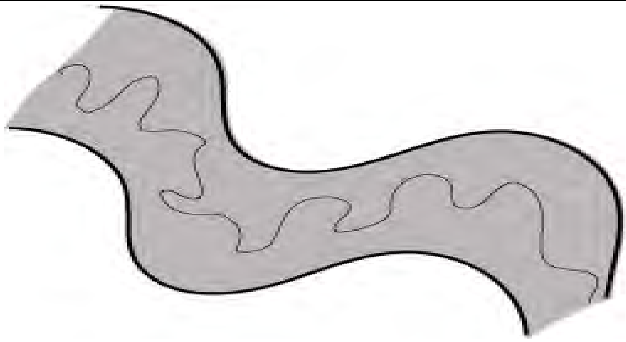
b)

c)

d)

Figure 4.6: Actively meandering streams in the Waimat headwaters
a) Note the floodplains at similar heights on both sides of the river. b) This is one of the very few areas in the headwaters are where the flat and fertile land allows crops to be grown. c) Note flood debris 2m+ from ground d) This tributary has incised through the contemporary floodplain.

Table 4.3: The character and behaviour of actively meandering rivers

Cross section		The stream lies on a contemporary floodplain , which is found on both sides of the channel.
Planform diagram		Generally found upstream of a choke point, where contemporary sediment creates a floodplain, possibly burying relict terraces. Variable stream and valley width.
Stream attributes	Flow is relatively slow compared to upstream segments.	
Bed and banks	Silt bed and banks, variable height.	
Channel geomorphic units	● Depositional units such as bars and benches. ● Pools, riffles, runs	
Floodplain geomorphic units	Continuous floodplain - flood channels and levees may exist.	
Behaviour	The downstream choke point effectively dams flows upstream. During low flows, water is able to move slowly through the system, but at high flows, sudden and deep flooding may occur. River is likely to flood after intense rainfall. Sediment previously stored may then be flushed downstream.	
Capacity for the bed to adjust its materials and texture	Considerable scope for adjustment - bed materials may change, according to the material available and the history of previous events. Depositional features may be reworked.	
Capacity for the banks and channel to adjust their morphology	The banks and bed are free to adjust, providing that there is sufficient stream power to rework the relatively cohesive banks.	
Capacity for the channel to adjust its course	The channel is free to move across the floodplain.	
Capacity to transport, store and release sediment	Sediment can be stored locally on the floodplain.	
Overall capacity for adjustment	**HIGH – NOT VERY RESILIENT**	

24 Earth flow tributaries

Thousands of years of subsurface movement within the earth flow regions has broken up the bedrock, producing a lithology that is far more erodible than materials found elsewhere in the catchment. The relatively mobile and frequently moved sediment tends to infill valleys, blocking tributary flow into the main trunk stream. Such 'trapped tributaries' are often separated from the main trunk by swampy areas or small wetlands (Figure 4.7 and Table 4.4). Valley infills are episodically eroded, when streams form narrow, relatively straight channels that cut through the accumulated sediment and which may reconnect with the trunk stream.

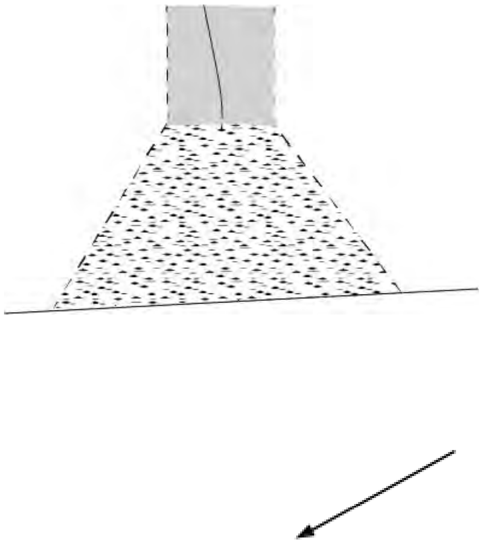
a)

b)

Figure 4.7: Earth flow streams
a) Tributary trapped downstream by accumulated sediment. Note the sloping tree trunks resulting from earth movements. b) This tributary lacks the energy to incise accumulated sediment on the floodplain. Note the willows planted to stabilise the banks of the main stem.

Where there is moderate relief, earth flows are concentrated in tributary valleys, in which sediment accumulates. Accumulation at the base of such tributaries can lead to 'entrapment', preventing flow into the main stem and the establishment of a swamp. These streams can later incise into this accumulated sediment, resulting in a sequence of 'cutting and filling' (Chappell and Brierley, 2014). As a result of these processes, channel morphology is variable, with a large capacity for adjustment near tributary junctions.

Table 4.4: The character and behaviour of earth flow streams

Cross section: tributaries		Incised through aggregated sediment / alluvial fans.
Planform diagram: tributaries	 Swamp atop accumulated sediment ‘traps’ the tributary and prevents it connecting to the main stem. Main stem.	Small, ill-defined streams that are subject to infill and movement when subsurface earth flows occur.
Stream attributes	Tributaries are relatively slow flowing, shallow, often discontinuous streams, which may have swamps and pools. Variable slope.	
Bed and banks	Tributaries have low/no banks in swampy infilled areas, but slot channels with cohesive banks may exist in places where alluvial fans have been incised.	
Channel geomorphic units	● Swamps ● Slumps ● Alluvial fans	
Floodplain geomorphic units	Relict channels and swampy areas in lower reaches. Higher reaches may be more deeply incised, with thin strips of floodplain.	
Behaviour	The transport capacity of tributaries is limited by the damming effect of downstream sediment accumulation as the unstable earth flows slowly downhill, following the course of previously incised valleys. Such earth movements may prevent the stream from reaching the trunk stream, forming a discontinuous channel in which free flowing reaches are punctuated by swamps and pools. These streams have alternating stages of ‘cut’ and ‘fill’, in which episodic periods of incision (associated with high flows) are followed by longer periods of slow accumulation. However, in periods of high flow, flash flooding may occur as flood flows breach downstream blockages between tributaries and the main river stem.	
Capacity for the bed to adjust its materials and texture	Bed and substrates are cohesive, and not easily moved or reworked by the relatively low stream power of these reaches.	

Capacity for the banks and channel to adjust their morphology	Some capacity for vertical adjustment in response to earth movements and subsequent incision.
Capacity for the channel to adjust its course	Some capacity for adjustment, especially if a stream lies atop relatively recently deposited sediments. Adjustment may also occur in response to movements of earth under and around the stream. Channel may vary between being continuous and being characterised by swampy infills. Ongoing long-term headward incision.
Capacity to transport, store and release sediment	Some space to store sediment locally in valley bottoms. Lateral sediment inputs (e.g. from slumps or landslips) are likely to accumulate at the base of slopes, forming alluvial fans.
Overall capacity for adjustment	MEDIUM – SOMEWHAT RESILIENT

25

Partly confined by terraces

Partly confined streams have a regular pattern of floodplain pockets, alternating on each side of the river. Occasional, relatively short straighter reaches occur between large river bends. One side of the valley is constrained by relict terraces, where the river directly abuts an old terrace, so that one bank is considerably higher than the other (Figure 4.8). The river is only free to move on the opposite side. The constraint fixes the outside of the river bend, with the inside bend abutting the floodplain pocket (Table 4.5). Such confinement means that there is little space for the river to spread out to dissipate energy or deposit sediment.

a)

b)

Figure 4.8: Streams partly confined by terraces a) A single very high terrace b) A flight of several relict terraces of various ages.

These reaches occur in the middle, transport zone of the main trunk of Waimatā River. Their comparatively wide channels have a large transport capacity, acting as fast-flowing chutes in rising floods and transporting large quantities of sediment downstream. The removal of fine-grained sediment exposes gravel bars, islands and allows pool-riffle sequences to develop. Although banks can be severely eroded, falling floods also redeposit sediment over the slumps, such that the banks are being continuously eroded and rebuilt (Figure 4.9).

a)

b)

c)

Figure 4.9: Erosion and deposition on the banks of floodplain pockets along partially confined reaches a)-c) Banks are frequently reworked, but slumps are later covered by fresh deposits.

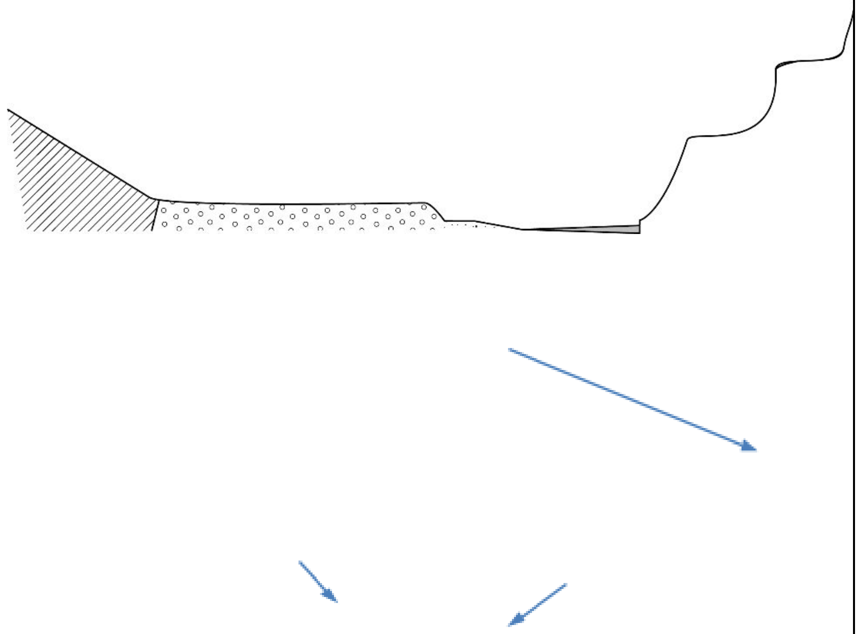
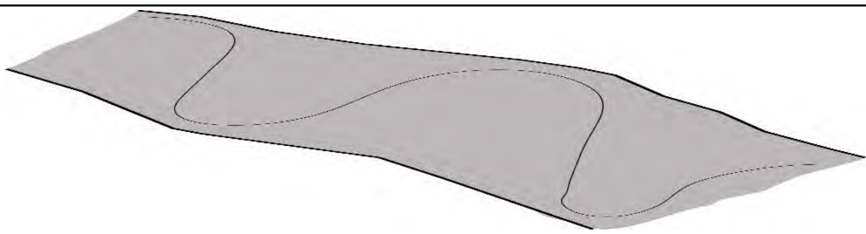
In the earth flow regions, surface erosion and subsurface movements have resulted in low-relief, hummocky terrain. Many terraces have been partly eroded or buried, creating more space for the main stem to widen and move laterally, and to accommodate floodplains upon which contemporary sediments may be stored. Alternate channels may occur on these floodplains during flood events, usually at the base of terrace risers. Since bedrock in these areas is very easily weathered, sediments tend to be more mobile, so that banks are easily eroded and contemporary floodplain pockets may be stripped during high floods (Miller, 1995). However, this erosion has not led to significant widening of the river, since the channel is still largely constrained by the relatively resistant material of the old terraces (Figure 4.10).

a)

b)

Figure 4.10: Reaches partially confined by terraces in the earth flow zone. a) Note that banks are different heights on each side of the river, and a second terrace level lies to the right. b) Terraces of various ages and heights have been reshaped and half buried.

Table 4.5: The character and behaviour of streams partly confined by terraces

Cross section	 Relict terrace(s) Floodplain Point bar	Partly confined valley with regular pattern of floodplain pockets on one side of the river only.
Planform diagram		Confinement due to relict terraces.
Stream attributes	Wider streams flowing more slowly than headwaters. Gentle slope.	
Bed and banks	Silt beds and silt/clay banks subject to undercutting and slumping.	
Channel geomorphic units	● Scalloped banks containing slumps, draped with recent sediment deposits ● Pool - riffle sequences, runs ● Gravel bars and islands	
Floodplain geomorphic units	Floodplain pockets. Tributaries may have incised through the terrace or may be trapped behind accumulated sediment atop the terrace. May have a flood channel at base of terrace riser.	
Behaviour	At low flows, sediment is stored on the outside of bends and in mid-channel islands. At bankfull stage, the channel is prone to widening as banks are stressed and slump. Point bar surfaces are reworked. As flow levels fall, banks and bars are draped with fine-grained sediment. During very high overbank flows, floodplain pockets may be stripped of sediment, but new layers of sediment will be deposited on the floodplain pockets as the flood falls.	
Capacity for the bed to adjust its materials and texture	The bed is generally bedrock, with some alluvial pockets. Hence there is little capacity for bed adjustment. Bed materials may change, according to the material available and the history of previous events. Pool- riffle sequences and gravel point bars may be reworked and replaced by deposits of silty material.	

