*Full Paper*

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# River Styles assessment and geomorphic sensitivity of the Waipā River Catchment, Aotearoa New Zealand

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**Key Points**

- In volcanic landscapes of New Zealand's North Island, rivers having capacity for adjustment are generally limited to unconfined, high-energy range-front streams.
- Additional channel constraints from flood protection, channelization and other anthropogenic modification have limited the capacity for contemporary geomorphic adjustment over the last 50 years to 3% of river length in the Waipā Catchment.
- Understanding of geomorphic river adjustment at the catchment scale provides a critical template to inform proactive and cost-effective river management applications.

## Abstract

River form within New Zealand's North Island volcanic landscapes is strongly conditioned by geologic structure and large-scale reconfiguration of the drainage system in response to volcanic episodes. Rivers have been further conditioned historically by widespread drainage of wetlands, straightening of meandering river courses, reinforcement of banks and stop-bank emplacement. Waikato Regional Council, Hydrobiology QLD Pty Ltd, Aerialsmiths New Zealand Ltd and The University of Auckland completed a River Styles assessment of the Waipā River Catchment, the first known River Styles assessment carried out for government in Aotearoa (Marson, Wheeler & Brierley, 2021). This was to provide council with a geomorphic baseline of their catchment, as well as a catchment-scale sensitivity analysis, highlighting reaches that were more sensitive to change to better prioritize management initiatives. Building on this sensitivity analysis, GIS tools were used to analyze stream power and historic imagery time series to examine the relative capacity for river adjustment along 3,000 km of channels (3$^{rd}$ Strahler order and greater) in the catchment. Only 3% of the studied river length showed any indication of significant planform adjustment since the 1950s. These dynamic sites were generally gravel-bed reaches in high energy, laterally unconfined settings within the piedmont zone. Elsewhere, the river was constrained by bedrock, valley fill terraces, and legacy effects induced by anthropogenic margin-controls. From the perspective of efficiently scoping sites that may hold promise for dynamic habitat evolution and ecosystem renewal, this work provides catchment managers with a basis in which to prioritize management initiatives.

## Keywords

River Styles, river change, sensitivity, river management, catchment management, rehabilitation

## Introduction

River managers are increasingly facing the problem of optimising available resources to implement a holistic and strategic plan for ecological recovery and enhancement of the river system. There is a growing need to understand the geomorphic sensitivity of different river types and controls that govern river adjustment. By understanding historical responses and contemporary river condition, it is possible to formulate a basis upon which to forecast future response to a range of stressors and tailor river management appropriately (Khan and Fryirs, 2020). In conceptual terms, the geomorphic sensitivity of a river reach refers to its capacity to recover following a disturbance event (Downs and Gregory, 1993, 2014; Reid and Brierley, 2015; Fryirs, 2017). Complex interactions among many factors often result in non-linear responses to environmental, geomorphological or climatological changes, challenging efforts to predict landscape sensitivity and/or resistance (Brunsden & Thornes, 1979; Downs et al., 2013; Fuller et al., 2019; Lisenby et al., 2018; Piégay et al., 2018; Thomas & Allison, 1993).

Building upon a long tradition of fundamental research, geomorphologists have developed a strong understanding of controls upon differing forms and rates of river adjustment, supporting effective prediction of associated magnitude-frequency relations (Wolman and Gerson, 1978; Gurnell *et al.*, 1994; Eaton *et al.*, 2004, 2010; Grabowski *et al.*, 2014; Hooke, 2015). Numerous studies have also assessed river sensitivity across spatial and temporal scales, and geomorphologists have defined sensitivity using a range of terms such as 'event sensitivity', 'robust', 'resilience', 'non-resilience,' 'sensitive' or 'insensitive' (Schumm, 1976, 1985, 1988; Brunsden and Thornes, 1979; Graf, 1982, 1979; Chorley *et al.*, 1984; Crozier, 1986; Thomas and Allison, 1993; Downs and Gregory, 1995, 2014; Schumm and Schumm, 1998; Thomas, 2001; Gordon *et al.*, 2001; Fryirs *et al.*, 2009; Reid and Brierley, 2015; Fryirs, 2015, 2017; Piégay *et al.*, 2018; Thoms *et al.*, 2018; Tooth, 2018; Ian C. Fuller *et al.*, 2019). Despite the existence of a solid conceptualisation of river sensitivity, few studies provide a consistent approach to assess sensitivity that can be applied and mapped at the catchment-scale (Fryirs, 2017). In applications of the River Styles Framework (Brierley & Fryirs, 2005), analysis of geomorphic sensitivity reflects assessment of the range of behaviour and 'capacity for adjustment' of a reach, wherein if a channel responds readily and recurrently it is considered sensitive, whereas if responses are negligible and infrequent the river is considered to be resilient to change. Building upon these principles, Reid and Brierley (2015) developed an approach to analyse geomorphic river sensitivity that incorporated appraisal of the likelihood of particular forms and rates of adjustment in response to disturbance events that are 'expected' as part of the behavioural regime of a given type of river. Therefore, the forms that arise and their capacity for adjustment define a river's inherent behavioural sensitivity, leading to a gradation of behavioural sensitivity amongst river types (Khan and Fryirs, 2020). Past geomorphic events and anthropogenic impacts can influence the capacity for contemporary river adjustment (Trofimov and Phillips, 1992; Crozier, 1999; Phillips, 2006), as well as reaction, relaxation and recovery times following disturbance (Chappell, 1983). This understanding forms the foundation for geomorphic forecasting of sensitivity to possible future disturbance (Fryirs, 2017). This paper aims to address this and has three objectives: (i) to use emerging GIS tools to identify reaches that have the most capacity for change via lateral adjustment, based on river stream power and relative channel confinement; (ii) to then assess the magnitude of past river dynamics in these reaches, and (iii) to review the landscape controls on river dynamism in volcanic terrain, emphasising how these dynamic river reaches (or reaches with dynamic potential) may be most effectively identified and managed.

