Assessing the value of a geomorphic toolbox to assist with determining ecological health of wadable streams within the Waikato Region

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Kaua e kōrero mō te awa, kōrero ki te awa

Don't talk about the river, talk to the river

Abstract

Ecological measures such as quantification of taxa and chemical indicators are well established as tools for assessing river health, but the geomorphic component is often left out despite forming the template on which all other processes occur. To address the missing geomorphic component in monitoring river health, this research focused on framing river health within a geomorphic context and formulated a Waikato Region-specific geomorphic toolbox to be integrated with existing river health monitoring, providing a more holistic understanding of rivers in the region.

Six indicators were chosen to assess geomorphic condition and develop a toolbox: riparian zone, wood, bank erosion, particle size, connectivity and geomorphic units. Reference conditions were established for each site based on 'minimally disturbed' conditions. Qualitative and semi-quantitative techniques for assessing each indicator were outlined and tested against six monitoring sites – four ecological reference state and two non-reference state – within the Waikato Region using desktop based '*apriori*' methods, as well as in-field monitoring. Assessment outputs included a qualitative proforma of each stream and a scoring mechanism to provide comparable results of each streams. Streams were given an assessment level from 'Excellent' to 'Very Poor' depending on their geomorphic quality.

Four reference sites were assessed as 'Excellent', while the two non-reference sites were assessed as 'Poor' for geomorphic quality. Comparisons to ecological monitoring data of the same reaches showed a relationship between ecological and geomorphic health, such as the excellent fish and MCI scores corresponding with 'Excellent' geomorphology. However, proximity to the coast can skew fish indicators due to the diadromous nature of many native New Zealand fish; whilst the Whangarahi Stream was considered 'Poor' for geomorphic health, it was inhabited by an order of magnitude more eels than any other reach assessed.

The use of reference conditions is integral to a well-functioning geomorphic toolbox, although further exploration is needed around whether reference conditions should represent 'minimally disturbed' or 'best attainable' condition given existing land use patterns. Inclusion of more encompassing geomorphic unit indicators, as well as bed structure would strengthen the toolbox.

The geomorphic toolbox was created to provide meaningful and comparable data for assessing geomorphic health in a time- and cost-efficient manner, which has been achieved. Subject to further testing and refinement of variables to maintain relevance to a range of geomorphic contexts, the toolbox is considered adequate for inclusion into State of the Environment reporting structures for the Waikato Region.

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1. Introduction

Rivers are of paramount importance to life, both in terms of human and ecosystem health (Reid *et al.*, 2008) and yet are some of the most degraded landforms worldwide (Raven *et al.*, 2010). River health is a measure of catchment health, which in turn provides an indication of both environmental and social health (Brierley & Fryirs, 2005). Given their necessity for quality of life and ecosystems, rivers are beginning to be seen and valued for their roles as the template in which other processes and functions of river and ecosystem health occur (Lake *et al.*, 2007; Brierley & Fryirs, 2016; Wohl, 2016; Fuller & Death, 2017; Fuller *et al.*, 2019). However, contemporary rehabilitation and river management tend to focus on the ecological, hydrological and chemical attributes of a river, while neglecting the geomorphic processes (Norris & Thoms, 1999; Brierley *et al.*, 2010; Wohl *et al.*, 2019). It is increasingly apparent that the geomorphic tapestry can dictate the efficacy of other river quality attributes such as taxa quantity and quality, water temperature, and even chemical indicators. Whilst the legislative context in New Zealand for the natural environment provides a degree of protection to rivers, a lack of integrated geomorphic measures presents a gap in the collective understanding of the current state of river health in the regions. Appropriate mitigation, rehabilitation and change cannot be achieved consistently without a comprehensive understanding of the drivers of change, including the geomorphology of New Zealand's river catchments (McFarlane *et al.*, 2011). This thesis assesses the suitability of creating a 'fit-for-purpose' geomorphic assessment toolbox for use alongside other existing river health assessments under national and regional statutory requirements, and to appraise the geomorphic quality of both reference and non-reference sites within the Waikato Region.

1.1. Research gap

Regional Councils, including Waikato Regional Council (WRC), are obligated under Section 35 of the Resource Management Act 1991 (RMA) to undertake monitoring and reporting on the state of the environment every five years. This includes freshwater (rivers) across the region to identify any temporal changes to water quality or river conditions. WRC has identified a geomorphological gap within the analysis whereby the current State of the Environment (SOE) approach for river condition assessments is primarily concerned with water quality, habitat quality, and indicator species

(McFarlane *et al.*, 2011). As a result, the opportunity to assess changes in river health and river condition through identification of geomorphic form, process and evolution (McFarlane *et al.*, 2011) is marginalised. Efforts to manage and monitor river condition in a meaningful way may be ineffective without genuine effort to detect the interrelationships between water quality, ecosystem health and geomorphology. This is important because river health is about more than just water quality and quantity; geomorphology sets the physical template upon which lotic processes operate (Fuller *et al.*, 2019; Wohl *et al.*, 2019). Therefore, WRC are seeking to develop a fluvio-geomorphic condition assessment to incorporate meaningful data into the SOE reporting to further strengthen their understanding of river health within the Waikato Region.

1.2. Objectives

The overall aim of this research was to answer the following question:

Can geomorphological characteristics of a reach contribute to a realistic measurement of the ecological health in a river or a catchment?

WRC undertakes annual ecological monitoring (macroinvertebrates and fish) at a number of 'natural state' (reference sites) and 'developed land' (non-reference sites) streams and rivers throughout the region. Reference conditions for SOE reporting are specified as "the chemical, physical or biological conditions that can be expected in streams and rivers with minimal or no anthropogenic influence" (McDowell *et al.*, 2013a, p. 6). The objective of the research was to determine if it is possible to develop a geomorphological toolbox that can contribute to determining the ecological condition of a reach and assist in explaining spatial or temporal differences between catchments and reaches. As such, temporal and spatial replication of the toolbox were imperative to the success of incorporating geomorphic assessment into the existing SOE reporting.

The aim was answered by using the following objectives to guide the investigation and research:

- Identify and establish the connections between geomorphology and ecological health in national and international literature;

- Identify existing geomorphic techniques and methodologies to determine the characteristics and methods that could apply to a New Zealand and Waikato perspective to infer ecological health;
- Formulate a toolbox approach for measuring geomorphic units within Waikato Region rivers to assess geomorphic diversity and / or quality;
- Compare the results of the toolbox assessment with ecological data collected independently by WRC;
- Critically assess the application of the geomorphic toolbox to wadable streams in the Waikato Region; and
- Provide recommendations for refinements and / or temporal applicability of the proposed toolbox.

2. Literature Review

2.1. Introduction

Rivers and streams are under significant threat from a range of anthropogenic stresses (Fuller & Death, 2017; Reid *et al.*, 2019) with habitat degradation a leading cause of population declines in freshwater systems (Reid *et al.*, 2019). This is concerning due to the reliance of communities on freshwater assets and ecosystem services (Beechie *et al.*, 2010). As a result, the benefits of monitoring river health are increasingly recognised for the purposes of understanding the state of the environment and undertaking appropriate management regimes for reversing degradation (Vaughan *et al.*, 2007). River health cannot be measured directly, and instead a range of surrogate measures and observations are used to indicate a system's capacity to support key processes (Davies *et al.*, 2010). Research prior to the 21st Century had a key focus on ecological and water quality considerations (Fryirs, 2003), perhaps due to their ability to provide a definitive quantitative assessment that can be readily compared and applied across different reaches and catchments. However, these measurements scale poorly (Feld *et al.*, 2010) and it is becoming recognised that physical, chemical, and biological characteristics must be successfully integrated if sustainable stream management practices are to be achieved (Norris & Thoms, 1999; Fryirs, 2003; Vaughan *et al.*, 2007). The geomorphic condition can provide a critical template upon which other biophysical interactions can be interpreted or measures measured, as shown in Figure 1 (Fryirs, 2003; McFarlane *et al.*, 2011; Fryirs & Brierley, 2013; Fuller *et al.*, 2019), although debate over its degree of influence and importance is ongoing. As such, understanding the connection between geomorphological characteristics and river health is arguably integral.

Figure 1 Geomorphology as a template upon with other processes and interactions can occur. An understanding of the geomorphic condition provides a greater understanding of processes occurring and interacting within the environment (Fryirs & Brierley, 2013)

This literature review discusses river health, and the relationship of fluvial monitoring within a New Zealand policy context. It also discusses specific morphological features and processes that indicate geomorphological quality of the riverine environment, in addition to providing an overview of key existing assessment frameworks. Significant challenges exist with successfully applying the geomorphic context to river health monitoring due to the highly context dependent set of parameters that exist for each river based on unique relationships between climate, geology, elevation, and biodiversity. Scale-related variability both within and between river systems also provides an added dimension of complexity for geomorphic assessments (Raven *et al.*, 2010). Regardless, steps toward integrating geomorphological considerations into river health assessments are essential to framing management and restoration strategies within a physical context of what the river landscape can be expected to achieve (McFarlane *et al.*, 2011).

2.2. River Health and Naturalness

Rivers are complex systems, with the form and behaviour reflecting the interaction of geomorphological and ecological processes (Dollar *et al.*, 2007) (Figure 2). Freshwater bodies are also among the most fragmented, degraded and threatened ecosystems in the world (Raven *et al.*, 2010), with their physical form significantly altered as a result of human intervention (Jungwirth *et al.*, 2002; Brierley & Fryirs, 2008). Brierley and Fryirs (2005) frame river health as "the ability of a river and its associated ecosystem to perform its natural functions" (p. 1).

Figure 2 Components and processes within a channel-floodplain ecosystem, with interactions between components shown as directional arrows (Davies et al., 2010)

Contemporary fluvial literature stresses the role of the physical environment as a template in which the lotic system can develop and flourish (Norris & Thoms, 1999; Brierley *et al.*, 2010; Wohl *et al.*, 2019). Therefore, if the physical habitat is in poor condition or not resilient, we could expect adverse effects on the biological health of the stream (Norris & Thoms, 1999; Fuller *et al.*, 2019). Elosegi and Sabater (2013) argue that even light hydromorphological impact can have far reaching effects on ecosystem function, and different variables can induce significantly diverse responses. River processes are also influenced by the wider catchment, such as the components of the riparian zone and the floodplain, which will also have an influence on the overall health of both physical and biological components of a waterbody (Fryirs & Brierley, 2013). Natural rivers can vary immensely in different landscape and climatic settings through variability of discharge regimes, vegetation coverage, slope and confinement, and sediment supply (Fryirs & Brierley, 2009). This means river naturalness can exist on a spectrum which reflects a continuum of environmental conditions including physical (e.g. flood or drought), chemical (e.g. trace elements, isotopes) and biological (e.g.

disease, predation, invasion) variability, whereby the natural regime in one location may never be exactly emulated under different conditions based on geology, elevation and vegetation (Stanford *et al.*, 2005; Vaughan & Ormerod, 2010). Fundamental to the assessment of river health and biotic integrity is an understanding of the links between riverine habitat and the factors that shape it (Fryirs & Brierley, 2013; O'Brien *et al.*, 2016) (Figure 2).

A geomorphic perspective views a natural river as one with a character and behaviour that is expected within the boundary conditions set by the landscape within which the river operates (Brierley & Fryirs, 2005; Fryirs & Brierley, 2009). Naturalness is therefore a functional state that adjusts in response to flow, sediments, and vegetation fluxes (Brierley & Fryirs, 2005; Fryirs & Brierley, 2009). In such a case, a river could feasibly be expected to function within its boundary conditions despite being 'degraded' or not representative of a refence condition stream. Given enough time, a natural river will respond with resilience to even the largest of disturbances because its natural form will adjust and recover over time; the problem being faced now is that many rivers are no longer in a natural catchment setting and therefore a river's natural resilience is also compromised (Fryirs & Brierley, 2013; Fuller *et al.*, 2019). Geomorphic resilience describes the amount of change a system can undergo whilst essentially retaining the same functions and structures through resistance to and recovery from internal and external forces (Fuller *et al.*, 2019).

Resilience trajectories can vary depending on the unique combination of variables for specific rivers and reaches, as described in Figure 3. Geomorphic resilience can be expressed as static or steady state, whereby disturbance has no effect on reach geomorphology due to not reaching necessary thresholds or being readily absorbed and quickly returning to pre-disturbance levels, or dynamic, whereby progressive change can occur in a system while adjusting to new boundaries as a result of a disturbance (Fuller *et al.*, 2019). As rivers are dynamic, a range of natural variation or disturbance is required to maintain resilience (Baron *et al.*, 2002). It is therefore clear that transformative boundaries being crossed do not automatically classify river health as poor, as long as the affected reach can function within expected parameters of its reference condition. On the other hand, not all resilient rivers are healthy rivers, particularly where anthropogenic intervention seeks to stabilise a river or reach when its natural tendency is for change and dynamism (Fuller *et al.*, 2019).

Figure 3 Resilience trajectories describing steady state or static resilience where a disturbance has little to no effect on the geomorphic template (a and c), compared to dynamic resilience that adapts to new geomorphic parameters as a result of a disturbance (b and d) (Fuller et al., 2019)

Contemporary research frames rivers within a social-ecological system that considers rivers for their ecosystem services potential; a river in which anthropogenic communities interact with in order to achieve social and economic wellbeings cannot (and should not) achieve a wholly 'natural' state (Brierley & Fryirs, 2005; Brierley & Fryirs, 2009; Pingram *et al.*, 2019). Monitoring should therefore serve the purpose of understanding the benchmarks of attribute qualities within a fluvial system that are necessary to achieve the function of that river, being some combination of environmental, social, economic, or cultural outcomes (Wohl *et al.*, 2019).

2.3. Policy Context – New Zealand

Natural resource use is managed by Regional Councils through the RMA. As the principal environmental legislation for New Zealand, the RMA sets the framework through which central government provides direction to Regional Councils through mechanisms such as National Policy Statements (NPSs) and National Environmental Standards (NESs) (New Zealand Goverment 1991, 1991). Additionally, the RMA requires ongoing monitoring to be undertaken by Regional Councils for the purposes of understanding the state of the environment pursuant to s35(2)(a) (New Zealand Goverment 1991, 1991; Tadaki *et al.*, 2014). The New Zealand legislative environment culminating in monitoring requirements within the Waikato Region is outlined in Table 1.

Table 1 Relevant central and local government legislation and policies that relate to geomorphic monitoring of rivers in New Zealand.

Government Hierarchy	Legislation / Policy	Relationship to geomorphic monitoring
Central	Resource Management Act 1991	▪ Principal environmental legislation in New Zealand ▪ Provides central government direction to Regional Councils ▪ Can require National Policy Statements and National Environmental Standards ▪ Requires regional council to undertake and publish state of the environment reports at least every five years pursuant to s35(2)(a) (New Zealand Goverment 1991, 1991)

Central	National Policy Statement for Freshwater Management 2017 (NPS-FM 2017)	▪ First released in 2011 and amended in 2014 and 2017
		▪ Purpose of the NPS-FM is to set national direction of the management of freshwater to reflect the catchment-level variation and different demands on freshwater across regions (Ministry for the Environment, 2017b)
		▪ Two Key Elements:
		  ▪ Te Mana o Te Wai: an integrate and holistic approach to the wellbeing of a freshwater body and the accompanying objectives for managing water in an integrated and sustainable way, while providing for economic growth within set water quantity and quality limits
		  ▪ The National Objective Framework, which is to provide a nationally consistent approach to establishing freshwater values that recognises regional and local circumstances.
		  ▪ Regional authorities manage freshwater within Freshwater Management Units (FMUs)

Government Hierarchy	Legislation / Policy	Relationship to geomorphic monitoring
		FMU scale is set by regional authority and dictates the location and extent of monitoring Water quality in FMU required to be maintained or improved Each FMU requires a monitoring plan No explicit requirement to incorporate geomorphological processes into monitoring.
Central	Proposed National Policy Statement for Freshwater Management 2020 (Draft NPSFM)	▪ Draft released in September 2019 and expected to be gazetted in late 2020 ▪ Further entrenches Te Mana o Te Wai, including a hierarchy of objectives stating that resources must be managed in a way that prioritises: ▪ first, the health and wellbeing of waterbodies and freshwater ecosystems; and ▪ second, the essential health needs of people; and ▪ third, the ability of people and communities to provide for their social, economic, and cultural wellbeing, now and in the future (Ministry for the Environment, 2019a) ▪ Similarly uses the National Objectives Framework ▪ Must manage freshwater through FMUs ▪ FMU to be set by regional council, including location and extent of monitoring ▪ Expansion of Ecosystem Health as a compulsory value to include biophysical component of Habitat: *"The physical form, structure and extent of the waterbody, its bed, banks and margins, riparian vegetation and connections to the floodplain"* (Ministry for the Environment, 2019a, p. 24) No parameters or guidance for undertaking habitat monitoring and therefore can still result in regional and FMU discrepancies.

Government Hierarchy	Legislation / Policy	Relationship to geomorphic monitoring
Central	Proposed RMA Resource Management Amendment Bill 2020	▪ Draft released in September 2019 and expected to be gazetted in late 2020 ▪ For the purpose of responding to the "urgent need to improve freshwater management" (Ministry for the Environment, 2019b, p. 5) ▪ Creates new plan making process that must give use to give effect to the draft NPS-FM within the Regional Policy Statement (RPS) and Regional Plan(s) ▪ Truncated timeline, whereby Regional Councils must publicly notify changes to the RPS to reflect the draft NPS-FM by 31 December 2023 and make final decisions by 31 December 2025 Currently regional councils have to 31 December 2030. Representative of the urgency necessary to reverse declining freshwater health trends Potential impacts on creating adequate monitoring schemes for each FMU.
Regional	Waikato Regional Policy Statement	▪ Waikato Regional Policy Statement (RPS) is required pursuant to s62 of the RMA ▪ RPS must give effect to any NPS pursuant to s61(1) and s55(2) of the RMA ▪ Overview of resource management issues of the Waikato Region, including polices and methods to achieve integrated management ▪ Must give effect to higher order documents including relevant NPSs and National Environmental Standards ▪ Objective 3.14(e) requires WRC to establish objectives, limits, and targets for freshwater bodies to determine how they will be managed ▪ Policy 4.1(h) – Integrated Approach establishes the requirement for a planning framework which sets clear limits and thresholds for resource use ▪ Method 4.1.14 requires WRC to develop and maintain processes and resources to enable the effects of activities to be monitored, and ensure an appropriate level of understanding is available and maintained ▪ Method 8.1.4 requires WRC to consider, among other values, the natural character, natural function, ecosystems and habitats. Whilst not explicitly included, Method 8.1.4 does not exclude the incorporation of geomorphological factors into monitoring.

Whilst geomorphic monitoring is not explicitly mandated within the central government or regional authority policy, the objectives and policies of the draft NPS for Freshwater Management (Draft NPS-FM) and Waikato Regional Policy Statement allow for the incorporation of geomorphic principles into existing monitoring regimes. Consideration of the Waikato River Authority Vision and Strategy is also required within the Waikato and Waipa River catchments., although no specific geomorphic metrics are indicated within this document. The release of the Draft NPS-FM and the Proposed RMA Resource Management Amendment Bill 2019 signal a stronger will by central government to improve historically degrading water quality by strengthening the mandate of Te Mana o Te Wai and the health of water above all other uses or values. Existing struggles with Freshwater Management Units (FMUs), whereby regional authorities are free to choose the catchment size (and therefore monitoring distribution and effectiveness) are not addressed within the Draft NPS-FM and may provide substandard monitoring outcomes that are disparate between regions.

2.4. Ecological and chemical indicators of river health

The assessment of biota in addition to chemical properties of rivers are widely accepted as key components for determining river health (Dickens & Graham, 2002; Munyika *et al.*, 2014). Typical biological indicators include macroinvertebrates, fish, and plants (Norris & Thoms, 1999; O'Brien *et al.*, 2016), while chemical indicators include a range of natural and anthropogenically generated elements. Combining multiple parameters into a single index tends to provide a more holistic description of ecological condition than individual parameters (O'Brien *et al.*, 2016; Blabolil *et al.*, 2017). Table 2 outlines the key indicators of river health and the assessments used to infer river health. An assessment of these key indicators outlines the prevalence of the use of reference sites by which to compare other monitoring sites.

Table 2 Ecological indicators of river health

Indicator	Purpose of use	Assessment	Examples of use	Caveats on use
Macro-invertebrates	General river condition, although originally focused on organic enrichment / water quality. Can provide baselines or reference conditions for comparison to river ecosystem processes in disturbed streams (Bunn *et al.*, 1999). Sensitive to short to medium term environmental changes (Davies *et al.*, 2010). Subject to a range of environmental influences on varying scales that affect community composition and relative abundances of macroinvertebrates.	Assessment of structure of benthic communities, abundance, and biodiversity present within a river or spatial extent of a river (Bunn *et al.*, 1999; O'Brien *et al.*, 2016).	Macroinvertebrate Community Index (MCI), which is widely used to evaluate river health in New Zealand (Wright-Stow & Winterbourn, 2003). Ratified as a measure of water quality within the National Objectives Framework and therefore used for Regional Authority state of the environment report and monitoring plans. MCI covers both quantitative and semi quantitative measures to assess organic enrichment in streams against a known index of species sensitivity to pollution in order to provide a taxon score for the monitoring site (Wright-Stow & Winterbourn, 2003).	Standard protocol applies only to wadable rivers – reference conditions rarely exist outside of wadable rivers (Stark, 2001). Application of reference conditions between soft and hard bottomed streams are not interchangeable. Issues with sample collection and data interpretation in larger rivers Range of drivers influencing macroinvertebrates presence and abundance.
Fish	Good indicators of habitat diversity, fluvial dynamics, water quality and hydrological connectivity (Jungwirth *et al.*, 2002). Can also indicate medium to large spatial scale environmental changes due to their actual or potential longitudinal occupation of a river (Davies *et al.*, 2010; Blabolil *et al.*, 2017). Short to long term (hours to years) with the latter owing to their proportionately longer lifespan than other biotic indicators.	Assessment of species richness and composition, trophic composition and fish abundance and condition as well as 'expectedness' and 'nativeness' as indicators of water quality (Norris & Thoms, 1999). Also pollution, through assessment of fish pollution tolerance, such as sensitivity to a lack of oxygen or heavy organic loads (Patrick & Palavage, 1994). Non-native species can reflect biological pollution, as generally in New Zealand these species are more tolerant of habitat and water degradation than native species (Joy & Death, 2004).	Reference condition sites: the monitoring of fish at a monitoring site and comparing this with unimpacted or minimally impacted sites to assess the differences. New Zealand also has the Index of Biotic Integrity (IBI), which is used similarly to the MCI; a large number of sites selected to represent the best stream conditions in a region and provide an upper bound for biological structure (Joy & Death, 2004). Monitoring sites are then compared to the IBI.	New Zealand has low fish species richness, comprising 36 species from 8 families (McDowall, 2001; Joy & Death, 2004), many of which are diadromous (migrate between fresh and salt water). Care is required when using fish / IBI as a measure of habitat quality as differences in fish distribution could be linked to factors other than habitat quality (Joy & Death, 2004). For example, Joy and Death (2004) found little to no association between watershed area and maximum species richness, with the latter more likely a function of elevation and distance from the coast.

Indicator	Purpose of use	Assessment	Examples of use	Caveats on use
Vegetation	The type and extent of vegetation (riparian, bank, and instream) within catchments can regulate the supply of food resources, affect adult (fauna) population dynamics, determine habitat structure and quality (e.g. water temperature, light levels, channel form, stream hydrology and fine sediment deposition), as well as being able to ameliorate some effects of catchment disturbances (Death & Collier, 2010). Sensitive to short- and long-term environmental changes as well as small to large spatial scales (Davies *et al.*, 2010; Gurnell, 2014). Good indicator of habitat diversity, water quality and provide insights into flow-vegetation-sediment feedbacks and landform building (Gurnell, 2014).	Vegetation across the channel-floodplain system has key trophic, energetic and geomorphic roles and responses (Davies *et al.*, 2010; Death & Collier, 2010) and ultimately have a fundamental role in determining river planform. The presence of vegetation in itself is not significant; rather, the appropriateness of vegetative species being located in a specific fluvial environment is necessary to consider for water quality. In the absence of riparian shade, large vascular plants (often exotic) and filamentous algae can thrive, restricting flow where it shouldn't and trapping sediments to result in notable changes to available habitat and lowered water quality (Bunn *et al.*, 1999).	A key advantage of using vegetation as an ecological indicator is the ability to identify and sample important vegetation remotely (Davies *et al.*, 2010) using remote sensing tools such as aerial photography and lidar . Methods for assessing vegetation as an ecological indicator can include calculating the percentage of canopy cover and using this to estimate direct and diffuse photosynthetically active photon flux densities above and below the canopy (Bunn *et al.*, 1999). Bunn *et al.* (1999) go as far as to say that measures of canopy cover alone could be used to predict stream health without the need for detailed measures of ecosystem processes.	In isolation, patterns of vegetation species distribution and abundance do little to contribute to an understanding of how a system works and should therefore be used within a suite of other river health attribute assessments (Bunn *et al.*, 1999; Bunn & Davies, 2000)
Chemical	Easily quantified and attributed to a quality index (McFarlane *et al.*, 2011). Chemical indicators can provide insight into the organisms that are able to withstand and survive in a given environment (McDowell *et al.*, 2013b). The benefit of chemical indicators that are quantifiable is the ability to directly compare river states and assess trends over time (McFarlane *et al.*, 2011).	The NPS-FM 2017 requires the following chemical and physical indicators to be tested for in each FMU: ▪ Nitrogen ▪ Phosphorus ▪ Dissolved inorganic nitrogen ▪ Dissolved Reactive Phosphorus ▪ Nitrate ▪ Ammonia ▪ Dissolved Oxygen ▪ E.coli ▪ Cyanobacteria	State of the Environment Reporting (Regional Authorities) and the NPS-FM 2017.	The often used physical and chemical indicators are highly specific and offer little integration with other indicators, which fail to recognise natural geographic variation in water chemistry and resulting impacts (Norris & Thoms, 1999), such as natural spikes in E.coli associated with large rain events or the presence of natural heavy metals such as arsenic from historic volcanic activity. However, the use of appropriate, site-specific reference conditions can alleviate misrepresentation (McDowell *et al.*, 2013b).

2.5. Morphological indicators of river health

Change, rather than stability is an underlying principle for river geomorphology; whilst rivers may trend toward equilibrium, they are better characterised as moving along an adjustment continuum, which is defined by the response of individual systems to disturbance (Fuller *et al.*, 2019) (Figure 3). Analysis of river health must take into account both natural and anthropogenic changes on a variety of timescales to interpret environmental change and the effect on biological health (Norris & Thoms, 1999). Ultimately, the stream biotic composition is strongly influenced by physical habitat, which provides the template upon which the ecological organisation and dynamics of fluvial ecosystems are observed (Norris & Thoms, 1999; Dollar *et al.*, 2007; Parsons & Thoms, 2007; Poole, 2010; Thoms *et al.*, 2017). Accordingly, the physical properties of a given habitat within a fluvial ecosystem will influence the type, abundance and distribution of biota found within that location (Parsons & Thoms, 2007; Poole, 2010). This concept is outlined in Figure 4, whereby the physical characteristics of a river interact with ecological conditions, with the output being a functional aquatic ecosystem (Baron *et al.*, 2002). Changes to catchment conditions and flow regimes can alter the processes within river channels and therefore also alter the habitat available for organisms (Norris & Thoms, 1999). It is important to consider indicators of the geomorphological condition in their own right, in addition to temporal variations. It may be possible to have geomorphologically degraded channels with healthy biota present (Norris & Thoms, 1999) depending on the physical requirements of the ecological community located within the fluvial environment. There is also a degree of redundancy in natural communities (Lake *et al.*, 2007; Elosegi & Sabater, 2013), meaning consideration of natural reference conditions and relevant processes are critical to a successful monitoring programme.

Figure 4 Conceptual model of major driving forces that influence freshwater ecosystems (Baron et al., 2002)

Physical habitat dynamics are primarily a function of sediment, wood, and water input (as described in Table 3 and Figure 5), which influence channel shape and formation of habitat features such as pools and riffles (Beechie *et al.*, 2010). Reach-scale processes, such as the delivery of wood, bank erosion and, flooding regimes also influence physical feedback mechanisms between channels and floodplains (Beechie *et al.*, 2010). This section outlines key geomorphological features and processes that can provide insight into ecological health of a fluvial system. As with using fish as an indicator, the level of ‘naturalness’ and ‘expectedness’ must be considered for geomorphological features; for example, bank erosion may be a health and natural process in one river, but may be indicative of negative anthropogenic influence in another (Florsheim *et al.*, 2008).

Table 3 Indicators of river system condition as a function of sediment and water input, as after Norris and Thoms (1999)

Indicator	Purpose of use
Sediment sequence and composition	▪ Rate of accumulation ▪ Sediment calibre ▪ Mineralogy ▪ Geochemistry
Soil and sediment erosion	▪ Rate of erosion ▪ Source of sediment ▪ Mode of transport
Stream flow	▪ Total annual flow ▪ Variability
Stream channel morphology	▪ Slope ▪ Pattern ▪ Cross-sectional dimensions
Stream sediment storage and load	▪ Sediment flux ▪ Mode of transport
Surface water quality	▪ Turbidity ▪ Total suspended solids
Floodplains / wetlands structure and hydrology	▪ Wetting and drying regimes ▪ Connectivity with the river ▪ Area

Figure 5 Diagrammatical depiction of the three major regimes (water, sediment, wood) and their interactions to form the geomorphological template on which ecological biodiversity can be established (Wohl et al., 2019)

2.5.1. Flow Regime

Flow regime has widely been recognised as an important factor influencing the distribution of benthic biota in wetted channels (Clausen & Biggs, 1997; Schwendel *et al.*, 2012). Flow regime encompasses the longitudinal connectivity of a catchment and drainage network, from headwaters draining small catchments to the creation of larger streams that progressively transport greater volumes of water and materials downstream to the marine environment (Stanford *et al.*, 2005). The flow regime also influences structural attributes such as substrate stability, habitat volume and channel morphology (Schwendel *et al.*, 2012; Booker *et al.*, 2015). Flow regime comprises many subsets, base flow, annual or frequent floods, rare and extreme floods, seasonality, annual variability, and longitudinal and lateral variability (Clausen & Biggs, 1997; Baron *et al.*, 2002). Additionally, the flow regime can also include flows originating outside of the river channel, such as groundwater recharge to rivers and overland flowpaths from hillslopes (Poole, 2010), as shown in Figure 6.

Figure 6 Pathways of water movement that comprise the flow regime. Note that flows can originate externally from the river channel, such as through groundwater recharge and overland flowpaths, which can result in dynamic habitat and geomorphic relationships occurring at within channel mixing sites (Poole, 2010).

2.5.1.1. Environmental Flow

Environmental flow, not just minimum flow, is a main driver of river structure and function (Hernández-Guzmán *et al.*, 2019). It is defined within the Brisbane Declaration as the "quantity, timing and quality of water flows, required to sustain freshwater…and the human livelihood and well-being that depend on these ecosystems" (Arthington, 2012, p. 11). As such, consideration of the environmental flow must include discharge variability, seasonal patterns, and temporal or climatic variability which can result in significant biological processes, such as the removal of biomass by flood disturbance (Arthington, 2012; Hough *et al.*, 2019), and high flows influencing patch and biotic resilience (Booker *et al.*, 2015). Changes to the flow and sediment regime can significantly alter the physical nature of a channel and consequently the habitats that support instream organisms, often in complex ways (Norris & Thoms, 1999; Elosegi & Sabater, 2013). The frequency of events exceeding three times the median flow of a wetted channel is considered to be a biologically important component of fluvial catchments (Clausen & Biggs, 1997; Booker *et al.*, 2015), although gradients in low-flow magnitude and high flow magnitude are also important for explaining distribution patterns (Booker *et al.*, 2015).

Five ecologically relevant characteristics of natural river flow regimes are: magnitude, frequency, time, duration, and rate of change of hydrological conditions (Arthington, 2012). Combinations of these characteristics determine many of the physical and biological processes of aquatic ecosystems and plays a critical role in sustaining biodiversity and ecosystem integrity. Of particular importance within river rehabilitation is matching the observed environmental flow within a river system to what natural flow regime could be expected; while it may not be feasible to return flows to the natural regime within a modified system, the creation of flow patterns to provide desired benefits can significantly improve ecological quality (Hough *et al.*, 2019).

As a result, hydrological indices are often used as predictors of change (Clausen & Biggs, 1997; Booker *et al.*, 2015), although Booker *et al.* (2015) argues that aquatic biota are more likely to show stronger responses to variables such as substrate movement or local scale physical habitat. Identification of the quantitative relationship between the hydrological regime and ecological responses is complicated by other co-varying environmental factors, such as climate, bedform, and position along the river network; as a result, the strength of the relationship between the hydrological regime and biological characteristics can be overestimated (Booker *et al.*, 2015). Norris and Thoms (1999) also outline the importance of scale when considering the effect of flow regime, as the scale at which geomorphological change is occurring may be far larger than the scale at which flow regime is measured. Nevertheless, the flow regime remains critical for the formation of other geomorphic processes such as sediment entrainment and deposition and providing a minimum water depth for biota dependent on submersion.

2.5.1.2. Spatial heterogeneity

Heterogeneity can be represented as a function of the frequency, diversity, spatial arrangement, and turnover of morphological patches within a riverine landscape (Thoms *et al.*, 2017). It can be used to interpret rivers as dynamic and complex systems, whereby heterogeneity and geomorphic units are products of geomorphic processes such as sediment sorting, erosion, deposition, and hydraulic variability, in addition to vegetation interactions with other components of the riverine system (Reid *et al.*, 2008; Reid *et al.*, 2010; Belletti *et al.*, 2017). Spatial heterogeneity operates on multiple scales and directly and indirectly influences the flow of energy and community structure on aquatic ecosystems (Thoms *et al.*, 2017). Rivers and streams with more heterogenous stream beds, such as those containing debris dams, microform bed clusters, and those with longitudinal, lateral and vertical connectivity therefore also provide a greater spatial diversity for habitat as well as refugia during high flows (Fuller & Death, 2017). Spatial heterogeneity is also a key component for the successful recovery of biota to disturbance (Reid *et al.*, 2010).