Capacity for the banks and channel to adjust their morphology	The banks can only adjust on the side that is not constrained by relict terraces. However the banks and channel width can adjust where floodplain pockets occur. Instream units, such as islands can adjust locally where space permits. Vegetation on such units will trap finer grained, more cohesive materials and so limit such adjustment. More adjustment is possible in the earth flow regions, where sediments tend to be more mobile.
Capacity for the channel to adjust its course	Lateral adjustment of the channel is largely constrained by terraces, but there is a little scope for widening and narrowing where floodplain pockets occur.
Capacity to transport, store and release sediment	Some space to store sediment locally in channel and on floodplain pockets.
Overall capacity for adjustment	**LOW-MEDIUM: LOCAL ADJUSTMENTS ONLY (MORE IN EARTH FLOW AREAS) – SOMEWHAT RESILIENT**

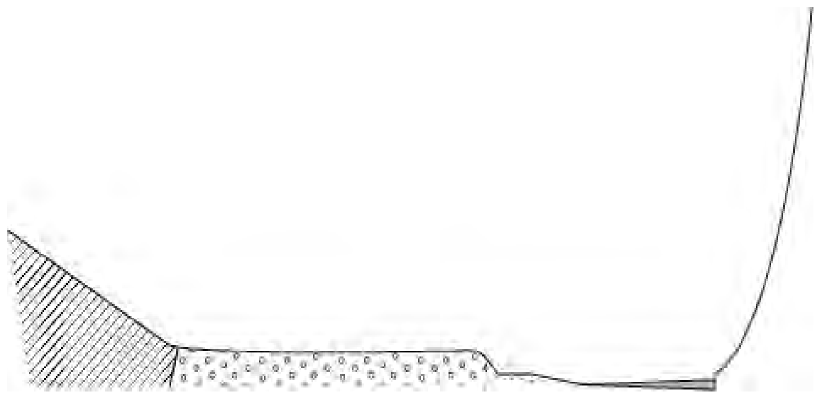
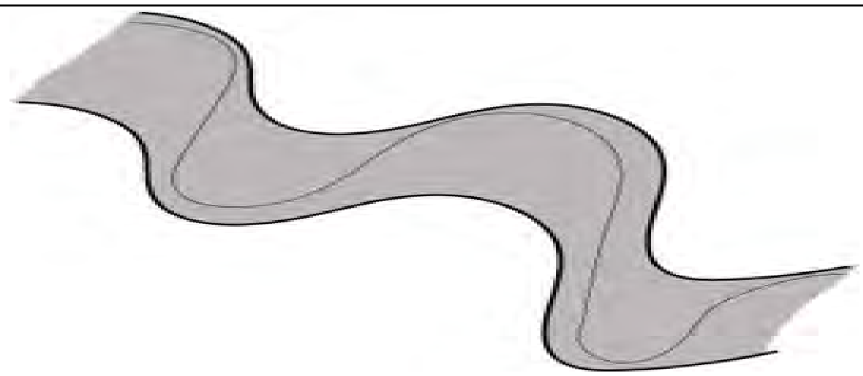
26 Partly confined by bedrock

In these reaches, the meandering stream lies within a relatively narrow, sinuous valley. The confinement of these reaches by bedrock severely limits their capacity for adjustment. Even though confinement is only on one side, it serves to pin the river in a certain position, allowing only small adjustments to the floodplain pockets on the opposite side of the valley (Table 4.6). The character and behaviour of these reaches is similar to those constrained by terraces. The main difference is that since bedrock is more resistant to erosion than terraces, valley walls on the bedrock side can be very steep. Streams have somewhat higher energy, so that deep pools may be scoured. (Figure 4.11).

a)

Figure 4.11: Streams partly confined by bedrock. Note the river bending round resistant bedrock the small floodplain pocket in the background b) Slumping banks, with new sediment deposited on top.

Table 4.6: The character and behaviour of streams partly confined by bedrock

Cross section	 Bedrock Floodplain Point bar	Partly confined valley with regular pattern of floodplain pockets on one side of the river only.
Planform diagram		The shape of the sinuous valley is determined by bedrock outcrops.
Stream attributes	Relatively wide stream, fast flowing round outer bends.	
Bed and banks	Gravel or silt beds and silt/clay banks subject to undercutting and slumping.	
Channel geomorphic units	• Deep pools on bends upstream of bedrock confinement • Scalloped banks containing slumps, draped with recent sediment deposits • Pool - riffle sequences • Gravel bars and islands	
Floodplain geomorphic units	Floodplain pockets. Tributaries may have incised through the terrace or may be trapped behind accumulated sediment atop the terrace. May have a flood channel at base of terrace riser.	
Behaviour	At low flows, sediment is stored on the outside of bends and in mid-channel islands. At bankfull stage, the channel is prone to widening as banks are stressed and slump. Point bar surfaces are reworked. As flow levels fall, banks and bars are draped with fine-grained sediment. During very high overbank flows, floodplain pockets	

	may be stripped of sediment, but new layers of sediment will be deposited on the floodplain pockets as the flood falls.
Capacity for the bed to adjust its materials and texture	Bed is bedrock constrained, at least in some places. Elsewhere, bed materials may change, according to the material available and the history of previous events. Pool- riffle sequences and gravel point bars may be reworked and replaced by deposits of silty material.
Capacity for the banks and channel to adjust their morphology	The banks can only adjust on the side that is not constrained by bedrock or relict terraces. However the banks and channel width can adjust where floodplain pockets occur. Instream units, such as islands can adjust locally where space permits. Vegetation on such units traps finer grained sediments to create more cohesive materials and so limits such adjustment.
Capacity for the channel to adjust its course	Lateral adjustment of the channel is largely constrained by bedrock, but there is a little scope for widening and narrowing where floodplain pockets occur.
Capacity to transport, store and release sediment	Some space to store sediment locally in channel and on floodplain pockets.
Overall capacity for adjustment	**LOW-MEDIUM: LOCAL ADJUSTMENTS ONLY – SOMEWHAT RESILIENT**

27 Tidal/urban reaches

Tidal/urban reaches occur within the urban area of Gisborne. These reaches are highly modified, with stop banks to contain high waters and prevent the river from moving laterally across the coastal plain. Flow is also controlled to some extent by a flood defence scheme. Despite such measures, the rivers often overbank, with extensive flooding in low lying areas of the city.

The Waimatā and Taruheru Rivers meet in the city, forming the Tūranganui, the shortest river in New Zealand. Many of these lower reaches are tidal, with banks that are reworked twice daily, producing mud flats of fine-grained sediments that abut the channel. The flats are incised at intervals by culverts draining stormwater from the town. Some depositional benches are also seen. (Figure 4.12; Table 4.7).

Like the streams of the Taruheru, the urban reaches of the Waimatā, Taruheru and Tūranganui rivers lie on flat floodplain. Also like those streams, the urban reaches would naturally flood extensively, with the channel able to migrate laterally and sediment being stored on the floodplain. However, since such behaviour jeopardises the city of Gisborne, flood defence measures been in place since the 1960s (Peacock and Philpott, 2009). Primary defence is provided by stop banks and revetments, which serve to contain the channel and prevent its migration. Thus the capacity for adjustment of these reaches is artificially limited to local adjustments to the tidal flats (Table 4.7). A side effect is that sediment can no longer be stored on the floodplain and so is swept out to sea, joining the huge deposits from the Waipaoa on a large offshore shelf (Carter et al., 2010).

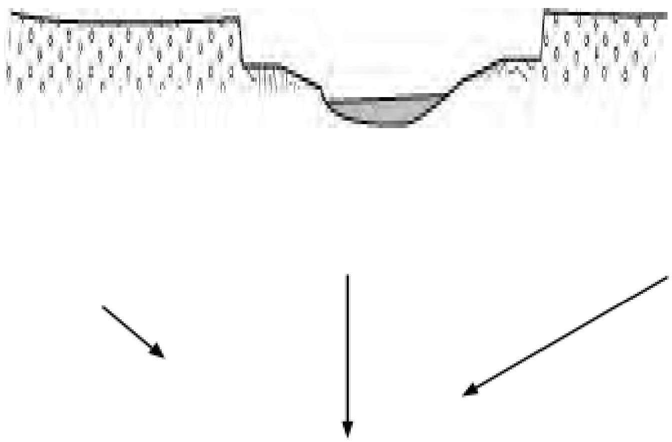
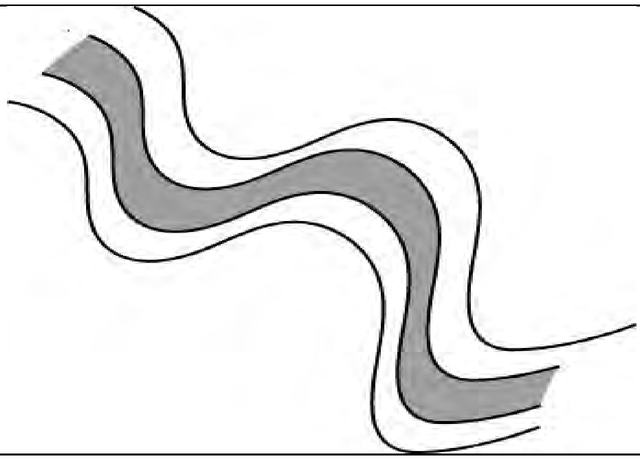
a)

b)

c)

Figure 4.12: Urban/Tidal reaches
Wide channels, stop banks and sediment coated flats characterise these reaches a) Note the reinforced banks and the stormwater culverts that dissect the flats abutting the channel b)Further upstream, there are no containing banks, but building are perched on relict terraces c) Tidal flats are continually reworked, with sediment drapes deposited daily.

Table 4.7: Tidal/urban reaches in the Waimat   and Taruheru catchments

Cross section	 Revetments keep river in fixed position. Banks draped with sediment. Channel tidal towards mouth.	Once unconfined and subject to expansive floods, these reaches are now constrained by concrete stop banks.
Planform diagram		The naturally meandering river that sits within a wide flat floodplain is now constrained by stop banks.
Stream attributes	Wide, relatively slow flowing river, with increasing tidal influence towards the mouth.	
Bed and banks	Silt bed and banks. Banks draped with very fine-grained sediments, continually reworked by tidal action.	
Channel geomorphic units	● Runs, elongate pools. ● In stream sedimentation, sometimes trapped by occasional in-stream vegetation. ● Drapes over tidal flats and benches.	
Floodplain geomorphic units	Wide, continuous floodplain. Levees and flood channels may once have existed.	
Behaviour	These reaches would naturally be subject to intense flooding and high mobility. However, stop banks and flood defences for the city of Gisborne keep the river relatively stable and in a fixed position.	
Capacity for the bed to adjust its materials and texture	The silt beds of the Tidal/urban reaches have little scope to adjust materials and texture, since only fine-grained sediment arrives this far downstream.	
Capacity for the banks and channel to adjust their morphology	Only local, temporary adjustments are possible within the constraints of the stop banks. Sediment is removed and redeposited in the tidal reaches on each tide, whilst further upstream the bed and depositional geomorphic units such as flats and	

	benches are reworked and then newly draped with sediment during each flood event.
Capacity for the channel to adjust its course	The stop banks prevent the river from adjusting its course.
Capacity to transport, store and release sediment	Since the river is generally contained within its banks, there is little scope for sediment storage on the floodplain. Following brief periods of storage on the banks and bed, the wide reaches have a great capacity to transport sediment out to sea.
Overall capacity for adjustment	**NATURALLY HIGH – BUT MAINTAINED IN AN ARTIFICIAL CONDITION**

28

Taruheru sidewaters

These streams are delineated as tributaries of the Taruheru found in the relatively low- elevation hills that abut the Waipaoa floodplain (Figure 3.2 above). All other tributaries of the Taruheru that occur in relatively flat areas are classified either as 'Flat drains' or 'Tidal/urban reaches'.