## Regional Setting

To the local iwi Ngāti Maniapoto, the Waipā River (catchment area of 3092 km$^2$) is an indivisible living (female) entity that commences its journey from the mountain ranges in Pekepeke in the Rangitoto Range, east of Te Kūiti, then flows northwards through the towns of Ōtorohanga, Pirongia and Whatawhata, before meeting the Waikato River (11,353 km$^2$) at Ngāruawāhia and is home to their tribal kaitiaki (guardian) taniwha known as Waiwaiā (Parsons & Fisher, 2020). The Waipā catchment lies within the Australian Plate, west of the boundary of the Australian-Pacific plate (Edbrooke, 2005). A succession of Cretaceous- to Holocene-aged sedimentary and volcanic rocks overlie basement rocks (Figure 1). The northern part of the Waipā Catchment is characterised by low rolling hills formed mainly on Quaternary alluvium and distal ignimbrite, with wide intervening valleys filled with volcaniclastic-rich alluvium (Edbrooke, 2005). This alluvium blankets the plain areas (Hinuera surface) and forms part of the Waikato Fan (unconsolidated pumice, clays, silts, sands, tephras, breccias). Blocked embayments and low areas of the plain in the northeast supported the formation of peat mires (Edbrooke, 2005). Uplifted sedimentary rocks of Eocene to Oligocene age within the Te Kūiti Group in the south-western part of the catchment near Waitomo have created distinctive karst landscapes in limestone areas, characterised by sinkholes and cave networks surrounded by irregular ridges and near vertical cliffs near Waitomo (Edbrooke, 2005; Kear & Schofield, 1959; White & Waterhouse, 1993).

Changes during the Quaternary and Holocene periods exert a strong imprint on the river systems in the Waipā Catchment. The 181 A.D. eruption of the Taupō volcano induced major sedimentary and geomorphic responses, triggering a major phase of alluviation (Grant, 1985; Manville, 2002). The Waikato River has recurrently switched its course, where the most recent avulsion resulted in the river diverting from the Hauraki Plains into the Hamilton Basin and formed a broad very low relief fan (the Waikato Fan) around 19 ka (Kear et al., 1978; McGlone et al., 1978, Manville, 2002; Manville & Wilson, 2004). Several break-out floods during the fan building period induced the river to switch back and forth across a braid plain, leaving various paleochannel courses along which some tributaries to the Waipā now flow (McCraw, 1967, 2011). Subsequently, the Waikato River incised and became entrenched, lowering base level (Manville, 2002). Tributary streams, including the Waipā, underwent renewed incision as they degraded to the new base level, generating paired recessional terraces (Manville, 2002), that now constrict contemporary river adjustment.

Following adjustment to base level, the Waikato River experienced ~1000 years of relative stability following the re-establishment of podocarp forests, before humans settled in this area around 750 years ago (Manville & Wilson, 2004; Pawson & Brooking, 2002). Since 1840, almost all native vegetation in low-lying areas has been converted to pasture, and over 90% of wetland areas have been drained, leaving behind only small residual pockets of wetland and 14 shallow peat lakes (WRC, 2012). In addition, many channels have been modified in the catchment to reduce flood risk, where valley floors across the catchment have long been susceptible to flooding. Since the 'Great Flood' of February 1958, stop banks were constructed in the 1960s around Ōtorohanga and embankments in Te Kūiti to prevent future flooding of the townships (Hurst, 1998a; Pollock, 2015). The largest flood on record for the Waipā River was on 29$^{th}$ February 2004 (442 $m^3/s$ at Ōtewa and 646 $m^3/s$ at Ōtorohanga). Further construction of a number of flood protection structures on both the Waipā and Waikato rivers (stop banks, channel straightening, flood gates, pumping stations) have significantly reduced this hazard (Hurst, 1998a, 1998b; Edbrooke, 2005). However, increased erosion and sedimentation rates from historic land clearance, channel modifications, erosion prone soils and instability of the river in sections has been exacerbated in recent decades by the intensification of livestock farming and growth of urban areas (Hughes *et al*., 2012; Paterson-Shallard *et al.*, 2020). Increased sedimentation, nutrient loads and bacteria are driving water quality decline in the Waipā River and tributaries (WRC, 2014), as well as having adverse effects on instream ecology, through reduced water quality or direct smothering of organisms and their habitats (Hughes et al., 2012). Hence there is a growing need for catchment managers to understand the sources of erosion (i.e., where channels are sensitive to adjustment).