Biota, their resources, and their habitats can therefore be viewed as being distributed within a fluvial channel as a mosaic of patches (Lake, 2000; Reid *et al.*, 2010). In simplistic terms, a patch is an area of relative homogeneity that differs from its surroundings (Winemiller *et al.*, 2010), with a river network as a unique and patchy discontinuum from the headwaters to the mouth (Poole, 2002). Fauna is distributed along the river corridor in a complex and often seasonally dynamic pattern, moving from one patch to another based on the benefits that can be found within (Stanford *et al.*, 2005). As with ecology, spatial heterogeneity for fluvial geomorphology varies with spatial scale and temporal parameters (Wohl, 2016). Patches can be linked with other patches longitudinally, laterally, and vertically (Lake, 2000; Reid *et al.*, 2010), while individual patches are also able to change position, and dimensions over time (Lake, 2000). Patch size and shape can vary with time and season and are heavily regulated by disturbance (Lake, 2000), although can also change position and boundaries even under steady flow. Each patch is not necessarily more related to a neighbouring patch compared with any other patches existing within the system (Reid *et al.*, 2010). Newson and Newson (2000) refer to this interaction as a channel habitat matrix, outlined in

Figure 7, with physical aspects of instream habitat dominating the biotic responses in headwater streams and downstream river segments heavily impacted by engineering design. Further, it is recognised that large-scale controls of rivers (i.e. flow regime) on smaller-scale features (i.e. individual patches) operate, resulting in the development of nested hierarchal models of river organisms that may operate to regulate species richness (Lake, 2000; Thomson *et al.*, 2001), as shown in Figure 8.

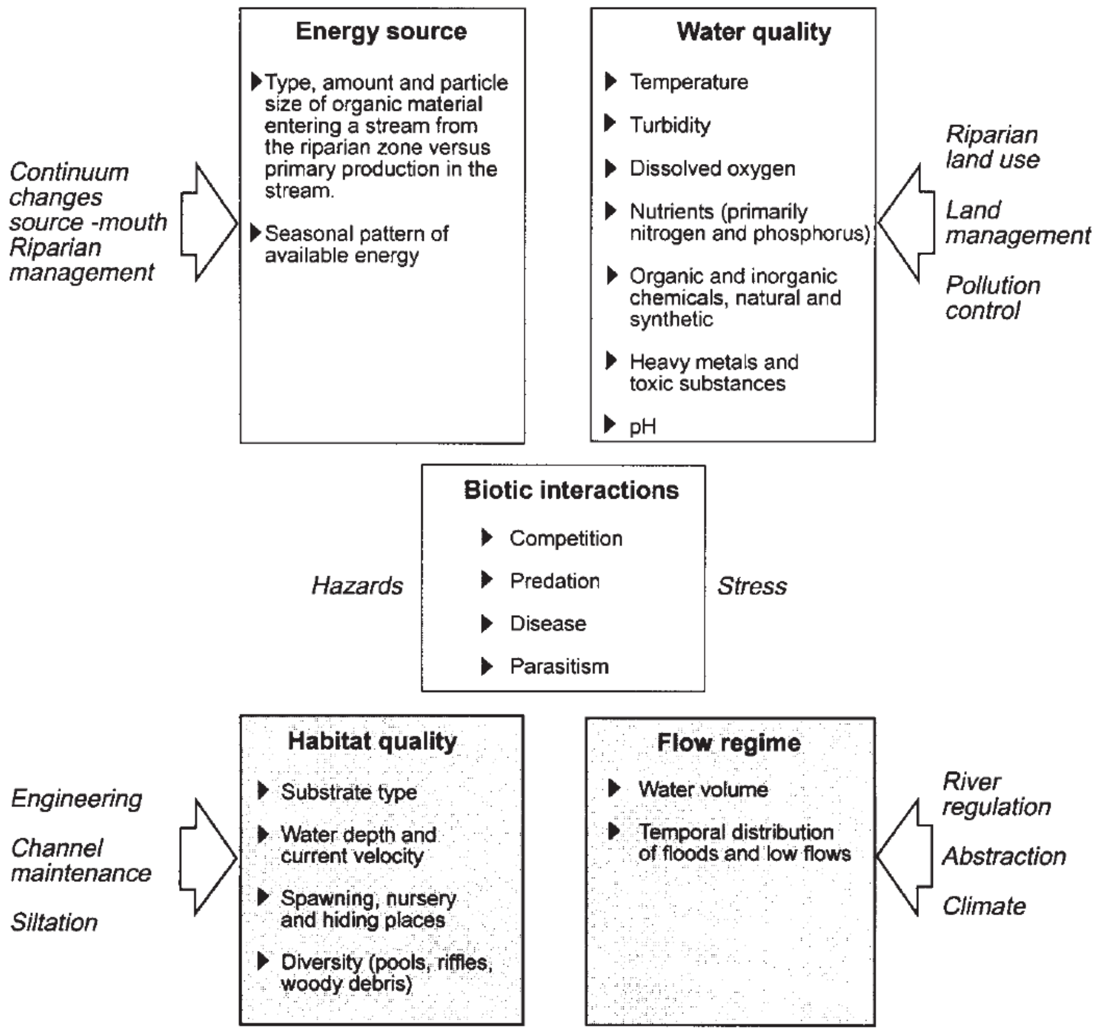

Figure 7 Instream freshwater habitat and its major influences from land use and water management (Newson & Newson, 2000).

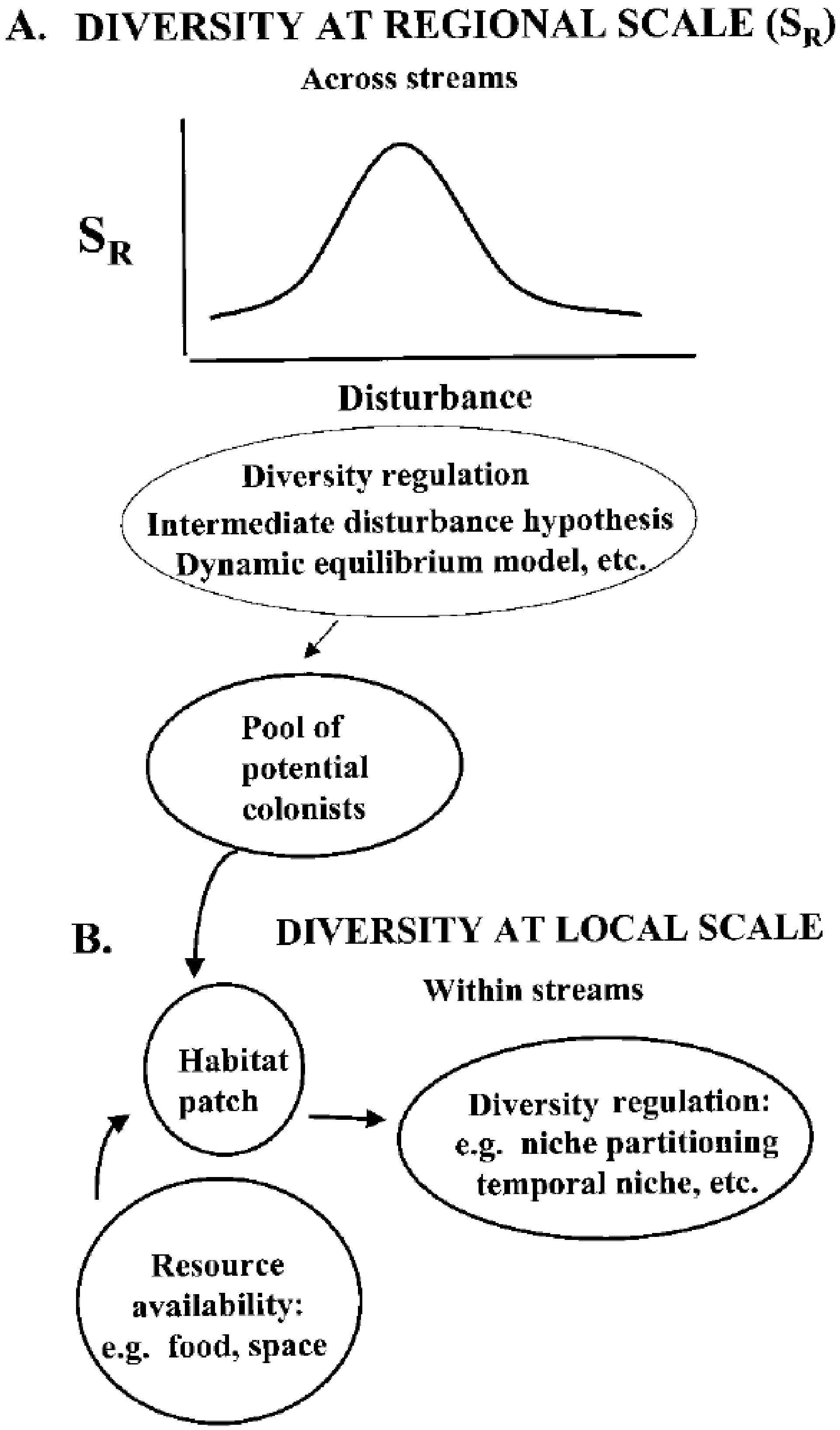

Figure 8 Diversity relationships of fluvial channels, with key processes occurring at both the regional and local scale to form the specific patch mosaic pattern that can be found within a wetted channel (Lake, 2000)

Diversity and overall habitat heterogeneity is well linked to benthic invertebrate and fish biodiversity, with a clear positive relationship between invertebrate richness and abundance and the structural complexity of riverine environments (Garcia *et al.*, 2012). Indeed, geomorphic units, including riffles, pools, bars, islands etc, in addition to hydraulic units such as individual boulders, sediment patches, plants or wood pieces constitute distinct habitat for fluvial flora and fauna (Belletti *et al.*, 2017). Thompson and Townsend (2005) studied 18 streams in New Zealand and infer that spatial heterogeneity plays a direct and indirect role of the invertebrate distribution through influences on algal productivity. Górski *et al.* (2013) studied whether fish distributions could be reliably predicted based on hydrological and geomorphic variables within the Volga-Akhtuba floodplain and conclude that spatial heterogeneity results in a spatial gradient in the occurrence of fish. Reid *et al.* (2010) analysed the role of heterogeneity on the colonisation of habitat by macroinvertebrates within the Twin Stream Catchment in Auckland, New Zealand and found that habitat mosaic followed a semi-predictable but interrupted pattern, which supports the view that river systems are a patch discontinuum (Benda *et al.*, 2004). As such, it is established that the greater the spatial heterogeneity of a riverine reach or network, the increased likelihood there will be an abundance of ecological diversity within the same area (Newson & Newson, 2000).

2.5.1.3. Disturbance

Disturbance is responsible for organising stream ecology and determining the structure of benthic communities (Lake, 2000; Death & Collier, 2010; Elosegi *et al.*, 2010). A disturbance is considered to occur when potentially damaging forces are applied to habitat space that is occupied by a population, community, or ecosystem (Lake, 2000). Thompson and Townsend (2005) found that disturbance was an important determinant of species richness and is therefore necessary for the long-term functioning of a healthy river. Fluvial channels generally have a stable flow for much of the time, termed baseflow levels. Disturbances (e.g. floods) can periodically disrupt stable conditions, and destroy habitat patches whilst simultaneously creating new ones that are then colonised and inhabited by biota upon the return of stable flow conditions (Lake, 2000; Barquin & Death, 2006). Disturbance regimes describe how rivers constantly adjust their morphology in response to changes to the boundary conditions within which they operate; change and disturbance should therefore be viewed as integral to the landscape dynamic (Fryirs, 2003). Some geomorphic systems may be better equipped to deal with disturbances than others, which stresses the need to recognise the natural state of the riverine system to understand whether the effect of the disturbance can be considered within the realms of what could be expected (Fuller & Death, 2017).

Disturbances are generally defined by the nature of their damaging (abiotic) properties, along with parameters such as frequency, spatial extent and temporal duration (Lake, 2000). The *effect* of a disturbance is, depending on the magnitude of forces present, that organisms may be killed, injured, or displaced, consumable resources depleted, and habitat structure may be degraded or destroyed (Lake, 2000). Lake (2000) describes three types of disturbances as characterised by their temporal patterns; pulses, presses, and ramps (Figure 9).

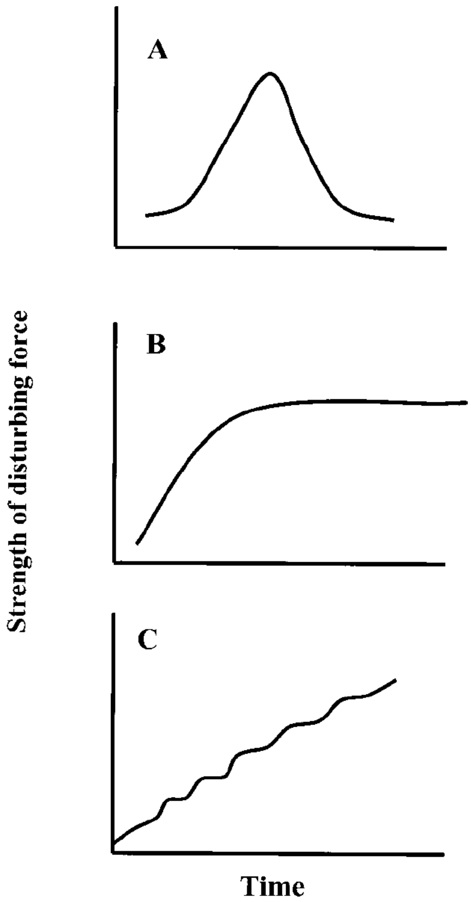

Figure 9 Three types of stream disturbance: A– Pulse, B – press, and C – Ramp. Each are distinguished based on the temporal trends of the disturbing force (Lake, 2000). Thus, a flood may be representative of a Pulse, a dam or blockage representative of a Press, and a drought representative of a Ramp

Floods are generally pulses, particularly in constrained rivers, whether by natural valley walls or engineered stopbanks. During flood events, large volumes of rapidly moving water creates high shear forces that suspend sediment, redistribute bedform patterns, scour and abrade the streambed, removes plants, and can kill, main, and displace biota (Lake, 2000; Schwendel *et al.*, 2011). Flooding causes a strong influence on ecosystem processes including nitrification and denitrification or litter breakdown (Elosegi & Sabater, 2013), while also causing movement of coarse bed substrate which can affect the abundance and occurrence of periphyton, invertebrate, bryophyte and macrophyte communities (Schwendel *et al.*, 2012). However, the availability of appropriate refugia, such as wood or pockets of lower flows will mediate the response and forms a critical aspect of resilience of ecosystems and communities (Lake, 2000; Lake *et al.*, 2007). Floods can also accentuate downstream and lateral links with damaging consequences, whereas droughts fragment longitudinal, lateral, and vertical connectivity (Lake, 2000).

Even if floods are predictable, they are still considered a disturbance given they rearrange the abiotic environment of both the floodplain and the channel (Lake, 2000). A pulse enacts a disturbance, but after a time, geomorphic conditions will return to the same conditions, even if the spatial patterns have been rearranged. Presses are disturbances that may rise sharply and then reach a constant level of new stability, such as sedimentation after landslides, or construction of a dam. Ramps occur when the strength of a disturbance steadily increases over time, such as droughts or the spread of an exotic organism (Lake, 2000).

2.5.2. Sediment Regime

2.5.2.1. Grain Size and sediment supply

Many invertebrate taxa are linked to grain size (Elosegi *et al.*, 2010) and coarse sediment, supplied from upstream and stored within the channel as bed material makes up substrate that is important for macroinvertebrates (Florsheim *et al.*, 2008). Coarse-grained substrate promotes oxygen exchange, provides space for protection from predators, serves as attachment sites for filter feeding invertebrates, and provides a food source for periphyton (Florsheim *et al.*, 2008). Conversely, sediment oversupply, when compared to transport capacity, can bury or damage aquatic habitats (Florsheim *et al.*, 2008; Fuller & Death, 2017). Boundary resistance to erosion has a fundamental influence on river process and form (Wohl *et al.*, 2019). As such, grain size and sediment supply must be viewed in a temporal context and against what may be feasibly expected within a reach given its position within the river system (i.e. headwaters versus floodplain). Longitudinal sediment transportation and slope-channel coupling are also important controllers of the sediment supply through the allowance or restriction of sediment entering the channel and then being transported downstream.

2.5.2.2. Bank Erosion

While stream bank erosion is often portrayed as a negative process of rivers, it is necessary for sediment transfer, geomorphic evolution, and ecosystem sustainability (Florsheim *et al.*, 2008; Hughes, 2016). Bank erosion includes both mass wasting processes and fluvial erosion (Florsheim *et al.*, 2008), which are often interrelated. Florsheim *et al.* (2008) argue bank erosion is desirable due to:

1. providing a sediment source that creates riparian habitat;
2. maintaining diverse structure and habitat functions within and external to the river channel;
3. riparian vegetation for both promoting bank stability and contributing large woody debris to the river; and
4. modulating changes in channel morphology and pattern.

Bank erosion from headwater areas can provide a source of coarse material to channels to form the physical structures for aquatic habitat (Florsheim *et al.*, 2008). However, in New Zealand, anthropogenic catchment disturbance is likely to have resulted in increased rates of erosion, deposition and sediment yields as a likely response to clearance of natural land cover, channel modification, and unrestricted access to streams by livestock (Hughes, 2016). Bank erosion must therefore be framed by reference conditions to assess appropriate levels of erosion corresponding to the geomorphic conditions of the fluvial system or reach.

Bank erosion is particularly important for contributing to floodplain – channel geomorphic feedback loops / connectivity, including adjacent riparian zones. Channel banks form an important ecotone between aquatic and terrestrial ecosystems through providing diverse structure and habitat functions, including vegetation succession (Florsheim *et al.*, 2008; Choné & Biron, 2016). Whilst riparian zones generally maintain bank stability outside of flood events, flow scour around individual pieces of large wood can accelerate bank erosion rates locally (Choné & Biron, 2016); in turn this can provide additional wood to the wetted channel for habitat, change the morphodynamics or hydrological regime of the channel over time, and open up the tree canopy to increase energy flow through the food web, which in turn can lead to greater production of invertebrates and fish (Florsheim *et al.*, 2008). On a microscale, bank sediment can expose tree roots or undercut and destabilise bank vegetation, forming new refugia for fauna to hide from predators and assist with low velocity patches during flood events (Florsheim *et al.*, 2008).

2.5.2.3. Connectivity

Geomorphic connectivity is four-dimensional: longitudinal (between reaches), lateral (between the floodplain and river channel), vertical (to groundwater, as well as to the air), and temporal (Lake, 2000; Stanford *et al.*, 2005; Poole, 2010; Corenblit *et al.*, 2015; Wohl *et al.*, 2019), as shown in Figure 10. Healthy rivers require a high degree of connectivity in order to support the complex lifecycles of many organisms and associated ecosystem and geomorphic functioning, such as allowing the flux of water and sediment to occur that drives channel-forming processes (Fuller & Death, 2017). The water mediated transfer of matter, energy and organisms dominates fluvial connectivity due to the hierarchical, unidirectional structure of fluvial systems, resulting in sediment and water transfers predominately flowing from headwaters to lowlands (Pringle, 2001; Lake *et al.*, 2007).

Figure 10 Idealised view of the four dimensions of fluvial connectivity, being longitudinal, lateral, vertical, and temporal (Corenblit et al., 2015)

Longitudinal connectivity controls the flux of water and sediment along a fluvial catchment and is responsible for facilitating the processes for shaping channel form (Elosegi *et al.*, 2010). Lateral connectivity between the channel floodplain controls sediment and materials being deposited on the floodplains, and the return of such material through lateral channel migration (Elosegi *et al.*, 2010). Vertical connectivity describes the hydraulic connectivity between the stream channel, groundwater, and hyporheic zone, although can also influence the exchange of water within the water column (Elosegi *et al.*, 2010). Fauna can be highly mobile and can seek refuge in discrete patches within high or low flow disturbances, and are able to utilise the connectivity to move between these habitats throughout their lifecycle (Death *et al.*, 2015; Fuller & Death, 2017). Therefore, for many organisms the patterns and degree of connectivity along the patch mosaic is critical, with the loss or change of connectivity, whether anthropogenic or otherwise, increasing the degree of fragmentation and subsequent local species extinction, biodiversity loss, and the potential weakening of processes such as the movement of nutrients (Lake *et al.*, 2007; Spurgeon *et al.*, 2018). As such, fragmentation and disconnectivity of fluvial processes is a leading cause of fish species declining globally where they are restricted in their ability to carry out essential lifecycle functions (Spurgeon *et al.*, 2018). For example, in New Zealand, a number of indigenous fish species are diadromous (migrate between fresh and saltwater) (McDowall, 2001; Joy & Death, 2004), such as the New Zealand longfin eel which lives as an adult in the upper reaches of rivers prior to swimming out to sea, spawning and dying. The larval eels make their way back to New Zealand and slowly move upstream as they mature into adults (Fuller & Death, 2017). Severing hydrological connectivity through dams, perched culverts, etc can isolate upstream populations and inhibit lifecycle completion (Fuller & Death, 2017).

The degree of connectivity required for the healthy functioning of an ecosystem is related to the degree of natural connectivity that could, or should be present in a fluvial system, given anthropogenic modifications. The severing of connectivity (or retention of disconnectivity already within a channel) can have benefits for threatened and endangered species by isolating and protecting them from harmful invasive species (Fuller & Death, 2017). Anthropogenic introduction of brown trout to New Zealand has severely impacted on native Galaxias species, whereby healthy populations now only occur where trout are excluded through the severing of hydrological connectivity (Lake *et al.*, 2007; Fuller & Death, 2017). For example, Townsend and Crowl (1991) found a strong negative association between the distributions of introduced brown trout on the native *Galaxis vulgaris.* In most cases, they only found *G. vulagris* above waterfalls that were large enough to inhibit trout migration. On the other hand, artificial dams, while severing the connection between brown trout and *Galaxis* species, can restrict the movement of diadromous fish either toward the coast or back upstream (Jellyman & Harding, 2012). Consideration of the effects of restoring connectivity are necessary within the wider catchment context to ensure that the benefits of connectivity are realised.

2.5.3. Wood Regime

The natural wood regime consists of wood recruitment, transport, and storage in river corridors (Wohl *et al.*, 2019) and is rapidly being recognised for its beneficial effects on the geomorphology and ecology of rivers. The wood regime has benefits to aquatic biota and for the maintenance of physical and hydraulic habitat (Chin *et al.*, 2008) as well as providing for the retention of organic carbon and leaf matter to promote nutrient cycling (Vannote *et al.*, 1980). Wood can also create flood hazards through instream accumulation, meaning that a natural wood regime may no longer be feasible to emulate in many catchments. Instead, a targeted wood regime can be developed for specific reaches and catchments, in which wood recruitment, transport and storage is considered in terms of both geomorphic, ecological, anthropogenic and landscape constraints (Wohl *et al.*, 2019).

2.5.3.1. Riparian Zone

The riparian zone and floodplain influence aquatic biota and water quality through organic matter inputs, shade, and nutrients to the wetted channel (Norris & Thoms, 1999). The riparian zone refers to the transition zone between a freshwater and terrestrial ecosystem, whereby the unique, dynamic, and complex nature of riparian habitat means that it can support high levels of biodiversity (Florsheim *et al.*, 2008; Bowler *et al.*, 2012). The main functions of riparian zones with regard to their relationship to wetted channels include fluvial hydrology, sediment dynamics, bank stabilisation, shading, retention and cycling of nutrients and pollutants, provision of wood and leaves into the wetted channel, as well as maintenance of habitat for wildlife such as invertebrates, amphibians, reptiles, birds, and mammals (Lake *et al.*, 2007; Florsheim *et al.*, 2008). Riparian zones are able to modulate the patterns of ground and surface water, fine sediment, organic matter, and nutrient and diaspore fluxes (Corenblit *et al.*, 2015). Further, they can modulate local microclimatic conditions, such as air and ground surface temperature and humidity, as well as light (Bowler *et al.*, 2012; Corenblit *et al.*, 2015). Riparian zones can also be important for the input of fauna into fluvial channels, such as arthropods (Lake *et al.*, 2007).

Given the influence of riparian zones on fluvial dynamics, it can be considered, then, that the destruction or removal of a riparian zone can therefore result in similar drastic changes to the fluvial ecosystem and physical setting. Degradation of the riparian zone can have flow-on effects such as a loss of bank stability, leading to increased erosion and chemical leaching from the surrounding land, in addition to increases in water temperature within the channel (Bowler *et al.*, 2012). As temperature is a known variable to affect fish and invertebrates, changes to the riparian zone can have a significant effect on the density and quality of these populations (Bowler *et al.*, 2012).

The width of the riparian zone is an important variable for allowing the effective interception of nutrient and sediments (Lake *et al.*, 2007). Florsheim *et al.* (2008) reports that the density and diversity of macroinvertebrates is higher in streams with a wider riparian zone, with the strongest relationship between macroinvertebrate indices and forest cover within a 100 m wide riparian zone, which is reiterated by Norris and Thoms (1999). Longitudinally, Lake *et al.* (2007) reports that the length of the forested riparian zone determines the effectiveness of stream structure and function, with temperature and oxygen levels able to recover in 300 m, and fauna recovering in 600 m relative to the upstream position. Fragmentation of riparian zones, even by small gaps, runs the risk of impairing these functions (Lake *et al.*, 2007).

2.5.3.2. Instream wood

Instream wood has a long association with fluvial processes and affects channel and floodplain ecological function (Wohl *et al.*, 2019). Historical descriptions indicate that orders of magnitude more wood were present in most forested river systems prior to widespread deforestation and wood removal from within streams (Wohl *et al.*, 2019), which have both greatly impacted on the New Zealand landscape. Wood is generally delivered into river channels from the riparian zone via flood induced channel erosion and can stimulate changes to the bed and bank morphology whilst increasing channel complexity such as pools (Lake *et al.*, 2007; Florsheim *et al.*, 2008). Table 4 outlines methods for recruitment, transportation and storage of wood within river channels.

Table 4 Components of wood regime, after Wohl et al. (2019)

	Recruitment	Transport	Storage
Magnitude	▪ Mass ▪ Individual	▪ Hypercongested / congested / semicongested / uncongested	▪ Abundant ▪ Minimal
Frequency	▪ Frequent ▪ Infrequent	▪ Frequent ▪ Infrequent	▪ Infrequent ▪ Infrequent
Duration	▪ Short recruitment time (episodic) ▪ Long recruitment time (continuous)	▪ Short transport time ▪ Long transport time	▪ Short residence time (mobile or quick to decay) ▪ Long residence time (immobile or slow to decay)
Timing	▪ Predictable ▪ Unpredictable	▪ Predictable ▪ Unpredictable	▪ Predictable ▪ Unpredictable
Rate	▪ Rapid delivery ▪ Slow delivery	▪ Rapid transport ▪ Slow transport	▪ Rapid change ▪ Slow change
Mode	▪ En masse ▪ Sliding / rolling ▪ Falling (snapping, leaning) ▪ Biotic addition (beaver, human)	▪ Floating (limited influence from obstructions ▪ Deflecting (influenced by obstructions) ▪ Dragging (sliding / rolling)	▪ Dispersed (ramp, bridge, parallel, oblique) ▪ Concentrated (channel-spanning, partial, floodplain, raft) ▪ Buried

Like sediment, the movement of wood can be intermittent, with long periods of locational stability interspersed with episodes of movement that are associated with high flows and water velocity (Wohl *et al.*, 2019). Wood is also associated with bank erosion through trapping sediment and providing essential habitat both instream and on the floodplain (Choné & Biron, 2016). Wood can create physical and ecological feedback loops, such as logjams causing greater bed scour and deposition of fine sediment when compared to an equivalent volume of dispersed wood (Wohl *et al.*, 2019).

The physical complexity and abundance of wood can affect the quantity and diversity of fish and macroinvertebrates. Wood provides mechanisms for energy dissipation, cover and habitat for fish, as well as enhanced channel stability, aquatic diversity (Chin *et al.*, 2008). As such, wood can be a noteworthy morphological indicator of river health since fish and macroinvertebrate taxa use wood directly as habitat, food, refuge and cover (Lake *et al.*, 2007; Elosegi *et al.*, 2010). Mobile wood can materially affect the floodplain and riparian regime by mechanically damaging or removing living plants, thus creating new germination sites (Wohl *et al.*, 2019). In rivers with a fine substrate, wood can provide a stable substrate for organisms where there would otherwise be none (Florsheim *et al.*, 2008).

Wood has traditionally been removed from rivers under active management, likely due to the perceptions of negative consequences such as flooding, bank erosion, and damage to infrastructure (Chin *et al.*, 2008). Removal of wood can have a negative effect on the dynamics of nutrients (Elosegi & Sabater, 2013), particulate organic matter storage and processing (Wohl *et al.*, 2019), riparian plant community development and structure, and aquatic habitat. However, flood hazards associated with wood accumulation within a channel comprise an unacceptable risk to humans and infrastructure; careful consideration should be given to what would constitute a feasible wood regime in a particular river or catchment (Wohl *et al.*, 2019), with due regard given to appropriate reference conditions for the reach or catchment.

2.6. Existing toolbox / morphological assessment approaches

The classification of rivers has not traditionally been well linked with that of river geomorphology (Norris & Thoms, 1999) and often fails to identify controls on river health at the catchment scale (Reid *et al.*, 2008). Geomorphologists and ecologists have been endeavouring for decades to successfully synthesise fluvial processes into a single hypothesis, such as the River Continuum Concept (RCC) and Riverine Ecosystem Synthesis (RES), detailed in Table 5. Classification and determining of fluvial characteristics using these overarching concepts has been attempted through several existing toolbox methodologies, as identified in Table 6. The River Habitat Survey (RHS), River Styles©, Stream Habitat Assessment Protocol (SHAP) and Morphological Criteria Index (MCI) are grounded within geomorphic processes and features guiding ecological health, while the Stream Ecological Valuation (SEV) is a New Zealand (specifically the Auckland Region) based toolbox used to infer ecological health through physical, chemical, and biological functions (Neale *et al.*, 2017). Challenges arise when considering both scale and the complexity of the fluvial environment; rivers behave and adjust in increasingly complex ways depending on the scale being considered, with no single explanation. Neither the RCC with its focus on longitudinal gradients, or the RES, with its focus on functional process zones (FPZ) can accurately describe the range of rivers and their characteristics and therefore all toolboxes grounded in such concepts will be similarly flawed. As such, it is clear that consideration of the specific and unique features of a reach or monitoring site need to be taken into consideration.

Table 5 Prominent fluvial process concepts that attempt to classify rivers and provide a framework for assessing individual reaches or rivers based on conceptual inferences on normal or common river processes.

	Methodological Concepts	
	River Continuum Concept (RCC)	**Riverine Ecosystem Synthesis (RES)**
Country of Origin	United States of America	United States of America
Guiding principles	That the structural and functional characteristics of stream communities and their distribution within a fluvial system are governed by their location within the river gradient, which presents a continuous gradient of conditions from headwaters to downstream, including width, depth, velocity, flow volume, temperature, and entropy gain (Vannote *et al.*, 1980).	Rivers as downstream arrays of large hydrogeomorphic patches formed by catchment geomorphology and climate. Unique ecological 'functional process zones (FPZ) are formed by individual types of hydrogeomorphic patches as a result of physiochemical habitat differences (Thorp *et al.*, 2006).
Purpose / Use	Classify and investigate stream ecosystems based on location within the river gradient and provide a conceptual framework for their organisation (Winterbourn *et al.*, 1981).	Provides a framework for understanding both broad, often discontinuous patterns along longitudinal and lateral dimensions of river networks and local ecological patterns across various temporal and smaller spatial scales (Thorp *et al.*, 2006).
Description of use	Synthesis of physical variables, including riverbed stratum, water temperature and stream size, along with biological factors such as primary productivity, ecosystem respiration, and invertebrate and fish communities. Placed into a predictive model where the longitudinal position in a stream network defines the physical and biological attributes of a stream (Vannote *et al.*, 1980; Collins *et al.*, 2018)	See Figure 11 for a schematic model of application of FPZ using a hierarchically nested mosaic of patches present in an idealised lotic ecosystem.