Valleys of the Taruheru hills are draped in legacy sediments resulting from base level changes associated with varying sea levels (see Section 2). Through the ages, movement of these sediments has buried streams, terraces and entire valleys. Sea level changes have also resulted in large marine terraces that abut the hills. Since these terraces are more resistant to erosion than the sediment surrounding them, they determine the position of Taruheru sidewaters. Given the low relief of the hills, these streams generally lack the energy required to incise through sediment, so that contemporary sediment often traps tributaries, thereby failing to connect with the main stem (Figure 4.13 and Table 4.8).

The sidewaters of the Taruheru behave similarly to earth flow tributaries in that they undergo 'cut and fill' sequences, albeit as a result of a different set of processes (Table 7.3). Whereas accumulation of sediment at the base of earth flow tributaries result from a sediment 'overload' associated with earth flow movements, in the Taruheru sidewaters it is primarily the flat plains and consequent low potential energy of the stream that limit its capacity to transport sediment downstream.

Much of the sediment at the base of the Taruheru sidewaters results from a long history of base level changes, the consequent rise and fall of the large rivers occupying the floodplain below and the adjustment of hillslopes to accommodate these changes. In more recent times, further sediment inputs have resulted from deforestation. Whatever the source, these streams lack the capacity to transport these sediments downstream into the main stem and beyond. Thus almost all these streams are now in the 'fill' stage, with little immediate prospect of moving into the 'cut' stage without a significant increase in stream discharge.

a)

b)

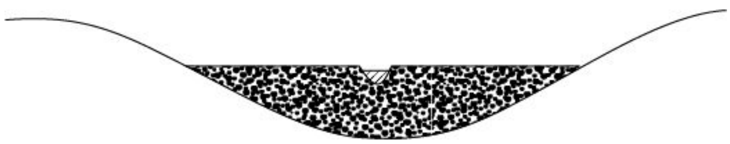
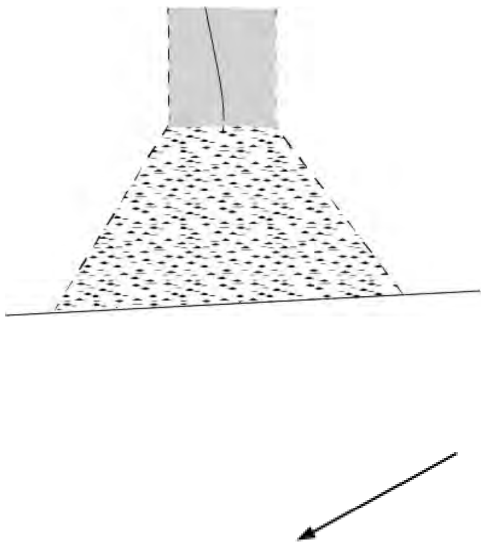
c)

d)

Figure 4.13:

Taruheru sidewaters, with Valleys draped in legacy sediments.
Note the half buried abandoned channel to the right in a), and the wetlands areas associated with trapped tributaries and relict terraces in c) and d).

Table 4.8: The character and behaviour of Taruheru sidewaters

Cross section		Incised through aggregated sediment / alluvial fans that are trapped on the flat floodplain of the nearby Waipaoa River.
Planform diagram	 Swamp atop accumulated sediment 'traps' the tributary and prevents it connecting to the main stem.	Similar processes as for earth flow tributaries- but sediment comes from lateral inputs over time rather than from earth flow movements.
Stream attributes	Small, ill-defined streams that are subject to infill. Variable slope.	
Bed and banks	Silt beds and variable banks (steeper when incised, shallow/ non-existent in swampy areas)	
Channel geomorphic units	● Swampy areas ● Alluvial fans	
Floodplain geomorphic units	Swampy areas in lower reaches. Higher reaches are generally more deeply incised with little/no floodplain. Flow onto the wide Waipaoa floodplain.	
Behaviour	Transport capacity is limited by the damming effect of sediments accumulating as alluvial fans on the flat Waipaoa floodplain. Potential energy to incise through these sediments is limited by the gentle slopes and relatively short distances travelled by these streams (compared to headwaters at higher elevations). These streams have alternating stages of 'cut' and 'fill', in which episodic periods of incision (associated with high flows) are followed by longer periods of slow accumulation.	
Capacity for the bed to adjust its materials and texture	Bed substrate and bank materials are cohesive, and not easily moved or reworked by the relatively low stream power of these reaches.	
Capacity for the banks and channel to adjust their morphology	Some capacity for vertical adjustment in response to sediment accumulations and subsequent incision.	
Capacity for the channel to adjust its course	Some capacity for adjustment. Channel may vary between being continuous and being characterised by swampy infills. Ongoing long-term headward incision.	

Capacity to transport, store and release sediment	Some space to store sediment locally in valley bottoms and on floodplains. Lateral sediment inputs (eg from slumps or landslips) are likely to accumulate at the base of slopes, forming alluvial fans.
Overall capacity for adjustment	MEDIUM – SOMEWHAT RESILIENT

29 Flat drains

The alluvial flats on the plains of the Taruheruand Waipaoa Rivers are well described as a 'domesticated landscape'. Most streams in this area have been highly modified to form an irrigation network for fertile (and valuable) horticultural land. It appears that many of these steams are dredged to form almost straight lines around fields, maintaining an (almost) continuous flow network. Although the fine-grained sediment that forms the bed and banks of these streams is relatively easily moved, the low relief means that these streams lack the energy to significantly incise vertically or horizontally (Figure 4.14; Table 4.9).

In theory, the main stem and tributaries of the Taruheru that lie within the wide floodplain of the Waipaoa River have a high capacity for adjustment. In their natural state, these streams would frequently change course, migrating across the plains through relatively mobile sediments stored on the floodplain (Table 4.9). However, in practice, these streams are maintained by private landowners and Gisborne District Council to provide flood control and irrigation to the croplands (Gisborne District Council, 2015).

a)

c)

b)

d)

Figure 4.14: Streams on the alluvial flats a) A 'domesticated' landscape b) Stream has been artificially straightened and dredged c) Steams have little energy for incision d) More sinuous streams and steeper banks are seen in some places.

Table 4.9: The character and behaviour of flat drains

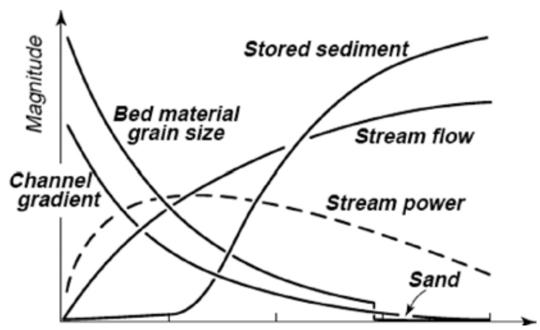
<table>
<tr><td>Cross section</td><td></td><td>Streams have been dredged and incorporated into artificial drainage network.</td></tr>
<tr><td>Planform diagram</td><td></td><td>Flat plains, with no defined valley. The naturally straight streams may be further straightened artificially</td></tr>
<tr><td>Stream attributes</td><td colspan="2">Were once small, ill-defined streams that are liable to move across the floodplainfloodplain – now are confined by dredging.</td></tr>
<tr><td>Bed and banks</td><td colspan="2">Silt bed and banks.</td></tr>
<tr><td>Channel geomorphic units</td><td colspan="2">● Pools
● Depositional units such as bars and benches, subject to frequent reworking.</td></tr>
<tr><td>Floodplain geomorphic units</td><td colspan="2">Continuous floodplain. Possible relict channels, paths obscured by cultivation.</td></tr>
<tr><td>Behaviour</td><td colspan="2">Once extremely mobile and subject to expansive flooding across the floodplain, these streams are now artificially constrained, forming a network of irrigation/ drainage channels.</td></tr>
<tr><td>Capacity for the bed to adjust its materials and texture</td><td colspan="2">Little, if any, coarse sediment is supplied to these reaches, so there is little/no potential for the bed material or texture to change.</td></tr>
<tr><td>Capacity for the banks and channel to adjust their morphology</td><td colspan="2">The banks and bed are free to adjust, since they are unconstrained by bedrock or valley walls. Left alone, they would vary through episodes of infilling and erosion. However, given the importance of maintaining drainage on this prime horticultural land, the drains are likely to be regularly dredged, maintaining them in a stable condition.</td></tr>
<tr><td>Capacity for the channel to adjust its course</td><td colspan="2">Although free to move across the floodplain, these reaches are maintained in position by dredging.</td></tr>
<tr><td>Capacity to transport, store and release sediment</td><td colspan="2">Sediment can be stored locally on the floodplain and in the (very small) valley bottoms. However it is likely to be mechanically removed.</td></tr>
<tr><td>Overall capacity for adjustment</td><td colspan="2">NATURALLY HIGH – BUT MAINTAINED IN AN ARTIFICIAL CONDITION</td></tr>
</table>

30 An idealised conceptual model of river connectivity

Given the high rate of sediment production in the Waimatā catchment, it is important to understand variations in the capacity of the river to transport and/or store this sediment at differing positions along the river course. Transport capacity depends on stream power, which is a function of the potential energy provided by the channel gradient, the amount of discharge and the character of the sediment. These characteristics generally vary systematically within a catchment (Figure 5.1). As catchment area increases downstream, slope and bed material size tend to decrease, while valley width, discharge and channel capacity increase. Accordingly, catchments are usually characterised by distinct sediment process zones: typically a source zone in the uppermost part of the catchment, a transfer zone in the middle reaches of the catchment, and a depositional or accumulation zone in the downstream reaches.

The **source** zone is typically defined by elevated bedrock areas that produce high sediment loads. These areas of incised, dissected relief have high drainage densities and hillslopes are directly connected to valley floors. However, given the confined valley settings, sediments are largely flushed through these zones. As transport capacity exceeds supply, a bedrock base is sustained, leaving only the coarsest boulders to line the channel bed. **Transfer** reaches are less dominated by direct inputs from hillslopes and residence times (the length of time sediment is stored within a reach) tend to be low. Erosion and deposition are roughly in balance. As flow energy decreases downstream with lower channel slopes, an **accumulation** zone develops. Sediment is stored over long timeframes, usually within floodplains.

a)



b)

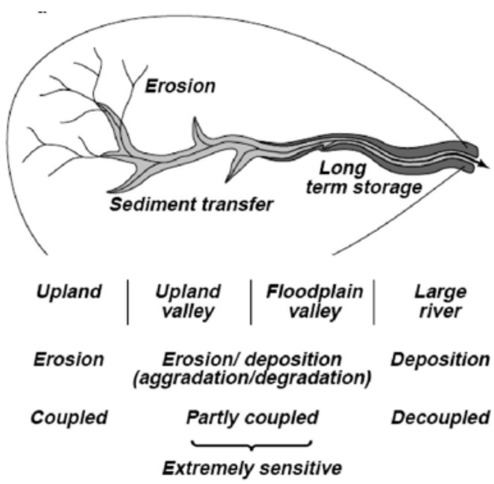


Figure 5.1: Schematic diagrams of factors influencing sediment transport in a catchment (a) typical downstream changes to channel gradient, stream power, bed material size, and volume of stored sediment (b) typical pattern of erosion, transfer and storage reaches (from Church, 2002).

The capacity to transport sediment is largely determined by stream power, which is a function of discharge. In the Waimatā and Taruheru catchments, 'Steep headwaters' have the greatest stream power, with high potential energy levels that allow sediment to be flushed through the reaches, limited only locally by woody debris and/or bedrock exposures. The 'Sidewaters' of the Taruheru act in a similar fashion, but with lower energy and capacity to flush sediment downstream, due to their gentler slopes and the way that the flat Waipaoa plain blocks downstream transport. The stream power of the mid-catchment 'Partly confined' reaches remains significant due to the increase in the catchment area and consequent discharge. As the stream slope flattens in the lower reaches of the catchments (e.g. Flat drains and Tidal/urban reaches), the flow loses competence to transport the sediment, resulting in the deposition of material both in-channel and on floodplains.