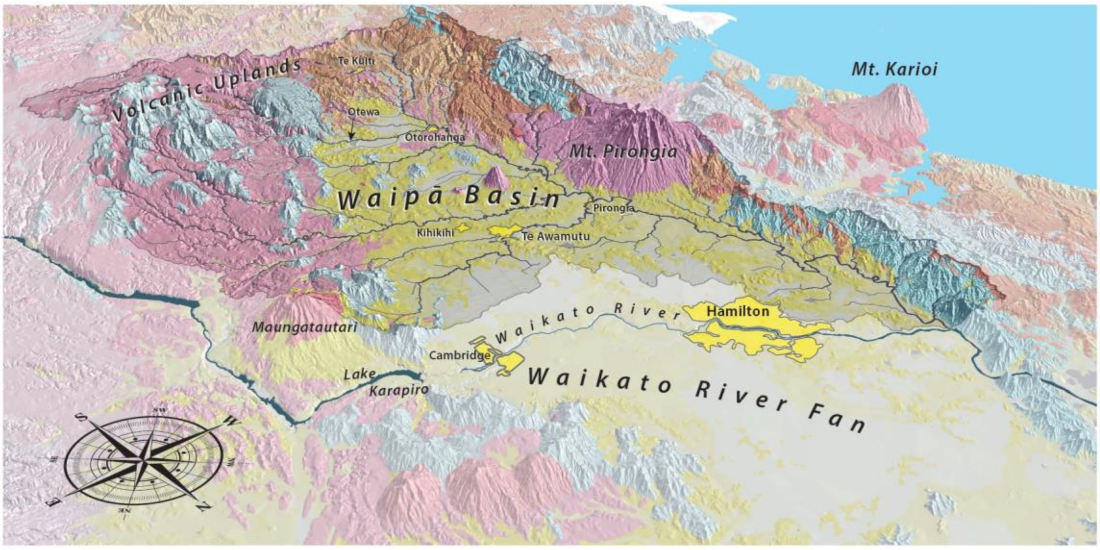


**Figure 1. The Waipā Basin surficial deposits consist primarily of Holocene swamp deposits (whitish yellow) and river floodplain units (medium yellow) with ignimbrite and sandstone (darker yellow). The basin is surrounded by volcanic ignimbrite (pink), sandstone, mudstone (oranges) and limestone (blues).**

## Methods

River typology was classified according to the River Styles Framework (Brierley and Fryirs, 2005; Fryirs and Brierley, 2018). This involved using a combination of Google Earth, LiDAR, other available imagery, and field verification to describe valley setting, planimetric form, the assemblage of geomorphic units in the reach, bed material attributes, and to assess potential geomorphic sensitivity (Figure 2). Sensitivity to geomorphic adjustment in the Waipā catchment was further assessed by determining the energy available for change (stream power) as well as the confining topography (bedrock and terraces). This was carried out using TopoToolbox 2 (Schwanghart and Scherler, 2014) in MATLAB (2020b) and a 4-m DEM (generated by fusing an up-sampled 8-m digital elevation model (LINZ, 2012) and a down-sampled 1-m LiDAR model (WRC, 2008)). The TopoToolbox long profile smoothing algorithm (constrained regularized smoothing (*CRS*), Schwanghart and Scherler, 2017) was used to minimize the stepped contour artefacts in the 8-m elevation model. The maximum elevation of confining topography adjacent to the river (within 100 m) was assessed using the *maplateral* function in TopoToolbox. Evidence of past river behaviour was assessed using both historic aerial photos and hillshade rendering of the 1-m LiDAR model. Imagery was georeferenced and orthorectified to the 2012 imagery dataset (see Wheeler, 2019). All available historic aerial image mosaics (1944-2012) were used to determine migration rates for 1 – 3 km reaches of the major river types identified using the Channel Migration Tool (Legg *et al.*, 2014).