	Methodological Concepts	
	River Continuum Concept (RCC)	**Riverine Ecosystem Synthesis (RES)**
Benefits	Emphasis on predictable and quantifiable change (Tornwall *et al.*, 2015)	FPZs are identified using standard geomorphic techniques (Thorp *et al.*, 2006), allowing discrete studies to be readily compared to other studies using the same techniques
Costs	Application of the RCC outside of North American forest-temperate streams has been critiqued for not being applicable, although modifications of the RCC in recent studies have provided relevance to other river types (Ellis & Jones, 2013). Does not infer, directly or indirectly, ecological health. Methodologies required to operate within RCC to presumably set a baseline based on RCC and record deviations from the RCC parameters	Whilst the nature of the river and distribution of FPZs are will reflect similar conditions to some degree, in practice it is almost debilitatingly complex to assess the relationship. Above the ecoregional scale, it becomes increasingly difficult to predict distribution of patches along a longitudinal dimension of the river network (Thorp *et al.*, 2006) As per the RCC, the RES does not infer, directly or indirectly, ecological health.
Scope	Catchment wide	Catchment wide

Figure 11 Schematic model of theoretical RES application using a hierarchical nested mosaic of patches (Thorp et al., 2006)

Table 6 Notable methodological toolboxes used to infer ecological health of fluvial environments

	Methodological Toolboxes				
	River Habitat Survey (RHS)	**River Styles© Framework**	**Stream Ecological Valuation (SEV)**	**Morphological Quality Index (MQI)**	**Stream Habitat Assessment Protocol (SHAP)**
Country of Origin	United Kingdom	Australia	New Zealand	Italy	New Zealand
Guiding principles	Compare site with appropriate reference conditions, use appropriate field assessment data to blend with other data, to infer the state of river habitats (Raven *et al.*, 2010). Provide an objective basis for determining the physical character of rivers which can then be used for inferring and assessing habitat quality (Raven *et al.*, 2000).	Compare like with like, the appropriate selection of 'natural' reference conditions for differing types of rivers, and measurement of parameters that are relevant for each type of river (Fryirs, 2003; Brierley & Fryirs, 2005).	Assesses the ecological condition of streams based on the performance of their key ecological functions by combining a range of physical, chemical, and biological functions into a single assessment framework (Neale *et al.*, 2017). This is done using field assessments against reference conditions to establish a stream baseline by comparing like with like (Storey *et al.*, 2011).	Assesses the stream morphological quality through a set of 28 indicators in order to understand deviation from undisturbed conditions specific to the Italian context (Rinaldi *et al.*, 2013). Comprises an overall methodology for assessing hydromorphology of all Italian streams through integrated analysis of morphological quality as well as channel dynamics hazards (Rinaldi *et al.*, 2013). Uses reference conditions, although takes into account the long term occupation of river catchments by humans in Italy (Rinaldi *et al.*, 2013).	Standardised protocol that is both practical and cost-effective for assessing physical habitat in New Zealand waterways. Focus on physical habitat parameters only, with no reference to water quality or biological data, while assessing the stream condition at multiple scales (Harding *et al.*, 2009). Parameters are to be assessed via a desktop analysis, stream bank evaluation, and measurement of in-stream conditions (Harding *et al.*, 2009).
Purpose / Use	Investigate relationships between habitat features and associated biota, including macroinvertebrates,	Provides a set of procedures with which to integrate catchment scale geomorphic understanding of river forms, processes,	To account for the loss of function due to human activity or development so that an equivalent gain in	Provide a semi-quantitative score for streams based on a set of pre-determined indicators (comprising longitudinal and lateral	Multiple reasons for use, but predominantly to categorise streams into typologies that aid in stream management and it

	Methodological Toolboxes				
	River Habitat Survey (RHS)	**River Styles© Framework**	**Stream Ecological Valuation (SEV)**	**Morphological Quality Index (MQI)**	**Stream Habitat Assessment Protocol (SHAP)**
	avifauna, bats, other river and riparian plants and animals (Raven *et al.*, 2010).	and linkages through a nested hierarchy (Brierley & Fryirs, 2005). Provides the physical basis to describe and explain the within -catchment distribution of river forms and processes, and also predict likely future river behaviour (Fryirs, 2003; Brierley & Fryirs, 2005).	ecological function can be achieved in another place. Can also be applied for other purposes such as catchment planning, state of the environment reporting (Storey *et al.*, 2011), identifying streams of high natural value, determining the effects of land-use change, and providing a basis for regional policy development (Neale *et al.*, 2017).	continuity, channel pattern, cross-section configuration, bed structure and substrate, and vegetation in the riparian corridor (Rinaldi *et al.*, 2013). This assessment is used as a measuring tool to help satisfy both the European Union Floods Directive and the European Union Water Framework Directive (Rinaldi *et al.*, 2013).	provide an assessment of the habitat available to stream life. However, the creators of SHAP specifically state the purpose and use must be decided by the users, including decisions about what to measure and what not to measure (Harding *et al.*, 2009).
Description of use	Relies on systematic collection of map and observational data (Erba *et al.*, 2006) Channel features and modifications are recorded at 10 equally spaced locations along a 500m length of river, which is coupled with an overall summary for the whole site, including information on valley form and land use in proximity to the site (Raven *et al.*, 2010)	See Figure 12 for River Styles© framework steps used to assess and explain the geomorphic condition of rivers in a catchment using guiding principles (Fryirs, 2003).	Consists of the 14 most important ecological functions, which are measured in situ by suitably qualified ecologists. These include the natural flow regime, floodplain effectiveness, connectivity, natural connectivity to groundwater, as well as biogeochemical functions, and habitat and biodiversity functions Variables are given a value, which are then weighted	Subdivision of river network into homogenous reaches based on existing information (i.e. current state with no allusion to reference conditions) with basic investigation of geology, geomorphology, climate and land use. Segments are then identified for confinement and then for their morphological typology before being further divided into reaches (Rinaldi *et al.*, 2013).	Desktop assessment followed by the use of one of three specified protocol depending on the use of the assessment. **Protocol 1** is designed to be an estimate of parameters such as wetted channel width, vegetated bank width and stability, channel shape, bed stability, shading, anthropogenic influences, and abundance of moss, wood, leaves and other

	Methodological Toolboxes				
	River Habitat Survey (RHS)	**River Styles© Framework**	**Stream Ecological Valuation (SEV)**	**Morphological Quality Index (MQI)**	**Stream Habitat Assessment Protocol (SHAP)**
			according to each variables contribution to the ecological health	Each reach is then assessed against indicators of geomorphic functionality followed by indicators of artificiality and channel adjustments (Rinaldi *et al.*, 2013). Each reach is then provided with a score based on expert judgment for each of the three sets of indicators to provide a total combined score for each reach.	vegetation within the stream. **Protocol 2** is designed as a semi-quantitative assessment of a site, and includes both rigorous assessment and visual estimates (Harding *et al.*, 2009). Increased measurement rigor for each of the Protocol 1 factors, as well as cross-sections of the channel, water depth and velocity, substrate size, embeddedness, and instream and riparian vegetative cover. **Protocol 3** all measured factors from Protocol 2 but requires additional comprehensive metrics for each.
Benefits	Simple, cost-effective, objective, and practical (Raven *et al.*, 2000; Raven *et al.*, 2010)	Alternative to schemes that rely heavily on quantification and scores, without a fundamental appreciation for the underlying river behaviour, capacity of the river for	Simple, cost effective, standardised measure of the ecological functions of a stream reach (Neale *et al.*, 2017)	Detailed and specific for each river reach, although expected to be able to be undertaken by those with a reasonable level of experience with geomorphology rather than	Adaptable to the objectives and outcomes for doing the assessment; practitioners can select the most appropriate protocol for

	Methodological Toolboxes				
	River Habitat Survey (RHS)	**River Styles© Framework**	**Stream Ecological Valuation (SEV)**	**Morphological Quality Index (MQI)**	**Stream Habitat Assessment Protocol (SHAP)**
		adjustment, and a geomorphological context (Fryirs, 2003). Views rivers in the context of what is appropriate or natural for that particular setting.		the exclusive domain of experts (Rinaldi *et al.*, 2013). Provides a rational framework that is useful for supporting analyses of interventions and impacts to prioritise management strategies (Rinaldi *et al.*, 2013)	their aims (Harding *et al.*, 2009). Can be scaled up and down according to the expected use of the assessment
Costs	Requires existing reference stream database from which to compare. Variables are based on United Kingdom geomorphic conditions and must be assessed and adapted for relevance and influence of controlling factors prior to being implemented elsewhere (time and expense) Sections of river viewed in statistic isolation without reference to spatial or temporal context (Belletti *et al.*, 2017)	Levels of subjectivity built into River Styles, and the accuracy of results depends on the skills of the person applying it (Fryirs, 2003).	SEV is predominantly an ecological toolbox with reduced focus on the geomorphic functions and principles (Storey *et al.*, 2011) Applicability is contestable outside of the Auckland Region and requires additional reference conditions (Storey *et al.*, 2011). Also untested in streams and rivers of fourth order or larger (Storey *et al.*, 2011). Streams and rivers with highly mobile gravel or cobble beds cannot be	Some indicators extremely simplified based on target end users, resulting in compromises between scientific rigor and practical applicability as well as a large number of reaches required to be assessed in a short time. (Rinaldi *et al.*, 2013). Indicators are processes based on static visual assessment (Rinaldi *et al.*, 2013). Large number of indicators and long duration for undertaking assessment, as well as operator bias.	Applies only to wadable stream and do not apply to larger rivers (Harding *et al.*, 2009). Potential for inconsistent use of the different Protocols, reducing meaningful temporal assessment. Adaptation to stream type is not provided for; all variables are within the Protocol regardless of stream location within a catchment, geology, and climate.

	Methodological Toolboxes				
	River Habitat Survey (RHS)	**River Styles© Framework**	**Stream Ecological Valuation (SEV)**	**Morphological Quality Index (MQI)**	**Stream Habitat Assessment Protocol (SHAP)**
			accurately tested (Storey *et al.*, 2011)	Not suitable for monitoring changes in channel conditions, particularly if such changes are over a short time or spatial scale (Rinaldi *et al.*, 2013)	Does not fit comfortably within State of the Environment Reporting as a proforma is the end result, rather than scoring or summary assessment.
Scope	Small and medium rivers (Raven *et al.*, 2000; Raven *et al.*, 2010) *Longitudinal:* 500 m length of river channel; *Lateral*: 50 m either side of banks (Erba *et al.*, 2006).	Catchment wide River Style: "section of river along which boundary conditions are sufficiently uniform (i.e. there is no change in the imposed flow or sediment load) such that the river maintains a near consistent structure" (Fryirs, 2003, p. 4).	Reach scale Identified reach, predominately chosen for its proposed impactedness or potential adverse effects through the resource consent process pursuant to the RMA (Storey *et al.*, 2011; Neale *et al.*, 2017).	Catchment wide Individual reaches are identified in the same context as River Styles and synthesised to provide an overview of the river network (Rinaldi *et al.*, 2013).	Reach scale Reach scale is identified as far as one can see upstream and downstream from one location for Protocol 1; the reach is identified as 20x the wetted channel for Protocols 2 and 3 (Harding *et al.*, 2009)

Figure 12 River Styles© Framework steps used to assess and explain the geomorphic condition of rivers in a catchment using guiding principles (Fryirs, 2003)

2.6.1. Methodological characteristics of the toolboxes

The five existing toolboxes share common methods and measures of specific features to infer ecological health. All methodologies state the necessity for the assessment to be undertaken by a suitably qualified and experience practitioner (Fryirs, 2003; Harding *et al.*, 2009; Raven *et al.*, 2010; Storey *et al.*, 2011; Rinaldi *et al.*, 2013) Notably, all of the toolboxes incorporate a mixture of field data and desktop derived data to synthesise and assess the range of features relevant to the methodology. Unlike RHS, SHAP and SEV methodologies, the River Styles© Framework requires the initial desktop data to be undertaken prior to any field work (*apriori*) to frame the reach characteristics in which the degree of variation is then measured (Fryirs, 2003; Brierley & Fryirs, 2005; Brierley & Fryirs, 2008). Regardless, similar characteristics for all five methodologies are measured, including flow type, vegetation, and connectivity (longitudinal). Given the SEV is not truly a geomorphic measuring tool, it has limited relation beyond a basic assessment of the range of geomorphic process outlined in Section 2.5. For example, the River Styles© Framework, Protocol 2 and 3 of the SHAP, and RHS require an appraisal of surrounding land use, whereas SEV does not. Given the importance of land use on fluvial processes through geomorphic change (i.e. increased sediment runoff through loss of the riparian zone) and water quality, it is necessary to consider lateral connectivity and surrounding land use during any geomorphic-led assessment.

The scale of assessment also varies between the five toolboxes. The RHS specifies 500 m of reach must be used each survey, whereby channel features and modifications are recorded at 10 equally spaced locations, in addition to an overall summary for the site (Raven *et al.*, 2010). This contrasts with other survey methods, including both the River Styles and the SEV, which specify a typology; for the River Styles Framework and MQI, a desktop analysis pre-determines the reach in which to be assessed based on a section of river along which boundary conditions are sufficiently uniform (Fryirs, 2003; Rinaldi *et al.*, 2013), whilst SEV reaches are usually chosen as the length in which will be affected through development during the resource consenting process (Neale *et al.*, 2017). The reach length for SHAP varies from however far one can see upstream and downstream in Protocol 1, and 20 times the wetted channel width for Protocols 2 and 3, with a minimum of 50 m and a maximum of 500 m (Harding *et al.*, 2009) There is no general consensus on how SEV scale is determined for monitoring or state of the environment reporting purposes. Raven *et al.* (2010) reassessed the requirement for a 500 m reach in RHS specific studies and found that at least 80% of attributes are captured over that distance and hypothesise that a 100 m survey unit would only account for around 40% of features.

2.6.2. Reference conditions

A common theme within the toolbox assessments are the comparison of rivers to reference sites or reference conditions. Reference sites refers to the selection of sites that are considered 'minimally disturbed' or untouched by human disturbance and compare the findings of the assessment against these conditions (Norris & Thoms, 1999; Stoddard *et al.*, 2006). Reference conditions for SOE reporting are specified as "the chemical, physical or biological conditions that can be expected in streams and rivers with minimal or no anthropogenic influence" (McDowell *et al.*, 2013a, p. 6). RHS, MQI, and SEV use reference conditions based on an existing compiled database through which the monitored reach is assessed against and given a score depending on the degree of variation (Raven *et al.*, 2010; Rinaldi *et al.*, 2013; Neale *et al.*, 2017) and are considered to be representative of objective analysis (Raven *et al.*, 2010). As a result, the application these three toolboxes outside of their original jurisdictions can be difficult and time consuming. RHS assessments are dependent on predominantly United Kingdom based reference conditions; whilst Raven *et al.* (2010) found the attributes measured in the RHS survey were applicable in other locations, such as mainland Europe, they also found that modifications were required to account for local characteristics, and that the process would greatly benefit from local benchmarking to account for important differences in river character. SEV is specific to the Auckland Region, particularly low-gradient wadable streams, and therefore is similarly difficult in applying to other regions possessing different geological and geomorphic characteristics without existing reference sites (Storey *et al.*, 2011; Neale *et al.*, 2017). Notably, the SHAP deviates from the use of reference conditions, considering them to be ambiguous and incorporate a degree of subjectivity in site selection. This can be problematic in terms of understanding what an 'ideal' stream should look like, particularly when considering the natural variation in some stream types over time (Harding *et al.*, 2009).

By contrast, the River Styles© Framework undertakes benchmarking of reaches against themselves (Fryirs, 2003) and accounts for the ability of the reach to adjust within a certain range of responses to given a set of disturbances. Through this framework, a 'reference' reach is one that sits within the natural range of variability and catchment boundary conditions *for that specific reach* and assessed as such through desktop analysis prior to fieldwork. In-field observations are then assessed against the natural reference conditions to understand the geomorphic condition of the river, which is the measure of difference between the physical system and the natural range of variability or expected natural state (Fryirs, 2003). As such, the River Styles© Framework can be utilised globally, given the emphasis on a flexible, open-ended approach that explicitly recognises the continuum of diversity of river forms and processes (Fryirs, 2003). However, the Framework requires specific training in the River Styles© methodology. Further the subjectivity of River Styles© does not correspond well into the desire for quantifiable and measurable results for state of the environment reporting (McFarlane *et al.*, 2011) by Regional Councils in New Zealand.

2.7. Challenges

Too often, approaches to river assessment and subsequent river management has emphasised concerns for water quality and ecological relationships without acknowledging the fundamental links to geomorphic attributes of a riverine system (Brierley *et al.*, 2010). The assessment of geomorphic indicators for river health is inherently complex; what constitutes a healthy process in one river, such as bank erosion, may indicate degraded state in another. Assessment of geomorphic indicators also gets more complex as the scope is extended, as found by Raven *et al.* (2010); inclusion of river bank and riparian zones to in-stream survey methods compound their level of complexity and amplifies uncertainties in underlying presumptions. This is further exacerbated by conflicting requirements for rapid, cost effective data collection needed for national policy (e.g. requirements under the NPS-FM) and more detailed specialist understanding of fluvial morphology to tailor management of individual catchments and reaches to increase the probability of successful rehabilitation (Raven *et al.*, 2010). Two major challenges to successful morphological monitoring are discerned:

- **Scale** at which monitoring is undertaken, such as morphological unit, patch, reach, or catchment; and
- **Variability** of river morphology and the resulting processes, and the difficulty in quantifying and classifying fluvial systems in a meaningful way.

2.7.1. Scale

Given the complexity and range of geomorphic influences on the fluvial system, it is difficult to quantify all potential sources of impact on processes and character of a given reach, river, or even catchment. Analysis of single sites cannot alone provide insight into spatial variability in system processes and connectivity (Brierley *et al.*, 2010; McFarlane *et al.*, 2011; Fuller *et al.*, 2019), although most monitoring applications are undertaken at the reach scale (Brierley *et al.*, 2010). However, geomorphic condition does not scale well (Norris & Thoms, 1999), such that measurements of a reach cannot infer catchment health. The catchment context is important because results from individual sampling sites cannot be considered without reference to channel and catchment processes elsewhere in the catchment, such as land use and geology (Raven *et al.*, 2000; Tornwall *et al.*, 2015). Instead, the geomorphological factors need to be considered at both the local and catchment scale (Fuller *et al.*, 2019), in addition to an assessment of the larger scale relationships and influences occurring within the catchment, and how they may explain the geomorphic distribution between reaches.

Geomorphic toolboxes run the risk of being misleading if the geomorphic conditions being quantified are not informed by ecological data, such as those collected – fish or macroinvertebrate assessment. For example, some non-migratory species may live wholly within habitats that occupy only part of one reach of a river, while other species, such as indigenous diadromous species require entire river systems and connectivity to the ocean for spawning, rearing, and maturation (Joy & Death, 2004; Stanford *et al.*, 2005). To provide for a more holistic appraisal of the Bega Catchment, Chessman *et al.* (2006), as part of the River Styles© application framework, utilised extensive reach mapping of the whole of the Bega Catchment to provide a catchment wide analysis of geomorphic condition. However, this approach is extremely labour and data intensive, with the risk of data obsolescence, should repeat surveys not be undertaken in a timely manner. As such, geomorphic toolboxes must consider the purpose and intended use of the results, such as objective monitoring, or to inform reach or catchment wide mitigation to target priority areas.

2.7.2. Variability of river styles and types / representativeness

Often, monitoring programmes fail to consider the representativeness of reach-scale data collected, instead being more preoccupied with collecting information in accordance with standardised approaches (Brierley *et al.*, 2010; McFarlane *et al.*, 2011). Exclusion of fine and broad scale geomorphic knowledge from assessments can lead to poorly informed decisions, such as undertaking inappropriate river rehabilitation activities in unsuitable riverscape localities (McFarlane *et al.*, 2011).

Emphasis is required on measuring the functionality of a reach or river rather than a check-list appraisal of river form (Brierley *et al.*, 2010), in addition to appropriate temporal considerations that capture the natural range of geomorphological adjustment. For example, a measure denoting sediment yield above a certain parameter as 'unhealthy' is unlikely to account for the variability between river systems. For instance, whilst the Manawatu River yields around 3.8 Mt / year, which is similar to the Waiho River in Westland (3.4 Mt / year), the processes resulting in each sediment yield are completely different, with the latter glacierised and draining some of the highest relief in New Zealand (Tadaki *et al.*, 2014). The River Styles© Framework provides an alternative monitoring regime to the standardised checklist by requiring each river reach to be considered within the parameters of its propensity for adjustment (Brierley & Fryirs, 2005), although results in large quantities of data that are framed subjectively and not always directly comparable to other river types. Nevertheless, the use of unique reference conditions for each reach rather than against a standardised list of features provides for greater representation of the characteristics present.

2.8. Principles of a Waikato-centric toolbox assessment

Any toolbox created for the geomorphic assessment of stream health must be based on measurable geomorphic processes, whilst considering the limitations of any simplification of inherently complex and interlinked environments. It must also be able to be replicated by both a range of practitioners and within different catchments in order to provide meaningful and consistent results that can inform temporal trends and subsequent river management. Meaningful monitoring of river condition is inherently place-based (Tadaki *et al.*, 2014), and therefore simply standardising biophysical measures will not provide insight into the significance of the variables across reaches and catchments. This is further complicated as rivers adjust naturally over time, and therefore consideration of geomorphic condition must also be based on understanding the natural range of adjustment for that specific reach or catchment (Reid *et al.*, 2008). As such, any analysis must be framed in relation to what could be feasibly expected for any given river type. Any assessment for habitat needs to be both ecologically and geomorphologically meaningful to allow relevant scales and variables to be placed within context of the reach and parameters of the overall monitoring (Belletti *et al.*, 2017). Finally, consideration of the end use of the monitoring data collected and for what purpose (such as policy formulation) is also necessary to frame what is assessed (Brierley *et al.*, 2010).

With regard to these guiding principles as identified in the literature, the following considerations and parameters were selected to formulate the geomorphic toolbox methodology:

1. *Use of existing Waikato Regional Council monitoring sites to allow comparison of geomorphic indicators versus known ecological and physical indicators currently assessed.*
2. *Assessment of river reaches compared to an appropriate reference condition; apriori work is required to determine the expected geomorphological parameters of a reach site*
3. *Comparison of 'like-with-like' rather than assessing against a check-list of required features to constitute 'good' river health*
4. *Balance of time and cost efficiency whilst accurately representing and recording relevant geomorphic features; the geomorphological monitoring is envisaged to be incorporated into the existing annual river quality monitoring*
5. *Accessible conclusions that can be analysed spatially and temporally, such as 'expected / modified but functional / degraded' geomorphic condition bands*
6. *Appropriate scale and nested hierarchy – reach to be assessed in relation to the catchment*
7. *Standardised approach that can be repeated by future users*

Elements of the River Styles© Framework (Brierley & Fryirs, 2005), RHS (Raven *et al.*, 2000; Raven *et al.*, 2010), MQI (Rinaldi *et al.*, 2013), SHAP (Harding *et al.*, 2009), and SEV methodology (Neale *et al.*, 2017) are utilised to formulate this methodology and framed within the geomorphic principles.

Particular emphasis is placed on discerning reference conditions through a desktop analysis ('apriori conditions'). This process provided the expected parameters within which the identified reach should be operating to be considered in 'good' health. The following physical features were chosen based on their significance for detecting geomorphic health of reaches and their ease of measuring to allow a wide range of practitioners to be able to apply the toolbox:

- Riparian Zone;
- Bank Erosion;
- Grain size;
- In-channel wood;
- Connectivity; and
- Spatial heterogeneity.

2.9. Conclusion

Geomorphic processes and features are relevant benchmarks and indicators of other ongoing processes within a fluvial system such as biological health and habitat distribution. Given geomorphology forms the template upon which other processes can occur, an understanding of the normal distribution and disseminating forces behind geomorphic processes and features can contribute to a toolbox for understanding ecological health. As with ecological and chemical indicators, geomorphic indicators represent a proxy of ecological health and are best suited to contribute to a suite of measures rather than used exclusively. Caution is also needed when applying geomorphic indicators, which are by design a simplification of the complex, interlinked natural environment so that what is being measured remains relevant and representative of the processes. It is evident that reference conditions are utilised through a range of ecological measures as well as for understanding individual geomorphic features or processes. It is desirable to assess ecological health on a catchment scale with monitoring undertaken at the reach scale. However, there are significant constraints with undertaking catchment level monitoring, including a lack of funding, political will, and a necessity for a large reference database. Finally, it is integral to ensure that the geomorphic toolbox is fit for purpose, such as monitoring or restoration. A set of principles were formulated to frame the toolbox methodology for geomorphic assessment for the Waikato Region, which draws together the key morphological indicators of river health, while entrenching reference conditions as key to ensuring the relevant considerations for individual reaches is not lost within a blanket quantitative checklist.

3. Methodology

This section outlines the methodological approach adopted for the formulation and use of the geomorphic toolbox. At the forefront of the methodology was the requirement to configure the monitoring around an understanding of rivers in their unique context (Tadaki *et al.*, 2014), with the overarching principle of a flexible approach that explicitly recognised the "continuum of diversity of river forms and processes" (Fryirs, 2003, p. 19). The selected approach consisted of three phases:

1. Pre-assessment
    a. Site selection
    b. Apriori assessment to establish reference conditions
2. Site work
    a. Site visits and field work
3. Post assessment and analysis
    a. Geomorphic assessment of individual reaches
    b. Assessment of geomorphic analysis versus ecological analysis

3.1. Pre-assessment

3.1.1. Site selection

WRC undertakes annual ecological monitoring of wadeable streams within the Waikato Region as part of their State of the Environment Reporting. Monitoring includes reference sites (minimal anthropogenic influence) that are monitored every year, supplemented by a selection of around 180 other streams of which 50-60 rotate on a three-yearly basis. WRC reach lengths are always 150 m as irrespective of location, this length accurately describes reach-scale fish species richness with additional species beyond this length rare (David *et al.*, 2010). To provide for a direct comparison, sites were selected for this study from the 2020 monitoring list. Four reference sites were targeted given the potential for providing annual results in the future. The non-reference (modified) sites were selected to provide contrasts to the reference sites, given the expectation of human intervention to the natural geomorphic processes arising from their locations. Table 7 and Figures 13-14 outline the location of the selected sites.

Table 7 Selected sites for testing the geomorphic toolbox

WRC Reference	Stream Name	Reference Site / Non reference site	Downstream boundary coordinates
11726_11	Upper Wainui Stream	Reference	E 1760523, N 5811768
1172_6	Wainui Stream (Raglan)	Reference	E 1762004, N 5813104
2079_1	3rd Order Stony Stream	Reference	E 1815954, N 5956604
2080_1	2nd Order Stony Stream	Reference	E 1815800, N 5956700
1262_18	Waiwhero Stream	Non-reference	E 1836904, N 5836119
1307_18	Whangarahi Stream	Non-reference	E 1822913, N 5929144

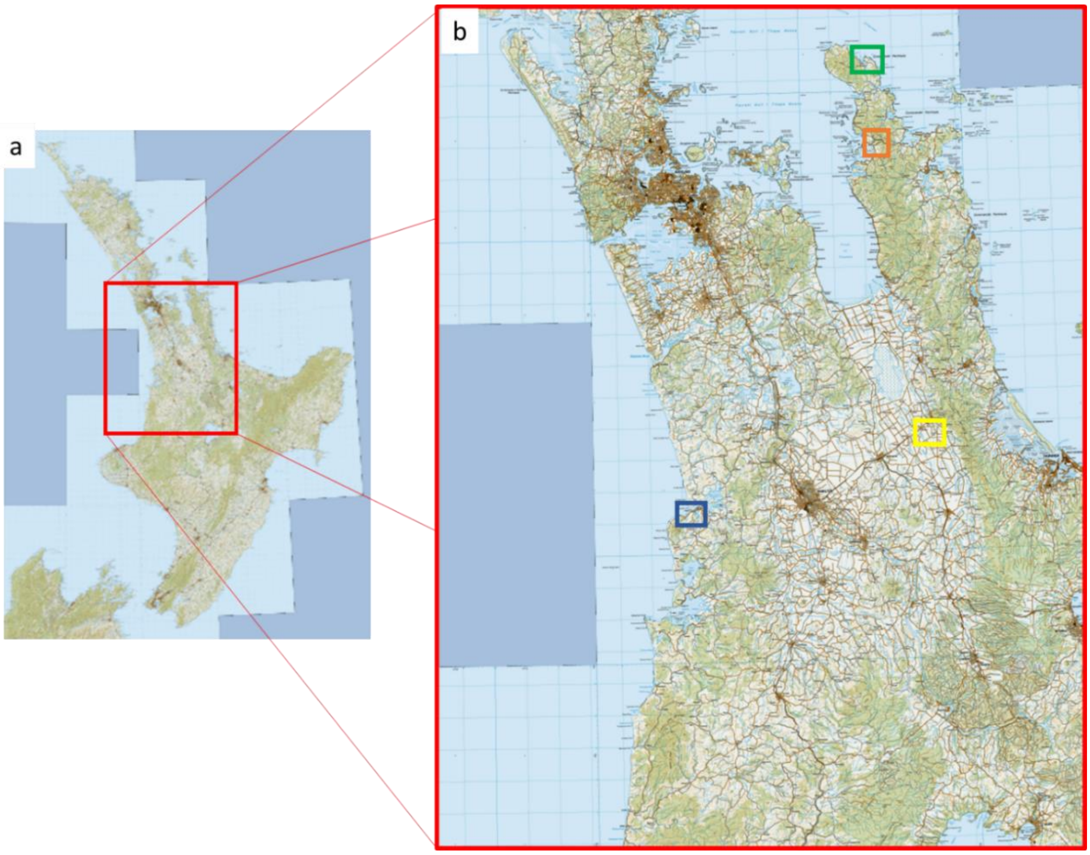

*Figure 13 Site locations. **a**: North Island of New Zealand locating the Waikato Region; **b**: Identification of the local areas with selected sites (map courtesy of topomap.co.nz)*

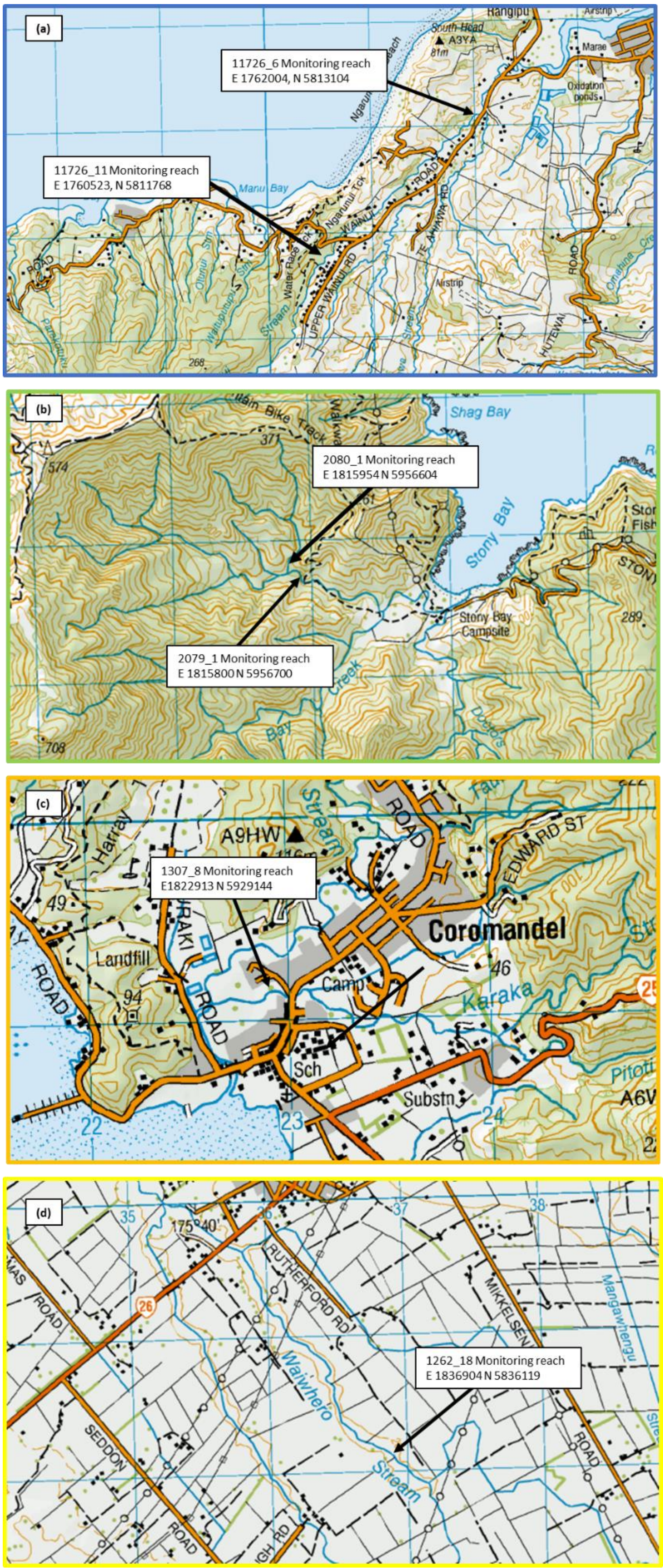

*Figure 14 Local site locations. **a**: Raglan – Upper Wainui Stream (11726_11) and Wainui Stream (1172_6); **b**: Stony Bay, Coromandel – 3rd Order Stony Stream (2079_1) and 2nd Order Stony Stream (2080_1); **c:** Coromandel Peninsula – Whangarahi Stream (1307_18); and **d:** southern Hauraki Plains – Waiwhero Stream (1262_18);*

3.1.2. Establishing reference conditions

Once the sites were selected, reference conditions were established for each reach based on the definition provided by McDowell *et al.* (2013b) for SOE monitoring. The reference conditions comprise an expected scenario of geomorphic condition in the absence of anthropogenic influence. The creation of reference conditions utilised existing information available for each site (including from GNS Science and WRC biodiversity and vegetation distribution research), such as location, stream order, site geology, soil types, and valley setting. A series of open-ended questions were then developed to frame reference conditions for each reach. This approach provided for "parameters used to interpret and explain system structure, function, and condition" (Brierley & Fryirs, 2005, p. 298), by using a series of qualitative questions that can be used to appraise each of the indicators (Table 8), emulating the approach undertaken by Reid *et al.* (2008) when assessing the geomorphic condition of the Twin Streams Catchment in Auckland, New Zealand.

Table 8 Reference framing questions to develop reference conditions for each reach

Indicator	Reference framing questions
Riparian Zone	▪ What is the proportion of native versus exotic cover within the Riparian Zone? Is there an indication of monoculture? ▪ What type of plants would be expected to make up the riparian zone for this reach? ▪ What density of riparian vegetation could be expected? ▪ What width of riparian vegetation could be expected for this reach?
Bank Erosion	▪ Should bank erosion be expected in this reach? ▪ How much bank erosion should be expected for this reach? ▪ Should the bank erosion in this reach be consistent along the banks, or in discrete locations (such as on the outside of bends)?
Grain Size	▪ What granularity should be expected for this reach? ▪ What range of grain sizes should be expected in this reach?
Wood	▪ How much wood should be expected within the wetted channel of this reach? ▪ Is the presence of wood rafts or wood jams expected in this reach? ▪ How much potential for sourcing wood is there from the banks of the reach (both dead / fallen wood and live vegetation)?
Connectivity	▪ Should natural connectivity be expected from the reach to the adjacent upstream and downstream reaches? ▪ Are there any notable disruptions to connectivity along the entire length of the catchment, from source to sink?
Spatial Heterogeneity	▪ How many geomorphic units could feasibly be expected within this reach? ▪ Are there key geomorphic units that should be present within this reach?