The 'Earth flow' tributaries are a special case, since frequent surface and subsurface movements loosen sediment, proving additional inputs into the streams. Frequent slumps and subterranean earth flows move sediment towards the valley bottom, where sediment may be stored for decades. This down-valley movement of sediment results in alluvial fans that can trap tributaries, blocking their access to the main river stem and hence reducing the ability of the system to flush sediment. However, sediment produced upstream, in the headwater or steeply dissected land types, can still be freely transported through the system, thanks to the competency and transport capacity of the main stem of the river (a function of valley confinement, with only pockets of floodplain through to the short coastal plain).

31 Connectivity in the Waimat catchment

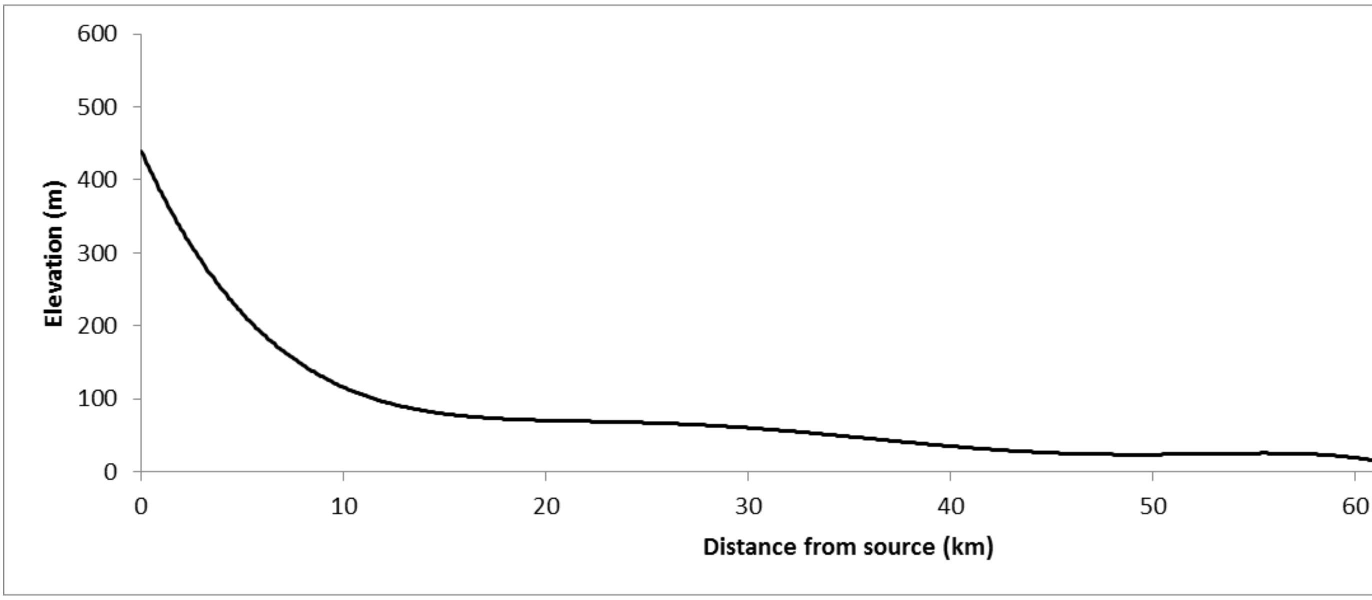
The idealised conceptual model shown in Figure 5.1 assumes that space is available to store sediment on the valley floor, either temporarily in the transfer zone, or longer term in the lower reaches of the accumulation zone. However, in the Waimatā system, much of the river is either fully or partly confined by bedrock or relict terraces, so there is limited space on the valley floor where sediment can be stored, either in-stream or on the contemporary floodplain. Given that flow is confined to a relatively small area and the huge volumes of sediment that are produced in this tectonically active region (see Section 2), storm impacts can be dramatic, with rapid flows and large pulses of sediment and debris moved downstream (Figure 5.2).

Figure 5.2: Gisborne flooding September 2015 Photos from Gisborne Herald

Tributary-trunk configuration is also a potentially important control on stream discharge and the consequent capacity for erosion and transport sediment. However, neither the Waimatā nor the Taruheru have large tributaries, so there is no pronounced change in the discharge (or stream power) through the middle sections of the river and the river is about the same width for much of its length (Figure 5.3).

Downstream changes in valley width are normally expected in a river system, with comparatively narrow streams and valleys in the source zone that widen through the transfer and deposition zones as the river gains water and sediment (Figure 5.1). However, confinement in the Waimatā system means that little systematic change is seen through most of the system (Figure 5.3). The Waimatā River has a typical concave upwards longitudinal profile, with systematic downstream decrease in the stream slope (and hence stream power). In steep headwater reaches, steep gradients result in relatively high stream power, such that medium and fine sized sediments are easily transported downstream. In the middle, partly confined, reaches, valleys are wider and the stream slopes less steeply, such that sediment is deposited and stored locally, at least temporarily. In the lowest urban/ tidal reaches, the channel and valley widths are wider still, with only a gentle gradient. Under these conditions, even fine grained sediment tends to be deposited accumulating within the channel and floodplain.

Although both valley and channel width tend to increase downstream, the increase is punctuated by narrow confinement imposed by complex geology (Figure 5.4). In the lower reaches, bedrock and terrace controlled river segments alternate through both the steeply dissected and the Waimatā lowlands landscape types.


Elevation (m)
Distance from source (km)
0
100
200
300
400
500
600
0
10
20
30
40
50
60

PC Terrace

Steep headwaters

Upper earth flow

Medium dissected

Steep dissected

Waimatā lowlands

Coastal plain

LANDSCAPE TYPE

RIVER STYLE OF THE MAIN STEM

Steep headwaters

Actively meandering

PC Terrace

PC Bedrock

PC Bedrock

PC Terrace

PC Bedrock

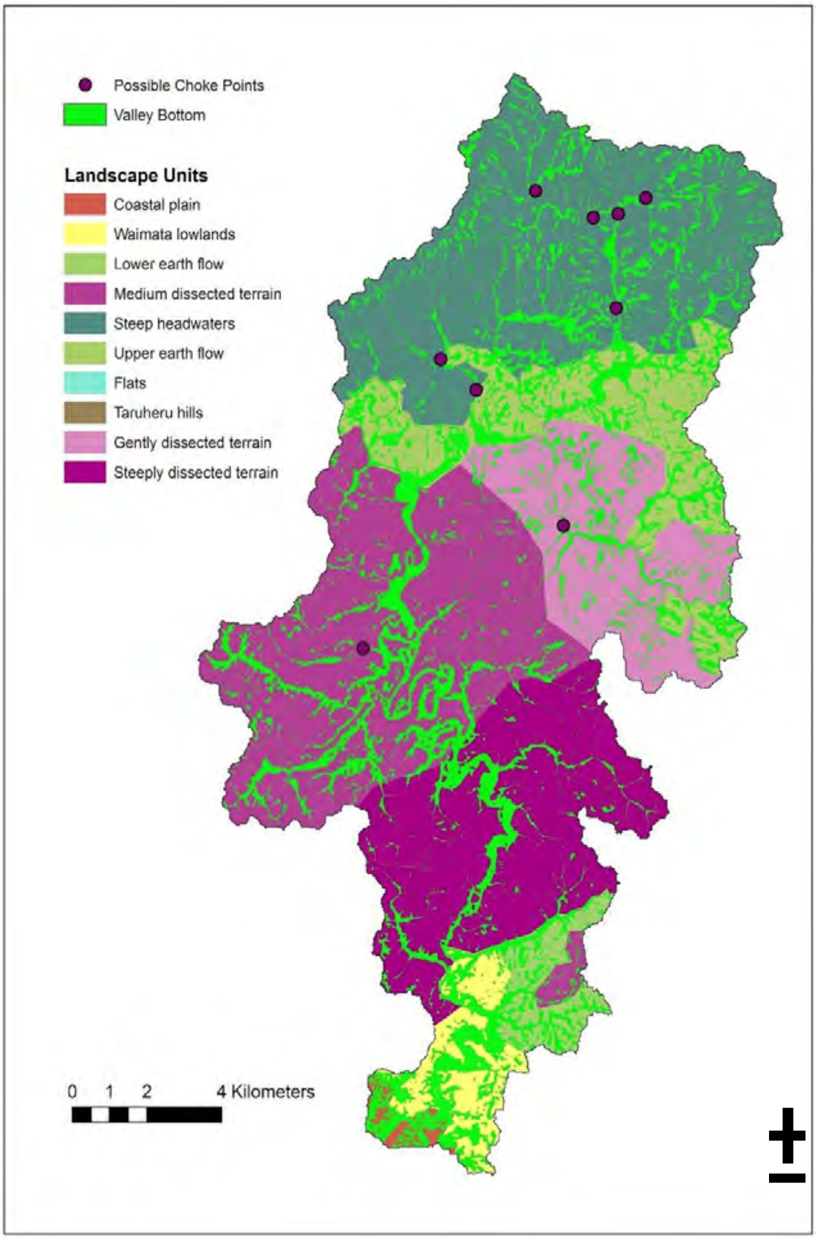
Urban/ tidal

Figure 5.3: Longitudinal profile of the Waimat   river, showing positions of river styles and landscape types

In order to explore variation in valley widths more explicitly, valley widths were delineated by identifying all areas where slope <= 15^0 and Topographic Position Index (TPI) <=0 (Figure 5.5). TPI is a measure of relative elevation, where the mean difference between the elevation of a pixel and its neighbours is calculated. In this case, elevation was based on an 8 m DEM and the neighbourhood of a pixel was defined as with a circle of 80m radius around the pixel. Choke points were delineated using a slope map to identify points where a valley narrowed downstream of a wider area.

Valley widths vary markedly in all sections of the river. Although most streams occupy narrow valleys in the headwaters, wider valleys are seen above choke points, where bedrock constricts flow. Valleys widen in the upper earth flow area, where channels are far less constrained by bedrock. Channels narrow intermittently downstream, particularly in bedrock constrained reaches in high relief areas in the lower - mid catchment. It is only on reaching the lowlands and coastal plains that the river and its valleys are able to widen significantly (Figures 5.4 and 5.5).

Figure 5.4: Valley widths, choke points and landscape types



'Chokepoints', where valley constrictions and/or temporary or permanent blockages prevent free flow, interrupt downstream flows of water and sediment, exerting a large influence on upstream river styles (Figures 5.4 and

5.5). Upstream of this confinement, the river ‘ponds’ during flood events. When the deep floods subside, sediment is deposited to form contemporary floodplains. This sediment is relatively mobile, so these ‘Actively meandering’ reaches can adjust laterally, periodically adjusting their course. This behaviour has been occurring for tens of thousands of years, as evidenced by the relict terraces found along these reaches, many of which are now semi-buried.

a)

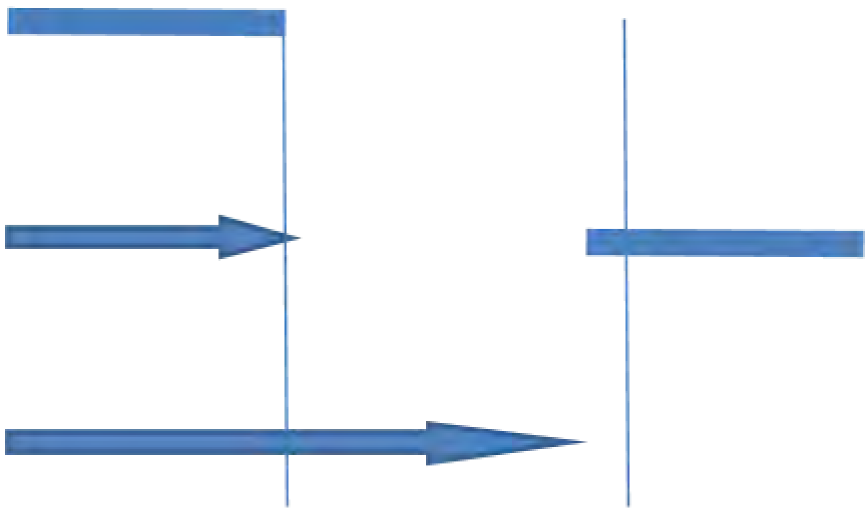
d)

b)

c)

Figure 5.5: A chokepoint on the Waimat River, near the turnoff to Kowhai station.
a) The narrow stream is constrained by high valley walls on both sides b) Note flood debris over 2m from the ground c) Contemporary floodplains are at about the same height on both sides of the river. d) This is one of the very few areas in the headwaters are where the flat and fertile land allows crops to be grown. Note the relict floodplain above the contemporary floodplain.