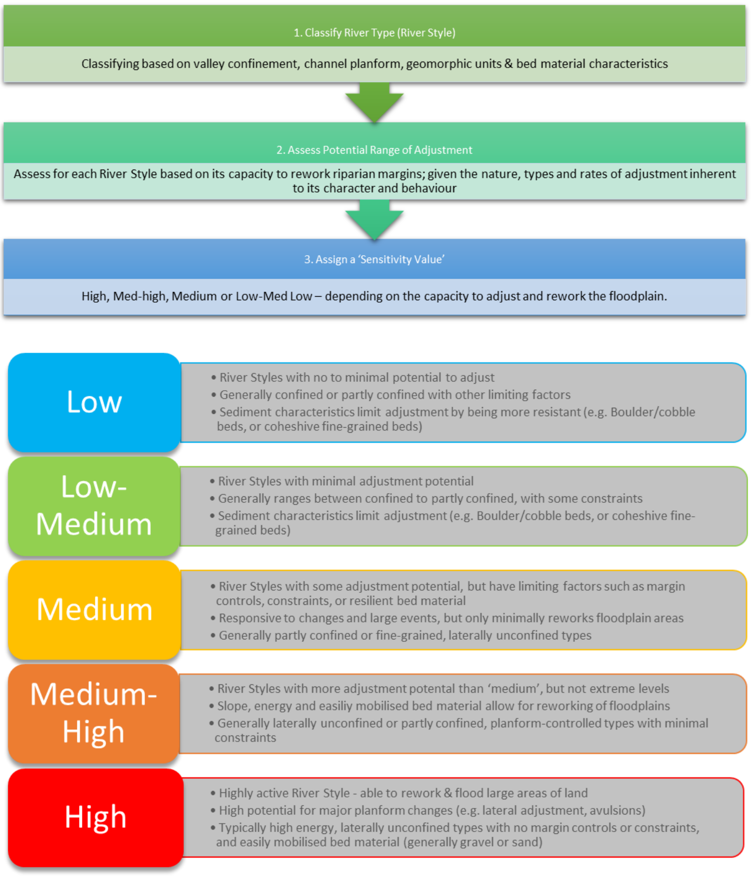


**Figure 2. An approach to analysis of potential geomorphic river sensitivity (adapted from Wheeler, 2019).**

## Results

### *Stream Power and Confinement*

In the steep upper reaches of the network, stream power was generally determined to be high, but channels were typically confined to semi-confined, limiting the capacity for river meandering and geomorphic change. In the lowermost reaches of the river, stream power was low, and the river had incised into the Waikato Fan, limiting capacity for lateral movement. In between these upper and lower bounds, the river exhibited various states of stream power levels and relative confinement. Figure 3 shows the co-variation in longitudinal channel elevation, upstream catchment area, degree of confinement and stream power. Stream power was particularly high in the bedrock canyons, with the highest stream power beyond the canyon persisting along a roughly 3 km reach between Ōtewa and Ōtorohanga that was unconfined by valley walls, but extensively stop-banked. This reach encompassed the confluences of the Waipā and the Mangapohue, Mangawhero, Mangapū, Waitomo, and Mangaoronga. Two other hotspots that were evident were located in the mid-lower reaches of the Pūniu and the Mangapiko (Figure 4). The lowermost 3 km of these rivers was confined within the valley fill and ignimbrite topography, but upstream of this point there was considerable evidence of past river migration and dynamic lateral movement.

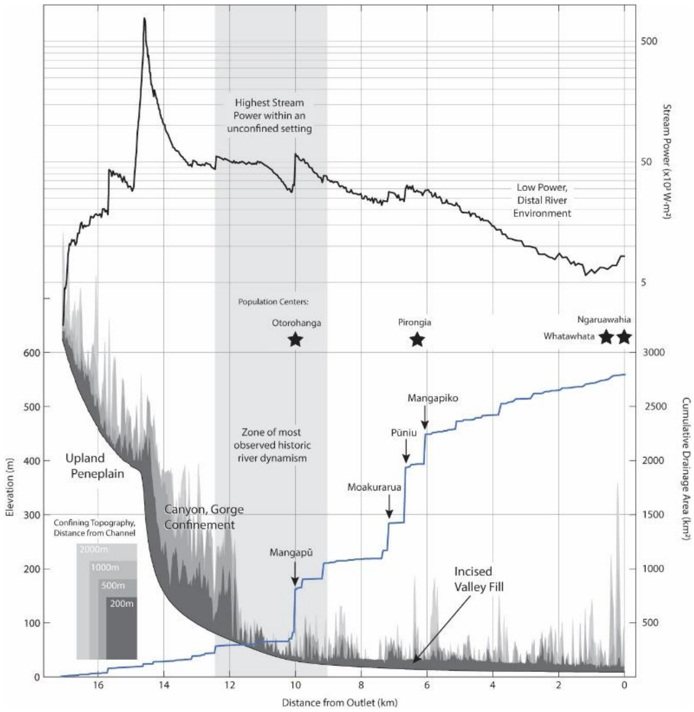


**Figure 3. Longitudinal plot of riverbed elevation, cumulative drainage area, relative topographic confinement and total stream power.**

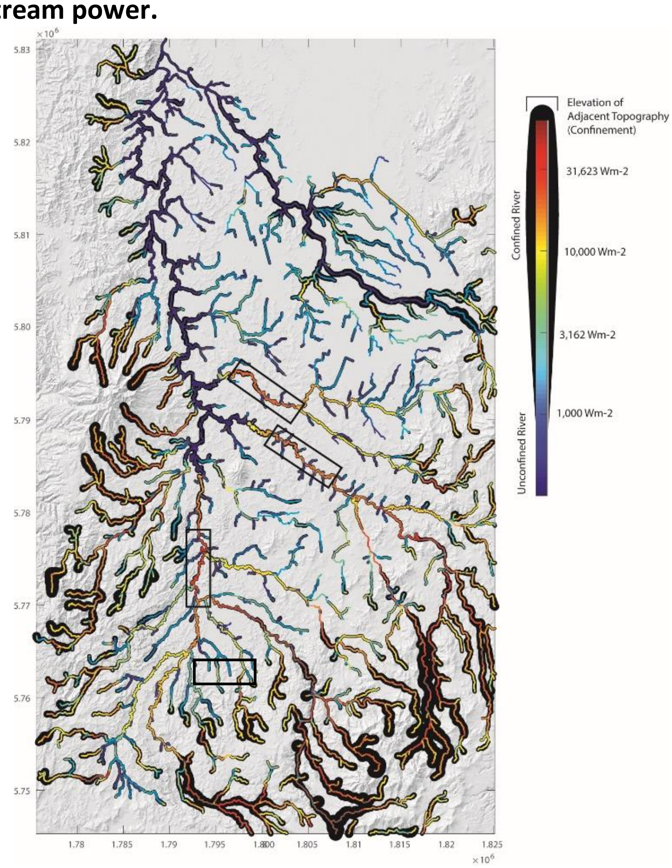


**Figure 4. TopoToolbox reveals the variation in stream power and channel confinement throughout the drainage network, identifying 'hotspots' (high stream power & no constraints) for channel dynamism.**

## *River Styles of the Waipā Catchment*

River Styles classes were identified and mapped for 45 river reaches in the Waipā Catchment (Figure 5). The diversity of River Styles displayed in each sub-catchment reflected the wide variability in landscape units (a product of the geological history) and associated downstream changes in slope and stream power. The most common River Styles included:

- C_BrMC_Hw_Bbed (confined, bedrock margin-controlled, headwater, bedrock bed; 11% of river length) - typically found in the steep volcanic uplands of the sub-catchments downstream of the volcanic plateau.
- PC_BrMC_DcFp_Gbed (partly confined, bedrock margin-controlled, discontinuous floodplain, gravel bed; 11% of river length) - found in all sub-catchments, reflecting locations where valleys widened and created space for discontinuous floodplains. Stream power values peaked in these relatively high energy, steep settings, but bedrock margins restricted the capacity for lateral channel adjustment.
- C_TrMC_OccFp_Fbed (confined, terrace margin-controlled, occasional floodplain pockets, fine grained bed; ~9% of river length) – prominent along lower courses of the Waipā River and Mangapiko Stream, where channels have degraded and cut back through the Waikato Fan deposits, adjusting to base level conditions set by the entrenchment of the Waikato River. Large terraces constrained the contemporary river course. Some of these reaches flowed as underfit streams within paleochannels of former Waikato River courses. Lower reaches of the Pūniu River also comprised this River Style, as the channel had adjusted to base level changes to become entrenched within its former deposits, which remained as large terraces.

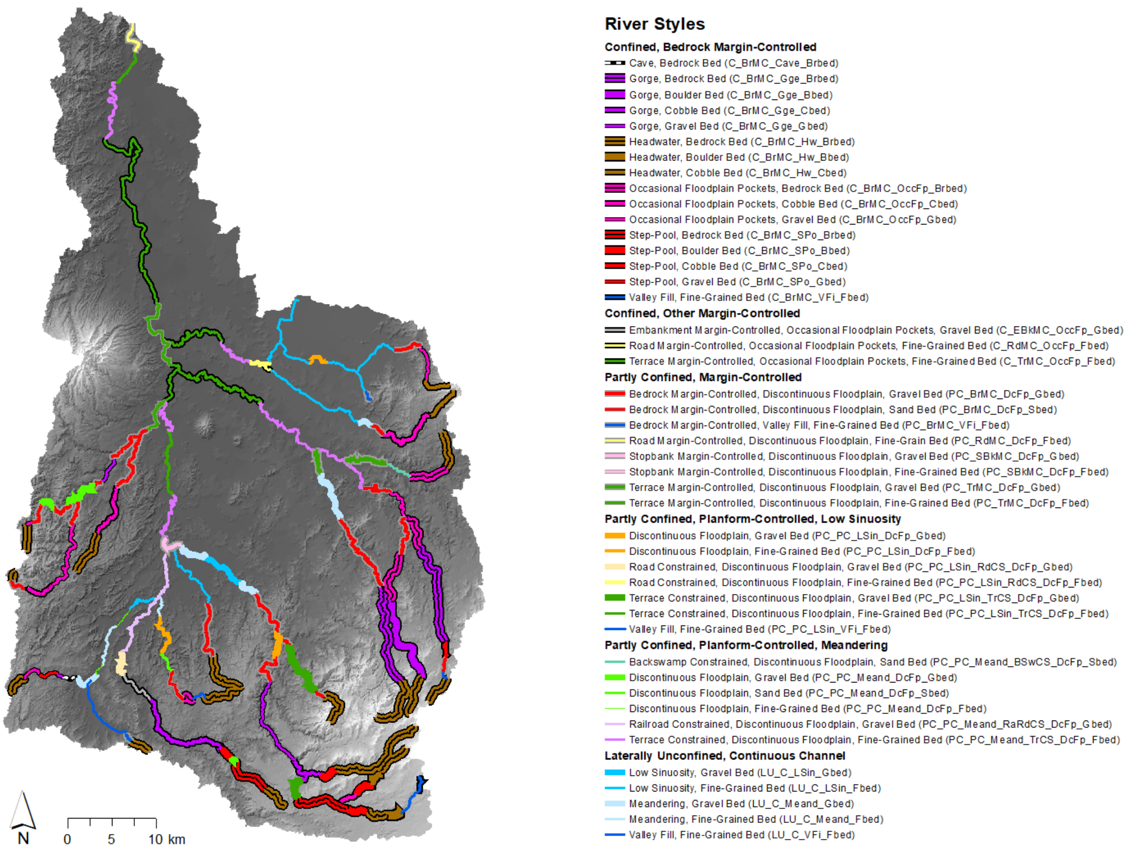


**Figure 5. River Styles identified within the Waipā River Catchment.**

Spatial patterns of valley confinement and the distribution of margin-control or constraints and bed material texture are key determinants of the different River Styles of the Waipā catchment (Figure 6):

- Confined reaches with limited capacity for lateral adjustment made up ~47% of the studied river length. Reaches in the volcanic ignimbrite uplands in the Upper Waipā and Pūniu River sub-catchments were confined, while terrace margins confined reaches of lower parts of the catchment. Around 3% of studied river length was constrained by anthropogenic structures, including stop banks, especially near towns and infrastructure in and adjacent to Te Kūiti, Ōtorohanga, Te Awamutu and Ngāruawāhia.
- As a relatively small proportion of the catchment was laterally unconfined (~15%), only localised reaches of rivers were able to freely adjust.
- In the upper catchment (~35 of the studied river network), channel beds were either bedrock or boulder/cobble based. Gravel bed rivers comprised ~30% of studied river network, primarily in mid-

catchment reaches. In the lower catchment (~38% of the studied river network), channel beds comprised cohesive fine-grained materials.