3.2. Fieldwork

While the specific characteristics of a reach determined the best approach for assessing the geomorphological features of the area, many of the techniques used were able to be deployed at all sites, with some variation to suit as required. Not all techniques were deployed at all sites, and adaptation was required at others, such as the measurement of clasts. This section details the generic methodology used to assess geomorphology at each of the six selected sites (Table 7), as well outlining the methodology variations adapted to the sites. The data sheets created for the purpose of this assessment are located in Appendix A of this report. Multiple photographs were taken within each segment of each reach to document the observed features. Table 9 summarises the methodology used at each of the sites. Additionally, a video walkthrough of each segment was undertaken to provide a reference during analysis, which is located within a Google Drive set up for the purpose of storing these walkthroughs (refer Section 4.1 for links to individual sites).

3.2.1. Site identification

Downstream coordinates and descriptions of all sites were provided by WRC (i.e. Figure 15). These coordinates were loaded into a free offline app Topomaps NZ on an Android device and the GPS function of the device used to locate the general area of the downstream coordinates (i.e. Figure 16).

WRC SITE DESCRIPTION SHEET – REMS/FISH SITES			
Waterway Name	Wainui Stm (Raglan)@Wainui Stm (Raglan) at Wainui	Land Owner Name	Waikato District council reserve
Located No.	**1172_6**	Land Owner Address	15 Galileo St/Private Bag 544, Ngaruawahia 3742
GPS Coordinates	**BD32: 721-747** **E 1762004** **N 5813104 Fish D/S Start**	Land Owner Phone Number	07 824 8633
Site Status	Longterm	Site Contact (if different to owner)	
Habitat type	Hard-Bottomed, wadeable, 100m, deep in places	Site Contact Phone Number	
Site Location Directions / Comments			
330 Wainui Rd Raglan. Map BD32. Head through Raglan and towards Wainui beach. Park at Wainui Reserve carpark on right before Wainui beach turnoff. From carpark walk on Beach trig walking track to first footbridge. Start sampling here and go upstream.			
GPS coordinates is the FISH downstream start			

Figure 15 Information sheet provided by WRC to assist with determining the downstream coordinate location for the Wainui Stream reach (reference 1172_6)

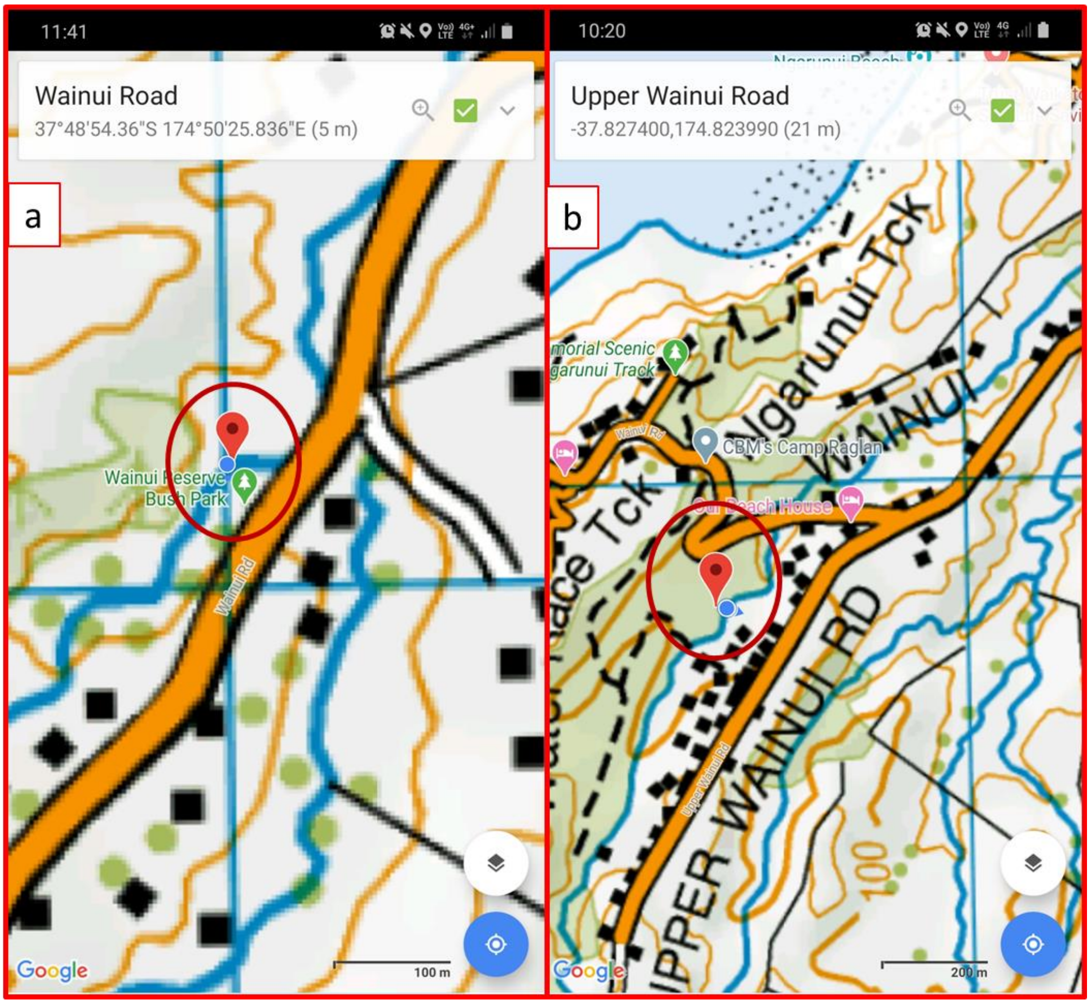

Figure 16 Use of handheld GPS to locate downstream coordinates for the (a) Wainui Stream reach (reference 1172_6) and (b) Upper Wainui Road reach (reference 11176_11).

Two people were used to assess the reaches. Small handheld Markers, numbered 1-13 were used as visual aids for demarcating the reach into 25 m segments. Marker 4 was placed on each side of the stream bank to demarcate the downstream boundary as specified by WRC. The tape measure was then used to measure 25 m reaches downstream of the downstream boundary along the true right bank, with markers placed at each 25 m mark (for a total length of 75 m downstream of the downstream boundary). This boundary is referred to as the *extreme downstream boundary* and is referenced as Marker 1. Figure 17 exemplifies a Marker in its true left bank location, which is visible to those upstream. The true right Marker faces downstream, so that assessors can determine the boundary of the segment being measured from both directions.

The upstream reach from Marker 4 was then measured along the true right bank, with each 25 m reach demarcated by ascending numbers, up to 150 m from Marker 4 (demarcated as Marker 10). 150 m is the length specified by WRC as the maximum reach length for any WRC ecological monitoring and was therefore specified as relevant to this study to provide a comparable assessment. An additional 75 m was also measured upstream of Marker 10 in 25 m increments. By the end of the measuring phase, a reach of 300 m in total was marked out, with the WRC monitored reach sitting between an additional 75 m upstream and downstream of the reach boundaries as diagrammatically reproduced in Figure 18.

Figure 17 Example of Marker used to demarcate a 25 m segment of the Wainui Stream reach (reference 1172_6). Marker 3 is located 25 m downstream of Marker 4 – the specified downstream boundary of the WRC monitored reach.

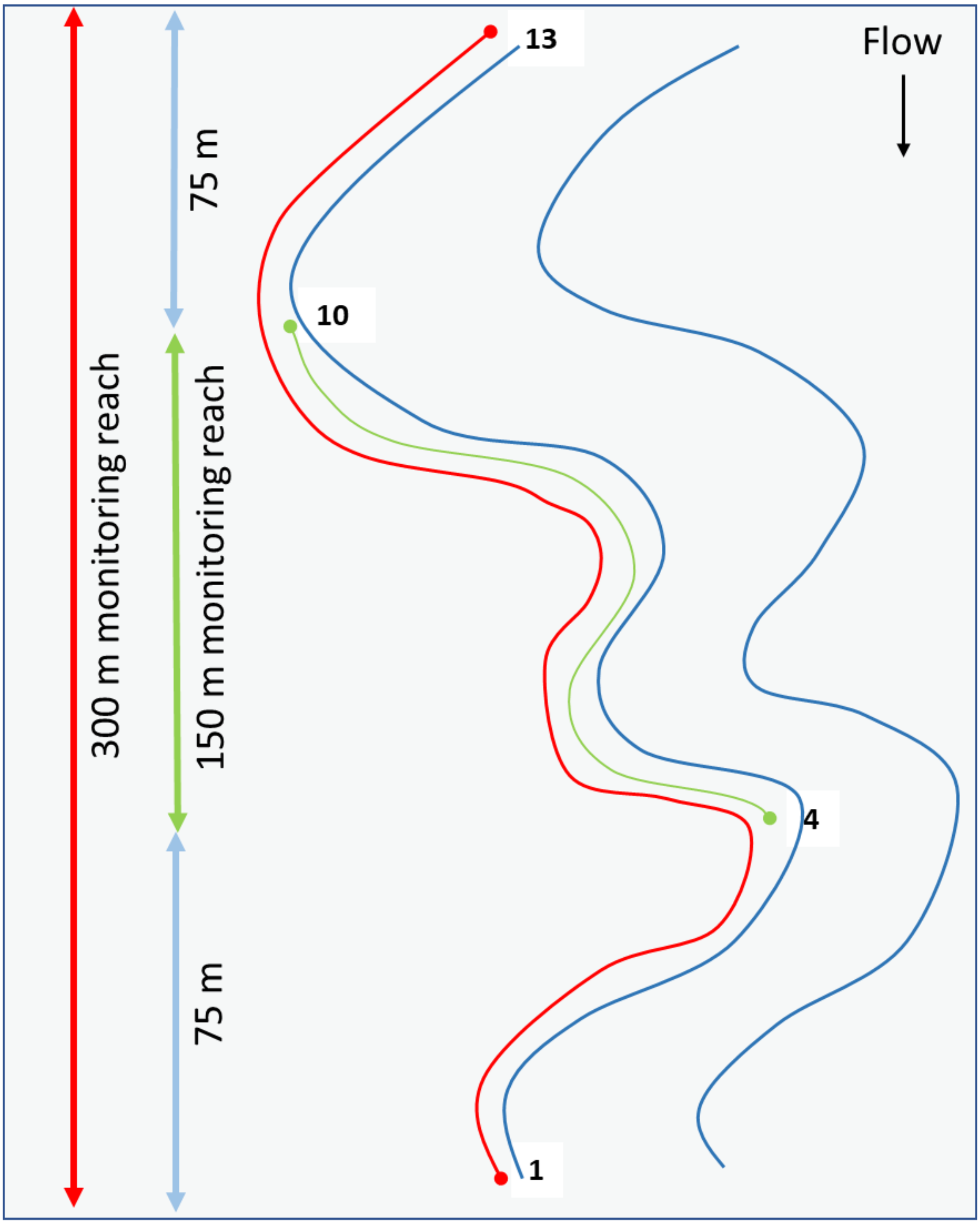

Figure 18 Diagrammatic representation of the monitoring reaches. The 150 m monitoring reach is specified by the WRC monitoring regime (green, between Markers 4 and 10), with an additional 75 m both upstream and downstream of the 150 m reach to create a 300 m monitoring reach as well (red, between Markers 1 and 13).

3.2.2. Flow

Flow of the reach was measured using a Valeport Model 801 EM flow meter at four locations: Markers 1 (extreme downstream boundary), 4 (downstream boundary), 10 (upstream boundary), and 13 (extreme upstream boundary). Flow was measured at 60%

of the depth for the purposes of comparing reach conditions to those when the ecological monitoring was undertaken by WRC.

3.2.3. Particle size

Clasts were to be assessed in two locations per segment using a surface sample grid count, as described by Bunte and Abt (2001), with 25 clasts to be measured in each locations (total of 50 clasts per 25 m segment). The locations were to be randomly selected within each segment by one assessor, with clasts measured along their *a-*, *b-*, and *c-axis* and their roundness observed and recorded on the field sheets for the reach by the second assessor. Power's roundness was chosen for this assessment as it is a rapid and easy method that can be deployed in the field which involves an assessor judging the angularity of each clast against a set criteria for roundness (Figure 19).

Figure 19 Power's roundness used to assess the angularity of the clasts in each location (Field Studies Council, 2016)

When measuring Monitoring Site 1172_6 Wainui Stream, it was found that this method was not feasible due to the significant time required to execute. Monitoring Sites 1176_6 Wainui Stream and 11726_11 Upper Wainui Stream were therefore subject to a modified version of this assessment. Segments 1-2, 5-6, 8-9, and 10-11 were used for the clast assessment, with assumptions to be built into the analysis of the results of the representativeness of these segments for the reach as a whole. Varying geomorphic units were identified for clast assessment, including pools, bars, and a riffle section.

For Monitoring Sites 2080_1 2nd Order Stony Stream, 2079_1 3rd Order Stony Stream, and 1307_18 Whangarahi Stream, a modified assessment was researched and used. A pebble count along a transect was used to determine the particle-size characteristics by assessing particles in even-spaced increments, following the method outlined by Bunte and Abt (2001). The measuring tape was stretched along a 30 m stretch predominantly within Segments 1-2, 5-6, 8-9, and 10-11 and particles were selected at exactly 1.0 m intervals (Figure 20). Two people were used for the particle count; one person was responsible for selecting a particle from the streambed or bar, measuring the *b*-axis with the callipers, and the other for recording the particle size.

Figure 20 Example of measuring particle size along a transect within the 3rd Order Stony Stream (reference 2079_1). A tape measure was laid out for 30 m and the particle exactly below each metre mark was measured along its b-*axis and recorded.*

A qualitative assessment of particle size and type was also undertaken for each segment. Starting from the extreme downstream position, each 25 m segment was assessed for the predominant particle size, shape, and variety. Consideration was given to the range, armour layer, consolidation and sorting, as well as whether a silty or sandy layer was overlaying the armour layer.

Given the lowland location of Monitoring Site 1262_18 Waiwhero Stream, clasts were not expected to be found and there was an expectation that fine silts and clays would make up the predominant soil and rock types. As such, sediments were obtained from the middle of the channel at Markers 1, 4, 10, and 13 and visually inspected for an estimation of particle type and makeup, as shown by Figure 21. During the sweeps of the channel for assessing other factors, an inspection was made within each segment for any larger clasts, such as pebbles or cobbles within the channel bed or the banks.

Figure 21 surface bed material obtained from the middle of the channel at Marker 4 within the Waiwhero Stream and assessed for particle type and size. The same process was used to assess the bed material at additional Markers 1, 10, and 13.

To provide additional comparison to other reaches, a video walkthrough of each of the 12 segments was undertaken. A post-field qualitative assessment was undertaken from these videos, with each segment assessment for the predominant particle size, shape, and variety. Consideration was also given to significant deviations from the visually observed average, such as large boulders, or sand bars as well as whether a silt or sand layer was present over the armour layer. Caution is required for use of these results compared to in-field results; the camera is unable to see through water, thus obscuring a portion of the clasts that are important to the assessment.

3.2.4. Riparian Zone

Starting from the extreme upstream position (Marker 13), each 25 m segment is assessed with regard to the riparian zone. For each segment, the assessor qualitatively assessed and recorded the vegetation density and species (indigenous versus non-indigenous) on both banks of the wetted channel. At the midpoint of each segment, the width of the vegetated riparian zone extending perpendicular to the bank was measured using a tape measure, with the exception of segments where the riparian zone exceeded a visual estimate of 30 m. Where the riparian zone exceeded 30 m, an estimate of the width was recorded and then checked against aerial imaging of the site at a later date. Gaps or an absence of riparian planting (such as Figure 22) were recorded as 0 m, and their length along the stream bank also measured.

Figure 22 Example of a gap within the riparian zone, near Marker 10 for Wainui Stream (reference 1172_6)

3.2.5. Bank Erosion

Starting from the extreme upstream position (Marker 13), each 25 m segment down to the extreme downstream position (Marker 1) was assessed with regard to bank erosion. For each segment, the assessor qualitatively assessed and recorded visual bank erosion for both sides of the wetted channel, including the potential for erosion to occur. The presence of bank erosion was recorded with reference to type, such as undercutting and slumping and potential immediate causes such as location on the outside of a bend, location of wood in the stream, or vegetation variation on the bank.

3.2.6. Wood Pieces

Starting from the extreme downstream position (Marker 1), each 25 m segment down to the extreme upstream position (Marker 13) was assessed for the quantity and position of woody pieces observed. For each segment, the assessor qualitatively assessed and recorded the presence of woody pieces within the wetted channel, including a gauge on quantity, size, location (such as near the bank, within a pool, or fallen branches or trees connected to vegetative material on the banks), and whether the woody pieces were discrete or within conglomerates such as wood rafts. Additionally, observations of woody pieces that were located on the banks of the wetted channel were recorded for their potential as sources of future woody pieces for the wetted channel.

Wood was not expected to be present in any great quantity at Monitoring Site 1262_18 Waiwhero Stream. This is due to the lowlands location of the reach on the Hauraki Plains, in addition to terrestrial vegetation clearance identified on an assessment of aerial photographs of both the reach and upstream catchment prior to the site work. As with the visual assessment for grain size for this stream, an inspection was made within each segment for woody pieces within the channel, along the banks, and further within the floodplain for potential future sources of woody pieces.

3.2.7. Geomorphic Units

Starting from the extreme upstream position (Marker 13), each 25 m segment down to the extreme downstream position (Marker 1) was assessed for the predominant geomorphic unit at the Unit and the Sub-Unit scale as specified within the Geomorphic Units survey and classification System (GUS), designed by Rinaldi *et al.* (2015, p. 13):

- *Unit: basic spatial unit, and corresponds to a feature with distinctive morphological characteristics and significant size located within a macro-unit e.g. riffle, bar, island.*
- *Sub-unit: corresponds to patches of relatively homogeneous characteristics in terms of vegetation, sediment and / or flow conditions located within a unit.*

Visible Units and Sub-units were identified and recorded for each segment within the wetted channel and the banks, although no assessment of the floodplain or valley floor was recorded. A video recording of each segment focusing on geomorphic units was undertaken for referral subsequent to the field.

3.2.8. Fieldwork summary

The techniques used at each site are summarised in Table 9.

Table 9 Summary of geomorphic assessment techniques used at each of the identified monitoring sites

	11726_11 Upper Wainui Stream	**1172_6 Wainui Stream**	**2080_1 2nd Order Stony Stream**	**2079_1 3rd Order Stony Stream**	**1307_18 Whangarahi Stream**	**1262_18 Waiwhero Stream**
Assessment Date and weather conditions	15th March 2020 Fair, with no rainfall in the preceding days, or on the day of assessment	14th March 2020 Fair, with no rainfall in the preceding days, or on the day of assessment	21st March 2020 Fair, with no rainfall in the preceding days, or on the day of assessment	21st March 2020 Fair, with no rainfall in the preceding days, or on the day of assessment	22nd March 2020 Fair, with no rainfall in the preceding days, or on the day of assessment	20th March 2020 Fair, with no rainfall in the preceding days, or on the day of assessment
Site Identification	Downstream Coordinates provided by WRC and loaded into TopoMaps NZ on an Android device. The GPS function of the device was used to locate the general area of the downstream coordinates and cross-referenced against photographs provided by WRC for assurance of the site location					
Number of assessors	2; one assessor and one field assistant					
Site Demarcation	150 m and 300 m reach, measured in 25 m increments along true right bank, with markers on each bank at each 25 m mark					
After-the-fact evidence	Video walkthrough recording of each segment for each of the Monitoring sites for further referral subsequent to the fieldwork					
Flow	Valeport Model 801 EM flow meter at four locations: Marker 1 (extreme downstream boundary), Marker 4 (downstream boundary), Marker 10 (upstream boundary), and Marker 13 (extreme upstream boundary)					
Particle Size	25 clasts in two locations (for a total of 50 clasts) within Segments 1-2, 5-6, 8-9, and 10-11 measured along their *a-, b-, and c-* axis and their roundness observed and recorded.		Pebble count along 30 m transect with Segments 1-2, 5-6, 8-9, and 10-11. Particles are selected at exactly 1m intervals and b-axis recorded using callipers. Qualitative assessment of particle size undertaken for each segment for predominant particle size, shape and variety. Consideration given to the range, armour layer, consolidation and sorting, as well as whether a silty or sandy layer was overlaying the armour.			Sediments obtained at Markers 1,4, 10, and 13 and visually inspected for an estimated of particle type and makeup. Inspection of each segment for any larger clasts such as pebbles or cobbles within the channel bed or the banks.
Riparian Zone	Starting from the extreme upstream position (Marker 13), each 25 m segment is assessed with regard to the riparian zone. For each segment, the assessor qualitatively assessed and recorded the vegetation density and species (indigenous versus non-indigenous) on both banks of the wetted channel. At the midpoint of each segment, the width of the vegetated riparian zone extending perpendicular to the bank was measured using a tape measure, with the exception of segments where the riparian zone exceeded a visual estimate of 30 m. Where the riparian zone exceeded 30 m, an estimate of the width was recorded and then checked against aerial imaging of the site at a later date. Gaps or an absence of riparian planting were recorded as 0 m, and their length also measured.					

	11726_11 Upper Wainui Stream	1172_6 Wainui Stream	2080_1 2nd Order Stony Stream	2079_1 3rd Order Stony Stream	1307_18 Whangarahi Stream	1262_18 Waiwhero Stream
Bank Erosion	Each 25 m segment assessed qualitatively, and visual bank erosion recorded for each bank for both sides of the wetted channel, including the potential for erosion to occur. Type of bank erosion was recorded to type, such as undercutting, slumping and potential immediate causes such as location on the outside of a bend, location of wood in the stream, or vegetation variation on the bank					
Wood	Each 25 m segment assessed for the quantity and quality of wood observed. Includes gauge on quantity, size, location (such as near the bank, within a pool, or fallen branches or trees connected to vegetative material on the banks), and whether the woody pieces were discrete or within conglomerates such as wood rafts. Additional observations of wood located on the banks of the wetted channel assessed for their potential as sources of future woody pieces for the wetted channel.					Woody pieces not expected in large quantities due to identification of significant clearance of the upstream and adjacent catchment through aerial photograph observation. Visual inspection made within each segment for wood within the channel, along the banks, and further within the floodplain for potential future sources of wood.
Geomorphic Units	Each 25 m segment assessed for predominant geomorphic unit at the Unit and Sub-Unit scale as specified within the GUS classification system designed by (Belletti *et al.*, 2015). Visible Units and Sub-units identified and recorded for each segment within the wetted channel and banks. No assessment of floodplain or valley floor					

3.3. Post assessment and analysis

3.3.1. Geomorphic assessment

The data collected from the data sheets were consolidated and uploaded into a Google Drive for storage. Each 150 m and 300 m reach for the six monitoring sites was then assessed against the reference conditions formulated as outlined in Section 3.1.2. Using the questions posed in Table 8, each reach was considered on their merits against the reference conditions using qualitative analysis. Cross reference to exemplified features or parts of the segment or reach were used to ratify the written data. The purpose of the analysis was to consider whether a reach could be considered to fit within the expected range of that that specific reach. A proforma was created for each reach, with the intention that these can be used for cross-referencing future years for temporal analysis. For each of the variables, the reaches were scored out of five, with the grades representing the following:

1: Extremely Poor – this feature was wholly outside of the reference condition parameters and should not occur in this reach
2: Poor – this feature sat somewhat outside of the reference condition parameters and is not representative of the reach
3: Some of the feature is considered to have sat within the reference condition parameters, with obvious or explicit deviation from reference conditions
4: Represented the reach reference conditions, with a few variations
5: Wholly represented of the reach reference conditions.

As such, the maximum score of a reach would be 30 (six features with a maximum of five points per feature), and a minimum score of 6. The following bands were created to categorise the reaches into 'excellent' 'good', 'moderate' and 'poor':

- 6 – 12: Reach is in **very poor health**
    - This is based on a reach achieving a maximum average of 2 points per feature
- 12-17: Reach is in **poor health**
    - This is based on a reach achieving an average less than 3 points per feature which is below the benchmark for sitting within the reference conditions
- 18 – 23: Reach is in **moderate health**

        - This is based on a reach achieving a minimum average of 3 points per feature, which is classified as generally sitting within the parameters of the reach.
    - 24 – 30: Reach is in **good health**
        - This is based on a river achieving a minimum average of 4 points per feature.
    - 27-30: Reach is in **excellent health**
        - This is based on a river achieving a minimum average of 4.5 points per feature

3.3.2. Cross-reference to ecological monitoring

To provide a sense check of the geomorphic toolbox, ecological data (fish and chemical indicators) were obtained from WRC for each of the Monitoring Sites. The summary results from the geomorphic assessment were then compared to the ecological data from each site to consider relationships and river health inferences. A high degree of caution was taken through this cross-assessment; IBI results were not available at the time of writing and MCI results are from previous years as the 2019/2020 monitoring has not been analysed. Other controlling factors such as distance to the coast are required to be considered. A direct comparison between indicators is not appropriate but can be used in conjunction with one another to create a wider understanding of river health.

4. Results

This section presents the analysis of the data collected from all six sites, which are assessed against reference conditions. For each site, the 150 m reach and 300 m reach are assessed independently and provided with a score for each of the identified geomorphological attributes. A summary table is provided, with the concluding score for each 150 m reach assessed against the corresponding data collected by WRC for fish and macroinvertebrate monitoring. A catchment map, based on aerials sourced from WRC and open source data from Land Information New Zealand (contours, 8 m Digital Elevation Model, and river centrelines) is also provided for each monitoring site. Collectively, the information gathered for each reach, excluding the summary scoring, is referred to as a proforma. A summary of available ecological data for each 150 m reach is provided in Section 4.2.

Consolidated results are located within this livelink: Stream Results.

4.1. Geomorphic assessment

The video walkthroughs, photographs and completed data sheets are provided in livelink format, with the appropriate data for each monitoring reach found in the following folder links:

- 11726_11 Upper Wainui Stream photographs and segment walkthrough
- 1172_6 Wainui Stream photographs and segment walkthrough
- 2080_1 Stony Stream 2nd Order photographs and segment walkthrough
- 2079_1 Stony Stream 3rd Order photographs and segment walkthrough
- 1307_18 Whangarahi Stream photographs and segment walkthrough
- 1262_18 Waiwhero Stream photographs and segment walkthrough

4.1.1. 11726_11 Upper Wainui Stream

Downstream coordinates	E1760523 N5811768
Stream Order	2nd
Valley setting	Partially Unconfined
Landscape Position	Source – Catchment is very short
Date of survey	15th March 2020
Duration of survey	4.5 hrs

Wainui Stream begins 640 m Above Sea Level (ASL) and is approximately 10.1 km to its river mouth located within the Raglan Harbour (Figure 23). It is classified by Waikato Regional Council as Natural State and Indigenous Fish Habitat Class. The monitored reach is some 5 km from the headwaters and sits around 100 ASL.

Upstream of the catchment, the Wainui River descends rapidly, dropping from 640 m ASL to 240 m ASL over 2 km. This descent is through dense indigenous vegetation before entering a valley where vegetation on the eastern side has been mostly cleared for pasture. The Wainui Stream continues along the steep valley, with pasture on the east making way for residential dwellings (Upper Wainui Road). The monitored catchment is located within the Wainui Stream below these houses, although vegetation cover remains dense and indigenous to the west. Wainui Stream runs below Wainui Road at 80 m ASL and begins a minor meander through pasture and residential dwellings, as well as Wainui Reserve Bush Park, before crossing beneath Riria Kereopa Memorial Drive and meandering to Raglan Harbour close to sea level.

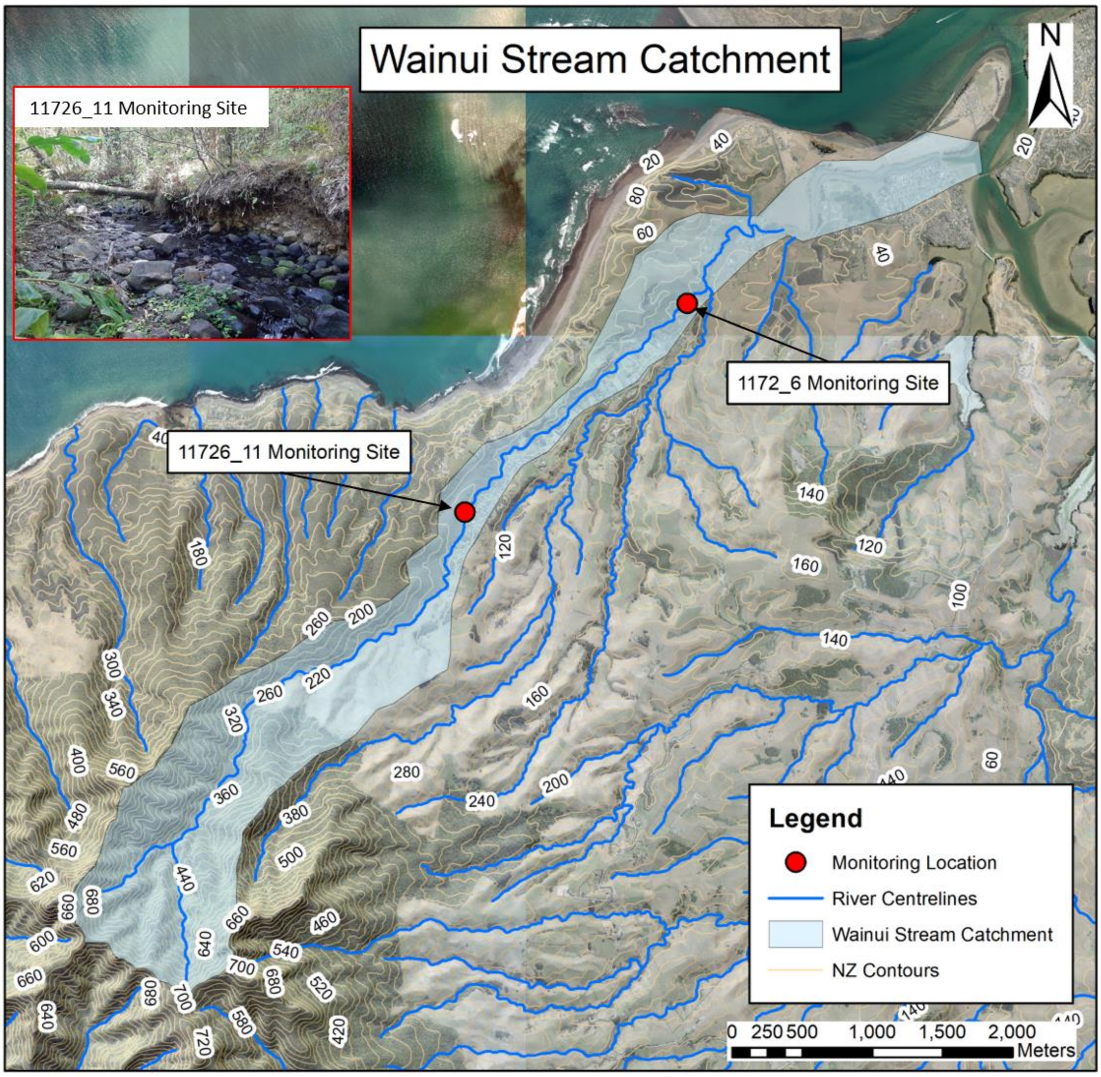

Figure 23 Wainui Stream catchment and Upper Wainui stream Monitoring Site (11726_11). Sourced from the LINZ Data Service and licenced for reuse under the CC BY 4.0 licence. Aerial and elevation data sourced from the LINZ Data Service and licenced by Waikato Regional Council, for re-use under the Creative Commons Attribution 4.0 International Licence. Inset: representative geomorphology of Monitoring Site 11726_11

Table 10 Assessment against reference conditions for Monitoring Site 11726_11

	Reference Conditions	150 m reach	300 m reach
Riparian Zone	Extensive indigenous forest – dense coverage greater than 100 m from bank edge. Predominantly manuka/kanuka forest as well as indigenous hardwoods and broadleaves. Canopy and dense understory should be expected. No gaps within riparian zone and should be wholly indigenous.	Coverage along true left bank greater than 100 m with indigenous ground coverage and a full canopy of hardwoods and broadleaf. The only discernible gap in the riparian zone is a gravel walking track near the bank. Refer Figure 24 as an example of the riparian zone along the true left bank. Riparian zone varies along the true right bank between 10 m and 20 m without interruption. Understory not always complete and dense, and grassed areas with minimal coverage observed toward adjacent residential properties in two segments (50 m length) after 10 m of riparian zone. Gaps in both the canopy and understory at different locations. Refer Figure 26 as an example of the riparian zone along the true right bank.	Coverage along true left bank greater than 100 m with indigenous ground coverage and a full canopy of hardwoods and broadleaf. The only discernible gap in the riparian zone is a gravel walking track near the bank. Refer Figure 25 as an example of the riparian zone along the true left bank. Riparian zone intact for greater than 30 m in the lower 75 m of reach, before giving way to a variable quality riparian zone between 1.0m and 20 m in width. Sparse ground cover with pasture grass and creeping vine. Canopy is open in locations. For 25 m, coverage comprises only one plant width (though indigenous, including flax and ti kouka) before giving way to exotic grass to residential properties. Refer Figure 27 as an example of the riparian zone along the true right bank.
Bank Erosion	Predominant geological unit is basalt, basaltic andesite and andesite lava (GNS Science, 2018). Concave erosion should be present along both banks but not uniformly – influenced by location of other geomorphic features such as boulders in stream flow. Bedrock protrusions expected in low quantity. Erosion expected on the outside of all bends in channel course and should be completed by	Undercutting of both banks, interspersed with armouring by way of lateral bars that provide protection from further erosion. Lateral bars are loosely consolidated and likely easy to mobilise during flood events. In some locations, erosion is for a significant length (such as along the length of Segment 8-9 – 25 m – on the true right bank (Figure 28). The outside bends of the channel are eroded, although there is no evidence of rapid channel changes or migrations occurring. Visual observation of bedrock which is not eroded at	Undercutting of both banks, interspersed with armouring by way of lateral bars that provide protection from further erosion. Lateral bars are loosely consolidated and likely easy to mobilise during flood events. In some locations, erosion is for a significant length. The outside bends of the channel are eroded as exemplified by Figure 29, although there is no evidence of rapid channel changes or migrations occurring. Visual observation of bedrock which is not eroded at a significantly

	Reference Conditions	150 m reach	300 m reach
	lateral bars on the inside of bends. Confined valley channel meaning erosion should be similar on both banks (exempting bends); there should be no evidence of river migrating significantly in either direction and should be evidently a single thread channel.	a significantly greater rate in any one location compared to any others. Channel is single thread.	greater rate in any one location compared to any others. Channel is single thread.
Grain Size	A range of grain size, from large boulders through to sand granules. Predominant grain size should be pebbles and cobbles; around 50 mm in size. Sorting not expected. Reasonably proportion of angularity can be expected due to proximity to headwaters. Larger boulders (greater than 1000 mm) can be expected, but not common.	b-axis average of 57 mm. Visual observation of cobble sized particles dominating bars above the water line, interspersed with smaller pebbles. Sorting not observed and predominantly rounded, with some angularity. A few larger boulders (500 mm estimate) dispersed within segments and two segments sporting boulders greater than 1000 mm	b-axis average of 56 mm. Visual observation of cobble sized particles dominating bars above the water line, interspersed with smaller pebbles. Sorting not observed and predominantly rounded, with some angularity. A few larger boulders (500 mm estimate) dispersed within segments and three segments sporting boulders greater than 1000 mm
Wood	Ample wood pieces within channel forming wood rafts and log jams. Areas of clear water without wood as well. Wood of some size should be found within every 25 m segment; evidence of more than one log jam or wood raft. Wood raft / log jam expected to be predominantly one or two tree trunks with other wood pieces backing in around rather than large quantities of trunks in one location. Abundant leaf litter. Fallen trees near channel as future sources of in-channel wood as well as numerous standing live trees near banks.	Wood pieces in all segments, including debris rafts in multiple locations Figure 30), large bushy manuka branches, and wood pieces collecting around a fallen tree in multiple locations. Dead trees falling into the river (Segment 8-9), as well as many live trees and branches overhanging the channel from the bank (Segments 5-6 and 6-7). Abundant wood both dead and alive present on the both banks in proximity to the channel.	Wood pieces in all segments, including debris rafts in multiple locations, large bushy manuka branches, and wood pieces collecting around a fallen tree in multiple locations. Dead trees falling into the river (Segment 8-9), as well as many live trees and branches overhanging the channel from the bank (Segments 2-3, 5-6, 6-7, 10-11, 11-12, 12-13). Abundant wood both dead and alive present on the both banks in proximity to the channel.