Connectivity between hillslopes and the valley floor can also be interrupted by floodplains and/or relict terraces (Figures 5.6 and 5.7). In many cases tributaries that flow onto the floodplain of the main stem no longer have the energy required to move the sediment they carry across the floodplain to the main river. Under such circumstances, sediment from upslope areas is stored locally, at least until the tributary is able to incise through the accumulated sediment to reach the main stem, so alluvial fans and trapped tributaries are formed. Given the high sediment loads carried by the Waimatā and Taruheru streams, this situation commonly occurs whenever tributaries flow onto a floodplain that is large enough to store sediment. However, sufficiently large floodplains are only generally found in the earth flow and Taruheru reaches. Elsewhere, streams are largely confined, with little or no space on the valley floor to form floodplains or store sediment. Under these circumstances, the river acts as a chute, transporting sediment downstream.



a)

c)

c)

b)

Figure 5.6: Tributary-trunk connectivity
Tributaries may be trapped by a) terrace at floodplain margin or b) lack energy to traverse the floodplain. Alternatively tributaries may connect to the main trunk c) at an outside bend, where there are no obstructions or d) by incision through the floodplain and any terraces present.

e)

b)

a)

d)

c)

f)

Figure 5.7: Trapped and incised tributaries
a) and b) Tributaries trapped by terraces; c) and d) Tributaries trapped by floodplains; e) and f) Incised tributaries

32 Connectivity in the Taruheru catchment

Connectivity issues on the Taruheru are framed by a very different geological and morphological setting. The river lies on the alluvial flats of the Waipaoa, bounded only on one side by low relief hills. The main stem of the river has no steep headwater zone, and the river falls only about 15m over its entire length. This lack of relief means that the river has very low energy and therefore only limited capacity for sediment movement. Instead, sediment is stored locally on the floodplain

Tributaries of the Taruheru are relatively short and mostly flow from the rolling hills east of the main stem (Taruheru sidewaters). These hills bear the imprint of changing base levels, large terraces and draped sediment reflecting historical sea level changes and tectonic movements of the Waipaoa valley. These sidewaters provide the main source of sediment to the Taruheru system. However, many of these tributaries are disconnected from the main stem, lacking the energy to transport contemporary and legacy sediments away from the source zone. Instead, sediment is stored at the base of slopes, forming alluvial fans. Many streams now lie on top of these fans, slowly incising through them (Figure 5.8).

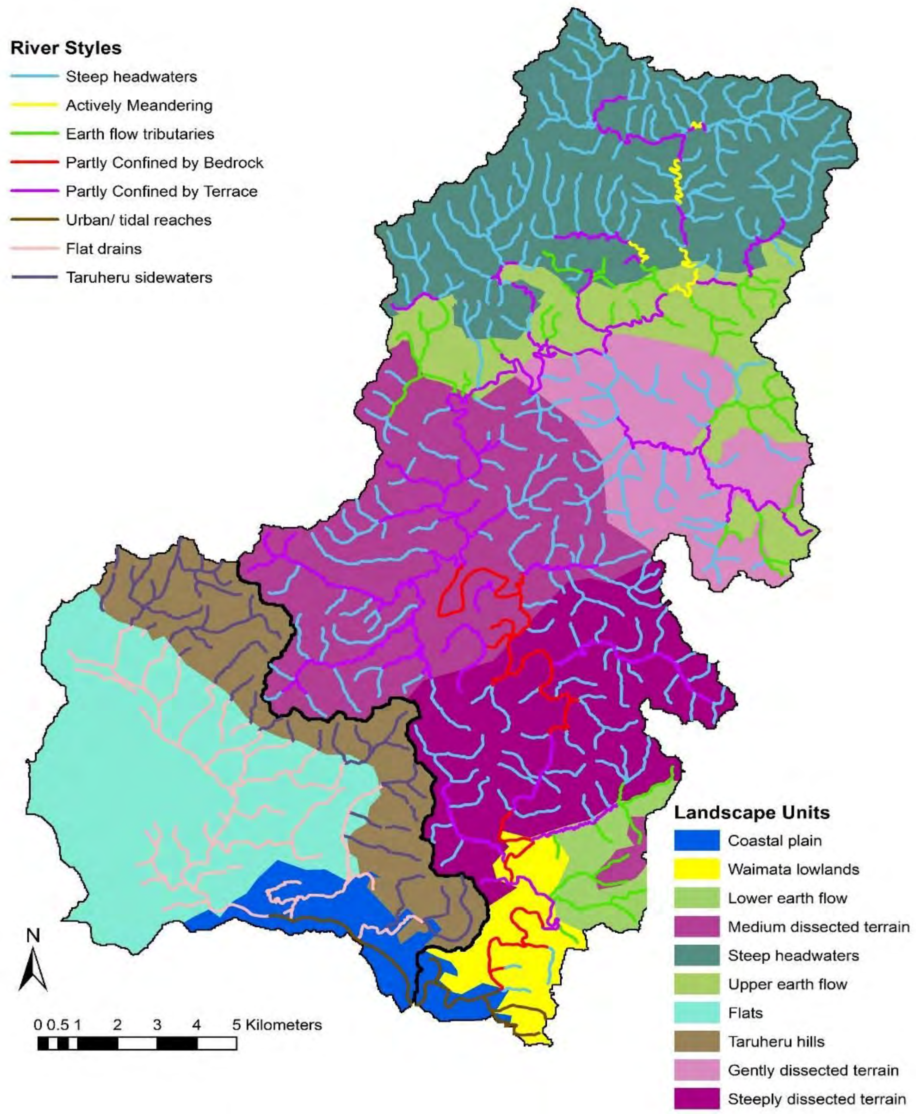
Figure 5.8: Taruheru hills and valleys draped in legacy sediments. The contemporary stream lies on an alluvial fan, with an abandoned channel to the right.

33

River styles and landscape types

There is a close relationship between landscape types and river styles (Figure 5.9). This is to be expected, since the underlying geology determines the nature of the stream processes that have created the landscape. For example, the high stream power and consequent erosion of headwater streams has created a finely dissected, steep landscape. Conversely, the Taruheru flats and the coastal plains result from streams in which deposition dominates over erosion, creating a landscape with subdued relief.

Figure 5.9:



Landscape types and river styles

POTENTIAL VARIABILITY AND THE CURRENT CONDITION OF RIVER STYLES IN THE WAIMAT AND TARUHERU CATCHMENTS

34 Potential variability of each river style

In this section we consider steps 2 and 3 of the River Styles framework (Table 1.2), assessing the current condition of the Waimatā and Taruheru Rivers in the context of their capacity for adjustment and their natural ranges of variability.

How would the Waimatā and Taruheru rivers and their catchments look and behave if they were in a state of 'ora', that is, if they were in an optimum and sustainable state of health? In general terms, reaches that are in 'good' condition for most river styles in the Waimatā and Taruheru catchments have heterogeneous geomorphic features and flow characteristics, offering a diverse range of habitats for flora and fauna. In turn, these biota reinforce the geophysical diversity present. By contrast, reaches that are in "poor" condition tend to be homogeneous, with little diversity of physical features, capable of supporting only a narrow range of biota. The particular ways in which condition can vary in each of the river styles found in the Waimatā and Taruheru catchments are shown in Table 6.1.

Many steep headwater reaches of the Waimatā are currently in poor condition, being prone to overloading by fine-grained sediments resulting from forest harvesting. Enhanced sediment loads also reduce local biodiversity and create a burden for downstream reaches. Sediment inputs from upstream reaches have infilled some valleys, creating streams that are now actively meandering across contemporary floodplains. Because of the lack of vegetation, these floodplains are frequently reworked and are therefore considered as being in poor condition. However, most other reaches can be considered as being in good condition from a geomorphic point of view. Sediments moved along many Earth flow and Taruheru sidewater tributaries are trapped, with local swampy areas providing habitat diversity. Channels in partly confined reaches are relatively narrow, showing little signs of the widening associated with such reaches in poor condition. Although there is much local bank erosion, slumps are redraped with alluvial deposits, forming oblique accretion depositional features that build the banks up again (Page et al., 2003). Urban reaches and flat drains are highly modified and are artificially maintained in a condition that is desired by local communities and businesses.

Human interventions can not only alter the current condition of the river, but can also constrain its overall capacity for adjustment. For example, the stop banks and revetments on urban reaches effectively prevent lateral migration of the channel, constraining its overall capacity for adjustment. Dredging the alluvial flats of the Taruheru to irrigate the valuable horticultural lands that occupy the floodplain prevents both lateral migration of these streams and the build-up of sediment on the adjacent floodplain. Without these interventions, both of these river styles would be very different. Unconfined and undredged, these streams would be free to wander over the floodplain. Furthermore, sediment coming downstream would be stored on the floodplain, since lowland floods would be extensive and suspended sediment would be draped over the land as floodwaters recede. Under such conditions, the amount of sediment reaching the sea would be much reduced.

Table 6.1: Assessment of potential geomorphic variability as a basis to assess the condition of river styles in the Waimat   and Taruheru catchments

River Style	*Good Condition*	*Poor Condition*
Steep headwaters	Cobble/gravel bed, with diverse roughness. Sediment can be stored locally, but is transported downstream in heavy storms. Geomorphic units include steps, pools, cascades, with more or less temporary dams and local sinuosity created by woody debris and boulders.	A silt-filled, straight "trough". Litt sediment is trapped locally and th fine-grained sediment inputs are There is little habitat diversity, so supported.
Actively meandering streams	Well defined pool-riffle systems. An asymmetrical channel with a well-defined thalweg scours pools and creates point bars on the inside of bends. Sediments are well sorted, creating a variety of habitats for aquatic creatures. Riparian vegetation creates diverse aquatic conditions and contributes debris that further increases biophysical diversity.	A silt-filled stream lacks diversity, are frequently reworked. Sedime are liable to be stripped in high fl
Earth flow tributaries	Trapped tributaries with local wetlands create landscape heterogeneity and serve to trap sediment high in the catchment.	Incised tributaries have the poter "trough" channels that concentra downstream.
Partly confined by terraces	As for active meandering streams, a good condition implies a well-defined thalweg, with pools, riffles and well sorted gravel bars providing diverse habitat. Vegetation protects floodplain pockets from being stripped by high floods. Instream vegetation and woody debris interrupts flow and dissipates energy, so that less bank erosion occurs.	Banks are eroded, widening the c the channel and banks become m on the outside of bends, leading t frequently stripped.
Partly confined by bedrock	Similar to terrace-confined streams, but with deeper pools.	Similar to terrace confined, with c floodplain pockets. Higher energy severe bank erosion.
Tidal/ Urban reaches	Well defined thalweg in a compound channel that reworks its banks as it moves over the floodplain. The channel has diverse depths, providing a range of habitats for aquatic and bird life	Homogenous channel with unifor
Taruheru sidewaters	As earth-flow tributaries	As earth-flow tributaries
Flat drains	Form part of a wetland complex, with small channels that frequently change position.	Either have too much or too little Incised channels concentrate flov Sediment overload chokes the sy

RECOVERY POTENTIAL FOR THE WAIMAT AND TARUHERU: MANAGEMENT IMPLICATIONS

35 Geomorphic responses to land use changes and implications for likely river futures

The debilitating effect on ecosystems of large loads of fine-grained sediment in rivers is well documented. For example, water quality is poorer (Parkyn et al., 2006) and both fish and invertebrates tend to be less abundant and less diverse in turbid river carrying heavy sediment loads (Richardson and Jowett, 2002). Not only does the turbidity and bed sediment cover decrease food resources for aquatic creatures (Reid and Page, 2003), the diversity of available habitat is also decreased (Gray and Harding, 2011). Severe erosion and sediment loading in East Coast rivers also have considerable cultural implications. These were documented for the Waiapu River, which holds considerable spiritual and cultural importance for local iwi, who treasure the water quality, biodiversity and food resources available in streams that are in good condition (SCION, 2012).