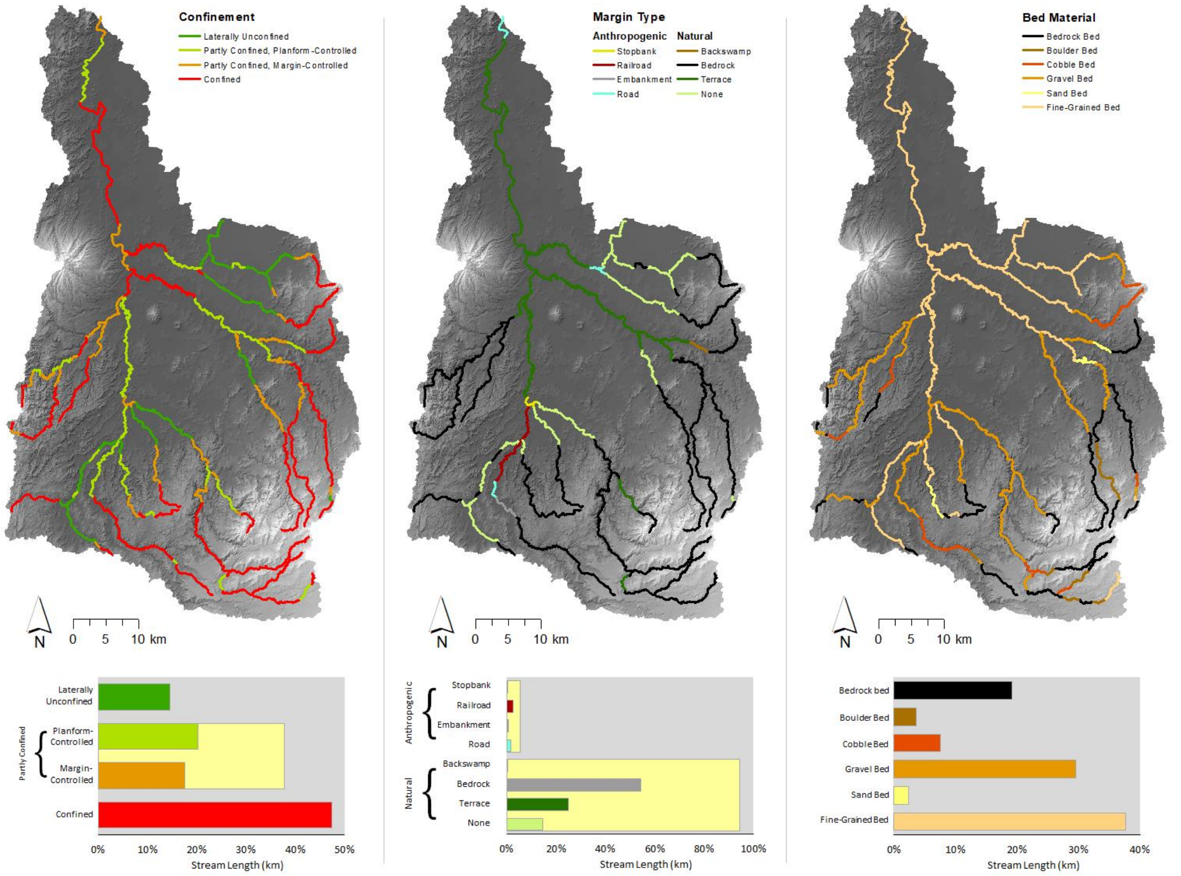


**Figure 6. Main attributes of River Styles identified in the Waipā River Catchment.**

## *Reach-scale analysis*

Migration rates varied depending on River Style type and catchment position. For most of the Waipā, channels were relatively resilient to channel adjustment and adjustment was highly localised to certain reaches and bends. Migration rates varied between about 1% and 9% of channel widths, with those more confined River Styles experienced lower rates of migration than less confined reaches (Table 1).

**Table 1. Examples from Reach-scale channel migration analysis.**

| Migration Rate | Example River Style | Example Location | Rate (channel width/year) | Characteristics |
|---|---|---|---|---|
| Low | Laterally unconfined, continuous low sinuosity fine grained bed style (LU_C_LSin_Fbed). | Lower reach of the Mangapū River, Mangapū sub-catchment. | 0.49% | Despite laterally unconfined setting, low rates due to reach scale factors; entrenched channel with cohesive banks and low energy conditions (flat, low sloping alluvial plain). |
| Low-Medium | Bedrock margin-controlled, gorge bolder bed style (C_BrMC_Gge_Bbed). | Upper reach of the Mangatutu Stream, Pūniu sub-catchment. | 1.09% | Expected low rates due to gorge setting; Channel confined by steep valley walls (200-300m high); Vertical degradation more common. |
| Medium | Confined, terrace margin-controlled, discontinuous floodplain, fine grained bed style (C_TrMC_DcFp_Fbed). | Lower reach of the Pūniu River, Pūniu sub-catchment | 2.20% | Adjustment constrained due to terrae-margin control. Adjustment only possible at outside of bends, or places of small inset occasional floodplain pockets. |
| Medium-High | Laterally unconfined, continuous low sinuosity gravel bed style (LU_C_LSin_Gbed). | Lower reach of the Upper Waipā River, Upper Waipā sub-catchment. | 4.42% | Former channel outlines indicated previous channel adjustments from a more sinuous course prior to engineered straightening. Although having become incised and become entrenched in places, reach had high capacity for adjustment being situated in a high energy setting that is unconfined, with bed material that was easily mobilised. |

| | | | | |
|---|---|---|---|---|
| High | Laterally unconfined, continuous channel, meandering gravel bed style (LU_C_Meand_Gbed). | Lower reach of the Upper Waipā River, Upper Waipā sub-catchment. | 8.86% | Adjustments were much greater compared to all other River Styles. Adjustment had occurred along 80-100% of river length (unlike localized adjustments of other River Styles). The 1 m LiDAR revealed multiple paleochannels which suggests this river has been sensitive to adjustment for a long time. Sensitivity is likely due to catchment location; located immediately downstream from a steep gorge, where the river first becomes unconfined and was set in the highest stream power setting in the catchment (Figure 3,4). |