	Reference Conditions	150 m reach	300 m reach
Connectivity	Unimpeded connectivity for entire length of reach. Unimpeded connectivity to upstream and downstream reaches. Unimpeded connectivity along length of entire stream from source to sink. Waterfalls could be expected, but unlikely.	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Wainui Stream, with passage under Wainui Road by way of a culvert with fish passage provisions	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Wainui Stream, with passage under Wainui Road by way of a culvert with fish passage provisions
Spatial Heterogeneity	Large number of geomorphic units expected within each 25 m segment and across reach overall. There should be a consistent abundance of units, i.e. there should be no 25 m segment that is uniform with only one or two identifiable geomorphic units. Expected units to include lateral bars, mid-channel bars, large individual boulders by bank and within wetted channel, pool and riffle sequences, steps, bedrock outcrops, cobble or pebble patches. Evidence of heterogeneity as a result of other factors, such as scour holes on bank from erosion	Diverse and abundance of geomorphic units within each segment including pools and riffle sequences in every segment. Deeper pools on the outside of bends complemented with point bars on the inside of bends. Large individual boulders within the wetted channel, such as in Segment 4. Bedrock evident in discrete locations such as Segment 9-10 Loosely consolidated mid channel bar temporarily separating flow into two channels in Segment 6-7, for 10 m. Lateral bars present in many locations and range in size from thin armouring of the bank to larger bars influencing flow to opposite bank. Non-uniform; units are consistently diverse between segments with more temporary features likely causing influence such as dead wood and bank cohesion by way of vegetation. Variable bank heights.	Diverse and abundance of geomorphic units within each segment including pools and riffle sequences in every segment. Deeper pools on the outside of bends complemented with point bars on the inside of bends. Large individual boulders within the wetted channel, such as in Segment 4. Bedrock evident in discrete locations such as Segment 9-10 Loosely consolidated mid channel bar temporarily separating flow into two channels in Segment 6-7, for 10 m. Lateral bars present in many locations and range in size from thin armouring of the bank to larger bars influencing flow to opposite bank. Non-uniform; units are consistently diverse between segments with more temporary features likely causing influence such as dead wood and bank cohesion by way of vegetation. Variable bank heights – up to 3.5 m incision on true left bank within Segment 1-2 on outside of bend.

Table 11 Results summary for Monitoring Site 11726_11

	Score	
	150 m reach	300 m reach
Riparian Zone	3	2
Bank Erosion	5	5
Grain Size	5	5
Wood	5	5
Connectivity	5	5
Spatial Heterogeneity	5	5
Total	28 / 30 **Excellent**	27 / 30 **Excellent**

Deviations from reference conditions:

- Variable Riparian Zone; mostly representative, but with gaps in lateral coverage as well as the canopy. Some exotic plants identified but predominantly indigenous vegetation.

Figure 24 Riparian zone within Segment 4-5 of Monitoring Site 11726_11; dense understory and full canopy exemplifying riparian zone of the true left bank (right hand side of photo).

Figure 25 Riparian zone within Segment 2-3 of Monitoring Site 11726_11; dense understory and full canopy exemplifying riparian zone of the true left bank (right hand side of photo)

Figure 26 Incomplete Riparian Zone located in Segment 6-7 of Monitoring Site 1126_11; singular trees forming incomplete canopy adjacent to riverbank, with grass pasture located immediately after.

Figure 27 Incomplete Riparian Zone located in Segment 12-13 of Monitoring Site 1126_11; singular trees forming incomplete canopy adjacent to riverbank, with grass pasture located immediately after.

Figure 28 Evidential bank erosion within Segment 8-9 of Monitoring Site 1126_11, which extends uniformly along the true right bank for much of this segment. Note the lateral bar (armouring on the true left)

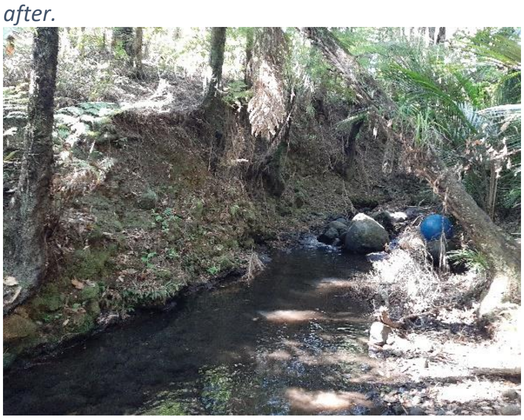

Figure 29 Evidential bank erosion within Segment 3-4 of Monitoring Site 1126_11 on the true right bank. Note bedrock present at the water line within the channel along the bank.

Figure 30 Wood raft within Segment 4-5 exhibiting a range of wood pieces of varying diameters.

Figure 31 Example of diverse and numerous geomorphic units present within Segment 7-8 of Monitoring Site 1126_11, including pools and riffles, larger individual boulders, a lateral bar on the true right, and variable bank heights and degrees of incision.

4.1.2. 1172_6 Wainui Stream

Downstream coordinates	E1762004 N58113104
Stream Order	2nd
Valley setting	Unconfined
Landscape Position	Sink – Catchment is very short
Date of survey	14th March 2020
Duration of survey	5.5 hrs

Wainui Stream begins 640 m Above Sea Level (ASL) and is approximately 10.1 km to its river mouth located within the Raglan Harbour (Figure 32). It is classified by Waikato Regional Council as Natural State and Indigenous Fish Habitat Class. The monitored reach is some 5 km from the headwaters and sits around 100 ASL.

Upstream of the catchment, the Wainui River descends rapidly, dropping from 640 m ASL to 240 m ASL over 2 km. This descent is through dense indigenous vegetation before entering a valley where vegetation on the eastern side is mostly cleared for pasture. The Wainui Stream continues along the steep valley, with pasture on the east making way to residential dwellings (Upper Wainui Road). Vegetation cover remains dense and indigenous to the west through this section of the stream. Wainui Stream runs below Wainui Road at 80 m ASL and begins a minor meander through pasture and residential dwellings, as well as Wainui Reserve Bush Park where the Wainui Stream monitoring reach is located around 11 m ASL. Wainui Stream then crosses beneath Riria Kereopa Memorial Drive and meandering to Raglan Harbour close to sea level.

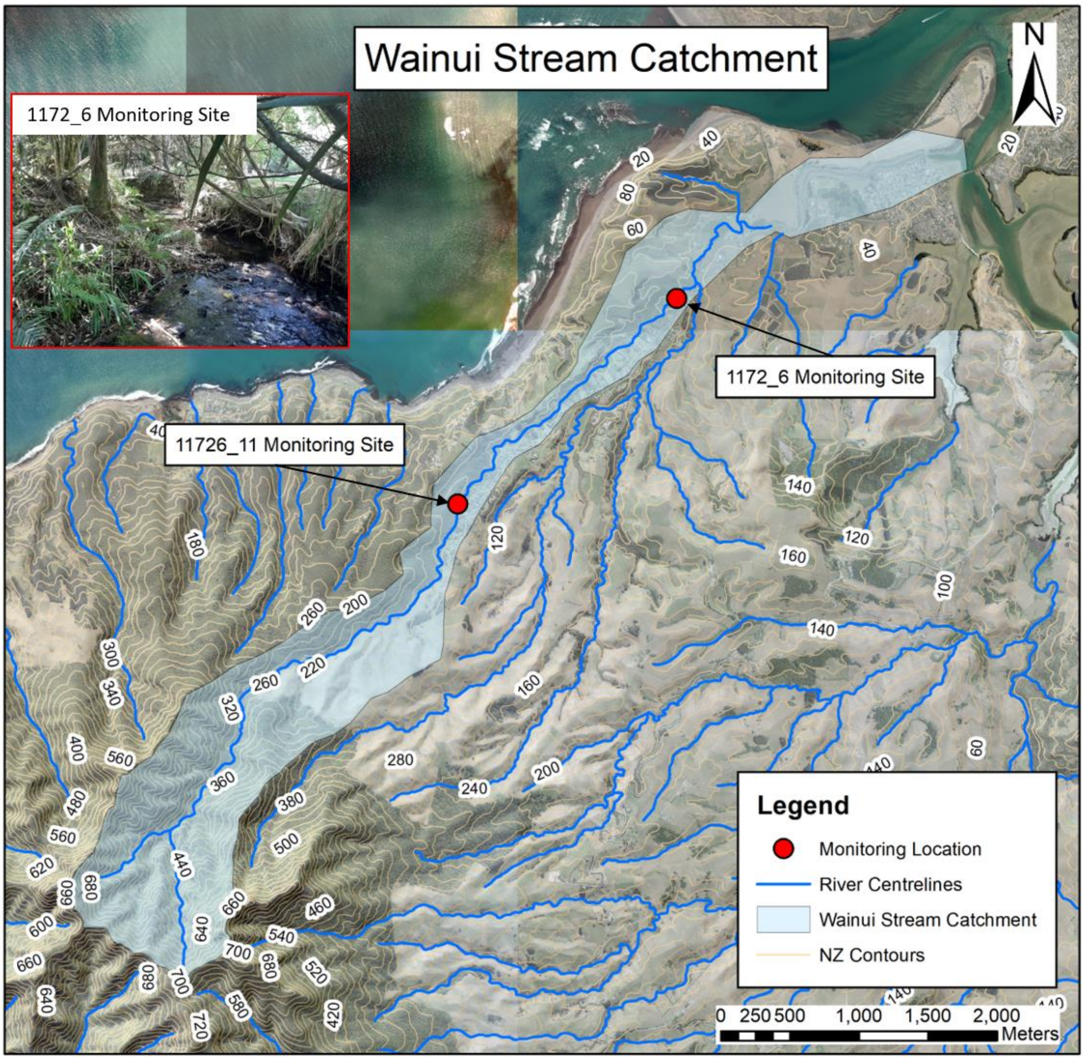

Figure 32 Wainui Stream catchment and Wainui stream Monitoring Site (1172_6). Sourced from the LINZ Data Service and licenced for reuse under the CC BY 4.0 licence. Aerial and elevation data sourced from the LINZ Data Service and licenced by Waikato Regional Council, for re-use under the Creative Commons Attribution 4.0 International Licence. Inset: representative geomorphology of Monitoring Site 1172_6

Table 12 Assessment against reference conditions for Monitoring Site 1172_6

	Reference Conditions	150 m reach	300 m reach
Riparian Zone	Extensive indigenous forest – dense coverage greater than 100 m from bank edge. Predominantly manuka/kanuka forest as well as both indigenous hardwoods and shrubs. There should be a mixture of large tall trees forming the canopy, as well as a dense shrub understory. No gaps within riparian zone and should be wholly indigenous.	Riparian Coverage is variable. Coverage is greater than 30 m in width on the true left bank and 15 m on the true right bank for Segment 6-7, but is inconsistent with the reaches on either side; Segment 5-6 has a width of 3.0 m and 2.0 m on the true left and true right banks respectively, whilst Segment 7-8 is 1.5 m from each bank. The smallest width is within Segment 8-9 at 0.5 m whereby the riparian zone comprises a single plant depth before as sealed walking path runs parallel to the bank Figure 33. Vegetation type is also variable, but predominantly indigenous, including ti kouka, flaxes, manuka and other manuka forest species. Gaps in the riparian zone were identified such as in Segments 8-9, and 9-10, in addition to all locations where walking bridges traverse the stream (three locations). Large grassed areas observed in close proximity to channel, and where vegetation exceeds one plant width, the canopy is not complete and cover coverage sparse.	Riparian Coverage is variable. Within Segments 1-2, 2-3, and 3-4, the riparian zone is greater than 30 m on both banks and indigenous, but with sparse ground coverage. Coverage is greater than 30 m in width on the true left bank and 15 m on the true right bank for Segment 6-7, but is inconsistent with the reaches on either side; Segment 5-6 has a width of 3.0 m and 2.0 m on the true left and true right banks respectively, whilst Segment 7-8 is 1.5 m from each bank. The smallest width is within Segment 8-9 at 0.5 m whereby the riparian zone comprises a single plant depth before as sealed walking path runs parallel to the bank. There is no riparian zone on the true right bank of Segment 12-13, whereby the bank is located immediately adjacent to a grassed recreational park. Coverage is less than 1.0 on the true right bank for Segments 10-11 and 11-12, which are adjacent to a sealed walking path and the same recreational area as Segment 12-13 Figure 34. Vegetation type is also variable, but predominantly indigenous, including ti kouka, flaxes, manuka and other manuka forest species. Gaps in the riparian zone were identified such as in Segments 8-9, and 9-10, in addition to all locations where walking

	Reference Conditions	150 m reach	300 m reach
			bridges traverse the stream (three locations). Large grassed areas observed in close proximity to channel, and where vegetation exceeds one plant width, the canopy is not complete and cover coverage sparse.
Bank Erosion	Predominant geological unit is Alexandra Volcanic Group basaltic rocks and described as Olivine basalt lava, scoria and tuff (GNS Science, 2018). Overlain with alluvial sediments – fine grained. Single thread channel. Concave erosion should be present along both banks but not uniformly – influenced by location of other geomorphic features such as boulders or vegetation. Erosion expected on the outside of all bends in channel course and should be complemented by lateral bars on the inside of bends. Pronounced meandering sinuosity expected due to low elevation and sink position. Possible to see channel course changes but not integral. Evidence channel has space to migrate within the floodplain toward either bank and not inhibited from doing so.	Erosion identified within all segments for both the true right and true left banks. Banks were observed as alluvial, generally fine-grained silts, although pockets of larger clasts suspended in the bank were observed (Segment 7-8). Undercutting of banks to form a concave bank shape observed in all segments, as well as slumping (Figure 35). Erosion not uniform, with some segments exhibiting larger exposed areas of erosion. Erosion on the outside of bends accompanied by point bars on the inside of the bend (such as Segment 7-8). Slumping observed more so on the true left bank than the true right. Erosion from scour from the build-up of debris near trees or roots within bank observed. Meandering not significantly pronounced, although numerous bends within channel. No evidence of recent channel migration within or near channel observed, although channel not restricted from doing so in areas where elevation is conducive i.e. where it is relatively flat floodplain extending from channel.	Erosion identified within all segments for both the true right and true left banks. Banks were observed as alluvial, generally fine-grained silts, although pockets of larger clasts suspended in the bank were observed (Segment 7-8). Undercutting of banks to form a concave bank shape observed in all segments, as well as slumping. Erosion not uniform, with some segments exhibiting larger exposed areas of erosion. Erosion on the outside of bends accompanied by point bars on the inside of the bend (such as Segment 10-11: Figure 36). Slumping observed more so on the true left bank than the true right. Erosion from scour from the build-up of debris near trees or roots within bank observed. Meandering not significantly pronounced, although numerous bends within channel. No evidence of recent channel migration within or near channel observed, although channel not restricted from doing so in areas where elevation is conducive i.e. where it is relatively flat floodplain extending from channel.

	Reference Conditions	150 m reach	300 m reach
Grain Size	A range of grain size, from boulders through to sand granules. Predominant grain size should be pebbles and cobbles; around 30 mm in size. Sorting not expected. Predominantly rounded, although angularity also expected due to short catchment. Larger boulders (greater than 1000 mm) only in very small quantities.	b-axis average 55 mm Predominant clast size is pebbles less than 50 mm and less with larger clasts (cobble size) found on bars (Figure 37). Variation between some segment, with visual inspections showing nothing greater than 300 mm in size in some segments (4-5, 5-6), with others sporting individual boulders (6-7, 9-10). Clasts mostly rounded and a silt layer present in all segments.	b-axis average 57 mm Predominant clast size is pebbles less than 50 mm and less with larger clasts (cobble size) found on bars. Variation between some segment, with visual inspections showing nothing greater than 300 mm in size in some segments (1-2, 2-3, 4-5, 5-6), with others sporting individual boulders (3-4, 6-7, 9-10, 11-12, 12-13): refer Figure 38. Clasts mostly rounded and a silt layer present in all segments. Visual observance of bedrock in one location on true left bank in Segment 12-13.
Wood	Ample wood pieces within channel forming wood rafts and log jams. Expect standalone wood pieces such as fallen punga. Areas of clear water without wood as well; evidence of more than two log jam or wood rafts. Wood raft / log jam expected to be predominantly one or two tree trunks with other wood pieces backing in around rather than large quantities of trunks in one location. Abundant leaf litter. Fallen trees near channel as future sources of in-channel wood as well as numerous standing live trees near banks.	Small wood pieces were observed in all segments, but with little consolidation except in a few instances. Two wood raft located in Segment 7-8; one on the inside of a bend – at least 30 individual pieces in addition to leaf litter and other debris – and one located directly upstream of a tree outcrop in the true right bank; areas of clear wetted channel as well (Figure 39) Significant wood loading on bar located in Segment 9-10 (Figure 40). Only punga trunk (Segment 8-9) observed within channel, without debris build up. No observed trees fallen in proximity to stream, predominantly leaf litter. Some live trees but none with a pronounced risk of falling directly into the stream channel in the short term.	Small wood pieces were observed in all segments, but with little consolidation except in a few instances. Two wood raft located in Segment 7-8; one on the inside of a bend – at least 30 individual pieces in addition to leaf litter and other debris – and one located directly upstream of a tree outcrop in the true right bank; areas of clear wetted channel as well (Figure 39) Significant wood loading on bar located in Segment 9-10 (Figure 40). Only punga trunk (Segment 8-9) observed within channel, without debris build up. No observed trees fallen in proximity to stream, predominantly leaf litter. Some live trees but none with a pronounced risk of falling directly into the stream channel in the short term.

	Reference Conditions	150 m reach	300 m reach
Connectivity	Unimpeded connectivity for entire length of reach. Unimpeded connectivity to upstream and downstream reaches. Unimpeded connectivity along length of entire stream from source to sink. Waterfalls could be expected, but unlikely.	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Wainui Stream, with passage under Wainui Road by way of a culvert with fish passage provisions	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Wainui Stream, with passage under Wainui Road by way of a culvert with fish passage provisions
Spatial Heterogeneity	Large number of geomorphic units expected within each 25 m segment and across reach overall. There should be a consistent abundance of units, i.e. there should be no 25 m segment that is uniform with only one or two identifiable geomorphic units. Expected units to include lateral bars, mid-channel bars, large individual boulders by bank and within wetted channel, pool and riffle sequences, steps, cobble or pebble patches. Evidence of heterogeneity as a result of other factors, such as scour holes on bank from erosion	Diverse and abundance of geomorphic units within each segment including pools and riffle sequences in every segment (Figure 41). Pools are observably more dominant than riffle and span a greater width and length within segments (i.e. Segment 4-5, 5-6). Deeper pools on the outside of bends complemented with point bars on the inside of bends. Lateral bars present in many locations and range in size from armouring to large bars proportionate to channel size (15 m x 2m lateral bar within Segment 6-7) and influencing channel flow to opposite bank. Lateral bars often alternate on bank side, with erosion of the banks following the inverse pattern. Variable bank height. Some individual boulders located within wetted channel. Scour holes and bank erosion	Diverse and abundance of geomorphic units within each segment including pools and riffle sequences in every segment (Figures 41 and 42). Pools are observably more dominant than riffle and span a greater width and length within segments (i.e. Segment 4-5, 5-6). Deeper pools on the outside of bends complemented with point bars on the inside of bends. Lateral bars present in many locations and range in size from armouring (Segment 3-4) to large bars proportionate to channel size (15 m x 2m lateral bar within Segment 6-7) and influencing channel flow to opposite bank. Lateral bars often alternate on bank side, with erosion of the banks following the inverse pattern. Variable bank height, particularly around bends, where the outside bank is higher (i.e. Segment 10-11).

	Reference Conditions	150 m reach	300 m reach
		from channel flow and materials being caught evident (i.e. Segment 7-8). Non-uniform; units are consistently diverse between segments with more temporary features likely causing influence such as dead wood and bank cohesion by way of vegetation and alluvial composition.	Some individual boulders located within wetted channel. Scour holes and bank erosion from channel flow and materials being caught evident (i.e. Segment 7-8). Non-uniform; units are consistently diverse between segments with more temporary features likely causing influence such as dead wood and bank cohesion by way of vegetation and alluvial composition. Variable bank heights.

Table 13 Results summary for Monitoring Site 1172_6

	Score	
	150 m reach	300 m reach
Riparian Zone	2	2
Bank Erosion	5	5
Grain Size	5	5
Wood	3	3
Connectivity	5	5
Spatial Heterogeneity	5	5
Total	25 / 30 **GOOD**	25 / 30 **GOOD**

Deviations from reference conditions:

- Variable Riparian Zone; sparse coverage – non-existent in other locations, with gaps. Ground coverage sparse, and open canopy in other locations
- Wood: It is expected to see more wood than present in the stream, with more branches and wood rafts. Wood pieces were small and rarely consolidated. Little in the way of potential for wood from banks and riparian zone to enter the channel due to sparse riparian zone.

Figure 33 Example of riparian coverage variability located at Segment 8-9 of Monitoring Site 1172_6. True left bank had greater vegetation coverage than the true right (right hand side of photo). Grassed recreational areas were common adjacent to this reach.

Figure 34 True right bank located at Segment 12-13 at Monitoring Site 1172_6. Vegetation is sparse and gives way immediately to a grassed recreation area on the right. No discernible understory and trees are widely spaced.

Figure 35 Example of undercutting with Segment 3-4 of Monitoring Site 1172_6, which was observed in numerous locations within the reach. Undercutting was interspersed with slumping, and lengths of reasonable stability

Figure 36 True right bank within Segment 10-11 of Monitoring Site 1172_6 portraying erosion potential of the outside bank. There is a sealed walking path adjacent to the channel which may exert influence on future erosional processes.

Figure 37 Typical particle size on a bar within segment 7-8 at Monitoring Site 1172_6.

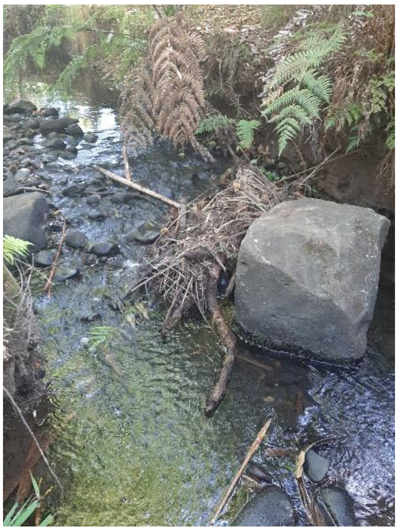

Figure 38 Example of particle size variations within Segment 11-12 at Monitoring Site 1172_11. Individual boulders were rare in this reach, with clasts predominantly pebbles and cobbles.

Figure 39 Segment 7-8 of Monitoring Site 1172_6 showing area with minimal wood pieces within channel

Figure 40 Wood raft located in Segment 9-10 of Monitoring Site 1172_6 comprising a range of wood piece sizes and located downstream of a large bend in the channel.

Figure 41 Representative view of Monitoring Site 1172_6 (Segment 7-8) showing predominance of pool, interspersed with riffle sequences and flow interruptions by way of clasts, a minor bar formation on the true left and evidence of armouring of the bank on the true right. Note some vegetation overhanging stream, and bank erosion is evident.

Figure 42 Representative view of Monitoring Site 1172_6 (Segment 2-3) showing diversity of geomorphic units, including pools and riffles, lateral bar, and concave erosion on the outside bend of the channel. Note evident gap in riparian zone.

4.1.3. 2080_1 2nd Order Stony Stream

Downstream coordinates	E1815800 N5956700
Stream Order	2nd
Valley setting	Confined
Landscape Position	Source
Date of survey	21st March 2020
Duration of survey	3.5 hrs

The Stony Stream catchment comprises numerous tributaries beginning at 770 m ASL. The monitored Stony Catchments are derived from the northern branch of tributaries (Figure 43). Monitoring site 2080_1 is located on a 2nd Order Stream that is just over 1 km in length upstream of the monitoring site. This tributary reaches an elevation of 300 m ASL. It is classified by Waikato Regional Council as Natural State and Indigenous Fish Habitat Class. The monitored reach is some 1.8 km from the mouth discharging into Stony Bay and sits around 80 m ASL.

Upstream of the monitoring site the Stony Stream tributary descends rapidly, dropping from 300 m to 100 m ASL over 1 km. This descent is through very steep and mountainous terrain covered by indigenous vegetation that covers the entire catchment. Below the monitoring site, the tributary merges with a 3rd Order stream tributary and descends further toward Stony Bay, passing through pasture used for sheep and finally through a campground before discharging into Stony Bay.

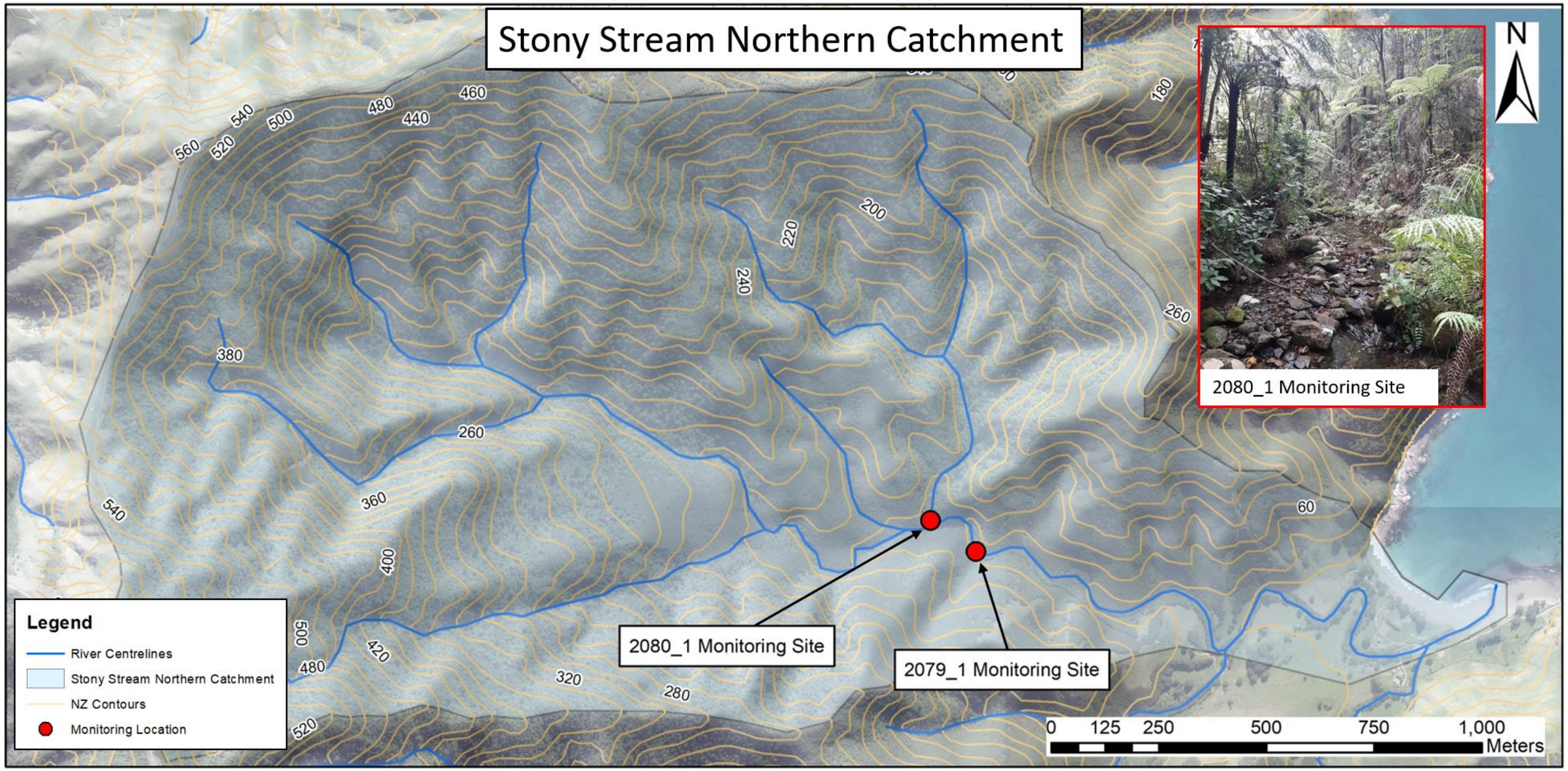

Figure 43 Stony Bay catchment and location of 2nd Order Monitoring Site (2080_1). Sourced from the LINZ Data Service and licenced for reuse under the CC BY 4.0 licence. Aerial and elevation data sourced from the LINZ Data Service and licenced by Waikato Regional Council, for re-use under the Creative Commons Attribution 4.0 International Licence. Inset: representative geomorphology of Monitoring Site 2080_1

Table 14 Assessment against reference conditions for Monitoring Site 2080_1

	Reference Conditions	150 m reach	300 m reach
Riparian Zone	Extensive indigenous forest – dense coverage greater than 100 m from bank edge. Predominantly manuka/kanuka forest as well as indigenous hardwoods and broadleaves. Canopy and dense understory should be expected. No gaps within riparian zone and should be wholly indigenous.	Extensive dense indigenous vegetation cover – range of broadleaf and hardwoods forming a complete canopy, in addition to a significant understory and ground cover diversity. No breaks in riparian zone detected, with coverage extending extensively in all directions as typified in Figure 43 and Figures 44-45.	Extensive dense indigenous vegetation cover – range of broadleaf and hardwoods forming a complete canopy, in addition to a significant understory and ground cover diversity. No breaks in riparian zone detected, with coverage extending extensively in all directions as typified in Figure 43 and Figures 44-45.
Bank Erosion	Predominant geological unit is Manaia Hill Group and described as Sandstone, siltstone and conglomerate (GNS Science, 2018). Single thread channel and predominantly bedrock channel overlain with some sediments and soils. Incised channel with evidence of slow erosion of bedrock. Examples include pitted bedrock and overhangs of bedrock as a result of undercutting. Where bedrock is overlaid by soils, concave erosion of banks is expected on straight sections – expect this to be relatively uniform due to bedrock being close to the surface and the channel being confined. Very little meandering and there should be no evidence of river migrating significantly in either direction due to steep elevation and / or confined valley floor.	Channel reasonably incised into bedrock, with low levels of short-term erosion (Figure 46). In Segment 4-5 it is estimated the near vertical true left bank is up to 10 m high) Overhanging bedrock in locations (Segment 5-6) and bedrock pitted and rough surface. Undercutting of an alluvial deposit within Segment 7-8 on inside of bend on true right; true left bank is bedrock with some erosion of topsoil layer and therefore undercutting on the inside bend can be expected (pathway of least resistance for flow).	Channel reasonably incised into bedrock, with low levels of short-term erosion (Figure 46). In Segment 4-5 it is estimated the near vertical true left bank is up to 10 m high) Overhanging bedrock in locations (Segment 5-6) and bedrock pitted and rough surface. Undercutting of an alluvial deposit within Segment 7-8 on inside of bend on true right; true left bank is bedrock with some erosion of topsoil layer and therefore undercutting on the inside bend can be expected (pathway of least resistance for flow). A step change over a bedrock outcrop is evident in Segment 1-2 (Figure 47) where the flow navigates the short and step elevation change.