In many other parts of the East Cape, deforestation and landslips have generated large 'slugs' of sediment stored in river floodplains and channels, degrading rivers to a poor condition (e.g. SCION, 2012). However, the Waimatā is quite different. For most of the length of the river, the capacity for lateral adjustment is severely limited by the valley setting. Bedrock and terraces that are resistant to erosion hold the river in place and severely limit the space available for sediment storage. The river can be likened to a fixed chute, down which sediment is transported to the sea. Under these circumstances only local adjustments can occur, as sediment is temporarily stored on the channel bed, banks or atop the small floodplain pockets, only to be flushed downstream during the next major flood event.

Only *the actively meandering* river style has a 'high' capacity for adjustment, and this style accounts for only 1% (<7km) of the total stream length in the Waimatā and Taruheru catchments. Although *earth flow* tributaries and *Taruheru sidewaters* have 'medium' capacity for adjustment, they account for only another 18% of stream length between them. These conclusions are borne out by close comparison of aerial photographs of October 1942 and January 2012, which reveal very few places where channel adjustments have occurred (Figure 7.1, Table 7.1 and Appendix 2).

Given limited capacity for geomorphic adjustment across the Waimatā catchment, where contemporary river activity is constrained by imposed valley confinement (by bedrock and low terraces), disturbance responses associated with deforestation and land use change have been relatively limited in this system. There is no indication that inputs of sediment from hillslopes has altered process relationships on valley floors. In contrast to other parts of the East Cape, there are remarkably few landslides and gully networks, so inputs of bedload calibre materials and associated bed aggradation are limited. However, forest management practices in headwater reaches, and earthflow activities in numerous tributaries have resulted in pulsed inputs of fine-grained material (wash and suspended load). These materials overload the system after storms, flushing through the system and building up at the river mouth. Although, to date, there is little evidence of a long term build-up, the potential for such accumulation is a significant local concern. It is feared that such a build up increases the severity of flooding, threatens the capacity of the river to support activities such as rowing, paddling and kayaking and increases the cost of dredging the port.

Figure 7.1: Places where streams in the Waimat   and Taruheru catchments have capacity to adjust

Table 7.1: Recovery potential for river styles in the Waimat   and Taruheru catchments

River Style	*Capacity for adjustment (from section 4)*	*Recovery Potential*
Steep headwaters	Low	Low: Condition depends largely on land use. Reforestation to limit lateral fine-grained sediment inputs is likely to take 30-50 years to establish and be fully effective. Short term initiatives to improve condition could include limiting forestry harvesting along riparian stream edges.
Actively meandering streams	High	Low: This river style can adjust easily – but their condition depends largely on upstream condition and a reduction in the amount of sediment delivered to these reaches. Although planting trees would significantly reduce the likelihood of floodplain stripping, increasing the capacity of these segments to trap and store sediment, trees would be unlikely to survive the high flooding in these areas.
Earth flow tributaries	Medium (Variable)	Tributaries that are already trapped/ or starting to be trapped have good recovery potential. The development of wetlands can be encouraged by appropriate planting and existing wetlands can be given a high priority for conservation. However, incised tributaries have low recovery potential.
Partly confined by terraces	Low-medium Medium- high in earth flow regions	These reaches are in good condition, having changed little, despite high throughputs of fine-grained sediment. There is little or no room for lateral movement of the channel, except in the low relief, wider valleys of the earth flow zone. Bank erosion is local and tends to self-repair, with no overall widening of the channel. Judicious planting on floodplain pockets that are well defended from slumping would improve local condition and enhance downstream prospects.
Partly confined by bedrock	Low-medium	Similar to terrace confined reaches. A wide planted riparian strip would better protect banks from erosion.
Tidal/Urban reaches	Very low (artificial)	These reaches are highly modified, so the only recovery interventions possible are the use of 'softer' engineering options that give the river more freedom to move and the introduction of artificial niches that provide habitat heterogeneity.
Taruheru sidewaters	Medium (Variable)	The deep legacy sediments in these valleys mean that many tributaries are trapped and that few are incising. Trapping can be encouraged through careful planting of incipient wetlands.
Flat drains	Very low (artificial)	These highly modified reaches provide a valuable service to horticulture. Local patches of wetland would enhance biodiversity in this area.

Recovery potential is low for steep headwaters and actively meandering streams, since their condition is largely dependent on land use and the sediments input into the river when pine plantations are harvested. Although short term gains may be achieved by improving harvesting techniques, long term improvement will require limited harvesting and reforestation. In partly confined reaches, the relatively low capacity for adjustment means that change is unlikely to occur naturally and management interventions are limited. However, these reaches are generally in good geomorphic condition. Tidal/urban reaches and the flat drains of the lower Taruheru are highly modified, with considerable benefit to the local community. Under these circumstances, the only feasible recovery interventions involve the use of 'softer' engineering, giving the river more freedom to move. However, localised interventions throughout the catchments could provide additional habitat and promoting biodiversity. Trapping more sediment at source could be achieved in the earth flow tributaries and the Taruheru sidewaters through judicious planting that encourages the development of local wetlands.

There is much evidence for the debilitating effects of fine-grained sediment deposits on stream and ecosystem function (e.g. Owens et al., 2005). However, from a geomorphic point of view, the Waimatā is in remarkably good condition compared to many other East Coast rivers. This is largely because the river is fixed in position by bedrock and terraces, such that there is no accommodation space for large volumes of sediment down much of its length. The river acts as a chute, efficiently flushing sediment through the system to the sea, with little effect on channel morphology, but contributing to sediment accumulations at the river mouth. Thus efforts to improve the condition of the river should focus on reducing the sediment load at source, increasing the capacity to trap sediments at source, in the headwater regions and in the sluggish tributaries of the earth flow zones and the Taruheru hills. Moreover, we recommend further research to examine trends in the accumulation of sediments at the river mouth (e.g. analysis of any dredging records or sediment cores).

36 Concluding comment

Given that this template constrains the character and behaviour of the entire system, a description of the template provides a context for integration of understandings across disciplines and a platform to link discourses from social and natural sciences with policy and management concerns. An appreciation of the biophysical template and the constraints it imposes on the wider socio-ecological system also supports efforts to collectively negotiate a vision and target conditions for the future of the catchments, ensuring that such visions are consistent with the processes that shape and maintain the channels and landscapes. Lastly, an improved understanding of the potential for change helps to prioritise restoration initiatives and to assess the potential for successful adjustment towards a desired system state.

REFERENCES

Allsop F (1973) *The Story of Mangatu the Forest Which Healed the Land by Allsop F - AbeBooks*. Wellington: A. R. Shearer, Government Printer.

Bailleul J, Robin C, Chanier F, et al. (2007) Turbidite Systems in the Inner Forearc Domain of the Hikurangi Convergent Margin (New Zealand): New Constraints on the Development of Trench-Slope Basins. *Journal of Sedimentary Research* 77(4): 263–283.

Berkes F, Folke C and Colding J (1998) *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press.

Berryman K, Marden M, Eden D, et al. (2000) Tectonic and paleoclimatic significance of Quaternary river terraces of the Waipaoa river, east coast, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 43(2): 229–245.

Brierley GJ and Fryirs KA (2005) *Geomorphology and river management : applications of the river styles framework*. Malden, MA: Blackwell Pub.

Brierley GJ and Fryirs KA (2016) The Use of Evolutionary Trajectories to Guide 'Moving Targets' in the Management of River Futures. *River Research and Applications* 32(5): 823–835.

Carter L, Orpin AR and Kuehl SA (2010) From mountain source to ocean sink – the passage of sediment across an active margin, Waipaoa Sedimentary System, New Zealand. *Marine Geology*, From mountain source to ocean sink – the passage of sediment across an active margin, Waipaoa Sedimentary System, New Zealand 270(1–4): 1–10.

Chappell PR and Brierley GJ (2014) Multi-scalar controls on channel geometry of headwater streams in New Zealand hill country. *Catena* 113: 341–352.

Church M (2002) Geomorphic thresholds in riverine landscapes.: 541–557.

Cullum C, Rogers KH, Brierley GJ, et al. (2016) Ecological classification and mapping for landscape management and science: Foundations for the description of patterns and processes. *Progress in Physical Geography* 40(1): 38–65.

Dymond JR and De Rose R (2011) Modelling landscape evolution in the Waipaoa catchment, New Zealand — A phenomenalogical approach. *Geomorphology* 132(1): 29–34.

Ewers RM, Kliskey AD, Walker S, et al. (2006) Past and future trajectories of forest loss in New Zealand. *Biological Conservation* 133(3): 312–325.

Finlayson B and McMahon T (1988) Australia vs the world: a comparative analysis of streamflow characteristics. *Fluvial geomorphology of Australia*: 17–40.

Folke C (2006) Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, 16(3): 253–267.

Fryirs K (2013) (Dis)Connectivity in catchment sediment cascades: a fresh look at the sediment delivery problem. *Earth Surface Processes and Landforms* 38(1): 30–46.

Fryirs K and Brierley GJ (2009) Naturalness and Place in River Rehabilitation. *Ecology and Society* 14.

Fryirs K and Brierley GJ (2010) Antecedent controls on river character and behaviour in partly confined valley settings: Upper Hunter catchment, NSW, Australia. *Geomorphology* 117(1–2): 106–120.

Fryirs KA (2015) Developing and using geomorphic condition assessments for river rehabilitation planning, implementation and monitoring. In: *Interdisciplinary Reviews-Water 2(6*, pp. 649–667.

Fryirs KA, Wheaton JM and Brierley GJ (2016) An approach for measuring confinement and assessing the influence of valley setting on river forms and processes. *Earth Surface Processes and Landforms* 41(5): 701–710.

Gibbs GW (1959) Soils of the Gisborne-East coast district and their problems for pastoral use. In: *Proceedings of the 21st conference of the NZ Grass association*, pp. 9–18.

Gisborne District Council (2015) *TAIR WHITI FIRST! 2015-2025 LONG TERM PLAN*. Gisborne: Gisborne District Council. .

Glade T (2003) Landslide occurrence as a response to land use change: a review of evidence from New Zealand. *CATENA*, Geomorphic Responses to Land Use Changes 51(3–4): 297–314.

Gomez B and Trustrum NA (2005) Chapter 7 Landscape disturbance and organic carbon in alluvium bordering steepland rivers, East Coast Continental Margin, New Zealand. In: Batalla CG and RJ (ed.), *Developments in Earth Surface Processes, Catchment Dynamics and River Processes,* Elsevier, pp. 103–116.

Gray DP and Harding JS (2011) Multi-scaled environmental determinism of benthic invertebrate communities in braided rivers: evidence for complex hierarchical controls on local communities. *Fundamental and Applied Limnology / Archiv für Hydrobiologie* 179(1): 3–15.

Hicks DM, Hill J and Shankar U (1996) Variation of suspended sediment yields around New Zealand: the relative importance of rainfall and geology. In: *Erosion and Sediment Yield: Global and Regional Perspec*, IAHS.

Holling CS and Meffe GK (1996) Command and Control and the Pathology of Natural Resource Management. *Conservation Biology* 10(2): 328–337.

Jones KE and Preston NJ (2012) Spatial and temporal patterns of off-slope sediment delivery for small catchments subject to shallow landslides within the Waipaoa catchment, New Zealand. *Geomorphology* 141–42: 150–159.

Kellerhals R, Church M and Bray DI (1976) Classification and analysis of river processes. *Journal of the hydraulics division, American Society of Civil Engineers* 102: 813–829.

Liébault F, Gomez B, Page M, et al. (2005) Land-use change, sediment production and channel response in upland regions. *River Research and Applications* 21(7): 739–756.

Marden M (2011) *Sedimentation History of Waipaoa Catchment*. Gisborne: Gisborne District Council.

Marden M, Herzig A and Arnold G (2011) Gully degradation, stabilisation and effectiveness of reforestation in reducing gully-derived sediment, East Coast region, North Island, New Zealand. *Journal of Hydrology (Wellington North)* 50(1, Sp. Iss. SI): 19–36.