### *Geomorphic Sensitivity*

Figure 7 shows the variation in geomorphic sensitivity across the catchment. It shows that a large proportion of the catchment was considered resilient to adjustment, with 44% ranked as 'Low' sensitivity and 36% ranked as 'Low-Medium' sensitivity due to the high degree of margin control. It also shows that only a small proportion (3%) of the catchment was ranked as 'High' sensitivity, with high capacity for geomorphic adjustment. Hence, the catchment was considered to be a resilient system, with only localised reaches that were sensitive to change (Wheeler, 2019). Where this is paired with high stream power, as well as easily mobilised sediments, dynamic reaches resulted.

## Discussion

### *Geomorphic sensitivity of the Waipā Catchment*

Analyses of river change reported by fluvial geomorphologists often emphasize dramatic forms and rates of adjustment in response to major disturbance events. Few papers in New Zealand report on low rates of channel adjustment, a notable exception being the work on Northland rivers by Richardson *et al.*, (2013). Most river reaches in the Waipā catchment are resistant to geomorphic change, with 3% of river length prone to significant adjustment over decadal timescales. Minimal adjustment in response to disturbance across the catchment indicates internal resistance of this system to change. Volcanic events have shaped the resistant plateau landscapes of south-eastern parts of the catchment and Mount Pirongia to the west. Many river courses in the upper reaches of the Waipā are confined by bedrock margins within uplifted volcanic and sedimentary rock. Resulting River Styles have limited capacity for geomorphic adjustment, with bedrock, boulder or cobble beds. In addition, many of the contemporary river courses in the lower reaches of the Waipā catchment are shaped by past incision into the Waikato River Fan, where channels are confined by terraces and paleochannels, restricting their capacity for adjustment. In addition, many of the plains consist of fine-grained, cohesive clays and silts, representative of remnant substrates of former lake and wetlands which have since been drained (McCraw, 1967, 2011). The prominence of fine-grained materials along valley floors, along with the inherited pattern of bends in incised (entrenched) reaches, exert a primary control upon local patterns and rates of bank erosion (c.f., Sylvester *et al.*, 2019). It is only in localised areas behind the Waikato Fan that locally aggraded, laterally unconfined reaches have significant capacity to adjust. Landscape history therefore exerts a significant control on where rivers are sensitive to change and likely to adjust within this catchment in the future. As noted by Lisenby and Fryirs (2016), reaches where channels have a high width-depth ratio, coarse (non-cohesive, readily mobilized) bed materials and high stream power conditions are especially prone to geomorphic adjustment. In the Waipā Catchment, these localized reaches present a 'window of opportunity' for change, and notable adjustments may occur when these areas are subjected to a 'perfect storm' of conditions. In a sense, these are geomorphic hotspots (*sensu* Czuba & Foufoula-Georgiou, 2015).

### *So what? Management Implications*

Given the lack of systematic baseline geomorphic information about the river system, misguided river works over the last 30 years have reactively responded to local adjustments, striving to 'fix' the channel in place rather than working with the river as a living entity (c.f., Brierley, 2019; Brierley *et al.*, 2019). In recent years, there has been a shift in management schemes towards reducing bank erosion and channel migration through soft engineering measures including fencing and riparian planting initiatives. However there has been little

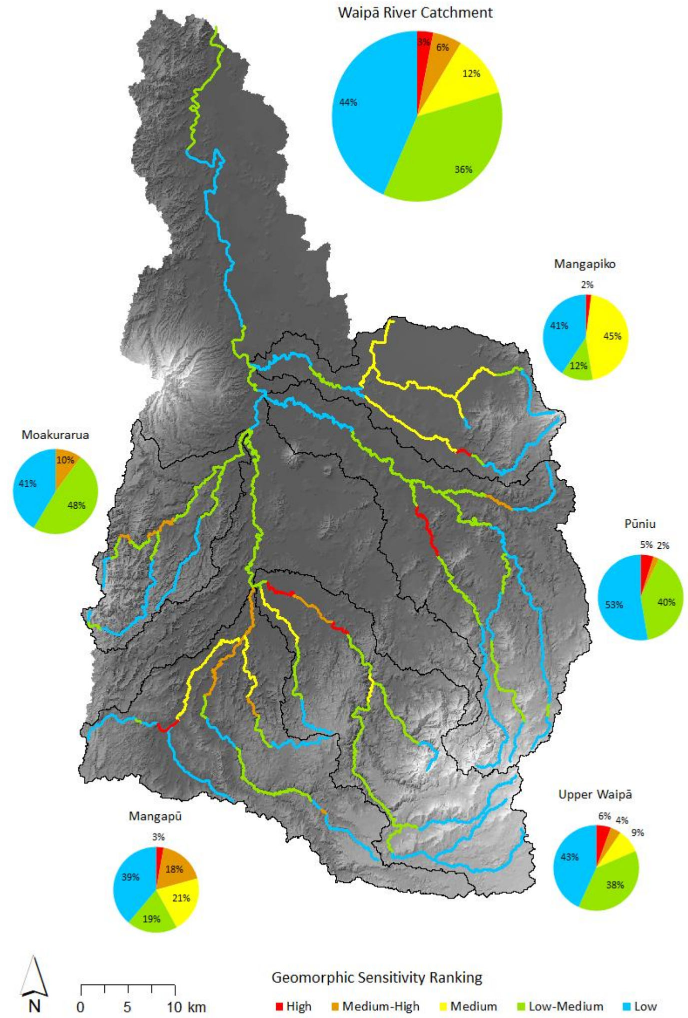


**Figure 7. Geomorphic sensitivity rankings of the Waipā Catchment and study sub-catchments. Pie charts show the proportion of each sensitivity ranking within each catchment.**