	Reference Conditions	150 m reach	300 m reach
Grain Size	Presence of bedrock dominating channel form. A range of grain sizes, from boulders through to sand granules. Predominant grain size should be cobbles; around 20-30 mm in size, although necessary for smaller clast sizes to also be present. Sorting not expected. Angular. Larger boulders (greater than 1000 mm) expected but not dominant particle size.	b-axis average of transect lines is 148 mm, though bedrock was encountered 3 times in Segment 4-5 and four times in Segment 9-10, resulting a null value recording for those counts. Bedrock dominates channel form in banks and also channel bed. Bedrock outcrops observed in channel. Large range of particle sizes, from pebbles and rocks within wetted channel between 10mm – 500 mm, and lateral bars having clasts closer to 100 m + (Figure 48). Minimal depth of covering before bedrock is reached on channel bed. Where pools are the dominant feature in the segment, a silty layer is observed. Clasts are predominantly angular. Some larger clasts found in most segments – boulders greater than 500 mm.	b-axis average of transect lines is 125 mm though bedrock was encountered 3 times in Segments 1-2, 4-5, four times in Segment 9-10, and twice in Segment 12-13 resulting a null value recording for those counts. Segment 1-2 also comprises a elevation step change of bedrock which was not possible to measure using the transect. Bedrock dominates channel form in banks and also channel bed. Bedrock outcrops observed in channel. Large range of particle sizes, from pebbles and rocks within wetted channel between 10mm – 500 mm, and lateral bars having clasts closer to 100 m + (Figure 48). Minimal depth of covering before bedrock is reached on channel bed. Where pools are the dominant feature in the segment, a silty layer is observed. Clasts are predominantly angular. Some larger clasts found in most segments – boulders greater than 500 mm. Boulders greater than 1000 mm observed in Segment 1-2.

	Reference Conditions	150 m reach	300 m reach
Wood	Ample wood pieces within channel forming wood rafts and log jams. Areas of clear water without wood as well. Wood of some size should be found within every 25 m segment. Wood raft / log jam expected to be predominantly one or two tree trunks with other wood pieces backing in around rather than large quantities of trunks in one location. Abundant leaf litter. Fallen trees near channel as future sources of in-channel wood as well as numerous standing live trees near banks.	Wood found in every Segment of this reach. In many segments, accumulation was not great and dominated by abundant leaf litter. Overhanging dead branches hanging over channel Wood raft in Segment 9-10 caused by a punga tree backing up other branches and trees (Figure 49). Fallen trees not reaching wetted channel observed in four segments. Tree roots also observed growing into water, in addition to live trees and ferns observed near banks.	Wood found in every Segment of this reach. In many segments, accumulation was not great and dominated by abundant leaf litter. Overhanging dead branches hanging over channel Wood raft in Segments 1-2, 2-3, 9-10, 10-11, 11-12, and a major log jam located in Segment 12-13 comprising many large tree trunks and exerting a considerable influence on flow. Most wood rafts caused by a punga tree backing up other branches and trees (Figure 49 and Figure 50). Fallen trees not reaching wetted channel observed in four segments. Tree roots also observed growing into water, in addition to live trees and ferns observed near banks.
Connectivity	Unimpeded connectivity for entire length of reach. Unimpeded connectivity to upstream and downstream reaches. Unimpeded connectivity along length of entire stream from source to sink. Waterfalls could be expected, but unlikely.	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Stony Stream. Culverts located near mouth of Stony Stream to enable a bridge crossing, but are fish friendly and flow is not impeded greatly (culverts partially buried into channel, short in length, and not perched)	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Stony Stream. Culverts located near mouth of Stony Stream to enable a bridge crossing, but are fish friendly and flow is not impeded greatly (culverts partially buried into channel, short in length, and not perched)

	Reference Conditions	150 m reach	300 m reach
Spatial Heterogeneity	Large number of geomorphic units expected within each 25 m segment and across reach overall. There should be a consistent abundance of units, i.e. there should be no 25 m segment that is uniform with only one or two identifiable geomorphic units. Expected units to include lateral bars, mid-channel bars, large individual boulders by bank and within wetted channel, pool and riffle sequences, steps, cobble or pebble patches, bedrock slabs pitted by erosion. Evidence of heterogeneity as a result of other factors, such as scour holes on bank from erosion	Diverse and abundance of geomorphic units, including pools and riffles in every segment, bank overhangs, predominant bedrock channel and banks providing for chutes and areas of lower flow velocity varying in depth. Lateral bars observed in numerous segments, as well as individual large boulders. Within Segment 6-7 an ephemeral flowpath enters from the true right, in addition to a plateau of vegetated soils within the channel confines but above waterline. Water turbulence caused from large individual clasts within the water. Within Segment 7-8 a high soil plateau (greater than 1.5 m in height) is evident on true right on the inside of a bend – estimated to be approximately 12 m long and up to 5 m wide and being undercut by the channel flow.	Diverse and abundance of geomorphic units, including pools and riffles in every segment, bank overhangs, predominant bedrock channel and banks providing for chutes and areas of lower flow velocity varying in depth. Lateral bars observed in numerous segments, as well as individual large boulders. Within Segment 6-7 an ephemeral flowpath enters from the true right, in addition to a plateau of vegetated soils within the channel confines but above waterline. Water turbulence caused from large individual clasts within the water. Within Segment 7-8 a high soil plateau (greater than 1.5 m in height) is evident on true right on the inside of a bend – estimated to be approximately 12 m long and up to 5 m wide and being undercut by the channel flow. A cascade / step change is observed over a bedrock outcrop within Segment 1-2 to overcome a steep gradient change (Figure 47). Large boulder accumulations were observed in Segment 12-13

Table 15 Results summary for Monitoring Site 2080_1

	Score	
	150 m reach	300 m reach
Riparian Zone	5	5
Bank Erosion	5	5
Grain Size	5	5
Wood	5	5
Connectivity	5	5
Spatial Heterogeneity	5	5
Total	**30 / 30** **Excellent**	**30 / 30** **Excellent**

Figure 44 Extensive Manuka / Kanuka forest cover adjacent to Segment 2-3 at Monitoring Site 2080_1

Figure 45 Extensive understory and ground coverage adjacent to Segment 3-4 at Monitoring Site 2080_1

Figure 46 Bedrock bank and channel incision within Segment 5-6 of Monitoring Site 2080_1. Bed rock is pitted and not smooth – erosion occurring at varying rates along the length of the channel. Note the overhang of bedrock over the channel to the left of the photo – both the undercutting and pitting were observed throughout the reach.

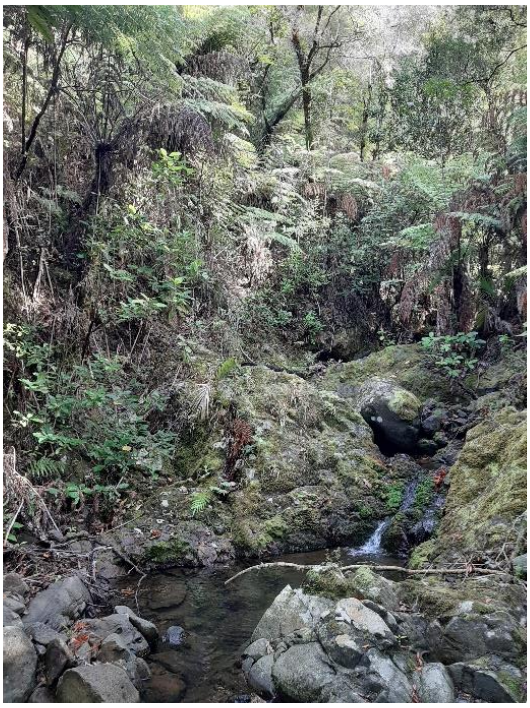

Figure 47 Steps created through erosion of the bedrock where the flow navigates a sharp elevation change over a bedrock outcrop within Segment 1-2 of Monitoring Site 2080_1

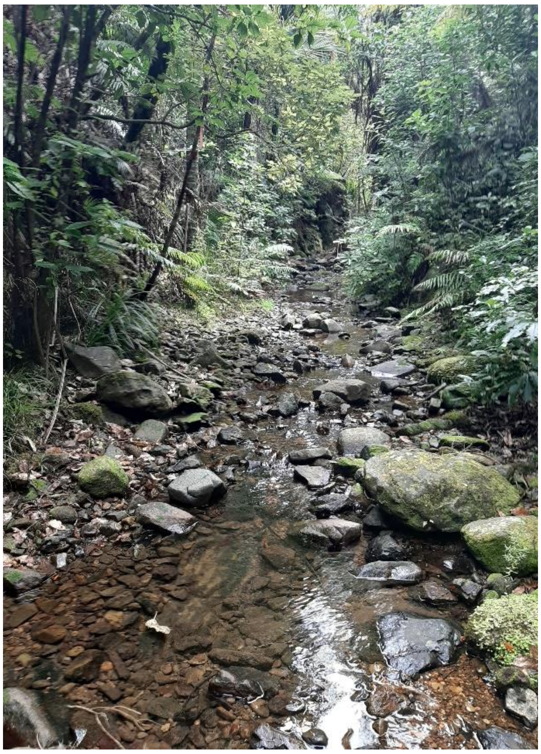

Figure 48 Typical clast variability within Segment 4-5 of Monitoring Site 2080_1. Note the larger clasts outside of the wetted channel, including boulders sticking out above the water. Within the wetted channel a range of sizes is also observed, including a small pebble patch located on the right hand side of the photo.

Figure 49 Typical wood loading within the channel - Segment 9-10 of Monitoring Site 2080_1.

Figure 50 Significant log jam located in Segment 12-13 of Monitoring Site 2080_1. The collection of tree trunks and backed up debris exerts a noticeable influence on flow within the channel.

Figure 51 Abundance of geomorphic unit diversity located within Segment 6-7 of Monitoring Site 2080_1. A small soil plateau is located on the true right bank (left hand side of photo) and is vegetated.

4.1.4. 2079_1 3rd Order Stony Stream

Downstream coordinates	E1815954 N5956604
Stream Order	3rd
Valley setting	Partially Unconfined
Landscape Position	Source
Date of survey	21st March 2020
Duration of survey	3.5 hrs

The Stony Stream catchment comprises numerous tributaries beginning at 770 m ASL. The monitored Stony Catchments are derived from the northern branch of tributaries (Figure 52). Monitoring site 2079_1 is located on a 3rd Order Stream that serves the tributary consolidating all branches of the northern half of the Stony Stream Catchment. The highest feeding tributaries reach 520 m ASL. It is classified by Waikato Regional Council as Natural State and Indigenous Fish Habitat Class. The monitored reach is some 1.6 km from the mouth discharging into Stony Bay and sits around 50 m ASL.

Upstream of the monitoring site the Stony Stream tributaries descend rapidly, dropping from 300 m to 100 m ASL over 2 km from their corresponding reaches. These descents are through very steep and mountainous terrain covered by indigenous vegetation that covers the entire catchment. Below the monitoring site, the tributary merges with a 4th Order stream tributary (Stony Stream proper) and descends further toward Stony Bay, passing through pasture used for sheep and finally through a campground before discharging into Stony Bay.

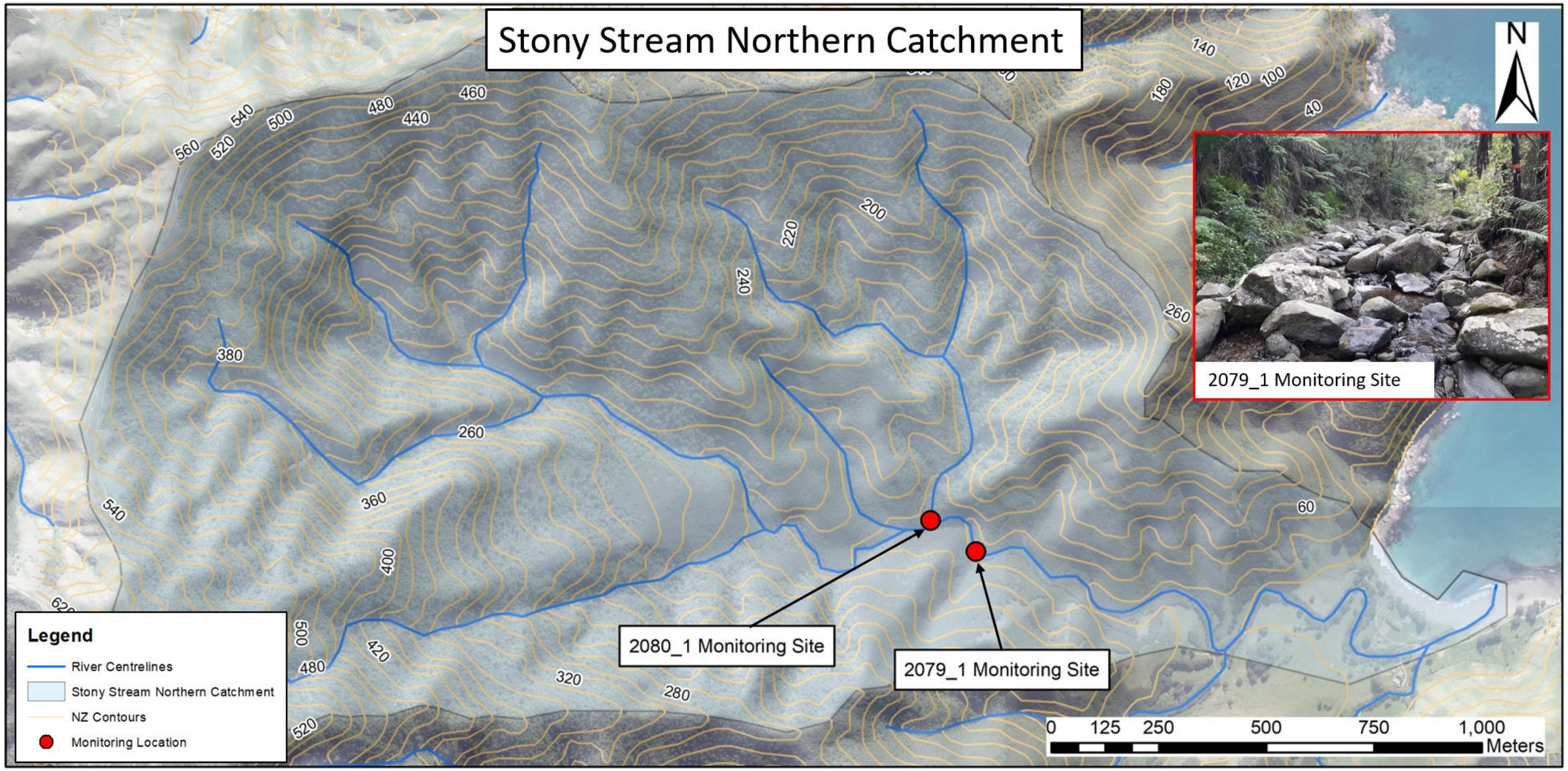

Figure 52 Stony Bay catchment and location of 3rd Order monitoring Site (2079_1). Sourced from the LINZ Data Service and licenced for reuse under the CC BY 4.0 licence. Aerial and elevation data sourced from the LINZ Data Service and licenced by Waikato Regional Council, for re-use under the Creative Commons Attribution 4.0 International Licence. Inset: representative geomorphology of Monitoring Site 2079_1.

Table 16 Assessment against reference conditions for Monitoring Site 2079_1

	Reference Conditions	150 m reach	300 m reach
Riparian Zone	Extensive indigenous forest – dense coverage greater than 100 m from bank edge. Predominantly manuka/kanuka forest as well as indigenous hardwoods and broadleaves. Canopy and dense understory should be expected. No gaps within riparian zone and should be wholly indigenous.	Extensive dense indigenous vegetation cover – range of broadleaf and hardwoods forming a complete canopy, in addition to a significant understory and ground cover diversity. No breaks in riparian zone detected, with coverage extending extensively in all directions as typified in Figure 53).	Extensive dense indigenous vegetation cover – range of broadleaf and hardwoods forming a complete canopy, in addition to a significant understory and ground cover diversity. One break detected in Segment 2-3 for approximately 10 m on both banks to accommodate a walking / biking track (Figure 54).
Bank Erosion	Predominant geological unit is Manaia Hill Group and described as Sandstone, silts and conglomerate (GNS Science, 2018). Predominant single thread channel and bedrock channel overlain with some sediments and soils. Incised channel with evidence of slow erosion of bedrock. Examples include pitted bedrock and overhangs of bedrock as a result of undercutting. Where bedrock is overlaid by soils, concave erosion of banks is expected on straight sections – expect this to be relatively uniform due to bedrock being close to the surface and the channel being confined. On bends, erosion of outside of bend is expected, with complementary deposition on inside of bend. Some evidence of channel	Channel somewhat incised into bedrock, with low levels of short-term erosion. Bedrock overlain with varying amounts of soils. Visible bedrock in all segments, overlaid with boulders along the bank, such as that in Segment 4-5. Erosion of soil banks where flow is displaced by large boulders as typified in Segment 4-5 (Figure 55). Localised erosion around trees in bank (undercutting) in soils and also observed on true left bank near the island in Segment 7-8. Channel single thread and stable. Erosion and incision is not pronounced.	Channel somewhat incised into bedrock, with low levels of short-term erosion. Bedrock overlain with varying amounts of soils. Visible bedrock in all segments, overlaid with boulders along the bank, such as that in Segment 4-5. Erosion of soil banks where flow is displaced by large boulders as typified in Segment 4-5 (Figure 55). Localised erosion around trees in bank (undercutting) in soils and also observed on true left bank near the island in Segment 7-8. Undercutting erosion is observed in Segments with a pronounced soil layer and elevated bank heights, such as from Segments 3-4 (primary channel), and 10-11, to 12-13. Undercutting of bedrock evident downstream of the secondary channel within Segment 3-4 (Figure 56). Channel single thread and stable. Erosion and incision is not pronounced.

	Reference Conditions	150 m reach	300 m reach
	migration within valley flood could be expected, but not necessary.		
Grain Size	Presence of bedrock dominating channel form. A range of grain sizes, from boulders through to sand granules. Predominant grain size should be cobbles; around 20-30 mm in size, although necessary for smaller clast sizes to also be present. Expect large particles – boulders greater than 1000 mm throughout entire length, but particularly conglomerating in patches. Sorting not expected. Angular. As 3rd Order tributary draining steep and elevated catchment with a noticeably less steep elevation compared to upstream, expect a reasonable quantity of very large particles corresponding to the drop in stream power and delivery of materials from multiple channels.	b-axis average of transect lines is 277 mm though, bedrock was encountered once in Segment 4-5 and seven times in Segment 9-10, resulting a null value recording for those counts. There were five additional instances of particle size being >2 mm within Segment 9-10. Bedrock dominates channel form in banks and channel bed. Very large boulder (estimated 2000 mm in width) exerting large influence on flow toward the true right bank. Silty layer in pools where water flow is slower. Reach is dominated by large boulders (1000 mm to 2000 mm) and medium sized boulders (500 mm to 1000 mm). Smaller cobble and pebble sizes found in pools. Very large clasts deposited on island within Segment 6-7 and 7-8.	b-axis average of transect lines is 214 mm, though bedrock was encountered once in Segment 4-5, seven times in Segment 9-10, and twice in Segment 12-13 resulting a null value recording for those counts. There were five additional instances of particle size being >2 mm within Segment 9-10. In Segment 1-2, one boulder extends over two measuring points, resulting in a null recording for that location. Bedrock dominates channel form in banks and channel bed. Very large boulder (estimated 2000 mm in width) exerting large influence on flow toward the true right bank in Segment 3-4. Silty layer in pools where water flow is slower. Reach is dominated by Large boulders (1000 mm to 2000 mm) and medium sized boulders (500 mm to 1000 mm) throughout most segment but particularly downstream of Marker 8. Smaller cobble and pebble sizes found in pools. Very large clasts deposited on island within Segment 6-7 and 7-8.

	Reference Conditions	150 m reach	300 m reach
Wood	Ample wood pieces within channel forming wood rafts and log jams. Areas of clear water without wood as well. Wood of some size should be found within every 25 m segment; log jams and rafts may be found, particularly if there are sheltered areas of evidence of more than one log jam or wood raft. Wood raft / log jam expected to be predominantly one or two tree trunks with other wood pieces backing in around rather than large quantities of trunks in one location. Abundant leaf litter. Fallen trees near channel as future sources of in-channel wood as well as numerous standing live trees near banks.	Wood pieces found in each segment, but not in large quantities (Figure 60). Abundant leaf litter and twigs. Fern and other tree branches found in a few segments. Large wood accumulation with Segment 7-8 with tree trunks (including punga) located in parallel to the true right bank within the primary flow. Heavy loading of wood on the island located within Segment 7-8 (Figure 59) as well as accumulation of wood within slow moving secondary flow between island and true left bank. Some vegetation and live trees located immediately adjacent to bank edge with potential as future wood sources, particularly in Segment 7-8. Channel is notably wide and there is a strong expectation that significant and major flows flush through reach at stream powers large enough to mobilise wood pieces downstream.	Wood pieces found in each segment, but not in large quantities (Figure 60). Abundant leaf litter and twigs. Fern and other tree branches found in a few segments. Large wood accumulation with Segment 7-8 with tree trunks (including punga) located in parallel to the true right bank within the primary flow. Heavy loading of wood on the island located within Segment 7-8 (Figure 59) as well as accumulation of wood within slow moving secondary flow between island and true left bank. Log pile located on true right bank within Segment 1-2. Some vegetation and live trees located immediately adjacent to bank edge with potential as future wood sources, particularly in Segment 7-8. Channel is notably wide and there is a strong expectation that significant and major flows flush through reach at stream powers large enough to mobilise wood pieces downstream.
Connectivity	Unimpeded connectivity for entire length of reach. Unimpeded connectivity to upstream and downstream reaches. Unimpeded connectivity along length of entire stream from source to sink. Waterfalls could be expected, but unlikely.	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Stony Stream. Culverts located near mouth of Stony Stream to enable a bridge crossing, but are fish friendly and flow is not impeded greatly (culverts partially buried into channel, short in length, and not perched).	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Stony Stream. Culverts located near mouth of Stony Stream to enable a bridge crossing, but are fish friendly and flow is not impeded greatly (culverts partially buried into channel, short in length, and not perched).

	Reference Conditions	150 m reach	300 m reach
Spatial Heterogeneity	Large number of geomorphic units expected within each 25 m segment and across reach overall. There should be a consistent abundance of units, i.e. there should be no 25 m segment that is uniform with only one or two identifiable geomorphic units. Expected units to include lateral bars, mid-channel bars, large individual boulders by bank and within wetted channel, pool and riffle sequences, steps, cobble or pebble patches, bedrock slabs pitted by erosion. Evidence of heterogeneity as a result of other factors, such as scour holes on bank from erosion	Diverse and abundance of geomorphic units, including pools and riffles in every segment, bank overhangs, predominant bedrock channel and banks providing for chutes and areas of lower flow velocity varying in depth (Figure 61). Lateral bars observed in majority of segments, as well as individual large boulders. Very large boulders exerting influencing on flow and bank erosion. 12-15 m length Cascade evident in Section 5-6, with deeper pools at each end than other segments. Large vegetated island located within Segment 7-8 with primary flow adjacent to the true right bank, with observable bedrock erosion. Secondary flow adjacent to true left bank, almost still water.	Diverse and abundance of geomorphic units, including pools and riffles in every segment, bank overhangs, predominant bedrock channel and banks providing for chutes and areas of lower flow velocity varying in depth (Figure 61 and Figure 62). Lateral bars observed in majority of segments, as well as individual large boulders. Very large boulders exerting influencing on flow and bank erosion. 12-15 m length Cascade evident in Section 5-6, with deeper pools at each end than other segments. Large vegetated island extending the length of Segment 7-8 with primary flow to the true left and secondary flow to the true right. Secondary flow almost standing water, providing a large pool. Large riffle and shallow pool sequences throughout main channel. Large vegetated island located within Segment 7-8 with primary flow adjacent to the true right bank, with observable bedrock erosion. Secondary flow adjacent to true left bank, almost still water. A tributary enters Stony Stream within Segment 10-11, which is separated from the primary flow by a well vegetated island sporting mature trees.

Table 17 Results summary for Monitoring Site 2079_1

	Score	
	150 m reach	300 m reach
Riparian Zone	5	4
Bank Erosion	5	5
Grain Size	5	5
Wood	5	5
Connectivity	5	5
Spatial Heterogeneity	5	5
Total	**30 / 30** **Excellent**	**29 / 30** **Excellent**

Deviations from reference conditions:

- Variable Riparian Zone; wholly representative with the exception of a 10 m gap on each bank to provide for a walking / biking track which traverses the channel.

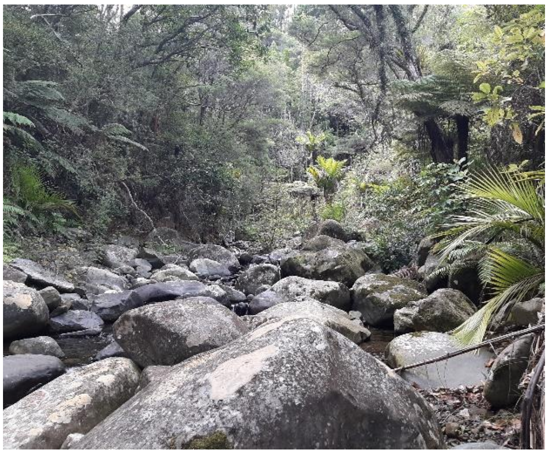

Figure 53 Extensive forest cover adjacent to Segment 6-7 of Monitoring Site 2079_1 which is typical of the entire reach.

Figure 54 Single break in forest cover within reach, located within Segment 2-3 of Monitoring Site 2079_1. The break in vegetation is to accommodate a walking / biking track and is located on both sides of the channel.

Figure 55 Erosion within Segment 4-5 of Monitoring Site 2079_1. Erosion concentrated around bank where flow deflected around large boulder within channel. Outside of this discrete location, it is evident the banks are relatively stable with little short term erosional processes acting upon them.

Figure 56 Undercutting of bedrock bank located at the convergence of the primary and secondary channels around an island for much of Segment 3-4 of Monitoring Site 2079_1.

Figure 57 Typical clast distribution, exemplified in Segment 6-7 of Monitoring Site 2079_1. Looking upstream to the island located in Segment 7-8, very large boulders deposited on the island surface are observed

Figure 58 Typical clast distribution as shown in Segment 10-11 of Monitoring Site 2079_1.

Figure 59 Multiple wood deposits on island within Segment 7-8 of Monitoring Site 2079_1. Likely evidence toward the high stream of the reach acting as a flush for the wetted channel, pushing larger wood pieces further downstream.

Figure 60 Low quantities of wood pieces found within reach as a whole – this branch and back up of woody and vegetative debris is located within Segment 3-4 of Monitoring Site 2079_1.

Figure 61 Variable geomorphic units within Segment 5-6 of Monitoring Site 2079_1, including massive individual boulders, lateral bars, pools and riffles (obscured by rocks, but evident by step change), and water depth changes.

Figure 62 Step change within Segment 1-2 of Monitoring Site 2079_1; pools are located either side of the step change, which is made up of a range of clast sizes. In the distance, the island diverging flow into two chutes within Segment 2-3 is observed.

4.1.5. 1262_18 Waiwhero Stream

Downstream coordinates	E1836904 N836119
Stream Order	2nd
Valley setting	Unconfined
Landscape Position	Source
Date of survey	20th March 2020
Duration of survey	2.0 hrs

The Waiwhero Stream is located to the west of the Waihau township and drains part of the Hauraki Plains (Figure 63). The total length of the Waiwhero River is recorded by Waikato Regional Council as 6.6 km. However, the uppermost location of the Waiwhero River is located at 16 m ASL at the confluence of two unrecorded drains or modified streams 85 m upstream of the monitoring site 1262_18.

The Waiwhero Stream has a confluence with the Waitoa River to the northeast of the Waihau township, at 9 m ASL. The Waitoa River continues to flow north, bypassing the Kopuatai Peat Dome before joining with the Piako River which discharges into the firth of Thames.

The Waiwhero Stream is highly channelised and located with a floodplain historically drained and used for agricultural farming. The Waiwhero Stream predominantly passes through dairy farms on all sides. It is classified by Waikato Regional Council as Surface Water only (not Natural State or Indigenous Fish Habitat Class).

The Hauraki Plains in the vicinity of the Waiwhero Stream is flat; over the 6.6 km length of the stream, the elevation reduces from 16 m ASL to 10 m ASL at the confluence with the Waitoa River.

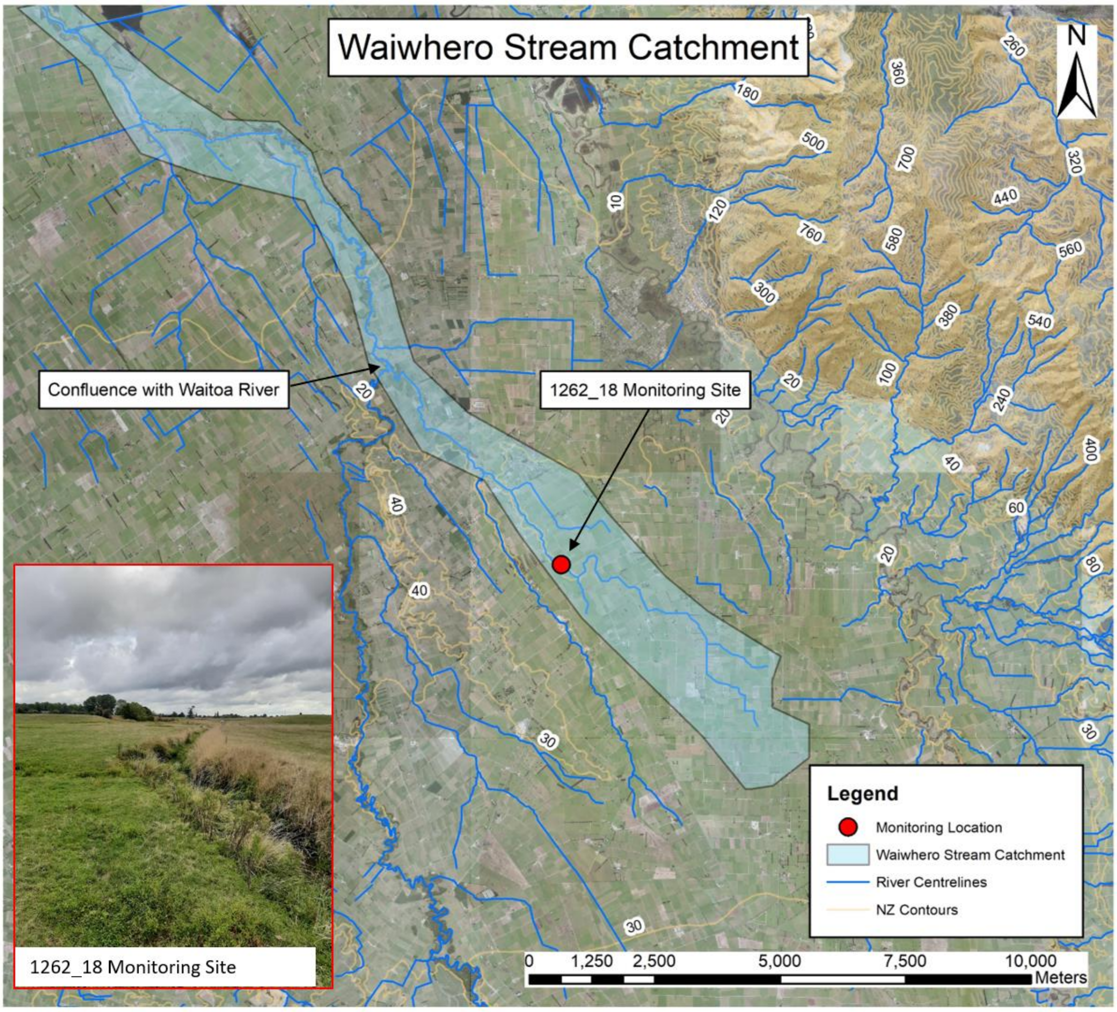

Figure 63 Waiwhero Stream catchment and location of monitoring site (1262_18). Sourced from the LINZ Data Service and licenced for reuse under the CC BY 4.0 licence. Aerial and elevation data sourced from the LINZ Data Service and licenced by Waikato Regional Council, for re-use under the Creative Commons Attribution 4.0 International Licence. Inset: representative geomorphology of Monitoring Site 1262_18

Table 18 Assessment against reference conditions for Monitoring Site 1262_18

	Reference Conditions	150 m reach	300 m reach
Riparian Zone	Extensive coverage of Kahikatea and Pukatea lowlands forest, with partial wetland species closest to river (damp and swampy areas). Coverage across immediate floodplain approximately 75 m width from each bank. Kahikatea dominant canopy with swampy areas providing for 'wet foot' species, without a true understory such as swamp lily and maire, and sedges. Ti kouka and pokaka also expected, as well as coprosma's, turepo, repo (flaxes). Expectation to see a diverse range of plant species. No gaps within riparian zone and wholly indigenous plants. In swamp areas, an open canopy in some locations is acceptable, i.e. closed canopy not required.	No observable riparian zone within floodplain (visual change in elevation) of channel. Floodplain is pasture for dairy farming with post and singular wire fencing off channel from surrounds. Area adjacent to channel (inaccessible to large stock) overgrown with coarse grasses and weeds. Observable spreading weeds	No observable riparian zone within floodplain (visual change in elevation) of channel. Floodplain is pasture for dairy farming with post and singular wire fencing off channel from surrounds. Area adjacent to channel (inaccessible to large stock) overgrown with coarse grasses and weeds. Observable spreading weeds
Bank Erosion	Predominant geological unit is Late Quaternary alluvium and colluvium and described as unconsolidated to poorly consolidated mud, sand, gravel and peat (GNS Science, 2018). Predominantly single thread channel but not greatly incised or with well-defined banks. Potential for multiple branches through some locations, separated by low lying alluvial islands. Low lying floodplain with expectation bankfull and overspill is experienced often. Exposed banks readily	Channel incision into floodplain and disconnected from surrounds – estimated to be 1.5 m – 2.0 m incision. Channel is single thread with well-defined banks and straight. Banks are stable, although some soils exposed, such as on the true left bank in Segment 8-9. Exotic vegetation covers the banks.	Channel incision into floodplain and disconnected from surrounds – estimated to be 1.5 m – 2.0 m incision. Channel is single thread with well-defined banks and straight. Banks are stable, although some soils exposed, such as on the true left bank in Segment 8-9. Exotic vegetation covers the banks.