Marden M, Arnold G, Seymour A, et al. (2012) History and distribution of steepland gullies in response to land use change, East Coast Region, North Island, New Zealand. *Geomorphology* 153/154: 81–90.

Marden M, Betts H, Palmer A, et al. (2014) Post-Last Glacial Maximum fluvial incision and sediment generation in the unglaciated Waipaoa catchment, North Island, New Zealand. *Geomorphology* 214: 283–306.

Mazengarb C and Speden IG (2000) Geology Of The Raukumara Area. Lower Hutt: Institute of Geological & Nuclear Sciences.

Miller AM (1995) Valley morphology and boundary conditions influencing spatial patterns of flow. In: Costa JE, Miller AJ, Potter KE, et al. (eds), Washington D.C.: American geophysical Union, pp. 57–81.

Ministry for the Environment (2012) *Land-Use and Carbon Analysis System: Satellite imagery interpretation guide for land-use classes (2nd edition)*. Wellington: Ministry for the Environment.

NIWA (2014) Suspended-Sediment Yield Indicator. Available from: https://www.niwa.co.nz/our-science/freshwater/tools/suspended-sediment-yield-estimator (accessed 6 February 2016).

Owens PN, Batalla RJ, Collins AJ, et al. (2005) Fine-grained sediment in river systems: environmental significance and management issues. *River Research and Applications* 21(7): 693–717.

Page KJ, Nanson GC and Frazier PS (2003) Floodplain Formation and Sediment Stratigraphy Resulting from Oblique Accretion on the Murrumbidgee River, Australia. *Journal of Sedimentary Research* 73(1): 5–14.

Page M, Marden M, Kasai M, et al. (2007) Changes in basin-scale sediment supply and transfer in a rapidly transformed New Zealand landscape. In: Helmut Habersack HP and MR (ed.), *Developments in Earth Surface Processes*, Gravel-Bed Rivers VI: From Process Understanding to River Restoration, Elsevier, pp. 337–356.

Page MJ, Reid LM and Lynn IH (1999) Sediment production from Cyclone Bola landslides, Waipaoa catchment. *Journal of hydrology. New Zealand* 38(2): 289–308.

Parkyn SM, Davies-Colley RJ, Scarsbrook MR, et al. (2006) Pine afforestation and stream health: a comparison of land-use in two soft rock catchments, East Cape, New Zealand. *New Zealand Natural Sciences* 31: 113–135.

Peacock D and Philpott J (2009) *Waipaoa River Flood Control Scheme Review*. Gisborne: Gisborne District Council.

Phillips CJ (1988) Geomorphic effects of two storms on the upper Waitahaia River catchment, Raukumara Peninsula, New Zealand. Journal of Hydrology (NZ) 27(2): 99–112.

Plummer N, Salinger MJ, Nicholls N, et al. (1999) Changes in Climate Extremes Over the Australian Region and New Zealand During the Twentieth Century. *Climatic Change* 42(1): 183–202.

Poff NL, Allan JD, Bain MB, et al. (1997) The Natural Flow Regime. *BioScience* 47(11): 769–784.

Reeve M (2015) *A place belonging to the heart: Spatially and temporally changing social connections to the Waimat River and its tributaries*. Unpublished report prepared as part of the Te Awaroa Project, Auckland.

Reid LM and Page MJ (2003) Magnitude and frequency of landsliding in a large New Zealand catchment. *Geomorphology* 49(1–2): 71–88.

Rhodes D (2001) Rehabilitation of deforested steep slopes on the East Coast of New Zealand's North Island. *Unasylva* 52(4): 21–29.

Schumm SA (1977) *The Fluvial System*. New York: John Wiley and Sons.

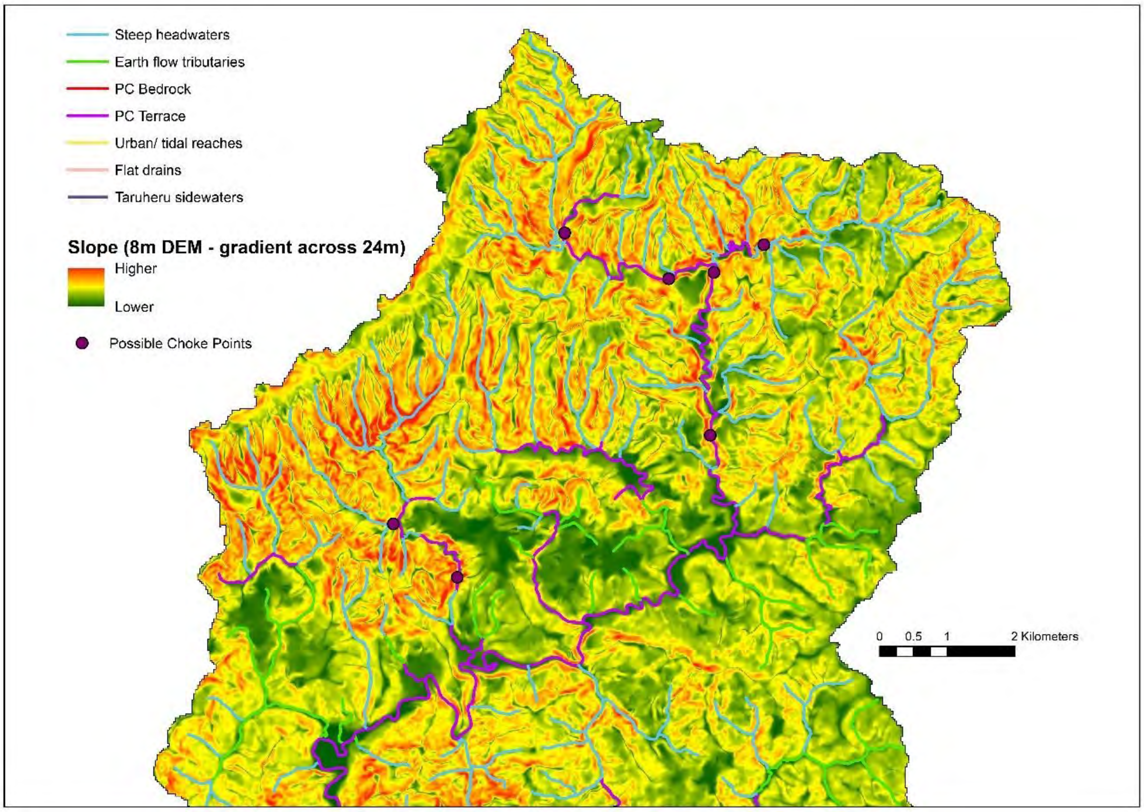
SCION (2012) *Waiapu River Catchment Study*. MPI Technical paper, Ministry of Primary Industries.

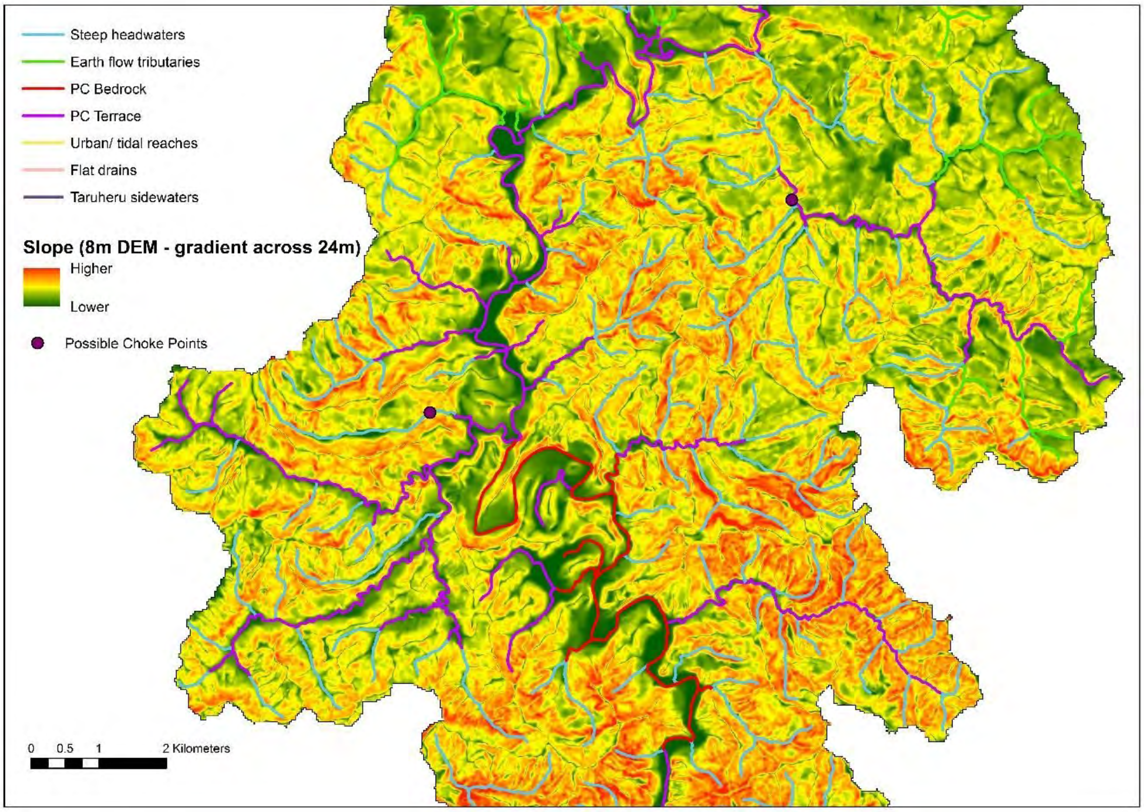
Wallace LM, Reyners M, Cochran U, et al. (2009) Characterizing the seismogenic zone of a major plate boundary subduction thrust: Hikurangi Margin, New Zealand. *Geochemistry, Geophysics, Geosystems* 10(10): Q10006.

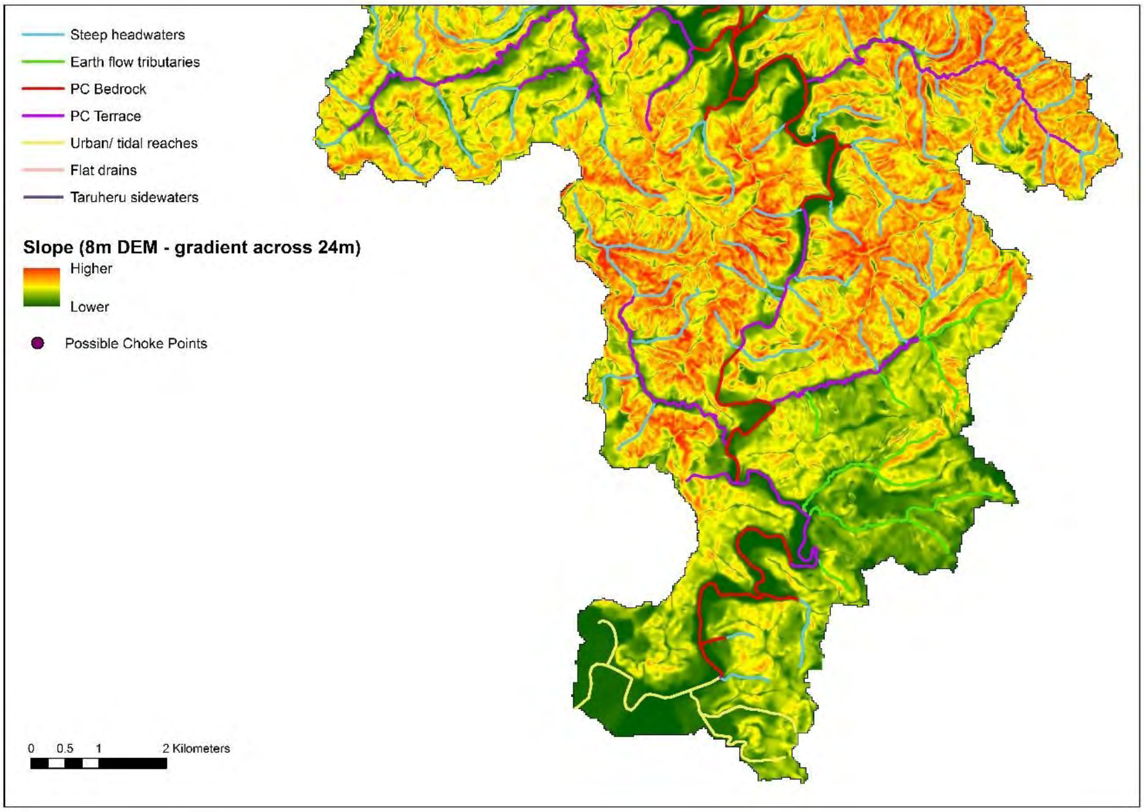
Wilmshurst JM, Eden DN and Froggatt PC (1999) Late Holocene forest disturbance in Gisborne, New Zealand: A comparison of terrestrial and marine pollen records. *New Zealand Journal of Botany* 37(3): 523–540.