guidance on *where* to target such initiatives. Analysis of the Waipā catchment has highlighted which reaches are more sensitive to change, lateral adjustment and bank erosion. These data provide an important platform for informed decision making, where carefully targeted management applications may be implemented.

### *Freedom space*

Kondolf (2011) argued that allowing a river to 'self-heal' by designating space for channel migration is the most sustainable approach to river restoration. In the Waipā, many anthropogenic margins which have resulted from past colonial mindsets and legislation are constraining adjustment and reducing habitat diversity through the concentration of flows. Williams *et al.*, (2020) showed that the removal of lateral constraints from a study reach resulted in greater adjustment and bank erosion that enabled greater channel-floodplain connectivity, an increased range in hydraulics and greater physical habitat diversity. In many downstream settings however, compromise and balance may need to be struck between restoring fluvial and ecological processes of rivers under a freedom space approach with maintaining important property and infrastructure (Biron *et al.*, 2014; Buffin-Bélanger *et al.*, 2015). In terms of achieving New Zealand national freshwater goals for improving the health of aquatic waterbodies, however, restoring lateral and other fluvial process of rivers (such as geomorphological, hydrological, and ecological) would seem intrinsically entwined within Te mana o te Wai.

### *Ecology*

Geomorphic complexity is invariably synonymous with ecological diversity (Miller *et al.*, 2010; Kail *et al.*, 2015). In New Zealand there are numerous endemic fish species that have evolved to occupy and exploit particular hydro-geomorphic niches within riverscapes (e.g., *Cheimarrichthys fosteri* adaptations enabling it to reside and feed in extremely high water-velocities (McDowall, 2006), *Gobiomorphus hubbsi* have tubular and upturned mouths to allow movement through interstices in cobble beds). Since these species may be found within the same river reach (but preferentially occupying different morphological habitat units) the importance of maintaining local geomorphic complexity to support local biodiversity is clear. Thus, in such situations there may be a direct conflict between controlling lateral erosional processes and preserving habitat complexity and ultimately aquatic biodiversity. Furthermore, information from geomorphic assessments suggests that the consequences of attempting to fix or 'fossilise' such reaches to a given river course is likely to be a misguided practice within river settings which are by their nature sensitive to adjustment.

### *Climate change*

Predicted climate warming is likely to change future flood magnitude and frequency as the hydrological cycle intensifies (Ian C. Fuller *et al.*, 2019). The variability in precipitation across Aotearoa has been shown to be modulated by ENSO and SAM at interannual timescales and such climate modes have driven river activity, including flooding (Richardson *et al.*, 2014; Fuller *et al.*, 2019). Predictions of more frequent extreme hydrological events and landuse change pressures to meet housing shortages are likely to have greater localized impacts in areas more adjustment-prone and sensitive to change, therefore emphasizing the importance of understanding catchment sensitivity. As only a small proportion of the catchment is considered sensitive to change, appropriate actions should be more effectively targeted in these areas. Management in sensitive areas may require reimagination, with the maintenance of old practices based on outdated legislation no longer sustainable or appropriate as they work against ecologically framed rehabilitation initiatives (e.g., Piégay *et al.*, 2005; Florsheim *et al.*, 2008), and not cost effective under future projections of climate change (Biron *et al.*, 2014; Buffin-Bélanger *et al.*, 2015).

### *Respecting River Diversity and Geomorphology*

Understanding geomorphic sensitivity and predicting forms/rates of likely geomorphic adjustment can aid in the design and implementation of different management initiatives that respects river diversity. Hughes (2016) argues that different erosion processes act upon stream banks in different parts of a catchment and therefore catchment managers need to consider this when implementing riparian management interventions. McKergow *et al.*, (2016) showed that targeted applications of riparian schemes, were more likely to have significant water quality and habitat benefits. Hence, the design and the effectiveness of such management schemes will and should vary for different River Styles in different parts of the catchment. This baseline geomorphic characterisation of reaches provides much needed geomorphic understanding to the processes acting upon reaches in the Waipā Catchment.

## Conclusions

This is a first catchment-scale example of a River Styles assessment and past river adjustments-based sensitivity index analysis undertaken for government of a catchment in New Zealand. It has offered a unique opportunity to provide a geomorphic perspective to river managers and highlights the value it can provide to help inform local management initiatives. In geomorphic terms, the Waipā catchment is a resilient system. Only a small proportion of river length is sensitive to adjustment, with significant capacity for adjustment. This reflects a significant imprint of bedrock, terrace, and anthropogenic margin-control. High rates of adjustment are localized, restricted to partly confined planform-controlled or laterally unconfined alluvial reaches in high energy settings. This understanding can support cost-effective targeted proactive management and rehabilitation of sensitive reaches, prospectively informing targeted applications of freedom space initiatives that support diverse habitat creation and ecological rehabilitation.

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