	Reference Conditions	150 m reach	300 m reach
	eroded due to loose unconsolidated materials and minimal armouring. Reasonable sinuosity in channel; evidence meanders being formed or enhanced through erosion outside of bend. Evidence of cutoff occurring on significant meanders. Concave erosion along bank sides where exposed, causing undercutting relatively evenly on both banks. No barriers, outside of vegetation to the migration of the channel across the floodplain.	Little erosion detected. Except for incision, there is no barriers to restrict the migration of the channel across the floodplain.	Little erosion detected. Except for incision, there is no barriers to restrict the migration of the channel across the floodplain.
Grain Size	Alluvial and fine-grained material. Predominantly alluvium given location within the middle of the Hauraki Plains. Coarse sand and clays. Pebbles and larger materials uncommon but could be present in discrete locations in small quantities. Material larger than 100 mm will be very uncommon.	Silty sediment representative of alluvial materials (Figure 66). No observable particles greater than coarse sands (i.e. no pebbles).	Silty sediment representative of alluvial materials (Figure 66). No observable particles greater than coarse sands (i.e. no pebbles).
Wood	Given location is in the middle of the Hauraki Plains, wood is not expected to be carried from higher elevations in great quantities. Wood derived from local wood, including some larger trees such as mature kahikatea. Mostly smaller understory trees i.e. ti kouka. Some smaller wood pieces expected on sand / gravel banks or forming small wood rafts near bank anomalies, such	No wood observed. No wood rafts observed of smaller pieces. No live trees providing potential future wood pieces. No leaf litter.	No wood observed. No wood rafts observed of smaller pieces. No live trees providing potential future wood pieces. No leaf litter.

	Reference Conditions	150 m reach	300 m reach
	as trees growing in the bank. Presence of leaf litter.		
Connectivity	Unimpeded connectivity for entire length of reach. Unimpeded connectivity to upstream and downstream reaches. Unimpeded connectivity along length of entire stream from source to sink. Lateral connectivity to the floodplain.	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity downstream to confluence with the Waitoa River.	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity downstream to confluence with the Waitoa River.
Spatial Heterogeneity	Presence of macro geomorphic units, such as larger lateral bars and point bars on the inside of bends. Reasonable level of visual homogeneity. Mid channel bars. Pool and riffles uncommon but acceptable. Thalweg expected in areas of meander and bends. Low degree bank slope.	Single thread channel with high degree of homogeneity (Figure 64 and Figure 67). Incised with little connection to floodplain. low sinuosity. Straight channel with sloping banks for 75 m along Segments 6-7, 7-8, and 8-9 with no meanders, bars, or other features. Lateral bars observed in Segment 4-5 (approx. 15 m length x 3 m at widest point), Segment 5-6 (approximately 10 m in length x 1 m wide) and a minor bar (approximately 2 m x 2m) within Segment 9-10). All bars are vegetated with exotic species and stable. An ephemeral flowpath traverses the floodplain and joins to Waiwhero Stream on the true left within Segment 5-6.	Single thread channel with high degree of homogeneity (Figure 64 and Figure 67). Incised with little connection to floodplain. low sinuosity. Straight channel with sloping banks for 75 m along Segments 6-7, 7-8, and 8-9 with no meanders, bars, or other features. Lateral bars observed in Segment 2-3 (approximately 50 m in length). Segment 4-5 (approx. 15 m length x 3 m at widest point), Segment 5-6 (approximately 10 m in length x 1 m wide) and a minor bar (approximately 2 m x 2m) within Segment 9-10). All bars are vegetated with exotic species and stable. Ephemeral flowpaths traverses the floodplain and joins to Waiwhero Stream on the true left within Segment 5-6 and from the true right within Segment 3-4 (Figure 65).

Table 19 Results summary for Monitoring Site 1262_18

	Score	
	150 m reach	300 m reach
Riparian Zone	1	1
Bank Erosion	2	2
Grain Size	5	5
Wood	2	2
Connectivity	3	3
Spatial Heterogeneity	2	2
Total	**15 / 30** **Poor**	**15 / 30** **Poor**

Deviations from reference conditions:

- Lack of Riparian Zone; non-existent and not representative.
- Bank Erosion: channel is incised and disconnected to the floodplain. Minimal erosion despite loosely consolidated alluvial material; expectation that erosion would readily occur and be present, and evident through channel meanders and chute cutoffs
- Wood: No wood pieces detected at any size or quantity, nor any wood potential observed on the banks
- Connectivity: minimal connection to surrounding floodplain due to channel incision.
- Spatial Heterogeneity: uniform and minimal changes between segments.

Figure 64 Typical channel located within Segment 4-5 at Monitoring Site 1262_18. Disconnected from floodplain, with no riparian zone and little geomorphic variation.

Figure 65 Ephemeral flowpath traversing the floodplain to join Waiwhero Stream in Segment 3-4 at Monitoring Site 1262_18.

Figure 66 Example of material from channel, located from Segment 4-5 at Monitoring Site 1262_18. Sediment is uniform throughout reach. No larger particles were observed (i.e. pebbles or individual cobbles).

Figure 67 Waiwhero Stream looking downstream from Marker 13. The edges of the floodplain are visible to both the true left and true right. The floodplain reference conditions specify a kahikatea covering across the whole of the floodplain - approximately 150 m wide.

4.1.6. 1307_18 Whangarahi Stream

Downstream coordinates	E1822913 N5929144
Stream Order	2nd
Valley setting	Unconfined
Landscape Position	Sink
Date of survey	22nd March 2020
Duration of survey	2.5 hrs

The Whangarahi Stream catchment comprises numerous tributaries and other streams flowing into it, with the highest elevation of the catchment being 500 m ASL. The monitored reach is located within the southern catchment of the Whangarahi Stream at 4 m ASL (Figure 68). Monitoring site 1307_18 is located on a 4th Order Stream and fed by a catchment totalling 20.1 km upstream of the monitoring site. The monitoring site is located 970 m from the mouth of the Whangarahi Stream where it meets the Coromandel Harbour. It is classified by Waikato Regional Council as Surface Water only (not Natural State or Indigenous Fish Habitat Class).

The headwaters upstream of the monitoring site descend rapidly through densely forested uplands, before reaching the lowlands surrounding the Coromandel Harbour. The densely forested uplands comprises both indigenous vegetation and forestry plantations. At the far reach of the southern catchment, an area of forest has been evidently clear-felled.

The monitoring site is situated within the urban township of the Coromandel Town; downstream of the site are further urban areas, including a road situated adjacent to the true right bank, in addition to pockets of grazing paddocks. A small marina is located near the mouth of the Whangarahi River, which is estuarine and tidal within the confines of the Coromandel Harbour.

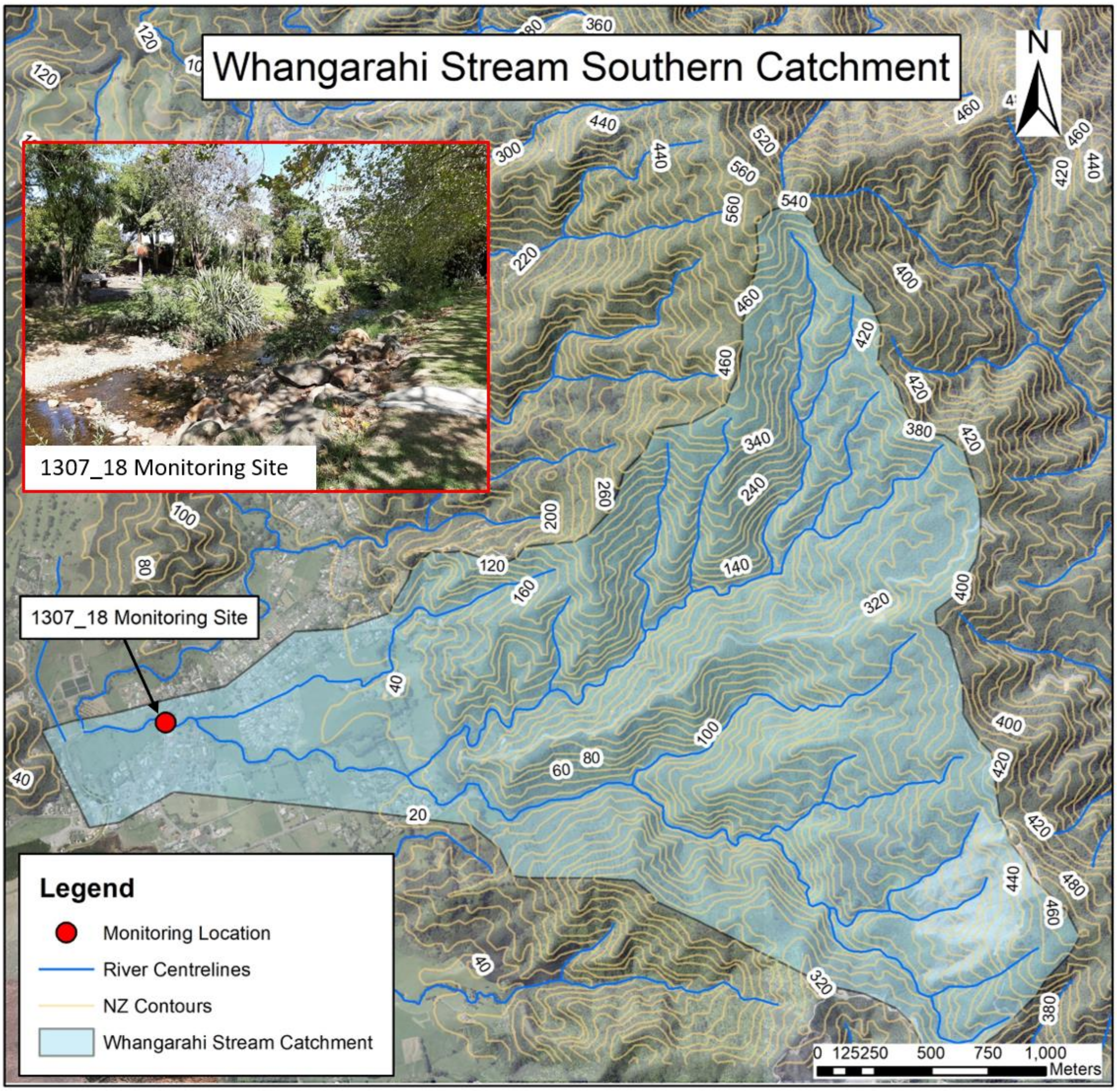

Figure 68 Whangarahi Stream catchment and location of monitoring Site (1307_18). Sourced from the LINZ Data Service and licenced for reuse under the CC BY 4.0 licence. Aerial and elevation data sourced from the LINZ Data Service and licenced by Waikato Regional Council, for re-use under the Creative Commons Attribution 4.0 International Licence. Inset: representative geomorphology of Monitoring Site 1307_18

Table 20 Assessment against reference conditions for Monitoring Site 1307_18

	Reference Conditions	150 m reach	300 m reach
Riparian Zone	Extensive coverage of Kahikatea and Puriri lowlands forest, with partial wetland species closest to river (damp and swampy areas). Coverage greater than 100 m in all directions. Kahikatea dominant canopy; in swampy areas expect to see 'wet foot' species, without a true understory such as swamp lily and maire, and sedges. Ti kouka and pokaka also expected, as well as coprosma's, turepo, repo (flaxes). Expectation to see a diverse range of plant species. Slightly elevated parts of the floodplain can expect a more diverse canopy and a developed understory, including totara, matai, rimu. No gaps within riparian zone and wholly indigenous plants. In swamp areas, an open canopy in some locations is acceptable, i.e. closed canopy not required.	No real riparian zone (Figure 71). A maximum of 4 m width of planting on true right bank (Segment 7-8), with 0 m within Segments 4-5, 5-6, and 9-10. Segment 6-7 has a width of one plant, whilst Segment 8-9 has a riparian zone of 2 m. Within all segments, large gaps and inconsistent coverage was observed. On the true left bank, no riparian zone is detected except for within Segment 4-10 at 10m, although with significant gaps and inconsistency in density. Plants are a mixture of exotic and indigenous plants including very large mature exotic park trees, flaxm manuka, and ti kouka,	No real riparian zone. Gorse identified on both true right and true left banks in Segments 1-2 and 2-3. A maximum of 4 m width of planting on true right bank (Segment 7-8), with 0 m within Segments 4-5, 5-6, and 9-10. Segment 6-7 has a width of one plant, whilst Segment 8-9 has a riparian zone of 2 m. No riparian zone is observed in Segments 10-11 and 11-12 for either bank, although some plants (gorse, large exotic trees, ti kouka, flax and mixed grasses) are identified on the bank. Within all segments, large gaps and inconsistent coverage was observed. On the true left bank, no riparian zone is detected except for within Segment 4-10 at 10m, although with significant gaps and inconsistency in density. Plants are a mixture of exotic and indigenous plants including very large mature exotic park trees, flax, manuka, and ti kouka.
Bank Erosion	Predominant geological unit is Late Quaternary alluvium and colluvium and described as unconsolidated to poorly consolidated mud, sand, gravel and peat (GNS Science, 2018).	Very minor undercutting observed in Segment 4-5. Remainder of reach is artificially armoured with riprap along the banks of both sides, with the exception of some locations in Segments 5-6 and 6-7 (Figure 72), and a formed pathway to the channel located on the true right bank with Segment 9-10.	Very minor undercutting observed in Segments 1-2, 3-4 and 4-5. Remainder of reach is artificially armoured with riprap along the banks of both sides, with the exception of some locations in Segment 6-7, and a formed pathway to the channel located on the true right bank with Segment 9-10. There is no

	Reference Conditions	150 m reach	300 m reach
	Single thread channel – not greatly incised or with well-defined banks. Low lying floodplain with expectation bankfull and overspill is experienced often. Exposed banks readily eroded due to loose unconsolidated materials and minimal armouring. Reasonable sinuosity in channel; evidence meanders being formed or enhanced through erosion outside of bend. Evidence of cutoff occurring on significant meanders. Concave erosion along bank sides causing undercutting relatively evenly on both banks. No barriers, outside of vegetation to the migration of the channel across the floodplain.		riprap located on the true left bank in Segments 10-11 to 12-13, although there is minimal to no erosion, except for discrete and isolated spots.
Grain Size	Alluvial and fine grained material. Pebbles around 50 mm interspersed with sands and smaller gravels. Rounded without sorting. Larger particles uncommon (greater than 200 mm) and no boulders.	b-axis average of transects is 47 mm. Thick silt overlaying pebbles, with individual cobbles larger but uncommon and not found within each segment. Uniform distribution across channel. Rounded. Refer Figure 73.	b-axis average of transects is 45 mm. Thick silt overlaying pebbles, with individual cobbles larger but uncommon and not found within each segment. Uniform distribution across channel. Rounded. Refer Figure 73.

	Reference Conditions	150 m reach	300 m reach
Wood	Wood remnants potentially from previous flood events bringing large wood pieces into the lower catchment, but unlikely and certainly not in any great quantity. Some smaller wood pieces expected on sand / gravel banks or forming small wood rafts near bank anomalies, such as trees growing in the bank. Presence of leaf litter.	No wood pieces observed in great quantity. individual twigs and some leaf litter. No build up of wood pieces detected. Little wood available from the bank for future deposit into the change.	No wood pieces observed in great quantity. individual twigs and some leaf litter. No build up of wood pieces detected. Little wood available from the bank for future deposit into the change. In Segment 1-2, a tree in the true right bank backing up other debris and clasts downstream of a lateral bar, with a deep pool forming downstream of the tree.
Connectivity	Unimpeded connectivity for entire length of reach. Unimpeded connectivity to upstream and downstream reaches. Unimpeded connectivity along length of entire stream from source to sink. Lateral connectivity to the floodplain.	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Whangarahi Stream and tributaries. Channel crosses underneath roads and accessways both upstream and downstream of catchment site but aerial observation does not denote impediments to connectivity. Lateral connectivity to the floodplain is impeded by an incised channel fossilised into place through bank armouring. Connectivity to the floodplain in some locations through slumping bank and less severe bank angle.	Connectivity unimpeded for entire length of reach. Reach is connected to both upstream and downstream reaches. Presumed unimpeded connectivity along entire length of Whangarahi Stream and tributaries. Channel crosses underneath roads and accessways both upstream and downstream of catchment site but aerial observation does not denote impediments to connectivity. Lateral connectivity to the floodplain is impeded by an incised channel fossilised into place through bank armouring. Connectivity to the floodplain in some locations through slumping bank and less severe bank angle.
Spatial Heterogeneity	Presence of macro geomorphic units, such as larger lateral bars and point bars on the inside of bends. Reasonable level of visual homogeneity. Mid channel bars. Pool and riffles uncommon but acceptable. Thalweg	Dominated by pools, often the entire width of channel (Figure 69). Riffles also observed. Channel is artificially confined on both sides by riprap for much of its length, although small lateral bars observed on true left within	Dominated by pools (Figure 70), often the entire width of channel although a noticeable thalweg is detected in Segment 1-2. Riffles also observed. Channel is artificially confined on both sides by riprap for much of its length,

	Reference Conditions	150 m reach	300 m reach
	expected in areas of meander and bends. Low degree bank slope.	Segment 4-5 where there is no artificial armouring. A bridge crosses the channel between Segment 7-8 and 8-9; a concrete box extends for approximately 15-20 m, with wingwalls.	although small lateral bars observed on true left within Segment 4-5 where there is no artificial armouring. A larger lateral bar (20 m in length) located on the true left within Segment 2-3 and bank slumping on the true right. A bridge crosses the channel between Segment 7-8 and 8-9; a concrete box extends for approximately 15-20 m, with wingwalls. An ephemeral tributary enters the channel on true right within Segment 11-12.

Table 21 Results summary for Monitoring Site 1307_18

	Score	
	150 m reach	300 m reach
Riparian Zone	1	1
Bank Erosion	2	2
Grain Size	5	5
Wood	3	3
Connectivity	3	3
Spatial Heterogeneity	3	3
Total	**17 / 30** **POOR**	**17 / 30** **POOR**

Deviations from reference conditions:

- Lack of Riparian Zone; non-existent and not representative.
- Bank Erosion: Armouring of banks restricting connection to floodplain and ability to erode.
- Wood: No wood pieces detected at any size or quantity; wood potential observed on the banks is minimal.
- Connectivity: disassociated from the adjacent floodplain in many locations through incised fossilised channel, coupled with bank armouring
- Spatial Heterogeneity: uniform and minimal changes between segments. Artificial units detected including bank armouring, pipeline, flood (material) control, and bridge box culvert.

Figure 69 Typical channel geomorphology within Segment 10-11 of Monitoring Site 1307_18. Armouring is evident on the true right bank (left hand side). A pool dominates this segment, though disrupted by (presumed due to location adjacent to recreational area) artificial dams perpendicular to flow.

Figure 70 Typical channel geomorphology within Segment 1-2 of Monitoring Site 1307_18, downstream of artificial armouring. Presence of lateral bars, pools, individual boulders, with sloping banks, and vegetation overhanging in parts over channel

Figure 71 Lack of riparian zone evident in Segment 6-7 of Monitoring Site 1307_18. Gorse and exotic grasses are identified, along with flaxes and ti kouka.

Figure 72 Bank shape in Segment 5-6 of Monitoring Site 1307_18. On the true right (left hand side) a thin line of armouring is detected, while on the true left bank, minor erosion of the loosely consolidated alluvial materials occurs.

Figure 73 Particle size typified in Segment 8-9 of Monitoring Site 1307_18. Particles generally around 50 mm, with small pockets of coarse grained sands (> 2mm) and isolated cobbles larger than 50 mm.

Figure 74 Landuse on immediate surrounding floodplain near Segment 9-10 of Monitoring Site 1307_18.

4.1.7. Summary of observed sites

Table 22 provides a summary for each Monitoring Site for both the 150 m and 300 m reach.

Table 22 Summary of results for observed Monitoring Sites

	11726_11 UPPER WAINUI STREAM		1172_6 WAINUI STREAM		2080_1 STONY STREAM 2ND ORDER		2079_1 STONY STREAM 3RD ORDER		1307_18 WHANGARAHI STREAM		1262_18 WAIWHERO STREAM	
	150 m reach	300 m reach	150 m reach	300 m reach	150 m reach	300 m reach	150 m reach	300 m reach	150 m reach	300 m reach	150 m reach	300 m reach
Riparian Zone	3	2	2	2	5	5	5	4	1	1	1	1
Bank Erosion	5	5	5	5	5	5	5	5	2	2	2	2
Grain Size	5	5	5	5	5	5	5	5	5	5	5	5
Wood	5	5	3	3	5	5	5	5	3	3	2	2
Connectivity	5	5	5	5	5	5	5	5	3	3	3	3
Spatial Heterogeneity	5	5	5	5	5	5	5	5	3	3	2	2
Total	28 /30 EXCELLENT	27 /30 EXCELLENT	25 / 30 GOOD	25 / 30 GOOD	30 / 30 EXCELLENT	30 / 30 EXCELLENT	30 / 30 EXCELLENT	29 / 30 EXCELLENT	17 / 30 POOR	17 / 30 POOR	15 / 30 POOR	15 / 30 POOR

4.2. Cross reference to ecological results gained from WRC

A comparison of the available ecological results obtained independently by WRC against the geomorphic results of the 150 m reach for each Monitoring Site is provided in Table 23. Some key chemical and ecological indicators for SOE reporting were not undertaken as part of these monitoring cycles, including E.coli, phosphorus, and nitrogen. Macroinvertebrate data for the 2020/21 monitoring season was not available for analysis at the time of writing and previous years are used (2016/17, 2017/18, and 2018/19). Additionally, IBI data was not available for this monitoring season; the comparison between the ecological and geomorphological results is expected to be exercised with a high degree of caution, with consideration of other controlling factors, such as proximity to the coast, whereby all diadromous species have a marked bias towards coastal rivers and streams, resulting in the presence of higher numbers and diversity of fish closer to the coast than further inland locations at higher elevations (Leathwick *et al.*, 2008).

Table 23 Comparison of WRC ecological data versus geomorphic data for the selected Monitoring Sites. MCI and Dissolved Oxygen (DO) are coloured against the relevant NPS-FM 2017 Attribute Tables and accepted National Objectives Framework (NOF) bands, with A being the best state, and D the worst. The National Bottom Line for attributes sits between C and D. For this table, Band A is represented by a green shade, Band B as blue, Band C is orange, and D is red. Geomorphic results are represented using the same colour scheme, with D encompassing both 'Poor' and 'Very Poor' on the assessment scale outlined in Section 3.3.1. Variables without a shade are not provided with a band scale due to not being included in either NOF or NPS-FM2017 attribute requirements.

Site Location		11726_11	1172_6	2080_1	2079_1	1262_18	1307_18
		Upper Wainui Stream	Wainui Stream	Stony Stream 2^{nd} Order	Stony 3^{rd} Order	Waiwhero Stream	Whangarahi Stream
Reference / Non-reference (Ref/ NR)		Ref	Ref	Ref	Ref	NR	NR
Geomorphic Result		Excellent	Good	Excellent	Excellent	Poor	Poor
Macroinvertebrate Community Index		139.2593 (Feb -18)	103.4483 (Feb -19)	131.0345 (Feb -19)	124.1026 (Feb -19)	75.47368 (Feb -17)	95 (Jan -17)
Chemical Indicator	Water Visibility	Good	Good	Good	Good	Average	Good
	Temperature (Celsius)	16.9	15.3	16.9	16.0	17.1	21.4
	DO % (dissolved oxygen) -	99.5	90.4	92.4	90.4	4.7	105.9
	DO mg/l	9.6	9.1	8.9	8.9	0.4	9.5
Fish	Longfin eel - Anguilla dieffenbachii	33	24	15	5	-	14
	Shortfin eel - Anguilla australis	2	24	3	7	5	461
	Banded kokopu - Galaxias fasciatus	13	12	48	20	-	1
	Redfin bully - Gobiomorphus huttoni	52	101	98	241	-	17
	Common bully Gobiomorphus cotidianus	-	-	-	-	-	71
	Koura - Paranephrops sp.	43	44	3	-	-	5
	Inanga - Galaxias maculatus	-	-	-	-	-	1
	Common smelt - Retropinna retropinna	1	-	-	-	-	85
	Torrentfish - Cheimarrichthys fosteri	-	-	-	10	-	28
	Cran's bully - Gobiomorphus basalis	-	-	-	-	2	-
	Goldfish - Carassius auratus	-	-	-	-	2	-

5. Discussion

This section draws on the findings of applying the toolbox in six stream segments and provides a critical analysis with regard to the factors at play for the successful use of geomorphology to infer river health. This assessment summarises results of the geomorphic assessments at six Waikato Monitoring Sites, analyses the variables selected as part of the toolbox, and evaluates the applicability of the toolbox for achieving the purpose and objectives of this research.

5.1. Geomorphology of the reaches

Of the six sites, three were rated as 'excellent', one as 'good', and two as 'poor'. Unsurprisingly, the four reference sites received significantly better scores than the two non-reference sites. Three reaches received the maximum score of 30 / 30 (150 m and 300 m reaches for Stony Stream 2nd Order – 2080_1 and the 150 m reach for Stony Stream 3rd Order – 2079_1) and represent conditions that precisely emulate an undisturbed reach; there were no observed deviations from the reference conditions. The 300 m reach for the Stony Stream 3rd Order – 2079_1 received a score of 29 / 30 due to a 10 m gap in the riparian zone to accommodate a walking track on both banks; Lake *et al.* (2007) found that even small gaps to the riparian zone can impede the function of a riparian zone, meaning even a relatively benign stream crossing such as that across Stony Stream 3rd Order can have detrimental effects on river health. Nevertheless, the 300 m reach still received the highest marks for the remaining geomorphic indicators and has a scoring of 'Excellent' overall which reflects its state as a reference site.

As a contrast, both the Waiwhero Stream (Monitoring Site 1262_18) and Whangarahi Stream (Monitoring Site 1307) each scored a 1 for riparian zone and a 2 for bank erosion indicators. The floodplain in the former is used for dairy grazing, with the surrounding landscape predominantly within exotic pasture, while the latter is within the urban area of Coromandel Town. The low riparian zone scores reflect the significant deviation from what should be a lowland Kahikatea forest in swampy conditions for both sites; the changed land use likely also accounts for the low values for bank erosion, wood, connectivity, and spatial heterogeneity of the reaches as well, although for differing reasons. When compared to reference conditions, both sites depart dramatically and exemplify significantly modified reaches along both the 150 m and 300 m lengths.

Further, in the Whangarahi Stream, hard infrastructure, including concrete steps to the channel side (Figure 75) and a bridge boxed culvert (Figure 73), as well as extensive bank armouring (Figure 76) restricts erosional processes of the stream channel, essentially fixing the channel in place and disconnecting it from the surrounding floodplain.

Figure 75 Hard infrastructure in the form of concrete steps within the Whangarahi Stream (Monitoring Site 1307_18) locking the stream form into one location to maintain land use

Figure 76 Hard infrastructure in the form of bank armouring within the Whangarahi Stream (Monitoring Site 1307_18)

All six sites contained grain size that was commensurate with the reference conditions for each reach. This emphasises the requirement to assess each reach within their specific geomorphic setting rather than against a pre-determined checklist of geomorphic factors. For example, both Stony Stream Monitoring Sites (2079_1 and 2080_1) were observed with a range of clast sizes, ranging from small pebbles (10 – 20 mm) up to boulders greater than 1000 mm in width as upland, partially confined reaches, whereas the Waiwhero Stream Monitoring Site (1262_18) was predominantly made up of silt and clay materials as a result of its position in the central lowlands of the Hauraki Plains. In both contexts, the clast size is representative of reference conditions.

Grain size alone cannot indicate the health of a stream, given the complex interrelationship between indicators and the processes causing them to arise (Dollar *et al.*, 2007), despite the presence and quality of macroinvertebrates being linked to grain size (Elosegi *et al.*, 2010). Grain size in a given reach is influenced by hydrology and land use, upstream of the site, which dictates stream power for sediment transport and deposition as well as availability of materials. Sediment oversupply or a disconnected transportation process are not captured within a grain size variable but are significant factors in determining ideal stream environments for organisms. It is therefore expected that streams are considered foremost through the contextualised proforma for each reach. Grain size and quantity is linked to boundary resistance (channel bed and banks) and erosion (Wohl *et al.*, 2019), which is captured through the erosion indicator and indirectly through the riparian zone as well. While scoring adequately for grain size, both the Waiwhero Stream (Monitoring Site 1262_18) and Whangarahi Stream (Monitoring Site 1307_18) scored 'poorly' for erosion and riparian zone indicators, signifying that processes that should be occurring within the reach are disconnected.

Both the Whangarahi Stream Monitoring Site (1262_18) and Waiwhero Stream Monitoring Site (1307_18) scored poorly for connectivity. Whilst there were no apparent barriers upstream and downstream of the reach, as well as longitudinally within the catchment, reference conditions for these lowland reaches specify a high degree of *lateral* connectivity with the floodplain, which is integral for the deposition of sediment, materials, and water being deposited on the surrounding land, and the return of materials through lateral channel migration (Elosegi *et al.*, 2010). A poor connection to the floodplain and riparian zone influences grain size, erosional processes, and in-channel wood; if erosion of the banks is inhibited, the volume of wood delivered to the stream channel can also be reduced, given the riparian zone is the greatest (and sometimes exclusive) source of wood material for a stream (Wohl *et al.*, 2019). Both reaches were observed as being incised and inset below the floodplain, with the Whangarahi Stream banks being armoured against erosion and lateral channel movement. Reference conditions for these two sites were generally similar, given their position on the north western plains within the Waikato Region; both would be expected to be covered by Kahikatea swamp forests, with a high degree of lateral and longitudinal connectivity, as well as a similar spatial heterogeneity composition. As shown by Figure 77 the resulting geomorphic composition is strikingly dissimilar as a result of differing land uses and anthropogenic intervention, which highlights the potential sensitivity of rivers as ecosystems, where influence on different variables can induce diverse responses (Elosegi & Sabater, 2013).

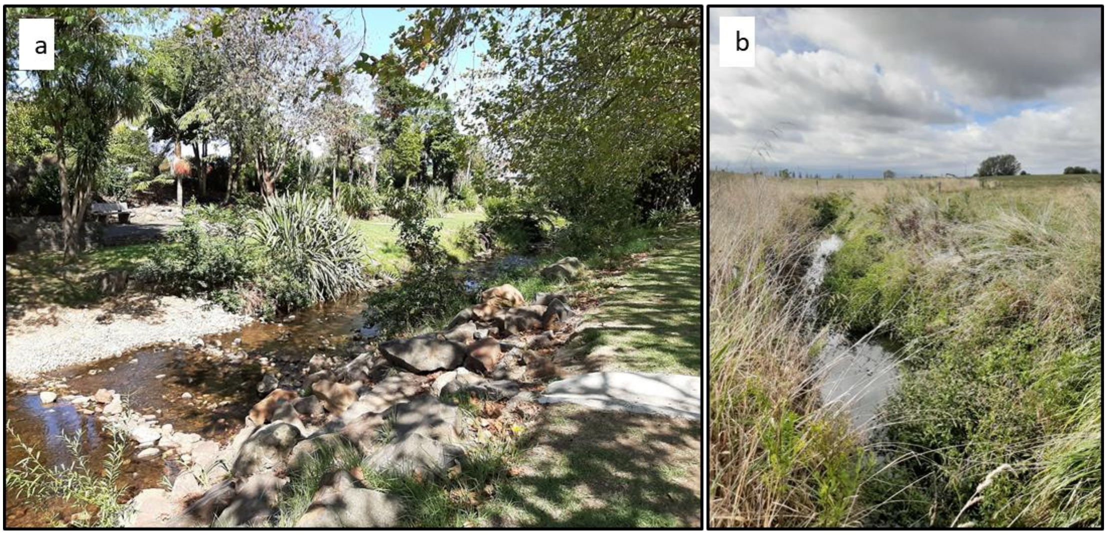

Figure 77 Differing geomorphological settings within the (a) Whangarahi Stream and (b) Waiwhero Stream, despite very similar reference conditions. Land use changes within the catchment are considered responsible for the stark change, as well as location within the catchment; whilst both are lowland reaches, the Monitoring Site for the Whangarahi Stream is near the ocean and with an upstream catchment including both forestry and agricultural land, whereas the monitoring site for the Waiwhero Stream is located a considerable distance inland from the firth of Thames within a large agricultural setting.

5.1.1. Comparison to ecological indicators

Comparisons can be drawn between the diversity and abundance of fish observed as well as the chemical variables to the 150 m reaches for each Monitoring Site. Within the three sites that scored 'Excellent' for geomorphology (Upper Wainui Stream – 11276_11 and the two Stony Stream sites 2079_1 and 2080_1), longfin eels, shortfin eels, banded kokopu, and redfin bully fish were observed, with each of these reaches also receiving a 'good' score for water visibility and sitting within Band A – the highest band – for both minimum Dissolved Oxygen level (DO mg/l) and MCI (Ministry for the Environment, 2017a, 2019a). However, the DO mg/l indicator is not strictly comparable the NPS-FM 2017 bands given WRC implemented daytime spot measuring for this variable rather than the continuous monitoring required for the NPS-FM 2017. No major dissimilarities were observed from the ecological indicators of the three 'Excellent' reaches, and the Wainui Stream Monitoring Site (1172_6) which received a 'Good' geomorphic score, likely due to the proximity to the Raglan harbour given diadromous fish are more likely to be located in reaches close to the coast (Leathwick *et al.*, 2008). The two sites that had 'Poor' geomorphic scores also received low MCI scores (Waiwhero Stream -1262_18 and Whangarahi Stream – 1307_18). The comparison between the geomorphic and MCI scores are not surprising, given the close relationship between macroinvertebrates and geomorphic diversity (Newson & Newson, 2000; Reid *et al.*, 2010).