Wilson K, Berryman K, Litchfield N, et al. (2006) A revision of mid-late Holocene marine terrace distribution and chronology at the Pakarae River mouth, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 49(4): 477–489.

APPENDIX 1: Slope and river styles






Steep headwaters
Earth flow tributaries
PC Bedrock
PC Terrace
Urban/ tidal reaches
Flat drains
Taruheru sidewaters
Slope (8m DEM - gradient across 24m)
Higher
Lower
Possible Choke Points
0 0.5 1 2 Kilometers

APPENDIX 2: Adjustments to the main stems of the Waimat and Taruheru Rivers between October 1942 and January 2012

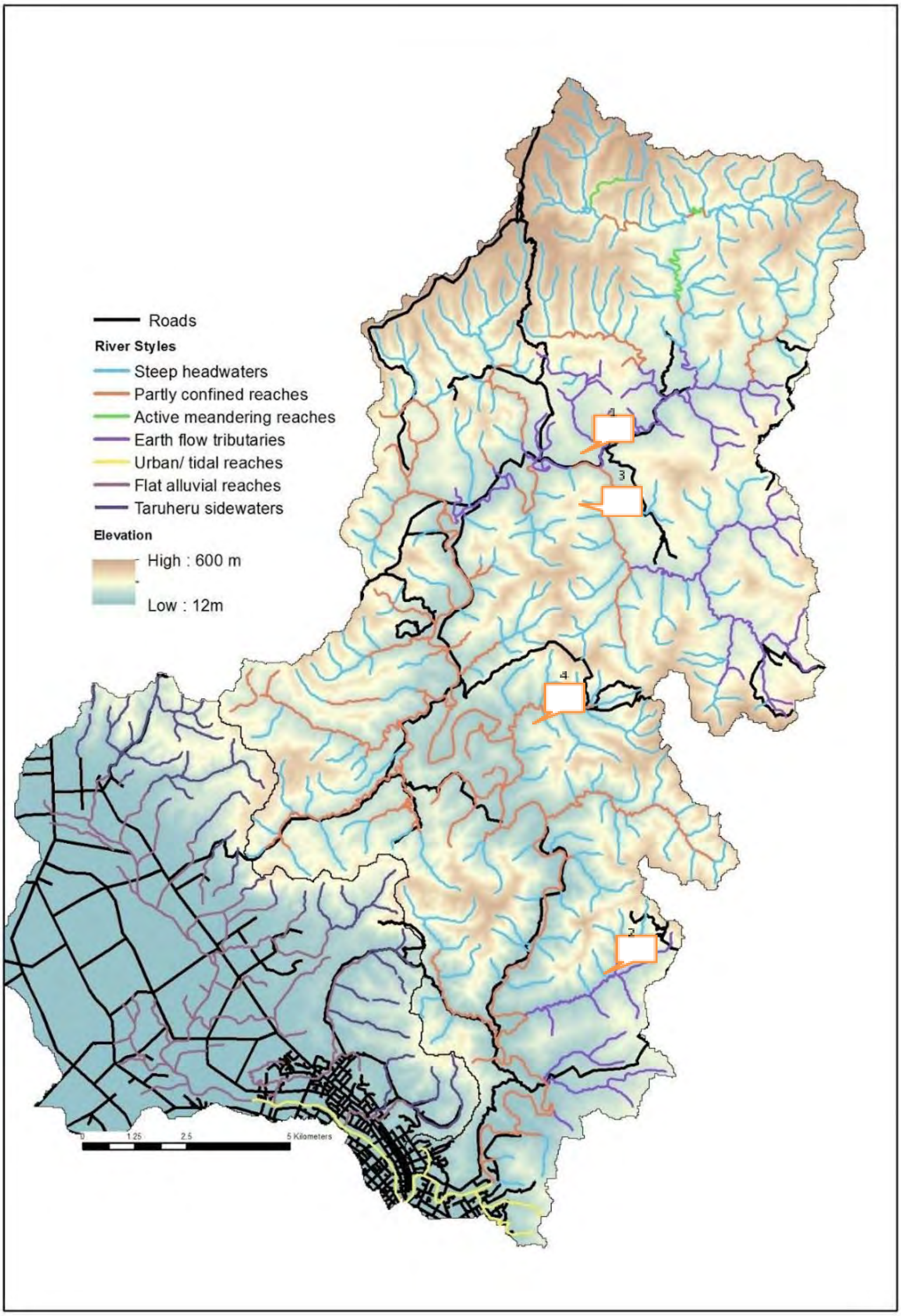
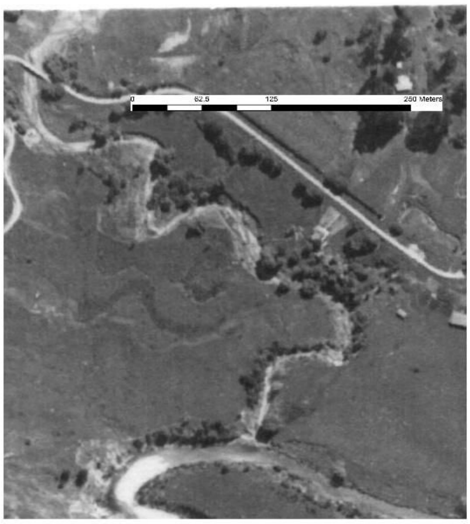


Figure 8.1: Sites with aerial photo comparisons between October 1942 and January 2012

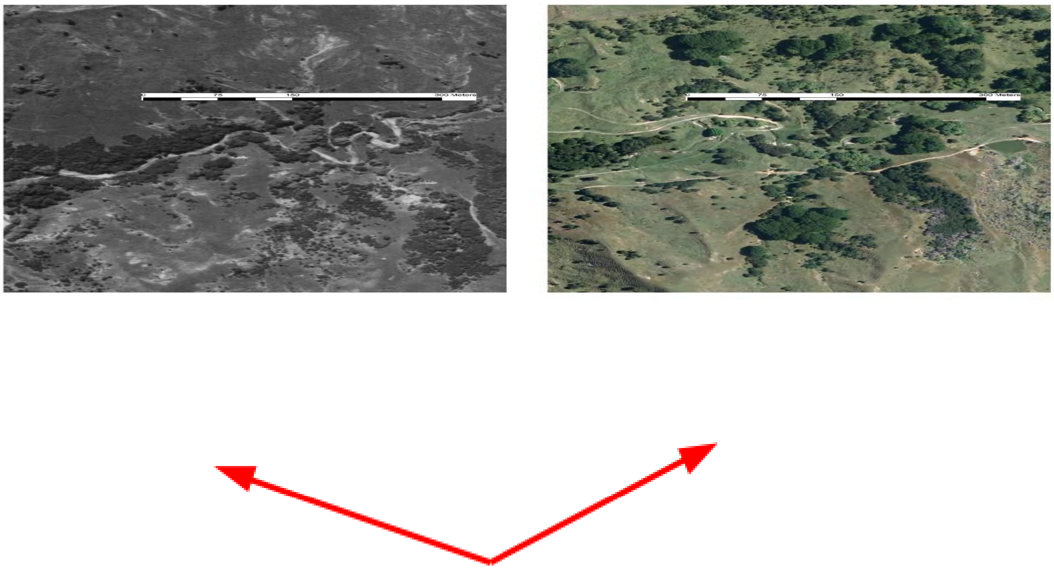
Earth flow tributaries (#1 in Figure 8.1)

Whilst meander loops have changed position in tributaries, the position of the main trunk has not changed, most likely because of relict terraces that hold the channel in place. Older abandoned channels can still be seen on the valley floor (Figures A2-A3).



Meanders of an earth flow tributary have changed position on the valley floor.

Figure A2: Changes to main stems in the earth flow region October 1942- January 2012
(#1 in Figure A1) Whilst meander loops have changed position in one of main stems on the valley floor, the position of the main trunk has not changed, most likely because of relict terraces that hold the channel in place.



Meanders of an earth flow tributary have changed position

Figure A3: Lateral adjustments to meanders in the lower earthflow region (#2 in Figure A1)

Streams partly confined by terraces
The main stem in the earth flow area is confined by terraces, so that it is not free to adjust laterally (Figure A4).

This reach has NOT adjusted – it is held in place by terraces

Figure A4: No adjustment to main stem meanders in the earth flow zone – these reaches are constrained by the position of relict terraces and are not free to move. (#3 in Figure 8.2)

Streams partly confined by bedrock

This main stem within the medium dissected terrain area is confined by bedrock, so that it is not free to adjust laterally (Figure A5).

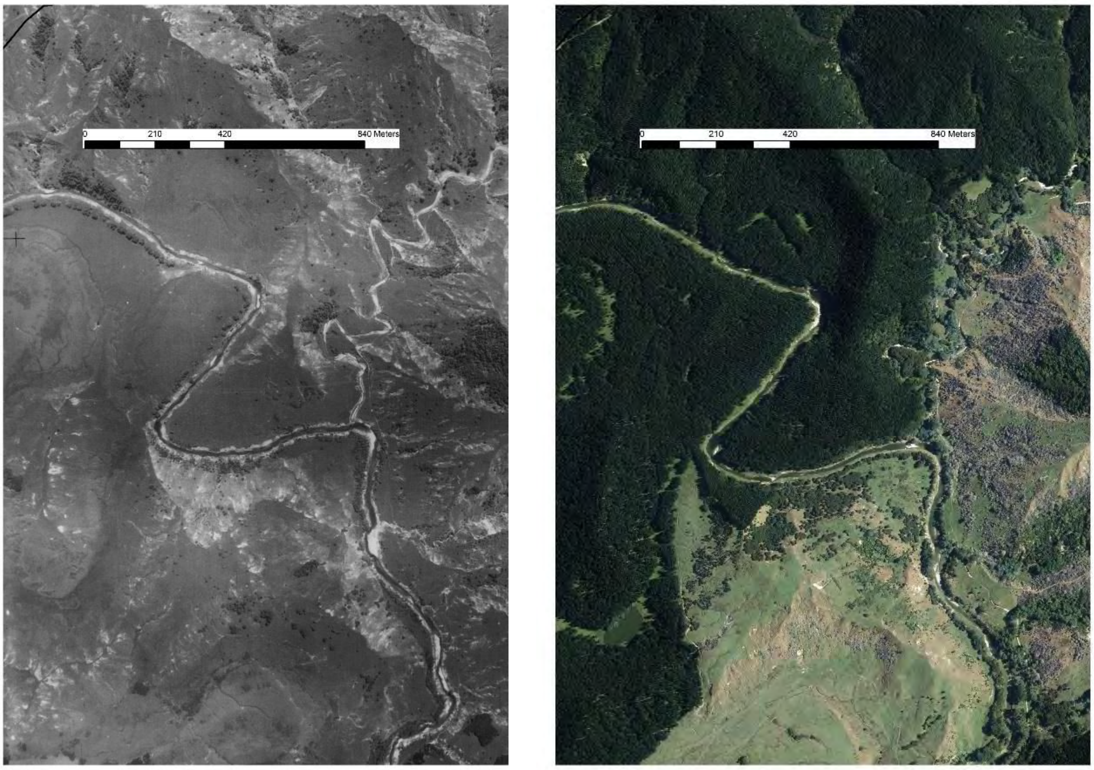


Figure A5: No adjustment to main stem meanders– these reaches are constrained by the position of bedrock outcrops and are not free to move. (#4 in Figure 8.2)