The coastal proximity likely also accounts for the ecological integrity observed in the Whangarahi Stream (Monitoring Site 1307_18). Despite receiving a 'Poor' geomorphic score, this reach sported a DO reading of 9.5 mg/l as well as the greatest number of fish in both diversity and relative abundance; over 460 shortfin eels, 71 common bully, and 85 common smelt were observed at this site. The quantity of shortfin eels are an order of magnitude above what was found in all other reaches. The ecological indicators for the Whangarahi Stream are particularly contrasted to the Waiwhero Stream Monitoring Site (1262_18), which also received a 'Poor' geomorphic score. The Waiwhero Stream was observed to have a DO reading of 0.4 mg/l, where the National Bottom Line in the NPS-FM 2017 is 5.0, and only five Shortfin eels and two Cran's bully's were observed throughout the 150 m reach. The Waiwhero Stream was also the only site of the six where exotic fish species were present (2 Goldfish) and scored within the D-band for the MCI attribute under the National Objectives Framework (NOF) monitoring, which is below the National Bottom Line. Proximity to the coast and altitude are arguably two of the most key variables for determining fish assemblages within rivers (Leathwick *et al.*, 2008). Chessman *et al.* (2006) found an overwhelmingly positive relationship between altitude and fish within the Bega River Basin, Australia; this association is also clear through the significantly abundant fish assemblage found at the Whangarahi Stream Monitoring Site 1307_18, which is located less than 1000 m from the estuarine coastline and yet scored 'Poor' for geomorphic condition. This stresses the importance of using the geomorphic toolbox as one of a range of indicators synthesised to create a holistic understanding of each monitored reach. Local geomorphic condition cannot alone determine the likelihood and expectation as to whether fish should be present within a stream; the geomorphic reference conditions for the Whangarahi and Waiwhero Streams are markedly similar but based on research by Poole (2002), Chessman *et al.* (2006), and Leathwick *et al.* (2008), it is apparent the ecological parameters are not analogous. It is recommended to expand the number of reaches subject to the monitoring to better assess the applicability of the toolbox to a range of geomorphic settings, including both upland and lowland reaches.

5.2. Variables of the toolbox

5.2.1. Selected indicators

The six indicators assessed at each reach used to infer geomorphic condition were selected based on the findings of the literature review and their relative measurability. Both quantitative and qualitative techniques were used across the indicators based on the efficiencies of the techniques, such as a visual assessment for geomorphic units and measuring the *b*-axis of particles within the reach. The connection between indicators is complex (refer Dollar *et al.* (2007) and Figure 2), with interrelationships between various factors potentially causing redundancy in the assessment through double counting. For example, the riparian zone both adjacent to the reach and upstream is the largest contributor of wood into the wetted channel; if the riparian zone is in good condition, it follows that wood potential and availability within the channel will also be in good condition (Lake *et al.*, 2007; Elosegi & Sabater, 2013; Wohl *et al.*, 2019) in addition to erosion of banks, contingent on the lack of hard infrastructure inhibiting this (Florsheim *et al.*, 2008). Conversely, the interrelationships risk being misconstrued in the separation of the indicators into siloed processes. For example, a stream could score well for an intact riparian zone, but still be subject to hard infrastructure reducing natural or expected bank erosional processes, thus limiting the adjacent and downstream riparian function and diminish habitat (Florsheim *et al.*, 2008). This entrenches the requirements to synthesise the indicators into a proforma, particularly if the objective use of the geomorphic toolbox is to inform rehabilitation or management programmes (Brierley *et al.*, 2013).

The assessment used for this research considers each indicator separately. The removal of some indicators, such as wood, would require other indicators, such as the geomorphic units, to be considerably more encompassing. Assessments for geomorphic units that incorporate both the riparian zone and wood pieces include the Geomorphic Unit Tool (GUT; http://gut.riverscapes.xyz/) which maps geomorphic units using high resolution topographic data, which can then be converted into a metric representing habitat heterogeneity and morphological unit abundance (Williams *et al.*, 2020) and the Geomorphic Unit survey and classification System (GUS), which creates a spatially-nested hierarchal framework for geomorphic units with a river reach through aerial photography supplemented with in situ topographic and qualitative surveys (Belletti *et al.*, 2017).

The GUT technique is effective at mapping geomorphic units while removing much of the subjective nature of user-interpretative techniques such as those used for this toolbox (Williams *et al.*, 2020). The consistency of deploying techniques is significant for assessing and understanding temporal changes, although time efficiencies are lost through the requirement of high-resolution topographic surveys of the entirety of the in-channel and floodplain (Williams *et al.*, 2020). This may be offset by the range of uses of topographic data of a reach, such as for restoration and alternative monitoring. Whilst the qualitative techniques deployed for this research are an acceptable medium between obtaining meaningful data while also being time- and cost-efficient, further investigation into the use of GUT as a geomorphic unit indicator to encompass other indicators is recommended.

The GUS technique uses a spatially-nested hierarchical framework to organise geomorphic units on three spatial scales and levels of characterisation (Belletti *et al.*, 2017). It uses both remote (i.e. LiDAR) and in-field techniques (i.e. topographic and qualitative survey) to identify the units of a reach. However, identification of the first tier of survey (macro-units) is done wholly by way of remote data sources, which limits the use of this technique to rivers with a channel width of greater than 30 m (Rinaldi *et al.*, 2015); 'small' rivers for the GUS technique are considered rivers with a channel width of less than 30 m. Additionally, a reliance on aerial or remote sensing data may prove inadequate for the Waikato context, given the vegetation coverage present near streams, particularly reference sites. Further characterisation is undertaken using in-field techniques and can be deployed in smaller streams but misses out on the full spatial analysis reserved for the larger rivers. This is also representative of the reach scale used for GUS; whilst it can be feasibly deployed for a range of reach sizes, generally the areas surveyed are specified as well over 1000 m in length (Rinaldi *et al.*, 2015) with the technique therefore designed for this level. Aspects of the GUS technique may prove instrumental for standardising the geomorphic unit assessment, such as the very thorough and detailed guidebook for the identification and classification of geomorphic units used for GUS. As with the other methodologies considered, of most importance is the toolbox being carried out by a suitably qualified and experienced practitioner in geomorphology as applying these techniques without the necessary background and skill can seriously affect the quality of the data collected (Rinaldi *et al.*, 2015), particularly when used for temporal analyses.

5.2.1.1. What is missing?

Consideration is given to the inclusion of additional indicators to enhance the toolbox. Surrounding land use was identified as providing contrasting outcomes to the stream reach, such as that seen between the Whangarahi Stream (Monitoring Site 1307_18) and Waiwhero Stream (1262_18). Whilst land use and land use change is not considered a geomorphic process, given the strong influence on the other indicators (Allan, 2004), it may be appropriate to include this as an indicator, particularly should reference conditions be framed as a 'best attainable outcome' for non-reference sites, as discussed below. Land use is assessed within the RHS, MQI, SHAP and the Twin Streams (Auckland, New Zealand) application of River Styles© methodologies to varying degrees (Reid *et al.*, 2008; Harding *et al.*, 2009; Raven *et al.*, 2010; Rinaldi *et al.*, 2013), reflecting the influence of the process. The incorporation of the floodplain is also included into these assessments for lowland rivers, providing an opportunity to describe both floodplain and land use into one indicator. 'Land use' for lowland sites could be framed as 'floodplain processes' and include the range of geomorphic features that could be expected to have an influence on stream health outside of the wetted channel, such as ephemeral or overland flowpaths as well as anthropogenic influence. It is recommended that land use as an indicator be investigated, given the degree of influence surrounding land use can have on a reach.

Another factor worthy of further investigation is that of bed structure. The embeddedness or compactness of the channel bed describes the level to which larger bed particles are surrounded or held within the silty layer of stream beds. It provides an indication of the availability of interstitial space, which can be used as refugia by both fish and macroinvertebrates (Lawrence *et al.*, 2013). It can also influence the relationship between the river proper and the hyporheic zone. As such, it is considered to be variable that would strongly enhance the particle size indicator, which would duly expand to incorporate the wider range of factors rather than just grain size. As the techniques for measuring embeddedness and bed compaction are relatively simple (qualitative observation for embeddedness and a scala penetrometer is used for bed compactness) (Clapcott *et al.*, 2011), the incorporation of such variables would fit within the objectives of the methodology remaining time-efficient and cost-effective. It is recommended that both embeddedness and compactness are investigated for their value as variables relating to the particle geomorphic indicator.

Environmental flow and disturbance were two factors identified as exerting an influence on the geomorphic quality of a river but were not incorporated into the toolbox. Environmental flow covers a range of flows a channel can be subject to, including low flows, floods, seasonal changes, and discharge variability (Arthington, 2012). Similarly, disturbances to a stream channel are not always consistent and comprise a dramatic deviation from normal circumstances (Lake, 2000; Death & Collier, 2010). The geomorphic toolbox captures the river state at a single point in time as a snapshot; whilst all geomorphic processes occur temporally, the indicators chosen can be represented by the physical state of the channel at the time of the assessment, whereas environmental flow and disturbance need to be considered on longer timeframes in order to provide a meaningful illustration of the process. To maintain the snapshot approach to fit in with other SOE reporting structures, it isn't considered viable to incorporate these variables without longer (and possibly continuous) monitoring of streams, which is inconsistent with the principle of the toolbox being time- and cost-effective.

5.2.2. Reach length and location

The 150 m reach length for geomorphic assessment was chosen to emulate the existing WRC reach length for assessing fish distribution in wadable rivers. This length is based on work by David *et al.* (2010), who observed that a greater than 90% confidence of detecting fish species present within a stream is found at 150 m, with little to no increase in reach scale richness for sampling a greater length than this. A principle of this research was to formulate a geomorphic toolbox that could be deployed as part of the existing WRC monitoring season, which justifies the use of the 150 m reach length and also provides for a direct comparison between ecological and geomorphic findings by using the same physical template. While Raven *et al.* (2010) specified 500 m must be used for each survey, there was little difference found between the 150 m reach and 300 m reaches surveyed. Except for the Upper Wainui Stream (11726_11) and the Stony Stream 3rd order (2079_1), the sites received the same scoring for all variables as well as the overall score. The two sites that did not achieve the same score were separated by one point within the riparian zone and this did not change their banded scoring (i.e. both still achieved 'Excellent').

The RHS survey specifies a 500 m reach as fundamental to capturing the range of geomorphic variables (Raven *et al.*, 2000), while other geomorphic assessments (River

Styles©, MQI, SEV and SHAP) determined the length by way of boundary conditions (Fryirs, 2003; Rinaldi *et al.*, 2013) or by the area which is expected to be affected by development (Harding *et al.*, 2009; Neale *et al.*, 2017). The geomorphic representativeness of the 150 m reach identified within the six sites may be a product of their stream width; Knighton (2014) describes the regular pool-riffle geometry spacing at a distance of 5-7 times the channel width, which would be captured within a 150 m reach for streams up to 21 m wide. Geomorphic representativeness can be expected to be captured within the pool-riffle geometry spacing. All six sites had a wetted channel width less than 20 m wide, with the exception of some locations within Stony Stream 3rd Order (Monitoring Site 2079_1). For streams considerably wider than the six sites monitored, consideration of the wetted channel width relationship to geomorphic variability may be necessary. As the number of wadable streams within in the Waikato monitoring regime that have a wetted channel width greater than 20 m is not large, the 150 m reach should be retained for geomorphic assessment for ease of deployment. The toolbox has not been assessed in non-wadable streams and therefore applicability to streams that would not be represented by the 150 m is further reduced. Ultimately, the choice of reach length is determined by the objective of the assessment; in this case it must be easy to deploy and time-efficient, while also providing meaningful and representative data toward the annual SOE monitoring undertaken. This representativeness could be considered compromised at a 300 m length, given two of the sites had tributaries present at this length (Stony Stream 3rd Order – 2079_1 and Whangarahi Stream 2080_1); SOE reporting does not allow reaches to have tributaries and confluences present.

Whilst surveying the 300 m reach instead of the 150 m reach does not double the time taken due to economies of scale, there seems to be little gain in undertaking the larger survey, particularly if there are other time constraints to factor in. However, the 25 m segments specified within each reach are somewhat arbitrary, with the primary use being to break the reach into manageable sizes given the quantity of observations required as part of the methodology. Adopting a 15 m segment size to match the reach division of fish monitoring (David *et al.*, 2010), or increasing the segment size to 30 m for efficiencies would both be acceptable for achieving the outcomes of the geomorphic toolbox.

The 150 m reach length is considered appropriate for capturing the geomorphic variables for small streams used for SOE reporting, though is not tested for further representativeness of a catchment. It is recommended the desktop *apriori* assessment is expanded to include a catchment-level analysis for observable deviations within the catchment, such as changes of land-use or planform. It is also recommended further investigation is undertaken through a quasi-River Styles© (Fryirs, 2003) method by identifying a range of representative sites within a catchment, including both lowland and upland sites, and assessing them using the geomorphic toolbox. This approach is also expected to highlight any longitudinal deficiencies in the catchment and provide a template through which to target catchment level initiatives such as riparian restoration.

5.2.3. Reference conditions

Reference conditions for the purpose of this research were defined as sites that were 'minimally disturbed' with little anthropogenic influence in alignment with SOE ecological reporting for stream health. Reference conditions were used to assess what the geomorphic condition of each site could be expected if there were no change arising from human impacts. This reference condition approach is used by River Styles© (Fryirs, 2003), which was also applied to the Twin Stream catchment research in Auckland, New Zealand (Reid *et al.*, 2008). The use of 'reference conditions' to form a baseline for river types based on a database of conditions from other sites, such as that for the RHS (Raven *et al.*, 2010) was precluded from the toolbox given each stream and reach is predicated in their exclusive space and time, meaning reference to a baseline of similar streams will not capture the unique variables of each site. More crucially, there is no such geomorphic database for wadable streams in the Waikato. The use of reference conditions of a reach as 'minimally disturbed' can have mixed outcomes, depending on the objective of the monitoring. The banded benchmarks set within the NPS-FM 2017 for a range of variables are not necessarily reflections of an untouched river state; a stream reach can sit within an 'A' (highest ranking) band despite not reflecting true undisturbed conditions. Instead, the 'A' band represents a lack of detractors from allowing taxa to flourish in those conditions (Ministry for the Environment, 2017b). Given many fluvial systems have been affected by historical and ongoing land-use change, such as drainage of lowlands around the Waiwhero Stream (Monitoring Site 1262_18) for pasture grazing, and exotic forestry production upstream of the Whangarahi Stream (Monitoring Site 1307_18), using pristine and untouched reference conditions may not be feasible or worthwhile (Rinaldi *et al.*, 2013; Brierley &

Fryirs, 2016), especially as there is no given endpoint for river adjustments (Brierley & Fryirs, 2016). 'Minimally disturbed' reference conditions for already identified reference sites within the Waikato Region has merit however; temporal changes can be clearly identified against a set of reference conditions for the reach given these conditions are mostly still achieved and observable, such as in the Upper Wainui Stream (Monitoring Site 11726_11) and the two Stony Stream reaches (Monitoring Sites 2080_1 and 2079_1).

Instead of exclusively focusing on 'minimally disturbed' templates, reference conditions for non-reference sites could pursue a 'best attainable condition' (Stoddard *et al.*, 2006). This could incorporate present and future conditions and constraints, and identify the least degraded and most ecologically dynamic state that could exist within that reach given the catchment context (Stoddard *et al.*, 2006; Rinaldi *et al.*, 2013) based on the German concept of '*leitbild*' (Palmer *et al.*, 2005). This would reflect the approach of other SOE reporting, whilst also allowing for reference against attainable future management and rehabilitation goals that would be significant for river health. 'Best attainable condition' can still be framed within overall river health and a stream's ability to perform its natural functions, which does not require pristine and untouched conditions to be achieved. For example, reference conditions for the Waiwhero Stream (Monitoring Site 1262_18) and Whangarahi Stream (Monitoring Site 1307_18) include being within a lowland Kahikatea swamp forest in all directions. Drainage and persistent land use patterns means a reversion back to 'minimally disturbed' conditions is unlikely to ever be attainable or desirable (Brierley & Fryirs, 2009). Partial restoration of the floodplain to a riparian zone could still provide river health benefits that represent the best attainable condition (Palmer *et al.*, 2005; Stoddard *et al.*, 2006; Rinaldi *et al.*, 2013). Careful consideration of the parameters of these alternative reference conditions is integral to their use; the use of *leitbild* is mainly for guiding restoration rather than assessing natural condition deviation. It is recommended that future annual iterations of the geomorphic toolbox consider the objectives of the reporting and adjust the reference conditions to suit the outcomes, being monitoring against 'untouched naturalness' or 'best attainable condition' for the reach.

5.2.4. Scoring System

A scoring system comprising five bands was incorporated into the geomorphic toolbox for ease of comparison. Stream reaches cannot be directly compared given the unique set of factors that result in the geomorphic template for its specific location and point in time; scoring of the reaches against their reference conditions allows ranking of streams. This could be used for identifying areas of targeted rehabilitation or river management, thus increasing the functionality of the geomorphic toolbox for a range of uses. The scoring system was modified from an earlier iteration that included three bands of reach quality: 'Poor', 'Moderate', and 'Good', which reflected the reach assessment for other geomorphic assessment approaches, namely River Styles© (Brierley & Fryirs, 2000; Fryirs, 2003; Fryirs & Brierley, 2013). The amendment to five bands is considered to better reflect the condition of the reaches and provides additional granularity for comparing the reaches. This revision is representative of the bands for SOE reporting and the NOF, which uses four band system, with three bands sitting above the accepted National Bottom Line, and one below. The geomorphic toolbox sits tidily within this framework, with three scorings that would be acceptable within the reference conditions, and two that are not ('Poor' and 'Extremely Poor'). The two lowest scoring bands could be combined as both would be below a bottom line such as those for the NPS-FM reporting. Given a purpose of the geomorphic toolbox is to be incorporated into the existing SOE reporting, there is merit in providing a quantifiable and standardised measurement of river health.

The SHAP methodology has a similar primary purpose to this research: to provide a practical, standardised, and cost-effective method for assessing physical habitat (as opposed to geomorphic condition) in New Zealand waterways (Harding *et al.*, 2009). Contrasted to this research, the SHAP deliberately steers away from the use of a scoring system due to the variability of stream parameters in New Zealand, such as geology and topography. The SHAP does not provide for reference conditions and therefore constitutes a baseline of testing all streams against the same set of conditions, which would, as correctly observed by Harding *et al.* (2009), result in difficulties in comparing what is expected in one location versus what is a deviation in another. The use of reference conditions is therefore considered imperative when implementing a scoring system for comparing streams across a region, or even within a catchment.

A sole focus on the final overall score would be short-sighted. The combination of the sub-scores for each indicator and the qualitative assessment (pro-forma) for each reach is considered of higher value than then single final score, as these provide a better understanding of the stream variables and pressures, as well as providing an avenue to assess relationships between the variables, such as the influence of the riparian zone on bank erosion and wood. A numeric score can also mask potential major geomorphic deviations that would be readily apparent in a qualitative proforma and result in either a misguided attempt toward future rehabilitation or misdirection as to the actual state of river health for a reach. Further, given the capacity of rivers to adjust over time, the proforma approach is necessary to assess whether the adjustments observed comprise an expected change along the evolutionary trajectory of a reach (Brierley & Fryirs, 2005; Reid *et al.*, 2008) or if deviations are occurring. Ultimately, the use of any combination of the proforma, sub-scores for each indicator, and the overall numeric score for the reaches will depend on the context in which the assessment is being used. The intention of use for the geomorphic toolbox must be clearly articulated and fit for purpose to avoid misrepresentation of the monitored reaches.

5.3. Application of the toolbox

A key principle of the geomorphic toolbox was to balance the time and cost-efficiency with accurately representing and recording relevant geomorphic features. It is also anticipated that the geomorphic toolbox, or subsequent iterations thereof, can be deployed and used as part of WRC's SOE reporting, and therefore must be both standardised and measurable. Similar to the MQI methodology, the limitations, strengths and weaknesses of this geomorphic toolbox are best appreciated when framed in the context of the principles and objectives of the work (Rinaldi *et al.*, 2013).

A trade-off evident within this toolbox is between the time taken at each site and comprehensiveness of the geomorphic assessment. The existing WRC SOE monitoring aims to assess each monitoring site in either a half day or a full day for more ecologically diverse streams; as the geomorphic toolbox would be expected to be deployed at the same time, it also needed to fit within these time constraints. This compromise is found within the range of geomorphic methodologies reviewed within this research, and often the decision to accommodate the time constraint or provide a more robust assessment is based on the objective of the work. For example the RHS focuses on being quickly deployed for national stream monitoring (Raven *et al.*, 2010) while River Styles© is predominately more research focused and used for river management and rehabilitation purposes (Brierley & Fryirs, 2000). The SHAP attempts to overcome the necessary trade-off by providing a tiered approach, whereby three protocols of varying complexity are available for use, depending on the level of comprehensiveness required to inform objectives and outcomes (Harding *et al.*, 2009). However, the tiered approach can form inconsistencies over time, such as comparing a detailed protocol against a previous one that is brief and lacks the same detail, which can undermine the usefulness for informing monitoring and future rehabilitation or river management. The trade-off present within the geomorphic toolbox created for this work is considered to align with the principles of the research, although there is scope to consider more comprehensive indicators, such as the GUT technique, by adding additional human resource to mitigate the time required.

Two people were necessary for the fieldwork, with some tasks divided for efficiencies in order to complete the surveys at each reach within a reasonable timeframe. A minimum of two people are also fundamental to achieving a safe working environment given the surveys require in-stream work as well as accessing remote, isolated sites. The time taken to complete the geomorphic survey ranged from 2.0 hours (Waiwhero Stream – Monitoring Site 1262_18) to 4.5 hours (Upper Wainui Stream – Monitoring Site 11726_11), excluding the 5.5 hours required for the Wainui Stream (Monitoring Site 1172_6) which was the first site in which the geomorphic toolbox was deployed. The time taken to complete the assessment reflected the geomorphic complexity of each site, which impacted on the time to visually assess and record geomorphic features, as well as longitudinal access through the site. Both Stony Stream Monitoring Sites (2080_1 and 2079_1) were remote, with large clasts and features which were difficult to traverse with equipment (flow meter, recording sheets, callipers, tape measure, and personal safety equipment), as shown in Figure 78. Changes to the assessment of geomorphic units, such as to the GUT methodology would increase both access (additional equipment such as surveying equipment) and observation time in order to undertake comprehensive topographic survey of the geomorphic features) Consideration is required in the trade-offs between maintaining time and cost efficiencies, given the GUT approach would also require greater post-field work data processing as well, and obtaining high quality representative geomorphic data.

Figure 78 Working environment: accessing the Stony Stream 2nd Order Monitoring Site (2080_1) requires walking approximately 1.2 km along the Stony Bay walking track from the Stony Bay Campsite, then traversing the Stony Stream for 200 m before reaching the downstream end of the monitoring site. Equipment must also be carried for the length of the Stony Stream 2nd Order Monitoring Site to assess the full length of the reach.

A strength of the toolbox is the range of results that can be elucidated through its deployment; reaches can be assessed temporally against themselves as well as at an indicator granularity using both the scoring system and perhaps more importantly, the proforma assessment. This use assists understanding catchment level pressures and changes, such as land use change, while also providing baseline data for rehabilitation measures for a catchment or reach; changes to the upstream catchment can be more important than the area adjacent (Lake *et al.*, 2007; Poole, 2010). This range also allows for a quantitative ranking for river reaches and their catchments due to the use of reference conditions, which fit within the style required for SOE reporting (McFarlane *et al.*, 2011), i.e. a quantitative metric. Practitioners would need to monitor closely the use of the scoring system, which is dependent on the qualitative proforma for informing the score. Actions, such as targeted rehabilitation based solely on the scoring system will inevitably be misguided without direct consideration of the reference conditions (whether as 'minimally disturbed' or 'best attainable outcome' based on the objective of rehabilitation).

A limitation in the toolbox for this purpose is the discrete location of sites to which it is applied within a catchment; the sites selected for this research were based on existing WRC monitoring sites which may not necessarily coincide with representative geomorphic reaches. Given time and cost constraints, it is not considered feasible to undertake mapping of entire catchments across the whole of the Waikato Region such as that done for the Bega Catchment in Australia using River Styles© (Brierley & Fryirs, 2000; Fryirs, 2003). A method to reduce the dependency of single site for representation could be to identify reaches in the catchment, both upland and lowland, that could be used to demonstrate the range of catchment geomorphology (such as River Styles©); while this would increase the time required per catchment, it would provide greater understanding of specific catchment character and processes, rather than relying on a single set of data.

Many of the indicators rely on subjective qualitative assessment and the identification of boundaries, units and features by the assessor. The indicators are also measured at a single point in time, with features used to judge the efficacy of the geomorphic processes occurring. Bank erosion, for example, is measured through a visual assessment of the banks on the day of the reach monitoring. Alternative and more sophisticated methods could include charting bank lateral movement over time to provide both a spatial change and quantity of sediment displaced. However, the aim of the toolbox is to assess geomorphological quality rather than quantify channel morphological processes or understand the underlying channel dynamics. A focus on more quantifiable and complex methods of assessment may reduce the usability of the geomorphic toolbox, which is intended to be deployed efficiently as part of SOE monitoring and provide an estimation of the changes undertaken. An exception to this would be to enhance the assessment of the geomorphic unit indicator, given its prominence as a driver of river health and ecology by encompassing many of the other indicators, including wood, bank erosion, the riparian zone, and particle size to some degree.

5.4. Recommendations

Overall, the proposed toolbox can achieve the objectives and principles of a geomorphic toolbox for assisting with assessing river health in wadable streams in the Waikato. The following recommendations are made with the intent of improving the efficacy of the geomorphic toolbox while still fitting within the principles of the toolbox for SOE monitoring and aligning with existing ecologically focused programmes:

- Deploy the geomorphic toolbox at the 150 m reach rather than the 300 m reach length, contingent on an ongoing review of contemporary literature with regard to optimum reach length / characteristics and adapt should superior information become available;
- Deploy the geomorphic toolbox at WRC monitoring sites to gain temporal data for each reach and assess the use of the toolbox for its ability to provide ongoing useful data for reporting on river health at a range of geomorphic settings;
- Investigate modifying the existing techniques used to provide more quantifiable results, namely the use of GUT for enhancing the geomorphic unit assessment;
- Investigate incorporating channel bed substrate embeddedness and compactness as variables relating to the particle geomorphic indicator;
- Consider incorporating land use as an indicator, given the degree of influence land use within a catchment can have on a reach;
- Expand the desktop *apriori* assessment to include a catchment-level analysis for observable deviations within the catchment, such as changes of land-use or planform;
- Investigate a quasi-River Styles© (Fryirs, 2003) method by identifying a range of representative sites within a catchment, including both lowland and upland sites, and assessing them using the geomorphic toolbox;
- Source and apply finer-grained catchment-wide LiDAR to provide greater analysis of the characteristics of the catchment for each monitoring site, such as through Digital Elevation Models;
- Future annual iterations of the geomorphic toolbox should consider the objectives of the reporting and adjust the reference conditions to suit the outcomes, being monitoring against ‘untouched naturalness’ or ‘best likely condition’ for the reach; and
- Incorporate geomorphology into river health monitoring using a toolbox approach.

6. Conclusion

The purpose of this research was to develop and assess the efficacy of a geomorphic toolbox as a realistic measurement of the ecological health of a river. Critically, the toolbox had to be fit for purpose; in this context this meant it had to provide meaningful and representative data of study reaches whilst also being both cost- and time-efficient. The success of the toolbox has been gauged against the degree to which the objectives of the research were achieved. The toolbox was developed based on identifying the connections between ecological health and geomorphic within national and international literature, as well and identifying existing geomorphic techniques and methodologies to determine what could be applicable to a Waikato context. Six key geomorphic indicators were identified as relevant: riparian zone, particle size, bank erosion, wood, connectivity, and geomorphic units, and were incorporated into a geomorphic toolbox to provide time- and cost-efficient techniques for assessment. The testing of the toolbox against four reference sites and two non-reference sites in the Waikato Region showed the techniques for assessment were easily deployed and can provide robust and user-friendly results for use within the SOE context as well as to inform potential river rehabilitation programmes.

Critical to the toolbox was the development of reference conditions for each of the sites being monitored in order to be able to compare each reach to their undisturbed nature as well as to provide an appropriate scoring compendium that allows the reaches to be ranks and compared to one another. A comparison of the geomorphic results to the corresponding ecological condition classes collected independently by WRC at the same monitoring sites showed the scoring of the geomorphic toolbox were comparable to the ecological variables, though proximity to coast was identified as a factor required to be considered when making comparisons. Recommendations to refine the toolbox include consideration of new techniques, such as GUT for geomorphic units, and expanding the testing of the toolbox against a range of Waikato monitoring sites. The objectives of the research for assessing the effectiveness of the geomorphic toolbox were achieved, with the resulting toolbox well-grounded within existing methodologies and assessment techniques. The toolbox, subject to ongoing refinement, testing, and framing within the latest literature and investigations for fluvial geomorphology, is fit for purpose for contributing to the holistic assessment of ecosystem health in rivers and streams of the Waikato Region.

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Appendix A

Monitoring Sheets – Example

Date		
Analyst		
Stream Name		
Coordinates	Downstream boundary Upstream boundary	
Valley Type	Confined Partially Confined Unconfined	
Connectivity	*Is this reach physically connected to its neighbouring reaches?*	Upstream Downstream
Slope	*Elevation change over the 150 m of reach AND 300 m of reach*	150 m [z coordinate] 300 m [z coordinate]
Flow regime	m^3/s	1-2 4-5 9-10 12-13
	State *(i.e. low flow, normal conditions, high flow, bankfull flood)*	
Other	Photographs taken that are ▪ representative of the reach ▪ Specific evidence of each of the above points. ▪ Any other significant feature requiring further assessment or consideration	Note what photographs are taken, where, and why
Commentary: e.g. any distinctive artificial features, things that could have an effect on stream health that are obvious (i.e. infrastructure)		

Rock / Clast units

Segment [downstream to upstream]	Choose 4 sites – one site between 1-4, 2 sites between 4-10, and one site between 10-13. Circle which reach is used in the left hand column and cross out those which were not. Measure 30 m along a bar (take a photo) using the tape measure. The tape measure should be along the location of the roughest set of clasts (i.e the biggest clasts). At each 1m interval, measure the b-axis of the rock directly below the mark. If																													
1-2 [0-24.99]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
2-3 [25-49.00]																														
3-4 [50- 74.99]																														
4-5 [75-99.99] - downstream boundary of reach	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
5-6 [100 – 124.99]																														
6-7 [125-149.99]																														
7-8 [150-174.99]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
8-9 [175-199.99]																														
9-10 [200-224.99] – upstream boundary of reach																														
10-11 [225 – 249.99]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
11-12[250-274.99]																														
12-13 [275-299.99]																														

Rock / Clast units

Segment [downstream to upstream]	Specify the range of rocks / sediment present for each segment. Is there a range? Is the sediment located where it could be expected? i.e. within pools. etc. Is there a sand or silt layer overlaying the bed? How thick? are the particles loosely consolidated? Is sorting evident?
1-2 [0-24.99]	
2-3 [25-49.00]	
3-4 [50- 74.99]	
4-5 [75-99.99] - downstream boundary of reach	
5-6 [100 – 124.99]	
6-7 [125-149.99]	
7-8 [150-174.99]	
8-9 [175-199.99]	
9-10 [200-224.99] – upstream boundary of reach	
10-11 [225 – 249.99]	
11-12[250-274.99]	
12-13 [275-299.99]	

Riparian Zone

Segment [downstream to upstream]	Width of riparian zone [can state the same for all segments if cover is consistent across reach]. Specify if there are any breaks within the vegetation of the riparian strip. Is it dense? Is their canopy and ground coverage?		Vegetation type	
	True Right Bank	**True Left Bank**	**True Right Bank**	**True Left Bank**
1-2 [0-24.99]				
2-3 [25-49.00]				
3-4 [50- 74.99]				
4-5 [75-99.99] - downstream boundary of reach				
5-6 [100 – 124.99]				
6-7 [125-149.99]				
7-8 [150-174.99]				
8-9 [175-199.99]				
9-10 [200-224.99] – upstream boundary of reach				
10-11 [225 – 249.99]				
11-12[250-274.99]				
12-13 [275-299.99]				

Bank Erosion

Segment [downstream to upstream]	Evidence of bank erosion (describe and photos)	
	True Right Bank	**True Left Bank**
1-2 [0-24.99]		
2-3 [25-49.00]		
3-4 [50- 74.99]		
4-5 [75-99.99] - downstream boundary of reach		
5-6 [100 – 124.99]		
6-7 [125-149.99]		
7-8 [150-174.99]		
8-9 [175-199.99]		
9-10 [200-224.99] – upstream boundary of reach		
10-11 [225 – 249.99]		
11-12[250-274.99]		
12-13 [275-299.99]		

Woody Debris

Segment [downstream to upstream]	**Woody Debris** *Observe the woody debris – what is it primarily made up of? Are there rafts or accumulations that would aid in habitat formation?*	
	Within stream	**Within Stream bank**
1-2 [0-24.99]		
2-3 [25-49.00]		
3-4 [50- 74.99]		
4-5 [75-99.99] -downstream boundary of reach		
5-6 [100 – 124.99]		
6-7 [125-149.99]		
7-8 [150-174.99]		
8-9 [175-199.99]		
9-10 [200-224.99] – upstream boundary of reach		
10-11 [225 – 249.99]		
11-12[250-274.99]		
12-13 [275-299.99]		